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CONTENTS

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INFLUENCE OF COMPOSITION AND NUMBER OF LAYERS OF POPLAR PLYWOOD (*Populus euramericana*) ON BENDING STRENGTH AND MODULUS OF ELASTICITY

Aleksandar Lovrić, Vladislav Zdravković, Lazar Jovanović

University of Belgrade, Faculty of Forestry, Republic of Serbia
e-mail: aleksandar.lovric@sfb.bg.ac.rs; vladislav.zdravkovic@sfb.bg.ac.rs

ABSTRACT

In this paper the influence of composition and number of layers for ten poplar plywood boards of different thicknesses to bending strength and modulus of elasticity has been investigated. Results showed that with both increasing of plywood thickness and number of layers, density, bending strength and modulus of elasticity in lengthwise direction have been decreed, while in crosswise direction, bending strength and modulus of elasticity increased until 18 mm thickness and after that decreased. Analysis showed that with increasing both of number of layers and veneers thickness in plywood composition, the difference of examined properties in lengthwise and crosswise directions decreased. The plywood composition decreasing also influenced on anisotropy: as the difference in percentage part of veneer thickness in crosswise v.s. lengthwise direction decreased, so the difference in bending strength and modulus of elasticity decreased.

Key words: poplar plywood, bending strength, modulus of elasticity, anisotropy

1. INTRODUCTION

Plywood panels are produced of at least three glued veneer layers with different orientation of adjacent veneer layers. Thanks to crossing of adjacent veneer layers, (common, in direction of 90 degrees) the final product is less susceptible to shrinking, swelling, splitting, and warping compared to initial wood spices. Among that, plywood panels have improved mechanical properties, stability, isotropy and they were more durable compared to massive wood (Nikolić 1971).

The main factors influencing to plywood panels properties are: wood species (Biblis 1999, Constant et al. 2003, Bal and Bektas 2014...), type of adhesive (Cremonini and Pizzi 1999, Grindl and Muller 2006, Zdravković and Stanković 1997...), pressing parameters (Nikolić 1971, Bekhta et al. 2012...), veneer quality (Neese et al. 2004, DeVallance et al. 2007...) and veneer preparing (Aydin and Colak 2002, Dai et al. 2003...). Baldassino et al. (1998), considered the influence of plywood lay-up to its mechanical properties in two directions (according to wood fibers orientation in plywoods outer layers).

The aim of this research was to determine on which way both construction of plywood panels and number of veneer layers influenced on board isotropy measured by bending strength (MOR) and modulus of elasticity (MOE) in two cross directions.

2. METERIALS AND METHODS

In this experiment the plywood panels of different thicknesses produced by standard production process (Hot-Press Schedule: synthesized UF adhesive, pressure 1MPa, pressing temperature 135^{o}C, pressing time 1 min/mm of total plywood thickness), were randomly chosen from production batches of company ``Novi drvni kombinat`` from Sremska Mitrovica. Thicknesses and plywood panels lay-up are shown in Table 1. For lengthwise layers veneer thicknesses were 2; 2.2 and 3mm, and for

crosswise layers veneer thicknesses were 1.5; 2.2 and 3mm. All plywood panels were slightly thicker than their nominal thickness, because of calculated over measure (of 6 to 8% for pressing losses) and around 1 mm for finishing.

Table 1. *Plywood panels thicknesses and constructions*

Nominal thickness (mm)	Number of layers	Plywood panel lay-up*
4	3	2 + 1.5 + 2 ‖ ⊥ ‖
6	3	2.5 + 2.2 + 2.5 ‖ ⊥ ‖
8	5	2 + 1.5 + 2.5 + 1.5 + 2 ‖ ⊥ ‖ ⊥ ‖
9	5	2 + 2.2 + 2 + 2.2 + 2 ‖ ⊥ ‖ ⊥ ‖
10	5	2 + 2.2 + 3 + 2.2 + 2 ‖ ⊥ ‖ ⊥ ‖
12	5	3 + 2.2 + 3 + 2.2 + 3 ‖ ⊥ ‖ ⊥ ‖
15	7	2.5 + 2.2 + 2.5 + 2.2 + 2.5 + 2.2 + 2.5 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖
18	9	2 + 2.2 + 2 + 2.2 + 3 + 2.2 + 2 + 2.2 + 2 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖
20	9	2.5 + 2.2 + 2.5 + 2.2 + 3 + 2.2 + 2.5 + 2.2 + 2.5 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖
28	11	2.5 + 3 + 3 + 3 + 2.5 + 3 + 2.5 + 3 + 3 + 3 + 2.5 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖

*Symbols ‖, ⊥ refers to the direction of other veneer layers.

From randomly chosen plywood panels the samples have been cutted according to EN 310 (Figure 1). The samples have been tested on computer controlled automatic testing machine WT4, in Laboratory for Wood properties in Faculty of Forestry of Belgrade University.

Figure 1. *Appearance of probes for MOR and MOE testing according to EN 310*

After the MOR and MOE testing, from every probe the samples were cutted for determination of MC and plywood density (according to EN 322 and EN 323), at the moment of testing (Figure 2). The all statistics was calculated by standard SPSS software.

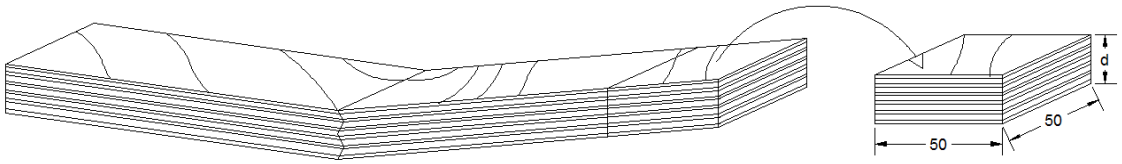


Figure 2. *Samples for determination of plywood MC and density*

3. RESULTS AND DISCUSSION

The main statistics for plywood moisture content (MC) and plywood density is presented in Tables 2 and 3. Besaide the average values ($\bar{x}$), the number of samples (N), standard deviation (SD), coefficient of variation (KOV) and standard error (SE) were presented.

Table 2. *Moisture content (MC) of plywood panels at the moment of testing (%)*

Plywood thickness (mm)	4	6	8	9	10	12	15	18	20	28
N	10	10	10	10	10	10	10	10	10	10
$\bar{x}$	**7.95**	**8.31**	**8.10**	**7.42**	**7.36**	**7.72**	**7.24**	**7.46**	**8.31**	**7.45**
SD	0.35	0.25	0.36	0.31	0.57	0.14	0.22	0.18	0.25	0.30
KOV	4.37	2.95	4.47	4.12	7.75	1.76	3.04	2.44	3.00	4.01
SE	0.11	0.08	0.11	0.10	0.18	0.04	0.07	0.06	0.08	0.09

Table 3. *Plywood panels density at the moment of testing (kg/m^3)*

Plywood thickness (mm)	4	6	8	9	10	12	15	18	20	28
N	10	10	10	10	10	10	10	10	10	10
$\bar{x}$	515.29	476.19	455.45	509.25	501.26	493.68	498.49	468.16	442.71	443.33
SD	51.20	19.43	13.75	16.93	19.69	20.12	20.59	16.37	9.96	14.75
KOV	9.94	4.08	3.02	3.32	3.93	4.07	4.13	3.50	2.25	3.33
SG	16.19	6.14	4.35	5.35	6.23	6.36	6.51	5.18	3.15	4.67

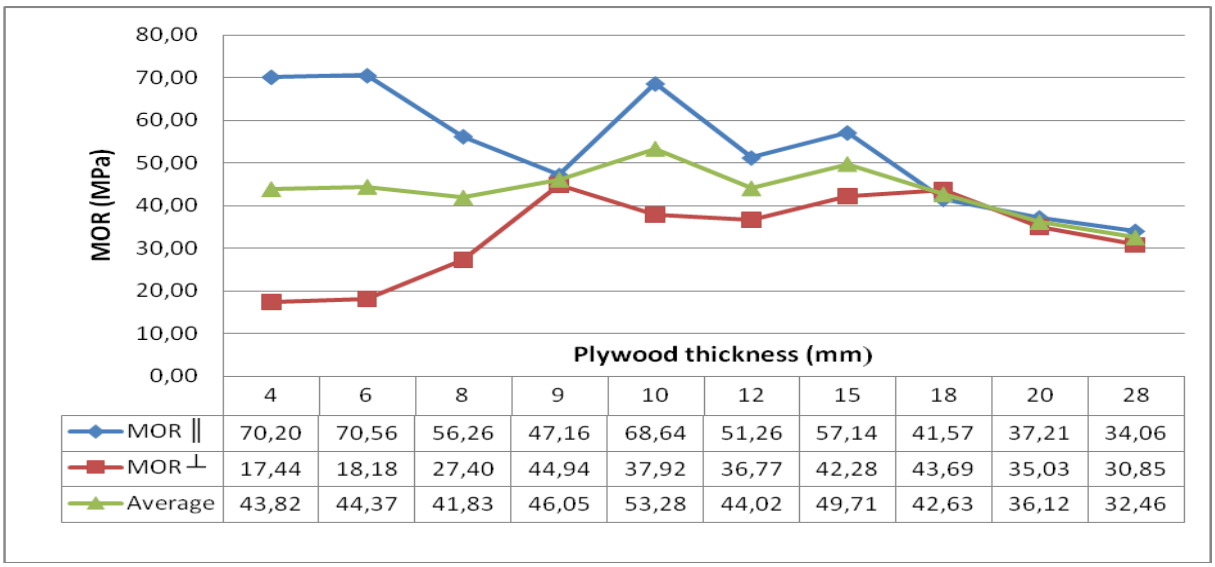
Table 2 showed that plywood MC at the moment of testing varied at little range of around 1% (min. 7.24%, max. 8.31%). Low values of all statistic parameters showed that plywood MC was pretty uniform, although most of them were below, or at the boundary of the lower limit of 10±2% prescribed by EN 322.

The plywood density fluctuated from minimum of 442 kg/m^3 to maximum of 515 kg/m^3 with increased variation in the case of plywood of 4mm thickness. The main trend was that as plywood thickness increased so and their density decreased. So the highest plywood density was noted in case of plywood thickness of 4 mm, and the smallest plywood density was noted in case of plywood thickness of 20 and 28 mm. This could bee explained as consequence of lower plywood thickness loss of thicker plywoods during the pressing (piezzo-thermic effect; Nikolić, 1988). One-way ANOVA and Bonferroni post hoc test showed significant influence of plywood thickness to plywood density ($F(9.90) = 13.845$, $p=.05$). Regarding increased variation of density in case of plywood thickness of 4 mm, tested plywood panels did not have homogeneous variance: Levene test ($F(9.90)=5.978$, $p=.05$).

Bonferroni post hoc test showed exactly that the most of tested plywood panels had significantly smaller density than board thickness of 4 mm and greater than boards of 20 and 28 mm.

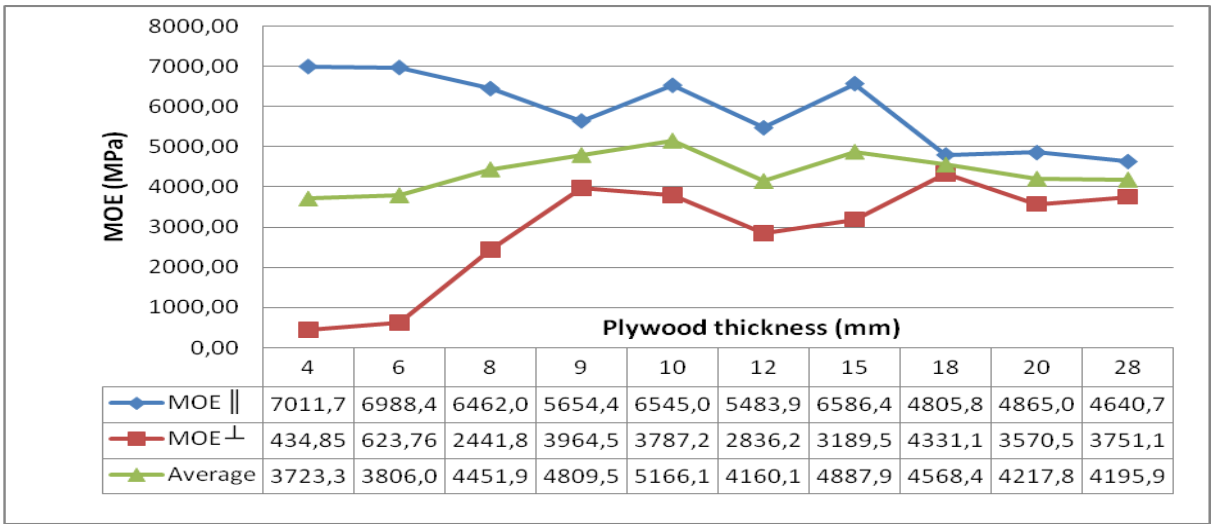
Figures 3 and 4 presents bending strength (MOR) and modulus of elasticity (MOE) of tested plywoods. Among the average values of MOR and MOE in lengthwise and crosswise directions for each plywood thickness, the average values in these two directions have been showed. Generally, the main trend was that in the case of lengthwise direction, both MOR and MOE decreased with increasing of plywood thickness. In the case of crosswise direction, both MOR and MOE increased until plywood thickness of 18 mm and then decreased. It was distinctly that difference between lengthwise and crosswise directions was the biggest in case of the smallest plywood thicknesses and the smallest in case of the biggest plywood thicknesses. Exception relative to this trend was in the case of plywood thickness of 9 mm.

Examining plywoods lay-up data (Table 1) it is obvious that there is significant difference in overall veneer thickness oriented in lengthwise direction v.s. crosswise direction. By subtracting oversize for finishing of 1 mm from overall veneers thickness in lengthwise direction (only outer lengthwise veneers have been sanded) graphs shown in Fig. 3 and 4 could be explained (Table 4).
The overall pressing losses are excluded on purpose, because such kind of calculation does not consider individual veneer layers, but only assembled veneers. Someone can only assume that there was consequence of higher pressing losses i outer veneer layers.



	4	6	8	9	10	12	15	18	20	28
MOR ‖	70,20	70,56	56,26	47,16	68,64	51,26	57,14	41,57	37,21	34,06
MOR ⊥	17,44	18,18	27,40	44,94	37,92	36,77	42,28	43,69	35,03	30,85
Average	43,82	44,37	41,83	46,05	53,28	44,02	49,71	42,63	36,12	32,46

Figure 3*. Bending strength (MOR) of poplar plywoods of different thicknesses*



	4	6	8	9	10	12	15	18	20	28
MOE ‖	7011,7	6988,4	6462,0	5654,4	6545,0	5483,9	6586,4	4805,8	4865,0	4640,7
MOE ⊥	434,85	623,76	2441,8	3964,5	3787,2	2836,2	3189,5	4331,1	3570,5	3751,1
Average	3723,3	3806,0	4451,9	4809,5	5166,1	4160,1	4887,9	4568,4	4217,8	4195,9

Figure 4. *Modulus of elasticity (MOE) of poplar plywoods of different thicknesses*

Table 4. *Difference in veneer thickness among lengthwise and crosswise direction*

Thickness (mm)		**4**	**6**	**8**	**9**	**10**	**12**	**15**	**18**	**20**	**28**
No. of layers		3	3	5	5	5	5	7	9	9	11
Sum in mm	∥	3	4	5,5	5	6	8	9	10	12	15
	⊥	1.5	2.2	3	4.4	4.4	4.4	6.6	8.8	8.8	15
Difference in mm		1,5	1.8	2.5	0.6	1.6	3.6	2.4	1.2	3.2	0
Share in %	∥	66.66	64.51	64.71	53.19	57.69	64.52	57.69	53.19	57.69	50.00
	⊥	33.33	35.49	35.29	46.81	42.31	35.48	42.31	46.81	42.31	50.00

The biggest difference of examined properties (MOR around 50 MPa and MOE around 6500 MPa) has been calculated in the case of two smallest plywood thicknesses (4 and 6 mm), with share of veneer thickness in lengthwise direction around 65% and in crosswise direction around 35%. The next board of 8 mm thickness has almost the same share of veneer thickness in lengthwise direction as previous, but difference in examined properties was smaller (MOR around 30 MPa and MOE around 4000 MPa). It could be explained considering number of veneer layers: the plywood of 8 mm thickness was composed of 5 layers while plywoods of 4 and 6 mm thicknesses were composed of 3 layers. Those results indicated that as number of layers increased so plywood isotropy has been improved (Figures 3 and 4).

In the case of 9 mm plywood thickness the calculated values for MOR were almost the same in the lengthwise and crosswise direction, while the calculated differences for MOE were significantly smaller than for thinner plywoods (around 1700 MPa). These values correspond to reduction of share of veneer thickness in lengthwise direction (around 53%), and increase of shear in crosswise direction (around 47%) (Table 4). In the case of 10 mm plywood thickness, the difference of veneer share in lengthwise direction v.s. crosswise direction was increased (58% - 42%) what contributed to the slightly smaller values of MOR and MOE in crosswise direction, but increasing of MOR in the first place, and MOE in lengthwise direction was unexpected high.

That increasing of number of veneer layers in the plywood construction was not only cause of isotropy improvement it can be seen from analyzed differences of properties in the case of plywood thickness of 12 mm. In this plywood thickness the veneer share of both directions was almost identical as plywood thickness of 8 mm, but the difference of properties in the case of plywood thickness of 12 mm was even smaller (MOR around 14 MPa and MOE around 2600 MPa, v.s. MOR around 30 MPa and MOE around 4000 MPa, for plywood thickness of 8 mm). As both plywood panels have 5 layers in their construction, logical explanation is that number of veneer layers and veneer thickness simultaneously affected to the isotropy improvement.

The difference of MOR and MOE in lengthwise direction and crosswise direction for plywood panel of 15 mm thickness was almost the same as for panel of 12 mm thickness. That was unexpected, because it does not follow the trend of decreasing the difference of observed properties with increasing of number of layers. With the further increasing of plywood thickness, MOR in both directions approaching each other as and MOE, so in the case of plywood thickness of 18, 20 and 28 mm they are quite uniform (Figures 3 and 4). Further increasing of plywood thickness and number of veneer layers probably would follow this trend.

Average values of MOR and MOE (green lines on Figures 3 and 4) indicated that values for MOE were quite uniform, but in the case of MOR there was noticeable decline after plywood thickness of 18 mm. This decreasing of MOR is probably consequence of statistically proven decreasing of plywood density for 20 and 28 mm thicknesses. It could be also caused by uncontrolled veneer lathe checks which affect to the plywood rolling shear properties (Zdravković 1999), but it is not subject of this research. This effect of the plywood density to the MOE values was smaller, as the slope of the curves shows (Figures 3 and 4).

4. CONCLUSIONS

In this research the simultaneous influence of plywood thickness and veneer share in lengthwise direction v.s. crosswise direction on MOR and MOE has been investigated. Analyzed data showed that both increasing of plywood thickness and number of layers, lead to isotropy improvement.

The biggest differences between lengthwise and crosswise directions have been calculated in case of 3-layer plywood (MOR around 50 MPa and MOE around 6500 MPa) and the smallest in the case of 9-layer and 11-layer plywood panels (MOR 2-4 MPa and MOE 500-1300 MPa).

The plywood lay-up also affect to isotropy improvement. This is obvious in the case of plywood panels thickness 9 and 28 mm. On these boards veneer share of both directions was almost identical, so differences in MOR in those directions were 2.2 MPa and 3.2 MPa and in MOE were 1600 and 900 MPa respectively.

Generally it could be said that plywood density decreases as their thickness increases. The main trend in the case of lengthwise direction was that both MOR and MOE decreased with increasing of plywood thickness and the number of veneer layers. In the case of crosswise direction, both MOR and MOE increased until plywood thickness of 18 mm and then decreased. This decreasing of MOR is probably consequence of statistically proven decreasing of plywood density for 20 and 28 mm thicknesses. But it must be noticed that in the case of bigger plywood thicknesses there is more pronounced influence of stress-strain relationships in the tensile zone of plywood.

Also, this research refers to industrial production batch and presents actual state. If we would have been able to control veneer peeling process, veneer drying and pressing regime, the results might be different.

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The Authors’ Addresses:

Aleksandar Lovrić, **Ph.D**.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: aleksandar.lovric@sfb.bg.ac.rs

Vladislav Zdravković, Ph.D.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: vladislav.zdravkovic @sfb.bg.ac.rs

Lazar Jovanović, Ph.D.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA

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ANALYSIS OF WOOD RAW MATERIAL CONSUMPTION AND FUTURE TRENDS IN SOUTHEAST EUROPEAN COUNTRIES

Andreja Pirc Barčić[1], Maja Moro[1], Branko, Liker[2], Darko Motik[1]

[1]University of Zagreb, Faculty of Forestry, Zagreb, Croatia
e-mail: apirc@sumfak.hr; mmoro@sumfak.hr; motik@sumfak.hr
[2]Drvenjača d.d. – Fužine, Fužine, Croatia
e-mail:branko.liker@drvenjaca.hr

ABSTRACT

Intensive competition, as a result of a globalization leads us to the necessity of looking at the current market situation, in order to predict the situation in the future. In this dynamic conditions it is necessary to use the economic theory for the qualitative and quantitative analysis of markets by interpreting the economic data and forecasting the future economic values.

It is known that a major part of forest product entering an international markets are in the form of raw material and /or semifinal products. Furthermore, it is significant that the ratio of wood raw material exports to production is generally higher among the secondary/final wood products.

Tradition in wood processing based on increased domestic wood material production, the quality of raw material and a rising trend in the use of wood as an ecological and renewable material which leads to increasement of production and total income are common elements in all Southeastern European countries when talking about wood industry.

The aim of this paper was to determine wood raw material consumption trends based on so-called apparent consumption and to present a future scenarios of wood raw material consumption in Southeastern European countries from 1990-ties up to present moment.

Key words: wood industry, raw material, Southeastern European countries, consumption trends, forecasting

1. INTRODUCTION

The economic development of a country is targeted towards improving the living standard of its citizens. This goal can be achieved by increased production, which in turn leads to increased employment and, finally, to the satisfaction of all forms of consumption (Bilen, 2007). In addition, at micro level the main objective of the business company is to be efficient and successful, that is to achieve maximum business results with a minimum invested funds. (Oblak, Jelačić, Grladinović, 2008).

Production is a very important element in the economy of any country. Its increase positively affects the economic growth and augments the country’s GDP. Four production factors of progress (growth) have been defined: human capability, natural resources, production of capital and technology (Samuelson, Nordhaus, 2000). Unlike production, consumption is physical expenditure, or expenditure of products and services for the purpose for which they were intended. It satisfies the needs that have caused the purchase of these same products (Bazala, 1991). The choice of products used to build, renovate, and operate structures also has significant environmental effects. When specifying any materials, it is important to consider their impacts over the lifecycle. Wood products play a significant role in a modern economy. By making forest sustainability and innovation top priorities, the wood products industry will continue to be a significant employer and supporter of rural economies (re Think Wood initiative, 2015). Wood has been used as a major structural material for centuries

(American Wood Council, 2004) and today presents a material of the engineer who uses technical data to design today’s sophisticated structures and products in everyday life. According to a market development agency for forest products Forestry Innovation Investment (2015) increased structural and architectural uses of wood offer economic, environmental and social benefits. In addition, greater use of wood supports the provincial forest sector through increased employment and revenues, while a greater use of engineered wood products fosters innovation and the growth of value-added manufacturers. Wood building products are climate friendly because of their higher levels of embedded carbon and lower life-cycle footprints in terms of energy consumption in their manufacturing, transport and application. Socially, designing with wood creates public buildings and facilities that are welcoming, attractive, and provide a tangible connection to nature and the outdoors.

Design of the product represents the element of differentiation in relation to competition products and thus becomes an important source of acquiring and maintaining competitive advantages on the market. Alas, the product design often enters the development process of the new and/or improved product too late, so that its significance and meaning remain neglected. Good product design presents very important function of company’s business success. Each of us experiences the world in a different way. Reality is for the individual only what is perceived to exist or what occurs, and reality is altogether a personal phenomenon founded on personal needs, wants, values and experiences. The above mentioned tells of the fact that creators of consumer perception are a very important element which assists so as to meet the consumer’s wants in terms of products and services quicker and better. (Markovina, Kovačić, Radman, 2004). Today, design and innovation are present in the focus of interest of almost every company, simply because the transformation of ‘a simple product into a successful business’ can be provide only by the combination of design and innovation. Slowly and surely by interdisciplinary cooperation design creates products, production and business innovation. Furthermore, design is improving quality, competitiveness and is promoting companies economic growth and employment (Ojurović, Pirc, Bublić, 2007). Southeastern European wood industry companies have to observe design as a part of a business strategy. In addition, products and services oriented towards customers can be realized there where the design is connected to research and development activities as well as with commercialization at different levels of a value chain. Marketing, public relations and price reduction can be helpful over a short time, but investments in design and innovativeness business processes is precisely what wood industry companies of Southeastern European countries need. Design, innovations, and openness to new ideas help and will help wood industry manufacturers to survive global changes and to identify new business opportunities on new markets.

After successive growth in period 2002-2008 the round wood production in South-eastern Europe fell in 2008 and 2009. Thanks to rapid growth of demand for round wood in wood fuels production, wood based panels production and in households for heating purposes, the round wood production continued to grow in 2010 followed by 2011, 2012, and 2013. According to Glavonjić (2012) an important factor of round wood production growth in the Region represents its export which has been continuously increasing in last few years. Although Southeastern Europe countries have a tradition in using wood for energy there is a poor perception of the quality of domestic wood products in southeastern European countries. In addition, investment in innovative R&D and education of the workforce are essential to help the wood industry innovate and become more competitive through stronger regional cooperation in southeast Europe (FAO/UNECE, 2010). Competitiveness based on increased domestic furniture production, the quality of raw material potential, long-lasting tradition in wood processing and a rising trend in the use of wood as an ecological and renewable material are very important elements in increased production and total income are common elements in all Southeastern European countries when talking about wood industry.

The aim of this paper was to determine wood raw material consumption trends based on so-called apparent consumption and to present a future scenarios of wood industrial wound wood consumption in Southeastern European countries from 1990-ties up to present moment.

2. METERIALS AND METHODS

To meet the objective of this paper, data on the production, export and import of Industrial round wood of Southeastern European countries (Albania, Croatia, Bosnia and Herzegovina, Bulgaria,

Macedonia, Montenegro, Serbia, Slovenia and Romania) were analyzed for the period from 1993 to 2013. The analysis involved data obtained from the FAOSTAT *(Food and Agriculture Organization of the United Nations Statistic Division)* and from FAO *Yearbooks of Forest Products*.

The consumption of wood Industrial round wood was calculated on the basis of so-called apparent consumption. The method involved adding total import values of the industrial round wood to overall production values of the industrial round wood and subtracting the export value of industrial round wood at county level. The obtained values are expressed in quantitative (m^3) values.

To calculate per capita industrial round wood consumption per capita for each of Southeastern European county overall consumption of the industrial round wood of certain county was divided with the number of inhabitants of the country. The number of inhabitants of the Southeastern European counters was taken from European statistics web page.

3. RESULTS AND DISCUSSION

Industrial round wood consumption in SE- European countries

According to results of industrial round wood, an average consumption of industrial round wood in SE-European countries can be categorized into four groups:

1. Romania with average consumption more than 10 million m3;
2. Bosnia and Herzegovina, Bulgaria and Croatia with an average consumption between from 2,4 and 2,7 million m3;
3. Serbia and Slovenia with an average consumption from 1,4 to 1,8 million m3; and
4. Albania, Macedonia and Montenegro with an average consumption from 71.000 to 185.000 m3 (Table 1 and Figure 1).

Group categories aggrading to an average consumption seen in Tables 1 and Figure 1 can be affirm by analysis of industrial round wood production of SE-European countries in 2013 (Figure 2) in which shares of production of individual SE-European countries in total production of SE-European countries were categorized in the same groups.

Table 1. *Descriptive Statistics of Industrial round wood consumption (IRW) in m3*

State Code	Valid N	Mean m^3	Std.Dev. m^3	Coef.Var. %	Minimum m^3	Median m^3	Maximum m^3	Conf. -95% m^3	Conf. +95% m^3
ALB	21	70.722	19.477	27,5	15.063	75.323	122.621	61.856	79.588
BIH	17	2.681.942	392.961	14,7	2.030.860	2.602.100	3.332.000	2.479.900	2.883.984
BGR	21	2.424.810	513.219	21,2	1.642.567	2.521.890	3.240.752	2.191.195	2.658.425
HRV	21	2.528.707	681.206	26,9	1.445.200	2.522.000	3.731.000	2.218.625	2.838.788
MKD	21	148.143	22.355	15,1	106.000	154.000	192.000	137.967	158.319
MNE	8	184.793	50.376	27,3	147.198	172.232	300.058	142.678	226.908
ROU	21	10.361.961	1.453.785	14,0	7.768.639	9.862.700	12.824.000	9.700.206	11.023.716
SRB	8	1.434.789	108.925	7,6	1.289.000	1.413.000	1.665.000	1.343.725	1.525.852
SVN	21	1.779.267	320.263	18,0	956.374	1.801.000	2.387.647	1.633.485	1.925.049

In 2013, as seen in Figure 2, a share of Romanian industrial round wood production was about 50% of total SE-Europe industrial round wood production. A share of industrial round wood production in Bosnia and Herzegovina, followed by Bulgaria and Croatia was between 10 and 15% of total SE-European Industrial round wood production. Furthermore, a share of Serbian and Slovenian industrial round wood production represent from 5 to 6 % of total SE-European IRW production.

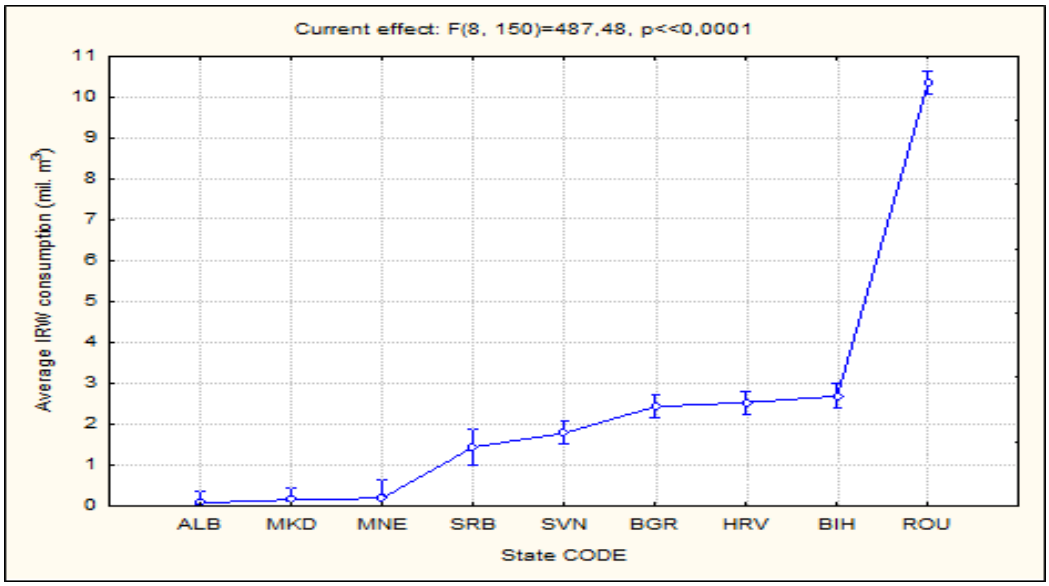

Figure 1. *Comparison of SE-Europe countries in average IRW consumption in* m^3

Industrial round wood production of Albania, Macedonia and Montenegro represent less than 1% of total production of industrial round wood in South Eastern European countries.

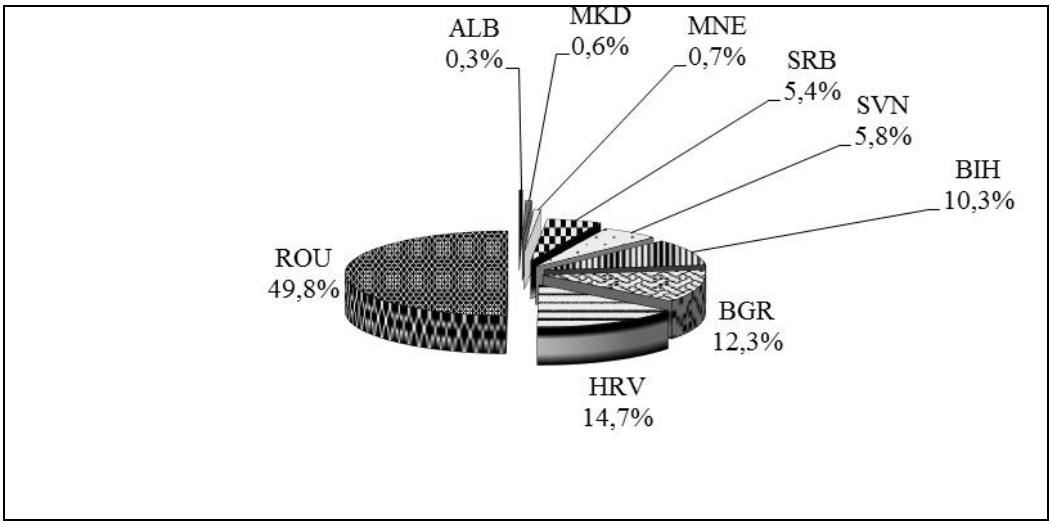

Figure 2. *Participation of the countries in IRW consumption in 2013*

Industrial round wood consumption per capita in SE European countries

As seen in Table 2 and Figure 3, an average consumption of industrial round wood per capita per year per 1000 people in SE-European countries can also be categorized into three groups:

1. Romania, Croatia, Bosnia and Herzegovina, and Slovenia with consumption from 500 to 900 m3/year per 1000 people;
2. Serbia, Macedonia, Bulgaria with consumption between 200 and 350 m3/year per 1000 people; and
3. Albania and Montenegro with consumption below 100 m3/year per 1000 people.

Table 2. *Descriptive Statistics of Industrial round wood consumption (IRW m3/year per 1000 people)*

State Code	Valid N	Mean m^3	Std.Dev. m^3	Coef.Var. %	Minimum m^3	Median m^3	Maximum m^3	Conf. -95% m^3	Conf. +95% m^3
ALB	21	24,4	6,7	27,5	5,2	26,0	42,3	21,3	27,5
BIH	17	700,1	102,6	14,7	530,1	679,2	869,8	647,3	752,8
BGR	21	334,7	70,8	21,2	226,7	348,1	447,3	302,4	366,9
HRV	21	595,4	160,4	26,9	340,3	593,9	878,5	522,4	668,5
MKD	21	238,4	36,0	15,1	170,5	247,8	308,9	222,0	254,7
MNE	8	89,5	24,4	27,3	71,3	83,4	145,3	69,1	109,8
ROU	21	517,6	72,6	14,0	388,0	492,6	640,6	484,5	550,6
SRB	8	200,8	15,2	7,6	180,4	197,7	233,0	188,0	213,5
SVN	21	863,3	155,4	18,0	464,0	873,8	1.158,4	792,5	934,0

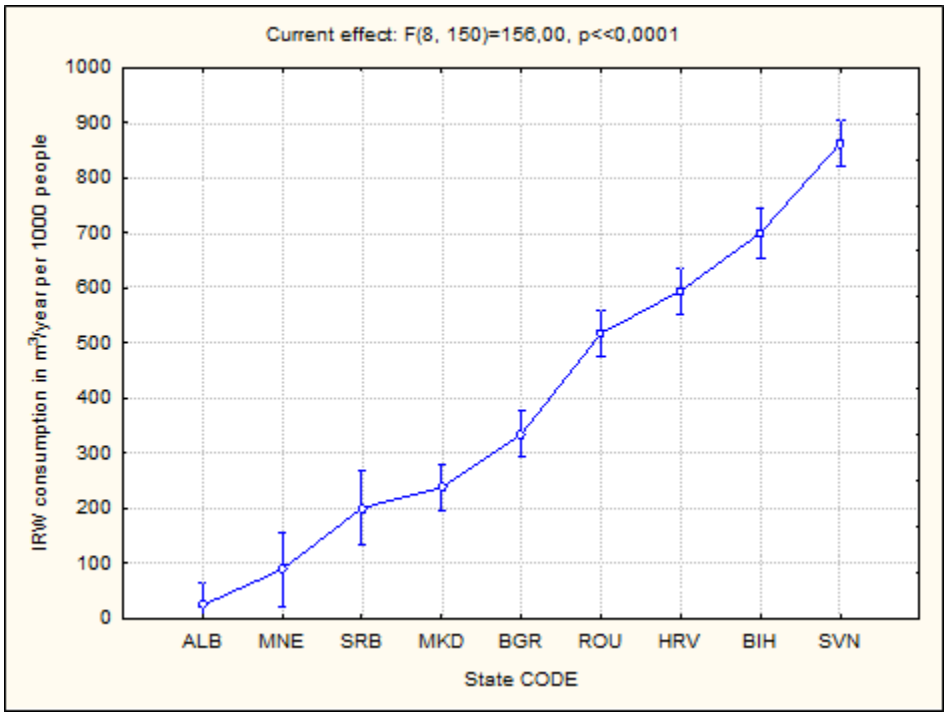

Figure 3*. Comparison of the countries in average IRW consumption in* m^3*/year per 1000 people*

Group categories aggrading to an average consumption *per capita* seen in Table 2 and Figure3 can be affirm by analysis of industrial round wood production *per capita* of SE-European countries in 2013 (Figure 3) in which shares of production *per capita* of individual SE-European countries in total production of SE-European countries were categorized in the same groups.

In 2013, as seen in Figure 3, a share of Romanian, Croatian, Bosnian and Slovenian industrial round wood production *per capita* was from 16 to 23% of total SE-Europe industrial round wood production *per capita*. A share of industrial round wood production in Serbia, followed by Macedonia and Bulgaria was between 5 and 11% of total SE-European Industrial round wood production *per capita*. Furthermore, a share of Albanian and Montenegro industrial round wood production *per capita* represent a less than 3% of total SE-European IRW production.

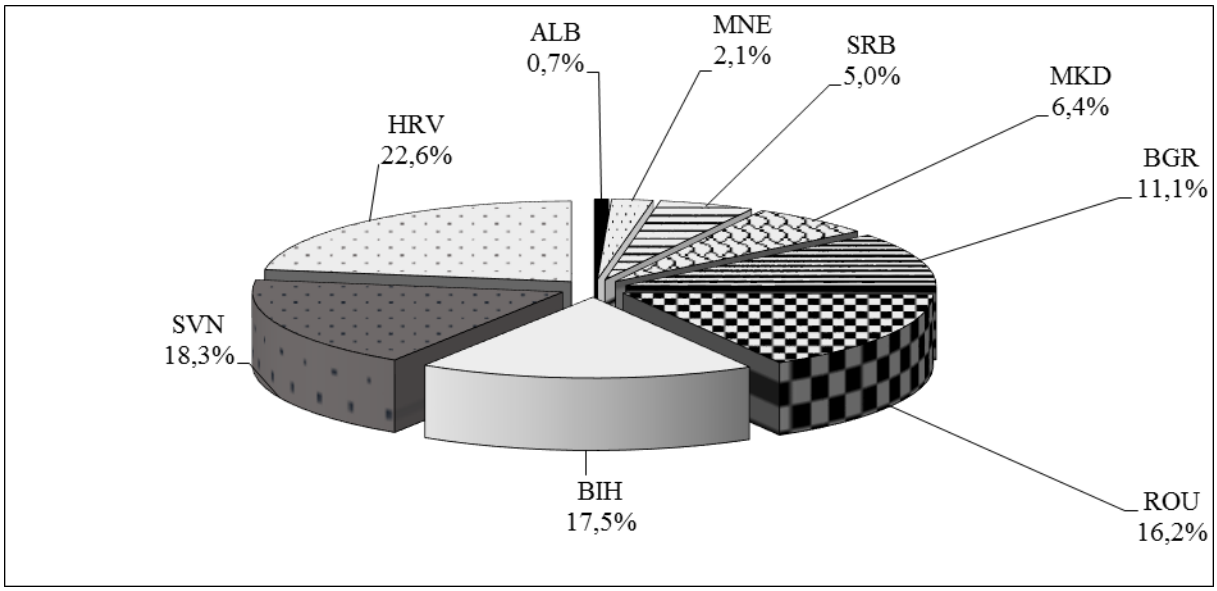

Figure 4. *Participation of the countries in IRW consumption per capita in 2013*

Industrial round wood projections of South Eastern European countries

For the purpose of projection for IRW consumption in SEE first we interpolate the missing data for BIH (1993-1996) and for MNE and SRB (1993-2005) with average values that they gained in original base.

According to Blažević (2007), when the rates of change in successive time periods are approximately equal, and assuming that the average rate of change will not change, with the average rate of change can be predict variable values in future period. Based on the average rates of change for IRW consumption in mil. m^3 (2,14%) and IRW consumption in m^3/year per 1000 people (1,78%) in the observed period, models A for prediction of future values of IRW consumption were developed.

Correlation analysis to determine the degree of correlation between the values of consumption as dependent variables and time (*t*) as independent variable was used. We found that the direction and strength of the correlation relationship was positive and relatively high in both cases (r_1=0,68; r_2=0,58), so we developed linear trend models (models B) for prediction of future values of IRW consumption.

In all models, *t* is mark for the *time*, where *t* = 0 compared to year 1993, *t* = 1 for year 1994; ... , *t* = 15 to year 2008, etc. Unit for predict values of IRW consumption is mil. m^3. Unit for predict values of IRW consumption per capita is m^3/year per 1000 people. Constructed models A and B for predicting the future values of IRW consumption are shown in Table 3.

Table 3. *Models A and B for calculating the future IRW consumption values for SEE countries*

Models	Export (mil. €)	Import (mil. €)
model A	$\hat{C}_A(t) = 16,6 \cdot 1,021^{(t-1)}$	$\hat{C}_A^{pc}(t) = 2732,8 \cdot 1,018^{(t-1)}$
model B	$\hat{C}_B(t) = 0,245 \cdot t + 19,166$	$\hat{C}_B^{pc}(t) = 28,408 \cdot t + 3279,9$

Comparison of existing and calculated predicted values by models A and B for IRW consumption in mil. m^3 are shown in Figure 5, while the comparison of existing and calculated predicted IRW consumption per capita values are shown in Figure 6.

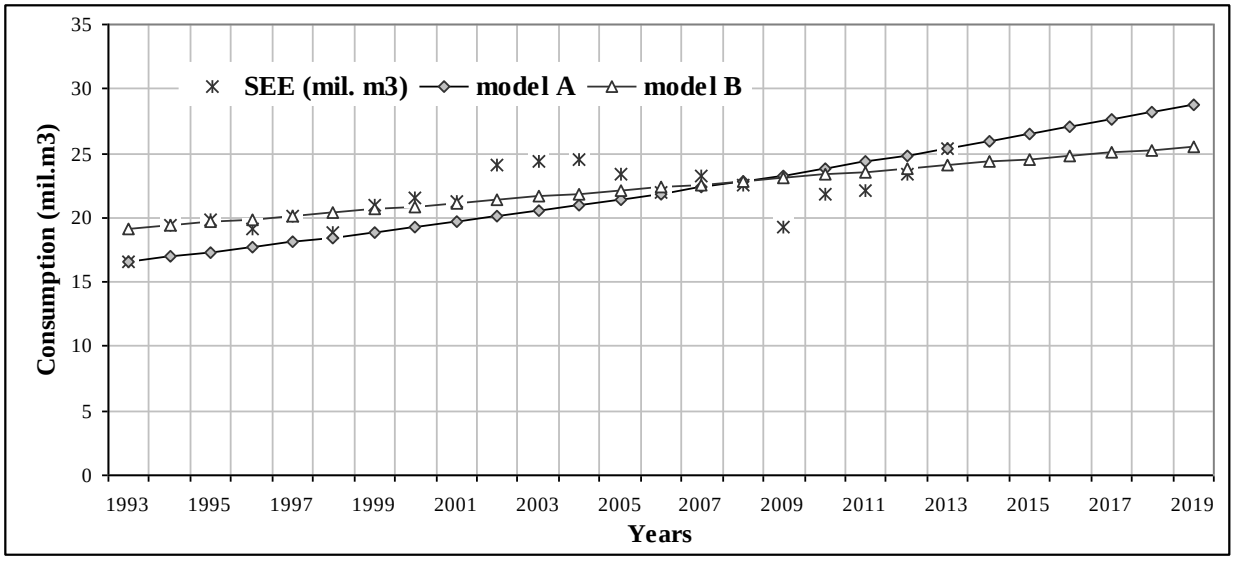

Figure 5. *Existing and projected IRW consumption values for SEE countries*

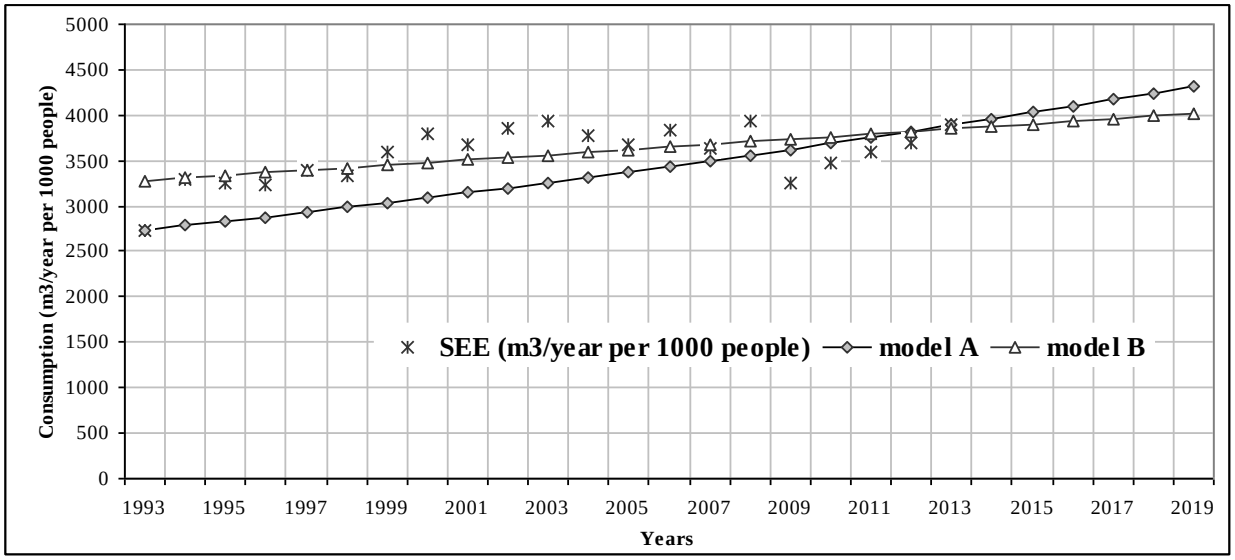

Figure 5. *Existing and projected IRW consumption per capita values for SEE countries*

According to the linear trend models (models B), the expected linear increase in the annual IRW consumption values for SEE countries is 0,245 million m3 and expected linear increase in the annual IRW consumption per capita values is 28,4 m^3/year per 1000 people.

4. CONCLUSIONS

South Eastern European countries according to an average consumption of industrial round wood can be categorized into four groups: (1) Romania, (2) Bosnia and Herzegovina, Bulgaria and Croatia, (3) Serbia and Slovenia, and (4) Albania, Macedonia and Montenegro with an average consumption from 71.000 to 185.000 m3 (Table 1 and Fig. 1). These categories can be affirmed by analysis of industrial round wood production shares in SE-European countries in 2013.

Additionally, an average consumption of industrial round wood per capita per year per 1000 people in SE-European countries can also be categorized, but into three groups: (1) Romania, Croatia, Bosnia and Herzegovina, and Slovenia, (2) Serbia, Macedonia, Bulgaria, and (3) Albania and Montenegro. These categories can be affirmed by analysis of industrial round wood production *per capita* shares of SE-European countries in 2013.

Furthermore, linear trend models (models B), the expected linear increase in the annual IRW consumption values for SEE countries is 0,245 million m3 and expected linear increase in the annual IRW consumption per capita values is 28,4 m^3/year per 1000 people.

The tradition in region of using wood should be built upon through modern and innovative production and business activities and well-designed wood products and SEE countries should promote consumption of wood and wood products.

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The Authors’ Addresses:

Andreja Pirc Barčić, Ph.D. (Corresponding author)
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: apirc@sumfak.hr

Maja Moro, Ph.D.
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: mmoro@sumfak.hr

Branko Liker, M.Sc.
Drvenjača d.d. – Fužine,
Donje Selo 62, Fužine, CROATIA
e-mail: branko.liker@drvenjaca.hr

Prof. Darko Motik, Ph.D.
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: motik@sumfak.hr

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RESEARCH OF THE PROCESSING QUALITY IN CUTTING POPLAR LOGS WITH DIFFERENT NARROW BANDSAW BLADES

Valentin Atanasov

University of Forestry, Faculty of Forest Industry, Sofia, Bulgaria,
e-mail: vatanasov_2000@yahoo.com

ABSTRACT

The report presents experimental results in the cutting logs with narrow bandsaw blades with normal, hardened and stellite-tipped teeth. As an evaluation indicator, roughness of the resulting surfaces, dimensional accuracy and straightness of the cut were used. The place of the studies was "Chakarov-Davidkov Co" manufacturing facility in the city of Boboshevo. The cutting logs are of poplar (Populus spp.). As a work station, a mobile horizontal bandsaw “Wood-Mizer” LT 40 was used. The obtained experimental results were analyzed.

Key words: logs, narrow bandsaw blades, mobile horizontal bandsaw, poplar

1. INTRODUCTION

In the recent years, mainly in small and medium sized woodworking manufacturing facilities, the modern horizontal bandsaws for logs are widely used. These machines are considerably easier to maintain and require a smaller investment than the classical vertical bandsaws for logs. Currently, there is not a wide variety of bandsaw blades for this machines. The profile shape of their teeth is *W* and they can be normal, hardened and stellite-tipped (Atanasov 2014). However, the price between different types can vary within wide range. The question “Is it necessary to buy expensive cutting tools?” arises.

Surface quality in mechanical processing of timber is determined by the resulting macro and micro bumps, residual deformation and destruction (Ivanovsky et al. 1972, Bershadsky and Tsvetkova 1975) (Figure 1).

$$h=m+h_1+h_2 \quad (1)$$

where: m is the maximum height of micro bumps;
h_1 – the maximum height of the resulting residual deformations and destructions;
h_2 – the maximum amplitude macro bumps.

The macro bumps represent depressions or protrusions on the flat surfaces of the parts and have a relatively large size. They are primarily concerned with the accuracy of the timber shape (straightness of the cut) rather than the roughness. The micro bumps represent traces of the cutting tool, micro destruction, mossiness and jamming (Gochev 2005).

Obtaining lumber with good quality is an important indicator which characterizes the work of the interconnected system “machine - cutting tool – work piece”. The very name of this system suggests that the main factors that influence the resulting timber will be associated with: working and geometric accuracy of the machine; linear, angular parameters and the preparation of the cutting tool; wood species, moisture content, density, defects etc. Besides them, as another important factor, the kinematics of the cutting process can be indicated as well. Perhaps the presence of such various factors

is the reason that still there are no usable mathematical models to evaluate the relation between indicators of assessment such as roughness and the input parameters (Wilkowski et al. 2010).

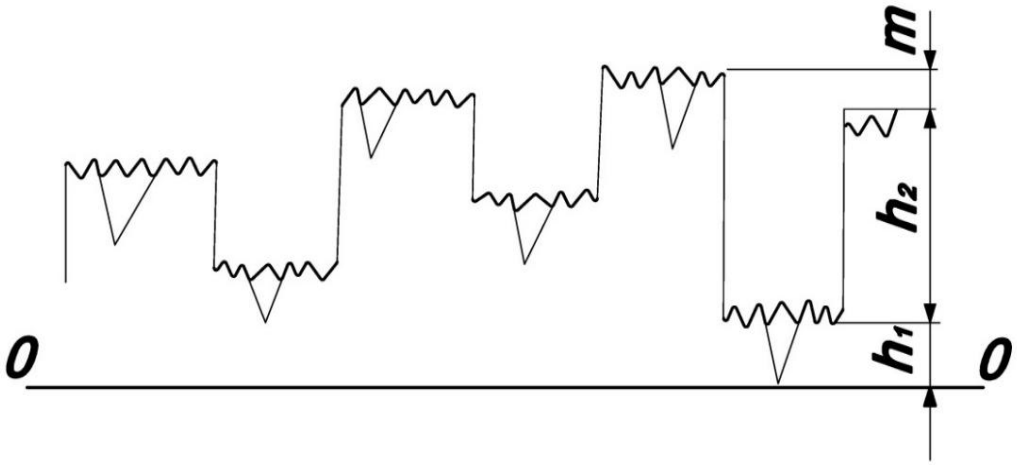

Figure 1. *Qualitative characteristics of the processed surfaces (by Bershadsky and Tsvetkova 1975)*

When cutting wood, the indicators for assessing the quality of processing are: roughness accuracy of shape and dimensions.

Roughness (cleanliness) of the machined surfaces depends on the degree of correlation between actually received bumps on the surfaces and their theoretical smoothness. This indicator is perhaps the most widely studied of the current considered when cutting logs with wide and narrow bandsaw blades (Tritchkov 2006, Gochev 2008, Atanasov 2014).

The accuracy of the shape of the object is determined by deviation of the building surface straightness (Kyuchukov et al. 2010). The determination of this indicator is interesting in harder regimes of cutting with bandsaw machines. The reason for this is the lower lateral stability of the bandsaw blade as a cutting tool.

Dimensional accuracy represents the difference between received and preset sizes of the lumber. This indicator represents the interest despite the low requirements for machines for primary processing of wood as well.

Often in the practice the poplar proved as a difficult for cutting wood species, especially in high moisture content. On the other hand, materials showing experimental results when cutting this wood species with modern narrow blades for horizontal mobile bandsaw are difficult to be found in the literature. Consistent results are of interest for the practice and determine the orientation of this study: determination of the influence of the type of the cutting tool on the quality of processing of the lumber.

2. METHODOLOGY

The experimental studies on the influence of the bandsaw blade over the quality of processing were performed in "Chakarov-Davidkov Co" manufacturing facility in the city of Boboshevo. They were part of preliminary experiments to determine the levels of variation of some technological factors when performing a more comprehensive study to determine the operational indicators of mobile horizontal bandsaws (Atanasov 2014).

One of the most widespread worldwide model of mobile horizontal bandsaw “Wood-Mizer” LT 40 was used. Figure 2 shows the general view of the machine.

Some of the more important technical features of the machine are:

– saw wheel diameter, $D_{w.}$=483 mm;

– power of the motor which drives the leading wheel, $N_{m.}$=11 kW;

– revolutions of the motor's shaft, $n_{m.}$=48,67 s^{-1};

– distance between the axis of the wheels, L_0 = 1240 mm;

– diameter of the electric motor pulley, D_1=100 mm;

– diameter of the wheel pulley, D_2=320 mm;
– cutting speed, V=23 m.s^{-1};
– length of the machine, $L_м$=8000 mm;
– width of the machine, B_m=2000 mm;
– height of the machine, H_m=3200 mm;
– weight of the machine, m_m=1769 kg.

The linear and angular parameters of the bandsaw blades, provided by the manufacturers, are presented in Table 1. The cutting tool № 1 is with normal teeth, № 2, 3 and 4 with hardened and № 5 stellite-tipped.

Figure 2. *General view of “Wood-Mizer” LT 40*

Table 1. *Used in the experiments bandsaw blades*

№	Name	Manufacturer	Rake angle α,°	Clearance angle γ,°	Width B, mm	Thickness s, mm	Pitch t, mm
1.	*Premium*	*Carl Röntgen* (Germany)	10	30	40	1,1	22,2
2.	*Premium*	*Carl Röntgen* (Germany)	10	30	40	1,1	22,2
3.	*X-treme*	*Carl Röntgen* (Germany)	10	30	40	1	22,2
4.	*DoubleHard*	*Wood-mizer* (USA)	10	30	38	1,1	22,2
5.	*RazorTip*	*Wood-mizer* (USA)	10	30	38	1,1	22,2

The preparation of the cutting tools include sharpening and making the part-set size (s' ≈ 0,55 of the teeth for all bandsaw blades). Pre-tensioning of the blade affects the accuracy of the shape and dimensions of the obtained lumber (Atanasov 2014). For these studies the pre-tensioning was fixed at 14,5 MPa.

The cutting timber was poplar. Some of the used for the experimental study logs are shown in Figure 3. Their moisture content was determined by a hygrometer “Lignomat” (Germany) with precision of the measurement 99,8 %. The density of the wood is calculated using a caliper and electronic scale “RADWAG WLC 1/A2” (Poland), with a measurement range 0,5 ÷ 1000 g and

precision 0,5 g. Another factor that influences the power-energetic parameters of the cutting process and the quality of machining is the temperature – especially when its values are below zero degree Celsius. In this study, the temperature and humidity are measured with the device “MASTECH MS 6300” (China).

Figure 3. *Test specimens of poplar*

The determination of surface roughness is performed by the parameter $\bar{R}m$ (*Rv* in BDS EN ISO 4287), which is defined as the distance between the line of protrusions and depressions within a base length (Gochev 2005). Indicator gauge with measuring clock according to standard BDS 4622-86 was used.

The accuracy of the shape is determined by considering the absolute values of deviations from straightness of the cut. A gauge blocks set, a feeler gauge and a measuring line with length 2 m were used (Figure 4).

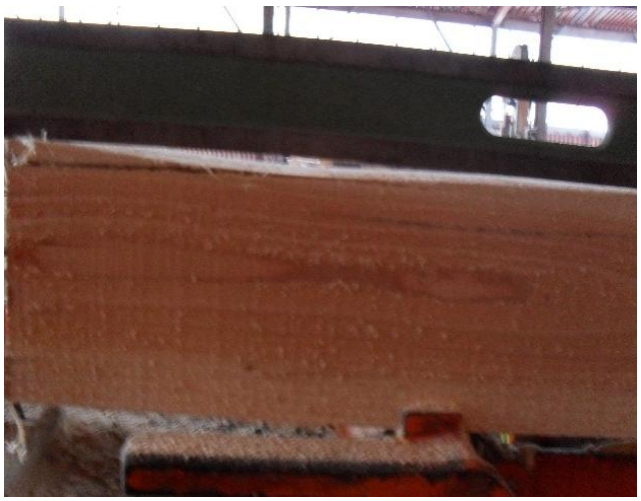

Figure 4. *Determination of the straightness of the cut (accuracy of the shape)*

The dimensional accuracy is determined by measuring the thickness of the resulting lumber of both sides.

The measurement points for the relevant indicators, adopted as criteria for quality of machining, are 20 – shown in Figure 5 (Genchev 1978, Atanasov 2014). The distance between them is equal and depends on the length of the cutting material. After their reporting the average value was calculated.

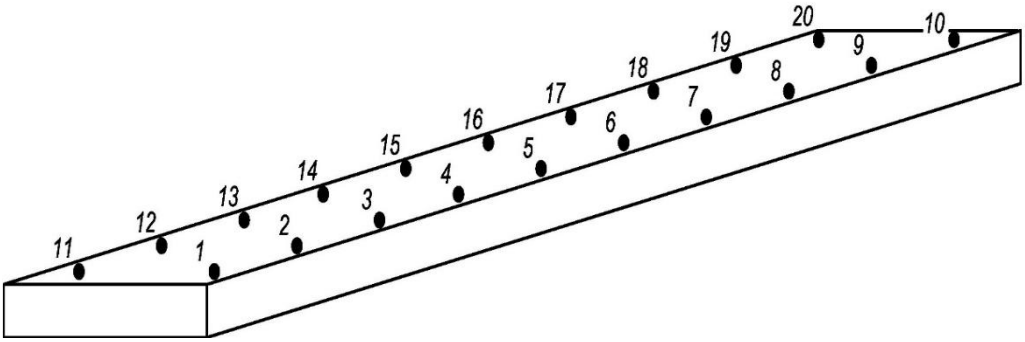

Figure 5. *Scheme for the determination of roughness, accuracy of shape and dimensions*

The feed speed was determined by measuring the length of the respective material and cutting time

$$u = \frac{L}{t}.60 \tag{2}$$

where L is the length of the cutting material, m;

t – duration of the respective cut, s.

The quantity of processed timber is associated with wear of the cutting tools which materially affects the quality of machining. In this study the quantity processed timber defined in m^2 and not in m^3

$$Q = L.h \tag{3}$$

where h cutting height, m.

The reason is that the logs cutting scheme would have a significant impact.

3. RESULTS AND DISCUSSION

When measuring the moisture content of the wood is determined that it is beyond the scope of the used hygrometer. Since the logs were cutting around 48 h after their minting, moisture content referred to in the literature was adopted ≈ 130% (Blaskova 2004). The measured density of the wood is 600 $kg.m^{-3}$. The average temperature in conducting the experiments is 15 ˚C and humidity 60 %.

During the experimental studies the values of the processed wood were defined, then the corresponding measurements were performed:

– at the lowest value of the feed speed: after cutting ≈ 10 m^2 of timber;

– at the middle value of the feed speed: after cutting ≈ 20 m^2 of timber;

– at the highest value of the feed speed: after cutting ≈ 30 m^2 of timber.

It should be noted that the cutting mechanism of the machine is equipped with debarker which cleans “the path" of the bandsaw blade. It protects the cutting tool of different abrasive particles caught on the bark of logs. Thus, the wear of the cutting tools is mainly due to the processed wood rather than the abrasive particles.

The results of measuring the surface roughness are shown in Figure 5. The values are obtained by cutting height of ≈ 200 mm. As can be seen from the figure, the blades *DoubleHard* and *Premium* with hardened teeth get the best results in terms of this indicator, i.e. roughness does not exceed 130 μm even after 30 m^2 processed wood and feed speed around 7 $m.min^{-1}$. The cutting teeth of these bandsaw blades have increased hardness obtained by electromagnetic induction.

Another cutting tool with good performance in terms of roughness is the bandsaw blade *RazorTip* which has welded stelitte to a top of the teeth. The stellite is a cobalt alloy consisting of cobalt (Co) to 65 %, chromium (Cr) to 30 % and tungsten (W) to 12 %. The properties that the stellite owns, as an alloy, create opportunities for quality processed lumber. Moreover, the obtained values with this

bandsaw blade are at higher rates of feed speed. As is known, the feed speed is an important factor influencing significantly over roughness on the one hand, and the productivity of the other. Their main disadvantage is during sharpening, when a layer of the hard alloy is removed. Therefore, after a certain operating period, this blades are converted into those with normal teeth. The same applies to blades with hardened teeth as well.

The bandsaw with normal teeth can be defined as the most unsuitable cutting tool. Later it proved to be a wrong choice in cutting poplar with high moisture content. As can be seen from Figure 5, the achieved roughness with this cutting tool reaches 150 μm, even at feed speed ≈ 6 m.min^{-1}. The main reason for this is the rapid blunting of the cutting tools teeth.

About this indicator it is important to note that despite the clear relationship between feed speed and roughness (Figure 5), because of the high moisture content and fiber structure of the poplar, the reporting of this indicator is a difficult task.

Figure 6 shows the results for the deviations of nominal dimensions of the obtained lumber. The lowest values for the corresponding output values were obtained after the use of bandsaw blades *X-treme*, *DoubleHard* and *Premium* with hardened teeth. As can be seen the deviation does not exceed 1,2 mm, in all three cutting tools. Comparing the results of the three blades can be seen that those for *DoubleHard* are obtained at a slightly higher value of the feed speed.

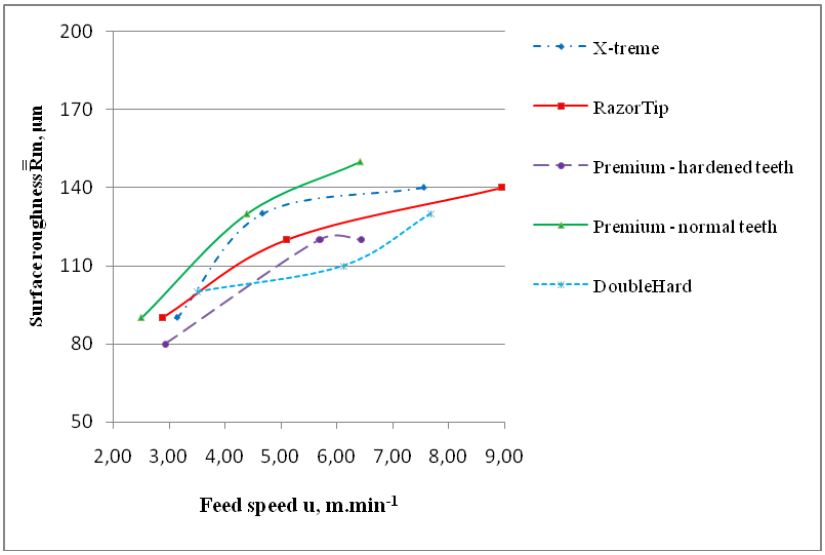

Figure 5. *Results of surface roughness measurements*

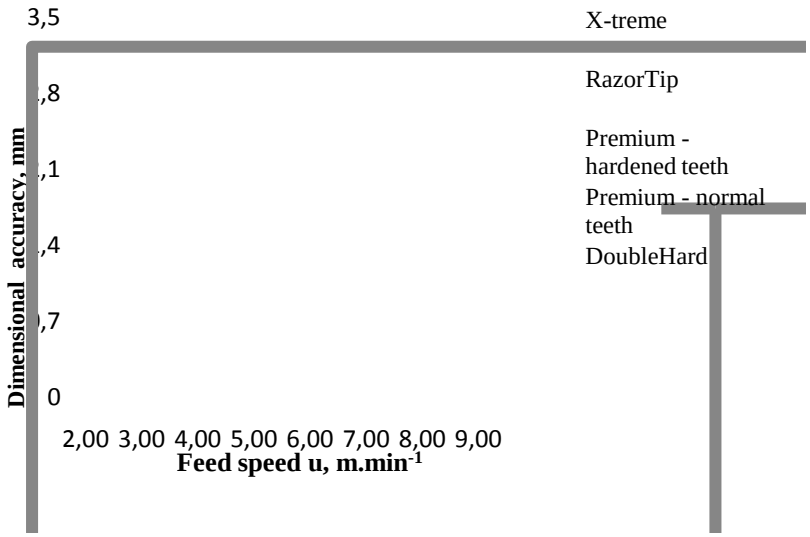

Figure 6. *Results of dimensional accuracy measurements*

The cutting tool with stellite-tipped teeth also showed good results compared to others. The largest deviations with this blade are 1,9 mm but the feed speed exceeds that of the other cutting tools.

Once again, regarding the dimensional accuracy, it was confirmed that the blade with normal teeth is not suitable for cutting poplar with a high moisture content. As can be seen from the figure, even after the cutting 20 m^2 and a feed speed of 4,2 $m.min^{-1}$, the obtained results exceed most of those for the other cutting tools, even after 30 m^2 processed timber.

The results of the accuracy of the shape measurements show that the most appropriate cutting tool is *X-treme*. As can be seen from Figure 7, the resulting deviations are from 0,3 to 0,5 mm, at a feed speed of more than 7 $m.min^{-1}$ and after more than 30 m^2 processed wood.

The average results on this indicator are obtained with the bandsaw blades *DoubleHard* and *Premium* with hardened teeth. The deviations from linearity with the blade *DoubleHard* after 30 m^2 are bigger, but they are measured at a feed speed of over 7,5 $m.min^{-1}$.

The blade with stellite-tipped teeth *RazorTip* obtained satisfactory results as well, again at a higher feed speed.

The results with the blade with normal teeth are not presented in Figure 7. As with the previously reviewed indicators, here once again, this cutting tool proved to be an inappropriate choice. Figure 8 shows a curved cut obtained by cutting with normal teeth bandsaw blade.

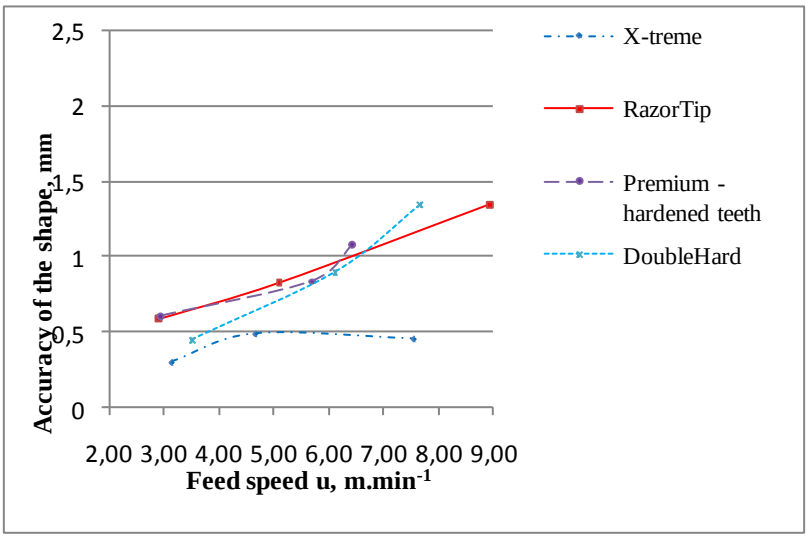

Figure 7. *Results of straightness of the cut measurements*

Figure 8. *Curvilinear cut in operating with Premium (normal teeth)*

4. CONCLUSION

Poplar has a lower density but its fibrous structure and high humidity proved that it is a difficult for cutting wood species. In addition, the availability of double heart, branching, fiber slope etc. can be identified. Moreover, when reaching the lower part of the trunk during processing, the cutting becomes transversely to the wood fiber. This produced an additional wear of the cutting tools.

Based on experimental studies on the quality of poplar logs processing in these conditions, the following conclusions and recommendations can be made:

1. The accurate measurement of surface roughness after processing fresh cut poplar logs is a difficult task. The reason for this is the high moisture content and fiber structure which leads to the eventual filling of the micro bumps. Therefore, the quality of processing in this case, is more appropriate to be determined mainly by the indicators accuracy of the dimensions and shape (deviation from nominal dimensions of the resulting lumber and deviation from straightness of the cut).
2. When cutting poplar wood with high moisture content it is recommended to use blades with hardened and stellite-tipped teeth. The blades with the normal teeth are not appropriate when cutting timber with more defects because they wear out even after several cuts.
3. The cutting tool with stellite-tipped teeth allows a higher feed speed. It is therefore appropriate when looking for higher productivity. However, its cost is significantly higher than that of the other considered cutting tools.
4. The cutting tools *X-treme*, *DoubleHard* and *Premium* with hardened teeth receive approximately the same results. Considering the fact that the results for the first two cutting tools are obtained at higher feed speed, they can be identified as the most appropriate.
5. Regardless of the blade, in cutting of poplar under these conditions, it is not recommended high feed speed. The reason for this is the risk of obtaining a curved cut (Figure 8).

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The Author’s Address:

Valentin Atanasov, Ph.D.
University of Forestry,
Department of Woodworking Machines,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: vatanasov_2000@yahoo.com

UDC (UDK): 684.4.07

COMPARATIVE ANALYSIS OF THE DEFORMATION BEHAVIOR OF UPHOLSTERY MATERIALS

Yancho Genchev, Teodor Lulchev

University of Forestry – Sofia, Bulgaria,
Faculty of Forest Industry –Sofia,
e-mail: genchevy@abv.bg; teodorl72@yahoo.com

ABSTRACT

The flexible polyurethane foams differ significantly in their characteristics depending on their application in the structure of the upholstery.

The study examines the deformation behavior of different types of polyurethane foam used in upholstery. As criteria for evaluation of the material are used coefficients of softness and requirements for general deformation of the structure of the upholstery for seat and back elements. Based on the results conclusions are made and recommendations for their application in the structure of upholstered furniture.

Key words: polyurethane foam, upholstery, density, force-indentation (load deflection) curves

1. INTRUDUCTION

Production of upholstered furniture in the countries of the European Union for 2013 amounted to 12.5 billion euros, including 4.2 billion for the new EU members. First is Poland with 2.55 billion. Unlike the Western European market of upholstered furniture, that in the new member states increased in 2013 compared to 2012 (Dupont, 2014).

The use of flexible polyurethane foam began in 1954 and since then its share is steadily increasing. He is also one of the main materials in the manufacture of mattresses. So in 2012 the market share of polyurethane mattresses sold in 7 Western European countries is 48.8% with 7.7 million units (Dupont, 2014). Over time except conventional polyurethane foam in production and use are introduced other types as the main are high resilience (HR) and low resilience (known as “viscoelastic”) foams. Viscoelastic foam is used mainly in mattresses, while HR gaining wider use in upholstery and mattresses.

The properties of the polyurethane foam are strongly influenced by the density. It is an important indicator of foam performance with regard to comfort, support and durability (PFA, 1991). Higher density foams will exhibit less firmness loss (PFA, 1994). Qualities are influenced by the type of material. The HR foam has a higher support factor (SAG factor), elasticity and durability according to polyurethane foam manufacturers and traders of upholstery materials. This makes it suitable material for luxury and regularly used furniture and somewhat competitor with latex foam in mattresses. The hardness is important for the behavior of the flexible foams, especially for small loads. (PFA, 1994).

To determine the stress-strain characteristics of polyurethane foam is introduced various indicators:

- determination of the 25 % - 40 % - 65 % indentation hardness characteristics, support factor, compressive deflection coefficient and hysteresis loss rate and etc. (BDS EN ISO 2439:2009, ASTM D 3574-01a, ASTM D 3574-01b)
- determination of the compression load deflection (BDS EN ISO 3386-1:2004, ASTM D 3574-01c).
- indentation residual gage load test (ASTM D 3574-01d).

The Euro and US standards, however, although are similar but have technical differences that do not allow to directly compare data. Moreover, the standard criteria are determined only for certain thicknesses of materials - mainly 50 mm for Euro- and 102 mm for the US-standard. Dependence on thickness is not well clarified. Some producers, traders and upholsterers give more detailed information and practical advice on the application of the materials. For use in Bulgaria upholstery materials has limited available information. The use of new materials in the structure of the upholstery is mostly intuitive. This creates difficulties and errors at the correct use of the materials in the upholstery production. In Bulgaria were made studies of materials and types of upholstery. That was a long time ago and the data can't be considered valid. A newer study is (Ganchev, 1998). It is a detailed and analytical. Generalized is experience up to 90s'. Different materials were tested at various thicknesses and combinations. But, the majority of concrete studied materials, in particular flexible polyurethane foams no longer apply. Have not been studied and HR foams due to non availability at that time. Since 2000, there have been not comprehensive studies in Bulgaria, while the production, import and use of new materials is expanding. This requires new research for service of upholstered furniture industry imperative. Were tested variations of upholstery with spring packages with different combinations of materials (Genchev, Lulchev , Hristodorova, 2013).

The purpose of this study is stress-strain behavior of conventional and HR flexible polyurethane foams with different densities and compression load deflection and the influence of thickness.

2. MATERIALS AND METHOD

Were studied high resilience flexible polyurethane foams – KOVAFOAM HR 3535, HR 3030 and conventional flexible polyurethane foams KOVAFOAM N 3535, N 3030 produced by the company Parallel Sevlievo Ltd. We chose this company because it is one of the main supplier of polyurethane foams for Bulgarian market. The production method was continuous slabstock with raw materials from company BASF. These foams were selected for the comparison of a different types of foam with the same density and same compression load deflection. HR 3535 и N 3535 are key in the seat upholstery and can also be used for mattresses. Foams with density 30 kg / m3 are used as an analogue of HR 3535 and N 3535 in the upholstery of seats, for the upper layer of the seats and can be used for upholstery of backs. So the studied materials are an important function in the upholstery.

The test was performed by standard method (BDS 8962:1990). Specimens with dimensions 600x600 mm were tested. With these dimensions, different from the ones used in the standards for hardness and compression load deflection (380x380 mm), is avoiding the influence of the width and length on the magnitude of the indentation force for the same deformation. This effect is about 10% and shall be significantly reduced for foam with dimensions 500x500 mm and disappear up to 600x600 mm (PFA, 1994a). Thus the test results are comparable to those of the details in the upholstery that are similar sizes. The samples were tested in three thicknesses - 40, 80 и 120 mm.
Prior to the test, the test pieces was conditioned, undeflected and undistorted, for over 16 h in the following atmosphere - (23 ±2) °C, (50 ± 5) % relative humidity. The test pieces were supported on a smooth, flat, horizontal and rigid base with holes, to allow the escape of air from below the specimen. Initially samples were three times preloaded with subsequent unloading. Then were left for 10 minutes to rest. The initial thickness (height) was recorded under a load of 30N. The force was increased smoothly and the indentation was reported at interval 50N in 50 to 200N and at interval 100N in 200 to 1000N. The indentor is flat and circular, with a diameter 250mm.

The studied indicators are:

Initial coefficient of softness S_i is calculated using the formula:

$$S_i = \frac{H_{50} - H_{150}}{100} \text{ , mm/N} \quad (1)$$

where : H_{50} and H_{150} are the thicknesses (heights) of the samples loaded with 50 and 150N, mm.

The general deformation of the elements for sleeping and backs is defined by the formula:

$$D_{\text{glb}} = H_0 - H_{300} \text{ , mm} \quad (2)$$

where: H_0 is the initial thickness of specimens determined at load 30 N, mm

H_{300} - the thickness of the samples at load 300 N, mm.

The general deformation of the elements for sitting is calculated according to the formula:

$$D_{gs} = H_0 - H_{700} \text{ , mm} \quad (3)$$

where: H_{700} is the thickness of the test specimens under load 700 N, mm.

The coefficient of softness of the elements for sleeping and backs is determined by the formula:

$$K_{slb} = \frac{H_{300} - H_{400}}{100} \text{ , mm/N} \quad (4)$$

where: H_{300} is the thickness of the specimens under load 300 N, mm;
H_{400} is the thickness of the samples at a load of 400 N, mm.

The coefficient of softness of the elements for sitting is determined by the formula:

$$K_{ss} = \frac{H_{700} - H_{800}}{100} \text{, mm/N} \quad (5)$$

where : H_{700} is the thickness of the specimens under load 700 N, mm;
H_{800} is the thickness of the samples at a load of 800 N, mm.

3. RESULTS AND DISCUSSION

The results for all indicators of all materials with a thickness of about 40mm, presented in Table 1, are with low values. Basically this is due to the small initial thickness and rigid base. HR 3030 is deflected 50% still in force of 50N (Figure 1). So it almost limited its capacity for additional deformation at higher loads. This makes it inapplicable for use alone in the upholstery with a small thickness. Its good soft feel makes it suitable for the top layer of upholstery with other basic materials (for example HR3535). Other materials have similar parameters (Table 1). Requirements for semi-soft upholstery for them can be achieved by using elastic basis.

Table 1. *Indicators of softness for polyurethane whit thickness of 40mm*

Polyurethane, 40mm	S_i [mm/ N]	D_{glb} [mm]	K_{slb} [mm/ N]	D_{gs} [mm]	K_{ss} [mm/ N]
HR 3535	1,1	20	0,15	25	0,05
HR 3030	0,5	12	0,1	16	0,05
N 3535	1,6	24	0,15	27	0,05
N 3030	1,1	19	0,15	23	0,05

Conventional foams have similar stress-strain curves and total vertical motion over HR 3535 foam. The dramatic change in the behavior of N3030 and N3535 foams over 200 N is due to the cause "bottom out" and creates discomfort. The curve of HR 3535 foam is more gradual, the support factor is higher (Figure 1).

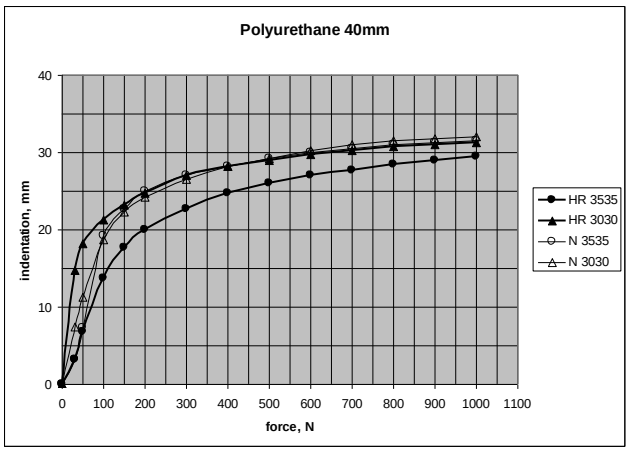

Figure 1. *Force-indentation curves for polyurethane whit thickness of 40mm*

The tested samples of conventional foams with 80mm thickness , meet (S_i) or near (D_{glb}) to criteria for soft upholstery of the elements for sleeping and backs (Table 2). They deflected more, but with a imbalance to 200 N and above this value (Figure 2), and therefore K_{slb} insufficient.

This thickness is also small to be able to HR 3030 foam has both softness at low load and deformation sufficient reserve for higher performance (Table 2, Figure 2). The high resilience test pieces deflected less, but their force-indentation curves are with smooth transitions and HR 3535 retain its supporting capacity to greater loads (Figure 2).

To achieve sufficient comfort with these thicknesses of material is necessary to use at least semi-elastic basis on the back and elastic for seat.

Table 2. *Indicators of softness*

Polyurethane, 80mm	S_i [mm/ N]	D_{glb} [mm]	K_{slb} [mm/ N]	D_{gs} [mm]	K_{ss} [mm/ N]
HR 3535	2,1	39	0,4	51	0,3
HR 3030	1,7	34	0,35	44	0,15
N 3535	2,7	48	0,4	60	0,15
N 3030	2,6	44	0,3	53	0,15

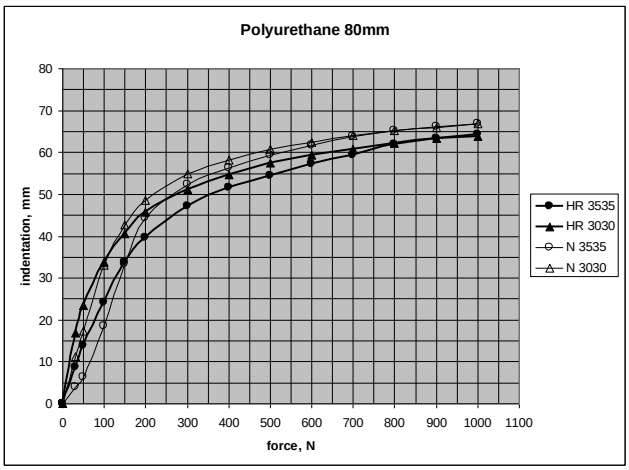

Figure 2. *Force-indentation curves for polyurethane whit thickness of 80mm*

When testing samples with thickness 120 mm, considering that these materials are used in combination with fiber wrap, the obtained indicators meet the criteria for a soft upholstery for sitting, sleeping and backs in a rigid base (Table 3). Force-indentation curves are with smooth transitions for all materials in the full range of loads (Figure 3). However, the linear region of the curves is less than that of the Pocket and Bonnell spring units of similar thickness (Genchev, Lulchev, Hristodorova, 2013).

Total vertical motion of the softer polyurethane foams exceeds that of its hardness analogues of HR and N type throughout the range with a gradual decrease for large loads. N-foams have greater indentation of their analogues in density and hardness of the series HR over 250 N load (Figure 3). As with other thicknesses HR-foams have a higher support factor, which is taken as an important indicator of the quality of the material and provide comfort.

Table 3. *Indicators of softness*

Polyurethane, 120mm	S_i [mm/ N]	D_{glb} [mm]	K_{slb} [mm/ N]	D_{gs} [mm]	K_{ss} [mm/ N]
HR 3535	2,3	52	1,1	82	0,4
HR 3030	2,6	53	0,8	73	0,3
N 3535	2,7	57	1,3	89	0,3
N 3030	3,0	62	0,8	86	0,3

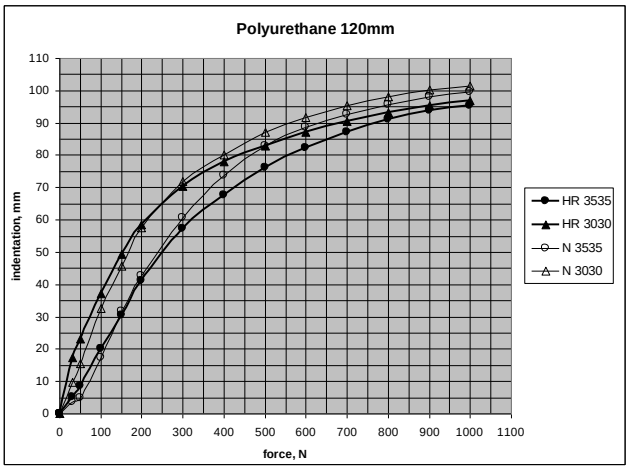

Figure 3. *Force-indentation curves for polyurethane whit thickness of 120mm*

4. CONCLUSION

1. For test materials type of flexible polyurethane foam (HR or N) is essential for the behavior under load and the degree of deformation.
2. Force-indentation curves become smoother transitions with increasing thickness.
3. Only in thicker softer foams (N3030 and HR 3030) are some indicators of softness that are larger than the more harder and dense foams. This determines the use for an upper cushioning layer of a small thickness or with a great thickness if is used alone.
4. HR 3535 and HR 3030 ensure better support at medium and large thicknesses. To achieve the performance of soft upholstery is necessary to have sufficient thickness over 80mm and used with elastic or semi-elastic basis.
5. The tested conventional polyurethane foams provide the required indicators of softness in smaller thicknesses, but it is also desirable to be thicker to ensure smoother stress-strain curves and sufficient load bearing capacity.

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The Authors' Addresses:

Yancho Genchev, Assoc. Professor,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
Tel: +359 2 91 907 / 209; Mob: +359 887 218 863
e-mail: genchevy @ abv.bg

Teodor Lulchev, Assist. Professor,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
Tel: +359 2 91 907 / 442; Mob: +359 885 803 604
e-mail: teodorl72@ yahoo.com

UDC (UDK): 662.63

CONTRIBUTION TO THE REDUCTION OF GHG EMISSION IN THE PELLET PRODUCTION

Gradimir Danon, Mladen Furtula

University of Belgrade, Faculty of Forestry
gradimir.danon@sfb.bg.ac.rs; mladen.furtula@sfb.bg.ac.rs

ABSTRACT

The paper presents possibilities of reducing greenhouse gas emissions in the production of pellets. The following two options are analyzed: reduction of the energy required to produce one tone of pellets and usage of electricity from renewable sources instead of electricity from the grid. Both approaches yield a positive result, but in the second case, the effects are more severe. The second case implies that the heat supply system for pellet plant is to be expanded with CHP equipment. Assumptions were confirmed by a detailed calculation made for the actual pellet plant of medium capacity.

Key words: energy efficiency, heat, electric power, GHG emissions, CHP (Cogeneration or combined heat and power)

1. INTRODUCTION

According to data for 2013 (Glavonjić and Vukadinović, 2014) in Serbia there was 42 pellet plant. The pellets production in that year, according to same source, was about 167,000 t (Figure 1).

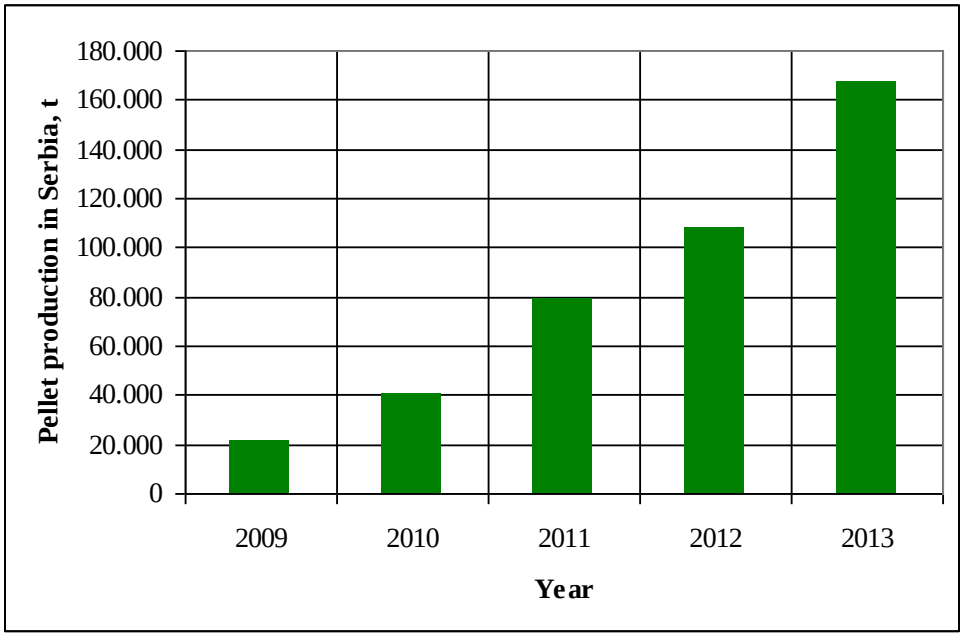

Figure 1. *The pellet production in Serbia (Glavonjić and Vukadinović, 2014)*

The raw material for the production of pellets is mainly beech wood. To produce one ton of pellets it is necessary to spend 1.553 m^3 of solid wood, or 2.2 m^3 of stacked wood (Furtula, 2014) so for total

production in 2013, it took 260,000 m^3 of solid wood or 360,000 m^3 of stacked wood. This is a significant amount of high-quality wood fuel. All pellet producers possess certificates on testing of quality of wood pellets usually preformed in export countries.

Domestic consumption of pellets in Serbia is constantly growing since 2009 (the year of the beginning of the industrial production of pellets in Serbia) but has not yet reached 40% of the production realized in the same year (Figure 2).

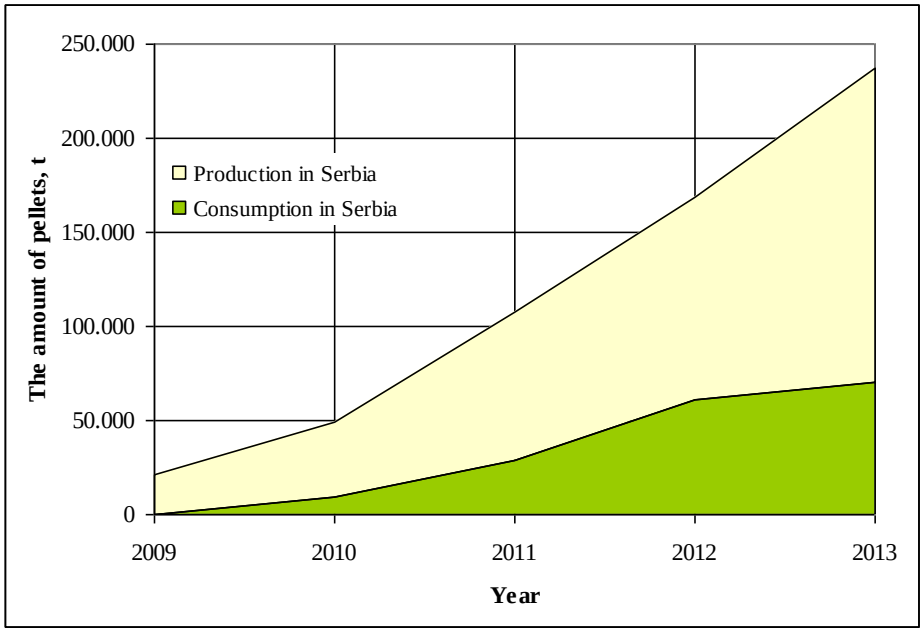

Figure 2*. The production and consumption of pellets in Serbia (Glavonjić and Vukadinović, 2014)*

Barriers to further increase of domestic consumption are underdeveloped and unregulated markets of pellets and equipment for their combustion.

The increasing awareness of climate change issues, unstable fossil fuel prices and concerns about energy security are leading to a rising demand for wood fuels (Lindholm, 2010). The decision of the majority of countries in the world to encourage use wood based fuels is based on the following assumptions:

- Wood is (conditional) a renewable energy source. The assumption is valid only on condition that the annual consumption of wood for all purposes, including for the production of energy, less than the annual increase of wood in the same territory. This assumption is fulfilled in Serbia because for many years there is a positive difference between the annual allowable cut and the volume of timber harvest. That conclusion is confirmed by official statistics (Bulletin, 2013) and the National Forest Inventory of Republic of Serbia (Banković et al, 2009).
- Wood is the (conditional) CO_2 neutral fuel. This condition is reached in Serbia if the previous assumption about wood as a renewable energy source is correct. In the case it is not so, part of the emissions of greenhouse gases from the combustion of wood would remain permanently in the atmosphere increasing the already high concentration.
- All required energy necessary for pellet production is provided from renewable sources. This requirement is not fully filled anywhere in the world. In the production of pellet, directly or indirectly certain amounts of fossil fuel are used, so that pellet "burdened" with a certain amount of greenhouse gases.

Problems related to the renewability of the forest fund and responsibilities for the harmful emissions of greenhouse gases have been even greater if produced wood fuel is solely or mainly exported. In this case, the negative effects on the environment remain with the manufacturer and the buyer acquires the benefits of using CO_2 neutral wood pellets.

The paper analyzes the consumption of wood and all forms of energy in a large pellet plant in Serbia. The raw material and energy necessary for the production of one ton of the pellets, as well as

emissions of greenhouse gases were calculated. Obtained results were compared with similar indicators from the literature. In the next step of the research of opportunities for improving energy efficiency of pellet production and reduction of emissions of greenhouse gases were done. The aim was to increase the ratio of usable energy acquired and expanded (EROEI) and reduce global warming potential (GWP) of gases emissions occurring in the pellet production process.

2. MATERIAL AND METHODS

The production of wood pellets begins with the generation of the raw material. In most cases, this raw material is a by-product of some other wood processing operation. It is an ideal raw material for the production of wood pellets because it is relatively dry and partially fragmented. The situation in Serbia is different. A raw material for the production of pellets are mainly firewood and round wood which should first be debarked (in our factories that is quite rare) and then reduced in size using chipper.

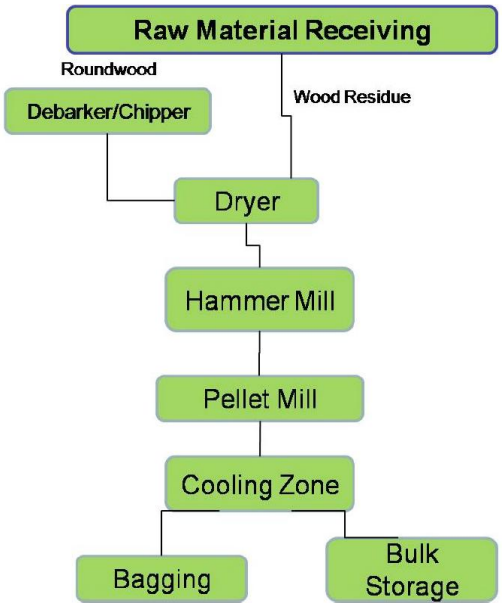

Figure 3. *Wood pellet production flow chart*[1]

As usual moisture content we shall take into account a value between 40 and 50% (on a dry-weight basis) for initial wet raw material and about 10% for final dried. Because of the high temperatures and pressures in the manufacturing process, higher moisture can cause problems. Within the different technologies for wood chips drying that are available on the market, (direct and indirect) rotary dryers and indirect belt dryers are commonly used (Duvia and Tavola, 2008). Regardless of the technology for drying is necessary to use between 1,000 and 1,200 kWh per ton of water evaporated from the wood (Obernberger and Thek, 2010).

Dried feedstock is fed into a hammer mill that makes the wood particles a consistent size. This helps make the pellets a consistent density so that they provide a consistent heating value. Formation of the Pellets are extruded, or formed, using special dies. Pressure and temperature softens components of the wood (the lignin) and binds the material in the pellet together. No additional adhesives are required. Once the pellets are formed and cooled, they can be packaged in bags or stored in bulk.

For research purposes, data was collected from one of the largest pellet plants in Serbia. In 2012, analyzed pellet plant produced 36,000 tons of wood pellets. Raw materials used in production were beech firewood (65,000 m^3)[2], beech sawdust (54 t) and long coniferous wood (1,240 m^3)[2]. Average moisture content of the raw material was 80% on a dry-weight basis (Furtula, 2014).

For the analysis, the total energy consumption of the factory rather than consumption by individual operations is used. It was presumed that all the jobs and all the consumptions of energy in company

[1] www.pelletheat.org/2/index/index.html/
[2] Solid wood

are directly or indirectly related to the production of pellets. We analyzed the consumption of wood necessary to obtain heat for drying, electricity required for the process and the administration building and fuels for various types of vehicles and equipment (diesel, petrol and liquefied petroleum gas). The total consumption of all types of energy is shown in Table 1.

Table 1. *The consumption of different types of energy in the analyzed pellet plant in 2012*

Energy source	kWh/year	%
Electrical energy	8,333,014	12.27
Diesel	1,200,519	1.77
Petrol	35,309	0.05
Liquefied petroleum gas (LPG)	176,547	0.26
Wood (for drying)	58,174,720	85.65
Total	67,920,109	100.00

The data in Table 1 indicates that the most necessary energy obtained is from wood (84.54%) and that it was used for drying of raw material. For this purpose bark and wood chips of lower quality are used. Heat consumption is directly proportional to the moisture content of feedstock. Wood residues from final processing of wood or wood that is naturally dry for a specified time require considerably less heat for drying than just cut down wood (Table 2). Calculations were made for the following input data: beech wood density is 680 kg/m^3.

Table 2. *Energy required for the evaporation of water from wood raw material of different moisture content*

Moisture content (d.b.)	Water content	Final water content (10% d.b.)	The water that should evaporated	Required thermal energy*	Required thermal energy**
%	kg/m^3	kg/m^3	kg/m^3	kWh	kWh
10	68	68	0	0	0
20	136	68	68	68	82
30	204	68	136	136	163
44	272	68	204	204	245
50	340	68	272	272	326
60	408	68	340	340	408
70	476	68	408	408	490
80	544	68	476	476	571
100	612	68	544	544	653

*The heat required for evaporation of water is 1,000 kWh per ton;
**The heat required for evaporation of water is 1,200 kWh per ton.

From Table 2 it is clear what the energy and financial benefits of using dry or naturally dried raw material can be obtained. In addition, saved up wood could be used for the production of pellets.

Next by participation in total energy consumption is electricity (13.22%), while the share of other forms of energy is very small (3.24%).

Power consumption is always followed with lower or higher emissions of greenhouse gases into the atmosphere. Measure of emissions is global-warming potential (GWP) which is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1). For example, methane (CH_4) has 25 times the impact or nitrogen dioxide (NO_2), which has even 298 times higher impact on global

warming than CO_2 (Forster et al, 2007). In the study, the following data for energy values and emissions for different fuels were used (Table 3).

Table 3. *Energy values and emission CO_2e for different fuel used for the production of pellets*

Kind of fuel	Energy	Emission CO2e
	kWh/kg	kg/kWh
Petrol	12.26	0.2532
Two-stroke petrol mixture	12.26	0.2944
LPG (Liquefied petroleum gas)	12.86	0.2532
Diesel	11.92	0.3418
Wood	3.01	0,0502
Lignite	2.2	0.4109
Electric Power Mix in Serbia	-	1.0312

* Sources: Staffell (2011) and Ecoinvent data base (2014)

It is important to note that wood do not have zero emissions, as might be expected. In the life cycle of wood (from the forest to the raw material) various types of fuel are consumed, mostly fossil (Furtula, 2014). The values shown in Table 3 are concerned with such greenhouse gas emissions.

Calculation of equivalent emission of consumed electricity is done for the following input data valid for Serbia. In Serbia, approximately 72% of the produced electricity originates from thermal power plants which use coal (lignite) and the rest is produced in water power plants. The data in the table are given for electricity at low voltage. The value of 1.0312 kg/kWh includes energy efficiency of the process of transformation in power station and average losses at all levels of transmission (Danon et al, 2012).

With more effective natural drying of the raw materials it is possible to achieve large energy savings but it will not make pelleting process more “greener”. The best way to reduce greenhouse gas emissions is to decrease the electricity consumption and the use of electricity from renewable sources. There are several possibilities for the use of electricity from renewable sources, but the most simple is to produces own electricity using the available raw material. It would mean a great reduction considering that the ratio of CO_2e emissions from wood and Serbian power mix is 1:20. In order to achieve this it would be necessary to install cogeneration equipment in the system for heat supply in the pellet factory.

Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. It was originally conceived as an opportunity to make use of "waste" heat energy created in the "classic" electricity production. The main advantage of cogeneration is increased efficiency of energy resource compared to conventional power plants. The introduction of cogeneration makes sense only in processes that have a constant and uniform heat demand nearby.

Another option that is gaining in popularity is the installation cogeneration plants in plants for the production of thermal energy for technical processes or heating of dwellings, public buildings, hospitals. Produced electricity could be used for their own use or sale. If power plant is using renewable fuel sales of electricity is simulated with favourable (higher) rates provided by the Government (Furtula et al, 2011).

Currently there are a number of technologies used for cogeneration production of heat and power (Kiehne et al., 2008; Thek & Obernberger, 2004). When choosing technology for cogeneration priority should be technologies that are already proven and are in commercial use. For the purpose of this study the Organic Rankine Cycle (ORC) technology was selected. The main reason is that this technology over the last 10 years demonstrated to be a well proven product for industrial application in small decentralized biomass CHP plants (0.5 - 2 MW_{el}) in (Duvia and Tavolo, 2008). Typical systems are based on the following steps (Figure 3):

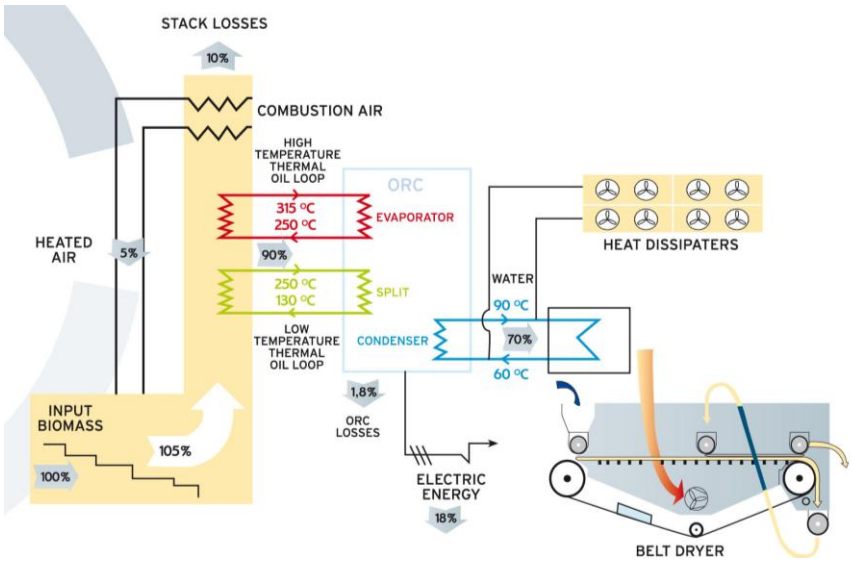

Figure 3. *ORC cogeneration: wood pellets manufacturing*

- Biomass fuel is burned in a combustor made according to the same, well-established techniques used for hot water boilers.
- Hot thermal oil is used as heat transfer medium, providing several advantages, including low pressure in the boiler, large inertia and insensitivity to load changes, simple and safe control and operation. The adopted temperature (about 315°C) for the hot side also ensures a very long oil life. Using a thermal oil boiler avoids the need for licensed operators, as required for steam systems in many European countries.
- An Organic Rankine Cycle turbo generator converts the available heat to electricity. Through the use of a properly formulated working fluid and an optimized machine design, both high efficiency and high reliability can be achieved. The condensation heat of the turbo generator produces hot water at typically 80°C - 120°C, a temperature suitable for wood drying.

The efficiency of the whole process of heat and electricity production, which includes installations, is 88%. The losses were 10% in the heat exchanger and about 2% in the ORC plant (Fig. 3). Efficiencies of the ORC equipment are shown in Figure 4.

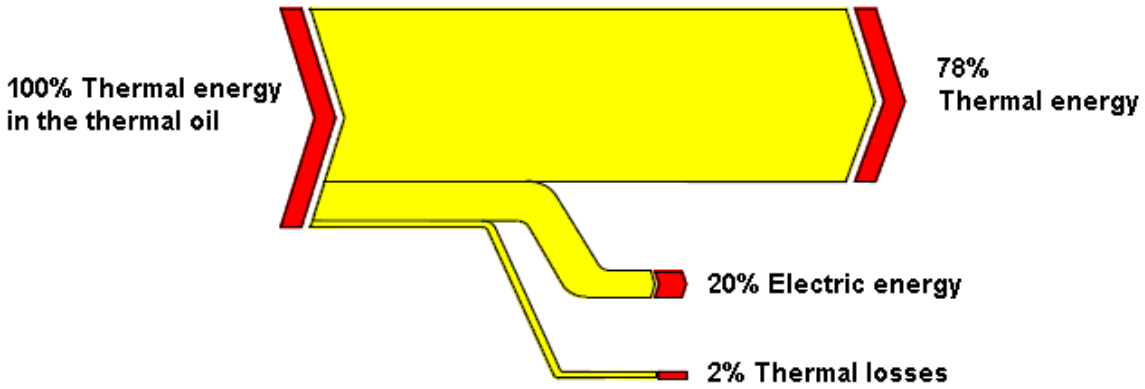

Figure 4. *Efficiencies of the ORC equipment*

20% of the total energy contained in the thermal oil is transformed in electricity, 78% is used for drying, while only 2% are losses.

The basic data for the selected technology are shown in Table 4.

Table 4. *Basic information about ORC technology (Pedrajas, 2012)*

ORC model	Gross electric power	Thermal power	Pellet production*	
	kW_{el}	kW_{th}	t/h	t/year
CHP-4	424	1,844	1.77	13,290
CHP-6	617	2,600	2.5	18,750
CHP-7	727	3,060	2.94	22,058
CHP-10	1,001	4,100	3.94	29,550
CHP-14	1,317	5,350	5.14	38,565
CHP-18	1862	7,850	7.82	58,650
CHP-22	2,282	9,630	9.59	71,948
CHP-27	2,830	11,700	11.65	87,375
CHP-30	3,340	15,150	15.08	113,100

*Calculation is done with following consumptions: moisture of raw material 50%; ambient temperature 10ºC and working hours 7500 hours/year.

In addition to energy and environmental factors, when deciding on the inclusion of CHP system, it is necessary to take into account the economy. Economics is not a subject of the research but the results of previous studies suggest that investment in ORC CHP technologies could have economic justification (Duvia and Tavolo, 2008) and (Danon et al, 2013).

3. RESULTS AND DISCUSSION

Table 5 shows the average value of energy consumed and the emission of greenhouse gases reduced for a ton of produced pellets. It was assumed that number of working hours in 2012 was 7.500 hours and total production during that time was 36,000 t of pellets. To produce one ton of pellets it is necessary to use 1,344 m^3 of wet wood which includes 2% of production losses. This is slightly more than 48,000 m^3 of dried (10% d.b.) and chopped wood. It is assumed that all of the rest of dried raw material (17.000 m^3) is used for heat production. The largest part of this heat is consumed for drying of a feedstock, and the rest is used for other parts of the process and space heating during the winter. The calculated amount of heat spent for evaporation of one ton of water was 1,880 kWh, and 895 kWh of heat for one ton of produced pellets. Other input data for energy and greenhouse gas emissions are taken from Table 1 and Table 3.

Table 5. *Unit consumption of different types of energy and specific emissions of greenhouse gases in the analysed pellet plant in 2012*

Kind of fuel	Energy	Percentage share in total consumption	Emission of greenhouse gases	Percentage share in total emission
	kWh/t_{pellet}	%	$kgCO_2e/t_{pellet}$	%
Electric power	236.0	20.15	231.0	85.93
Diesel	34.0	2.90	11.8	4.39
Petrol	1.0	0.09	0.3	0.11
LPG	5.0	0.43	1.3	0.48
Wood (fuel for dryers)	895.0	76.43	24.4	9.08
Total	1171.0	100.00	268.8	100.00

The Table 5 shows that 76.43% of the total energy was spent for drying. The amount of heat needed to evaporate one ton of water from wood in the particular case is e= 1,880 kWh and it significantly exceeds values (1,000-1,200 kWh) that are commonly used for the calculations (Obernberger and Thek, 2010), (Danon et al, 2011), (Danon et al, 2012) and (Furtula, 2014). The theoretical amount of heat required to evaporate to one ton of water (under normal conditions) is 810 kWh (Danon and Ranisavljev, 1992)[3] so that the remaining energy may be classified into energy and the wood fuel losses. An indicator EROIE is the measure of the effectiveness of energy efficiency. This indicator in this particular case is:

$$EROIE = \frac{Usable\ Aquired\ Energy}{Energy\ expended} = \frac{4{,}619\ \frac{kWh}{t_{pellet}}}{1{,}171\ \frac{kWh}{t_{pellet}}} = 4.43$$

Where are: "Usable Energy" is 4,619 kWh/t_{pellet} and is equal to lower heating value of wood pellets; Energy exended is 1,171 kWh/t_{pellet} (see Table 5). These results refer exclusively to the energy consumed in the production of pellets. If we take into account the other phases of the life cycle (Figure 5) EROIE value would be somewhat lower.

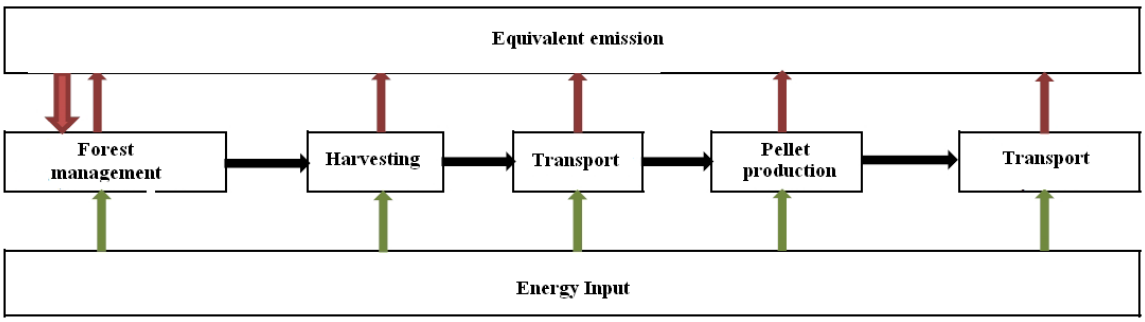

Figure 5. *Model of pellet production from fuelwood (Furtula, 2014)*

According to the results given in paper (Furtula, 2014) EROI values for all phases of the "cradle to gate" lifecycle are presented in Table 6.

Table 6. *The values of the coefficient of EROIE related to the life cycle of pellets (Furtula, 2014)*

Moisture content (d.b.) %	20	40	70	80
EROIE	7.18	5.12	3.40	3.03

To reduce energy and wood fuel consumption at least three things would be required to do:

- Improve handling of wood fuel in internal transport and manipulation at the depot including more accurate measurement of mass;
- Increase the energy efficiency of the boiler plant and drying process what could be achieved with the modernization of existing equipment;
- Reduce the humidity of the input raw materials.

Figure 6 shows the results of analysis of the impact of increasing energy efficiency and reducing raw material moisture content on energy consumption and greenhouse gas emissions.

[3] The calculation is made by adding the heat necessary for heating water in the wood from 20°C to 100°C (93 kWh/t), evaporation of the water at normal pressure (630 kWh/t) and the heat required for the release of the bound water from the timber (87 kWh/t) . This is when you added up 810 kWh per ton of evaporated water.

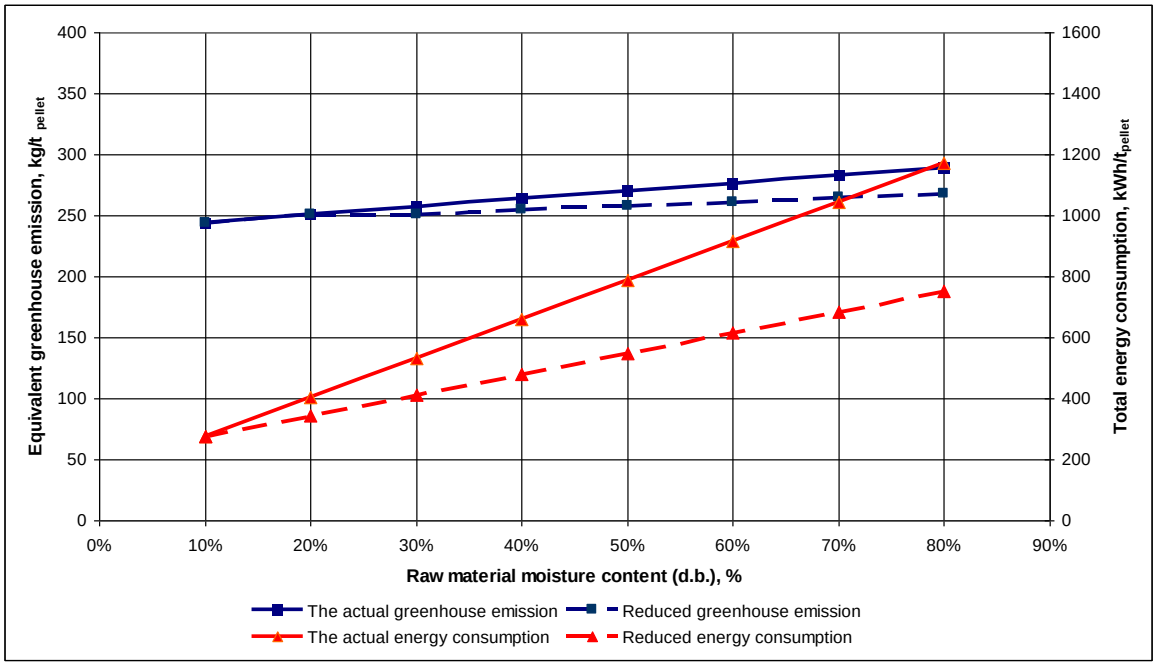

Figure 6. *Effect of moisture content of raw material on required energy for pellet production and equivalent greenhouse gas emission*

With a better handling of wood fuel and with the better energy efficiency of the boiler and dryer up to 35% of energy can be saved. With lowering the humidity of the incoming raw materials possible savings will decrease. The calculation for “reduced energy consumption” (see the dotted line with triangles) is made with the assumption that the amount of heat required to evaporate 1 tone of water from the wood is 1,000 kWh.

The Fig. 5 shows that the energy required for producing 1 ton of pellets is decreased from 1,170 kWh/t_{pellet} to 276 kWh/t_{pellet} if the wood raw material has a moisture content of 10% instead of the current 80%. In the case that the moisture content of feedstock is reduced from 80% to 30% by natural drying savings would 640 kWh/t_{pellet} or almost 50% of the initial energy consumption. Indicator of EROIE in that case is somewhat larger (see Table 6).

Reducing of the consumed energy for production would mean a significant reduction in the required wood fuel too, but the effects on the reduction of greenhouse gas emissions would be small (Fig. 5). According to the calculations shown in Figure 6, the differences in greenhouse gases emissions between the two extreme cases of moisture content of feedstock (80% and 10%) is 24.4 kg/CO_2e/t pellet, or 9% starting value.

A better way to reduce greenhouse gas emissions would be to use their own factories electricity using wood as a fuel instead of electricity from the grid. This implies the installation of CHP equipment in the pellet plant heat supply system. Earlier it was said that ORC CHP technology is chosen.

The CHP capacity should be selected on the basis of heat consumption per hour, or on the basis of the total capacity of the pellet presses (Table 4). For this calculation, it was necessary to determine the average hourly production of pellets which, for data from 2012, was as follows:

$$m_h = \frac{m_{year}}{T_{year}} = \frac{36{,}000\ \frac{t_{pellet}}{year}}{7{,}500\ \frac{h_{working}}{year}} = 4.8\ \frac{t_{pellet}}{h},$$

where are: m_h- average hourly production of pellets [t_{pellet}/h]; m_{year}- annual pellet production [t_{pellet}/year]; T_{year}- number of working hours of the pellet plant per year [h/year].
Required heat is:

$$Q_{heat1} = m_h \cdot e_{heat} = 4.8 \frac{t_{pellet}}{h} \cdot 1880 \frac{kWh}{t_{pellet}} = 9{,}062.4\ kWh$$

Where: Q_{heat1}- heat required for one hour operation of the plant [kWh]; e_{heat}- heat required to produce 1 tone of pellets [kWh / t_{pellet}].

$$Q_{power1} = m_h \cdot e_{power} = 4.8 \frac{t_{pellet}}{h} \cdot 234 \frac{kWh}{t_{pellet}} = 1.123\ kWh$$

Where: $Q_{powert1}$- electrical energy required for one hour operation of the plant [kWh]; e_{power} – electrical energy required for production of 1 tone of pellets [kWh / t_{pellet}].

According to this calculation comes out that, according to the required thermal energy, corresponding ORC plant is a CHP-22 (thermal power: 9,630 kW and electrical power: 2,282 kW) (Duvia and Tavolo, 2008). Thermal energy is slightly larger than needed and produced electricity would be twice as large as necessary.

If the management of the factory, before thinking about the introduction of CHP technologies, implemented the necessary rationalization of heat consumption situation would be somewhat different:

$$Q'_{heat1} = m_h \cdot e'_{heat} = 4.8 \frac{t_{pellet}}{h} \cdot 1{,}100 \frac{kWh}{t_{pellet}} = 5{,}280\ kWh$$

Emissions of greenhouse gases in the case that the CHP included in energy system of the pellet plant would be much. Four different variants are analyzed:

- I variant is present condition of energy efficiency;
- II variant is production with improved energy efficiency;
- III variant is present condition of energy efficiency plus CHP; and
- IV variant is production with improved energy efficiency plus CHP.

The results of the analysis are shown in Table 7.

Table 7. *Calculated values of greenhouse gases emissions of pellet production – CHP included*

Alternative	Type of intervention	Greenhouse gases emissions, $kgCO_2e/t_{pellet}$	Remarks*
I	The current situation	268.8	The collected data
II	Reduced specific consumption of thermal energy	258.7	The heat required for evaporation of 1 ton of water from the wood is 1,100 kWh/t_{water}
III	With CHP - current situation	61.56	Without improvement of the energy efficiency of boiler and dryers
IV	With CHP- improved situation	51.37	With improvements of the energy efficiency of boiler and dryers

*Input moisture content 80% d.b.

Table 7 shows that the greenhouse gas emissions will be reduced by 207.2 $kgCO_2e/t_{pellet}$, or 77% if the pellet factory has installed CHP.

4. CONCLUSIONS

The analysis of energy consumption and material production facility for medium-sized pellet was done. It was found that the consumption of thermal energy (1880 kWh per tone of evaporated water from the wood) is significantly higher than the recommended values (1000-1200 kWh). In the paper, appropriate measures of reducing heat losses and increasing equipment energy efficiency have been presented. The calculation indicates that with better handling of wood fuel and with improved boiler and dryer energy efficiency up to 35% of energy can be saved. With lowering the humidity of the input wood material reduction in energy consumption can be also achieved. In the case that the

moisture content of feedstock is reduced from 80% to 30% by natural drying savings would be 640 kWh/t_{pellet} or almost 50% of the initial energy consumption. This can be done by ensuring greater participation of residues from wood processing and/or in cite conditions for natural drying of wood raw material prior to its use.

Reduction of the consumed energy for production would mean a significant reduction in the required wood fuel too, but the effects on the reduction of greenhouse gas emissions would be small. Research shows that the emission of greenhouse gases in the factories for the production of pellets can be reduced in several ways. Selection of ORC technology for CHP in a pellet plant of medium size is a good solution. All calculations were made assuming that ORC technology is used. Possible reduction in emissions for a particular company whose data were analyzed could be significant. Global-warming potential (GWP) of pellet production would be reduced from 268.8 $kgCO_2e/t_{pellet}$ to only 61.56 $kgCO_2e/t_{pellet}$. A better way to reduce greenhouse gas emissions would be if they used their own factories electricity using wood as a fuel instead of electricity from the grid. It should be kept in mind that when deciding about the procurement of CHP plants, other than the technical, energy and environmental factors finances should be also taken into account.

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The Authors'Addresses:

Gradimir Danon, Ph.D.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: gradimir.danon@sfb.bg.ac.rs

Mladen Furtula, Ph.D.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: mladen.furtula@sfb.bg.ac.rs

UDC (UDK): 674.031.681.81.028.9

INFLUENCE OF THE DIFFERENT PRESSURES ON THE RADIAL AND TANGENTIAL PENETRATION INTO POPLAR WOOD AND ON THE SHEAR STRENGTH OF ADHESIVE JOINTS

Ivana Gavrilović-Grmuša[1], Manfred Dunky[2], Milanka Djiporović-Momčilović[1], Mladjan Popović[1], Jasmina Popović[1]

[1] University of Belgrade - Faculty of Forestry, Kneza Višeslava 1, 11030 Belgrade, Serbia,
e-mail: ivana.grmusa@sfb.bg.ac.rs; milanka.djiporovic@sfb.bg.ac.rs; mladjan.popovic@sfb.bg.ac.rs; jasmina.popovic@sfb.bg.ac.rs
[2] Kronospan GmbH Lampertswalde, D-01561 Lampertswalde, Germany, e-mail:m.dunky@kronospan.de

ABSTRACT

The work reported here deal with the influence of the specific pressure during the press process on the radial and tangential penetration of urea-formaldehyde (UF) adhesive into poplar as well as on the shear strength of lap joints prepared at these different pressures. For that purpose, test blocks of poplar wood of radial and tangential surfaces were bonded with an UF adhesive including safranin as a coloring agent. Three different specific pressures were applied: 0.5 N/mm², 1.0 N/mm², and 1.5 N/mm². The press temperature was 120°C. Epi-fluorescence microscope was used for measuring the adhesive penetration when investigating microtome slides (20 μm thick) cut from the each joint sample.

The average penetration depth (AP) and the size of the interphase region (IR) increased with the increase of the pressure from 0.5 to 1.0 N/mm². AP increased by 69 % in tangential and 76 % in radial direction. Further increase of the pressure to 1.5 N/mm² did not provide any significant change in AP or IR compared to 1.0 N/mm². Contrary, the area of filled lumens and rays (A) shows a steady decrease as the specific pressure increased. Such behavior had crucial influence on the filled interphase region (FIR) which also decreases with increased pressure.

Tangential samples (radial penetration) obtained higher values of lap shear strength and showed less dependence on the specific pressure than the radial samples (tangential penetration). Higher shear strength based on radial penetration corresponded to the greater interphase region of these samples. The highest shear strength based on both, radial and tangential penetration was obtained for the specific pressure of 1.0 N/mm².

Key words: penetration, poplar, urea-formaldehyde adhesive, microscopy, shear strength

1. INTRODUCTION

Penetration is the ability of an adhesive to enter into the lumen and into cell walls as a process of fluid movement (Marra 1992). Adhesive penetration into wood occurs (i) on micrometer level as hydrodynamic flow and capillary action through the large voids into the porous and capillary structure of wood (bulk penetration); it mostly fills cell lumens, as well as fractures and surface debris caused by processing (Marra 1992); and (ii) on sub-micrometer level as diffusion penetration into cell walls and micro-fissures through the micro voids within the wood cell walls (Johnson and Kamke 1992).
The interphase region of the adhesive bond as zone of bulk penetration of the adhesive comprises wood and adhesive; penetration is determined (i) by wood related parameters (like diameter of the lumen and exposure on the wood surface due to grain slope), (ii) by the properties of the resin and the

adhesive mix (such as chemical structure like molar mass distribution, composition of the adhesive mix, viscosity and surface energy, amount of adhesive spread, hardening time, and rate of resin curing), and (iii) by bonding processing parameters (like assembly time, press temperature and pressure, or moisture level) (Gavrilovic-Grmusa 2010a). Hydrodynamic flow especially is initiated by the external compression force applied to the wood surfaces to be bonded.

By forming the interphase, the adhesive bulk penetration strongly determines the bonding effect. Though mechanical interlocking is not the main reason for bonding, still an adequate penetration of the resin into the wood surface as porous network of interconnected cells enables formation of a sufficient large bonding interface as two-dimensional contact area between the molecules of wood and adhesive and helps in creating strong bonds (Marra 1992; Wan and Yan 2005). Anyway, main part of penetration must take place before curing of the resin starts.

Usually, due to their greater molar masses the penetration of adhesives considers the filling of the lumens by bulk penetration rather than cell wall penetration (Gindl et al. 2003, Konnerth et al. 2008). In order to investigate cell wall penetration Gindl et al. (2003) had used a low molar mass impregnation resin, which on the other side cannot be used as adhesive resins due to risk of overpenetration.

Bulk penetration is highly controlled by the size of the molecules with easier access by low molar mass adhesives; this effect additionally is enhanced by the decrease in viscosity due to the increasing temperature in a bond line during hot pressing. The molecules with higher molar mass preferably remain at the wood surface.

Adhesive penetration into hardwood is likely to be dominated by flow into vessel elements. Poplar has transport elements with wide lumens (vessels), surrounded by mechanical elements with far narrower lumens (factor 3 - 5) and lignified walls with cracked pits. The vessels amount for only 27% of the total mass of the xylem, while the mechanical elements (wood fibers) make up to 70%. Penetration into poplar is characterized by significantly higher adhesive penetration depths compared to hardwoods with higher density or to fir, despite the similar porosity of poplar and fir, due to the different anatomical structure of these species resulting in different mechanism of penetration (Gavrilovic-Grmusa 2012b).

Low bond strengths result from either under- or over-penetration. Under-penetration means that the adhesive is not able to move into the wood substance enough in order to create a large active bonding surface (interface) within the interphase and hence strong interaction between wood and the adhesive. Over-penetration means that a big portion of the adhesive can penetrate into wood substance causing starved joints as insufficient amount of adhesive remains in the bond line to bridge between the wood surfaces and to establish bond strength.

Furthermore, the bond strength between two wooden surfaces is determined by wood related parameters (like density, strength of the wood tissue, or grain angle), by the properties and penetration behaviour of the resin, the adhesive mix as well as the bonding processing parameters. The viscosity of the adhesive, especially in dependence of the temperature in the bond line during the press cycle, has to be adjusted by proper composition and molecular structure (molar mass distribution, degree of condensation) of the adhesive. Additionally the applied pressure influences the penetration, causing increased and deeper movement of the adhesive from the surface into the wood tissue.

In a series of papers Gavrilovic-Grmusa et al. (2010a+b; 2012a+b) had investigated (i) the penetration of urea formaldehyde (UF) resins of different molecular structure (size of the adhesive molecules, degree of condensation) into various wood species as well as (ii) the achievable bond strengths (shear strengths). Especially the degree of condensation is one of the most important characteristics of a condensation resin and determines several properties of the resin (Dunky 2003).

The determination of the extent of lumen penetration into the wood structure is preferably performed by examination of the cross section of a bond line, using several microscopic methods: light microscopy (Mahrdt et al. 2015, Nuryawan et al. 2014, Singh et al. 2008), transmitted end reflected microscopy, fluorescence microscopy, epi-fluorescence microscopy (Edalat et al. 2014), (fluorescence) confocal laser scanning microscopy CLSM (Singh et al. 2008), scanning electron microscopy SEM (Singh et al. 2008), transmission electron microscopy TEM, SEM in combination with an energy-dispersive analyzer for X- rays SEM/EDAX, TEM-EDXS (Singh et al. 2015), X-ray microscopy, and autoradiography; for an overview and extensive list of references see Gavrilovic-Grmusa (2010a).

Microtomography facilitates the sample preparation when investigating the penetration of various adhesives into wood (Evans et al. 2010, Kamke et al. 2014, Modzel et al. 2011; Hass et al. 2009, 2012; Gavrilovic-Grmusa et al. 2012c, Paris et al. 2013, 2014).

Pressure has two main functions in bond formation: to bring surfaces together, and to aid in penetration and wetting of the adhesive (Marra 1992). Though it is general experience that the applied pressure enhances resin penetration (under consideration of all other factors influencing penetration), surprisingly only very little information is available in literature on quantitative evaluation of resin penetration as a consequence of the applied pressure. Brady and Kamke (1988) mentioned that pressure might increase penetration because it is the driving force for hydrodynamic flow. However, little evidence of consolidation pressure influencing penetration of a PF resin into aspen was found. The authors suspected that flow parallel to the bondline may have overruled the effect of pressure towards an enhanced penetration, especially at low moisture content and at higher pressure; higher moisture content in the bond line before pressing then rather promotes penetration than spreading.
Sernek et al. (1999) reported that penetration of an UF resin was enhanced by application of pressure during the bonding process. Whereas at no applied pressure no differences have been noticed between radial and tangential penetration into beech, the radial penetration was higher compared to penetration in the tangential direction when applying pressure; the increase was approx. 50% at parallel lamination of solid-sawn beech wood, but nearly up to 10 times at cross lamination of rotary-peeled beech veneers.

The objective of this study, hence, was the evaluation of the influence of the pressure applied during the press cycle on the distribution of an UF resin within the wood substance by means of microscopic investigation. For this purpose an UF lab batch was prepared (UF resin “UF I”, as the version with the lowest degree of condensation as described by Gavrilovic-Grmusa et al. 2010a).

2. MATERIALS AND METHODS

2.1. Urea formaldehyde (UF) resins

A laboratory UF resin with rather low degree of condensation (DOC) according to a recipe described in literature (Pizzi 1999) was prepared. This resin is the version with the lowest DOC in the series as described by Gavrilovic-Grmusa (2010a), with viscosity 218 mPa* s and therefore called “UF I” throughout this paper; the molar ratio formaldehyde to urea (F/U) was 2.0 with no extra urea added after the condensation step.

The adhesive mix applied onto the wood surfaces was prepared by addition of 10 mass% of wheat flour as extender and 0.05 mass% of Safranin as marker (both numbers based on solid resin). The addition of ammonium sulphate as hardener was 0.5%, expressed as solid hardener based on resin solids.

Table 1 summarizes the characteristics of UF I and the adhesive mix.

Table 1: *Characteristics of the UF resin UF I and the adhesive mix*

Property	Unit	UF I	
		Resin	Adhesive mixes
Solid content	%	53.7	54.4
Brookfield viscosity (20°C)	mPa*s	218	545
Gel time	s	58	59

2.2. Preparation of the bonded joints and preparation of microtome slices

The poplar log was cut from the trunk at the height of 1.3 m. Boards of 42 mm thickness were cut using a band-saw. After initial air drying the boards were further dried in a laboratory kiln drier and planned to the final dimensions of 1000 mm * 150 mm * 30 mm. These boards were then cut into radial and tangential blocks of 100 mm * 30 mm * 5 mm in order to get tangential and radial surfaces for the penetration investigations and to be bonded for the shear strength tests (Figure 1). The majority of the poplar blocks was taken from sapwood.

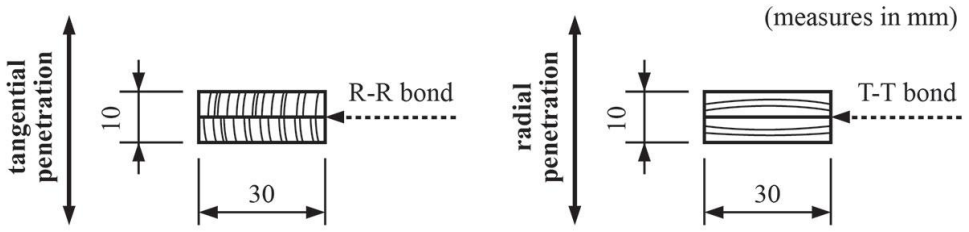


Figure 1. *Scheme of bonded samples for penetration tests and shear strength tests, with the bond line between two radial or two tangential plies; all measures in mm (Gavrilovic-Grmusa et al. 2012a) Before bonding, the blocks were conditioned in standard climate (T = 20 ± 2°C and φ = 65 ± 5%), yielding moisture contents (MC) of approx. 10%*

Assembling was performed following parallel grain directions, with the adhesive applied only to the block in the upper position of the joint; this should help to improve the penetration into the bottom block. The loading level of the UF adhesive mix was 200 g/m^2. Five bonding samples were pressed at the same time in a hydraulic press at 120°C and at different specific pressures (0.5 resp. 1.0 resp. 1.5 N/mm²) for 15 minutes. After hot pressing the bonded samples were conditioned again in standard climate before performing the various investigations.

Three microtome test specimens (20 µm thick and with side lengths of 10 mm) were prepared from each joint sample at various positions in the transversal plane by a sliding microtome apparatus, exposing the bond line within the cross-sectional surface of the two jointed blocks.

2.3. Determination of penetration

From each of the microtome slides (Figure 2) five photos (with 1.4 mm width on each photo) were taken at different positions along the bond line using epi-fluorescence microscopy (LEICA DM LS); so in total approx. 7 mm of the whole width of the bond line of 10 mm in the microtome slide was investigated. The used set of optical filters consisted of a 450 nm excitation filter, a 510 nm dichromatic mirror, and a 515 nm emission filter. The image analysis system included a color video camera (LEICA DC 300) and the image processor with analysis software (IM1000 by LEICA Microsystems, Heerbrugg, Switzerland). These photos were then evaluated for penetration of the UF resin adhesives.

The individual depths of penetration (µm) were determined from each photograph of the microtome slides at 45 positions within the 1400 µm width of the bond-line shown. The depth of penetration here is defined as the sum of the distances the resin could penetrate into the two blocks starting from the geometric center of the bond line (Figure 2).

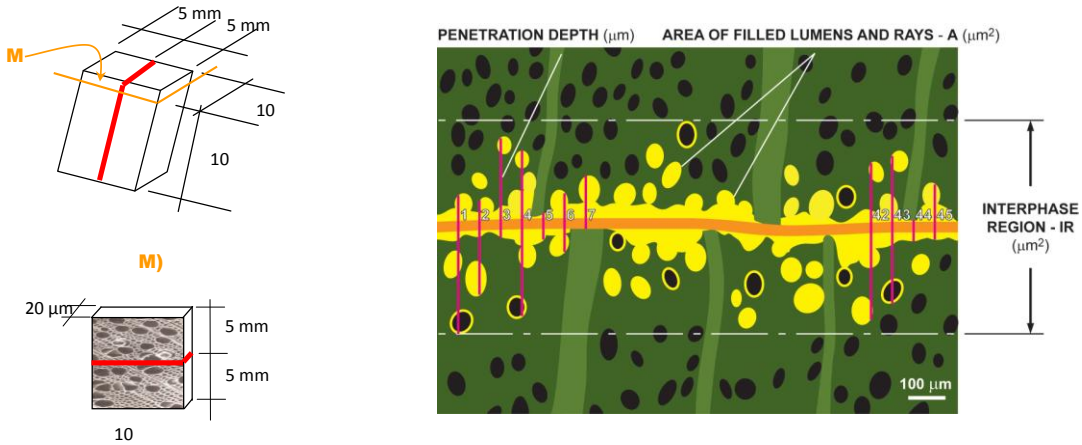


Figure 2. *Scheme of microtome specimens (M); the thick red line indicates the bond line. Right side: scheme of determination of A and IR (Gavrilovic-Grmusa et al. 2012a)*

Based on the individual depths of penetration (µm) four main values have been evaluated:

a) average penetration depth (AP): mean value of penetration depths (µm)

b) total interphase region (IR, mm²): IR is calculated as maximum individual penetration depth times width of the bond line (1.4 mm). IR includes the unfilled lumen area and the area of all filled lumens or filled rays (A) as well as all wood material cross sections;

c) area of all filled lumens and filled rays (A): determined from the photomicrographs by summarizing all filled lumens and rays;

d) filled interphase region (FIR): expressed as percentage A/IR (%).

No separate evaluation for the two joined blocks was done during the evaluation of AP and FIR, even there might be some difference in the individual penetration (i) between the one block where the adhesive mix has been applied and the other block without application of adhesive mix, or (ii) especially if different portions of earlywood or latewood were given in the two blocks. Higher penetration into earlywood than into latewood was observed in a former paper for the radial penetration into fir and beech (Gavrilovic-Grmusa et al. 2010a).

2.4. Testing of the shear strength

The lap shear tests were conducted on a hydraulic test machine (ZWICK, Germany) at 6 mm/min in tensile mode. The failure zone was examined using a light microscope in order to determine the proportion of wood failure and the thickness of the wood layer in the wood failure. Ten replications had been performed for each set of parameters.

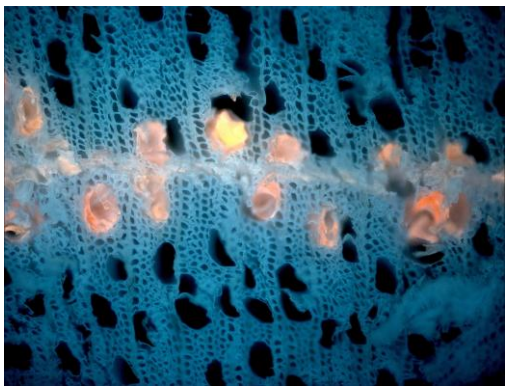
3. RESULTS AND DISCUSSION

3.1. Photo-micrographs of the penetration into poplar at various pressures

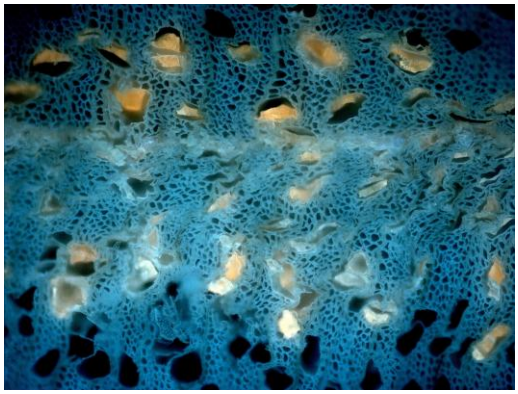
Figure 3 shows characteristic epi-fluorescence microphotographs of radial and tangential penetration for the adhesive mix of UF I into poplar at two different applied pressures (lowest and highest pressure applied in the work presented here). The light colored sections on both sides of the bond line represent the UF adhesive mix, which has penetrated to a certain extent into the wood material. Depending on the anatomical structure of poplar, the adhesive mix mainly fills lumens of the vessels as well as rays. Only bulk penetration was investigated and evaluated, but not wood cell penetration.

The upper row shows radial penetration (into the two tangential surfaces). Low pressure (on the left side) leaves the bigger part of the resin in the bond line, with rather low penetration depth. At higher applied pressures (examples with maximum pressure at right side) the resin penetrates much further into the wood tissue, away from the geometrical bond line. At this highest pressure used in the work reported here already significant changes in the wood cell structure occurs, caused by the pressure and supported by the plasticizing effects of heat and moisture; the vertical ellipses of poplar were already crushed, whereby this effect really only occurs in the interphase. Away from the interphase the structure of the wood tissue has not changed; here also partly or fully filled lumens with still the original structure and size can be seen.

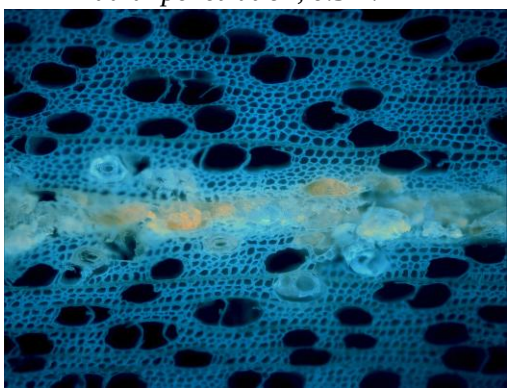
The same effect but much stronger influenced by high pressure is seen in the second row showing two examples for tangential penetration into radial surfaces (low pressure on the left side; highest pressure on the right side). Again the depth of penetration increases at higher applied pressures. The effect of changing the wood cell structure is much stronger in tangential direction of pressure application; the originally horizontally elliptic lumens are reduced dramatically in size by narrowing the cell walls to each other; more or less all lumens including adhesive are strongly compressed.



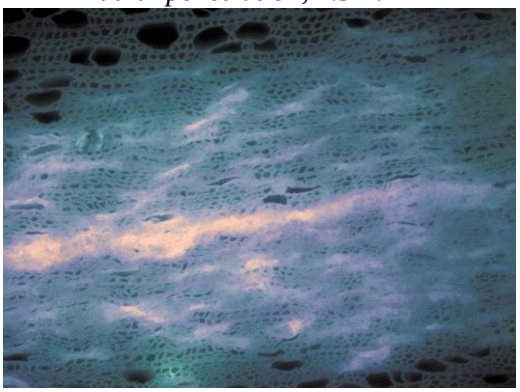
Radial penetration, 0.5 N/mm²



Radial penetration, 1.5 N/mm²



Tangential penetration, 0.5 N/mm²



Tangential penetration, 1.5 N/mm²

Figure 3. *Example of epi-fluorescence microphotograph with the penetration of UF resin I into poplar at two different pressures applied during the press cycle: 0.5 N/mm² (= lowest level of pressure; left) and 1.5 N/mm² (= highest level of pressure; right) for radial (above) and tangential penetration (below)*

3.2. Penetration data of UF resin (UF I) into poplar at various pressures

Table 2 summarizes the penetration data for the UF resin (UF I) and poplar for the three applied pressures and the two directions of penetration.

Table 2. *Summary of results of penetration measurements of UF resin (UF I) into poplar at three different pressures during the press cycle: (i) average penetration depth (A), (ii) average size of the interphase region (IR), (iii) average sum of filled lumens and rays within the interphase region (A), and (iv) filled interphase region (FIR = A/IR)*

Poplar UF I	Pressure (N/mm²)	AP (μm)	IR (mm^2)	A in IR (mm^2)	FIR (%)
TT	0.5	185	0.91	0.25	27
	1.0	324	1.16	0.23	21
	1.5	331	1.21	0.21	18
RR	0.5	210	0.85	0.25	29
	1.0	355	0.98	0.23	23
	1.5	341	0.97	0.19	20

TT: two tangential surfaces bonded (radial penetration)
RR: two radial surfaces bonded (tangential penetration)

The Average penetration depth (AP) (µm) of UF resin I into poplar increases statistically significantly when increasing the specific pressure from 0.5 to 1.0 N/mm², but levels out at higher specific pressures with no statistical significance between 1.0 and 1.5 N/mm² of applied pressure (Figure 4). Tangential penetration is slightly higher at all pressure steps, but the difference to radial penetration is not statistically significant.

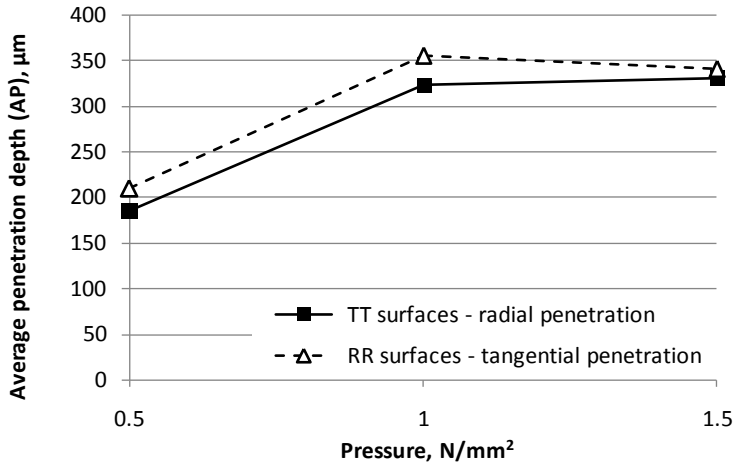


Figure 4*. Average penetration depth (AP) (µm) for poplar and UF resin I as a function of the specific pressure during the press process*

The interphase region (IR) is determined by the maximum individual penetration depth observed (Figure 5). It apparently increases with the increase in pressure, but for the tangential penetration (RR samples) this is not statistically proven. In addition, the radial penetration is higher than in the tangential direction, which is contrary to AP; this difference is significant for the two higher pressures applied (1.0 and 1.5 N/mm²). In radial direction single flow paths enable deep penetration; this means that the resin is distributed in a broader layer as interphase; contrary to this the resin distribution in tangential direction yields in a narrower interphase but higher average penetration depth. Statistic difference only is given for the radial direction between the two lower pressures.

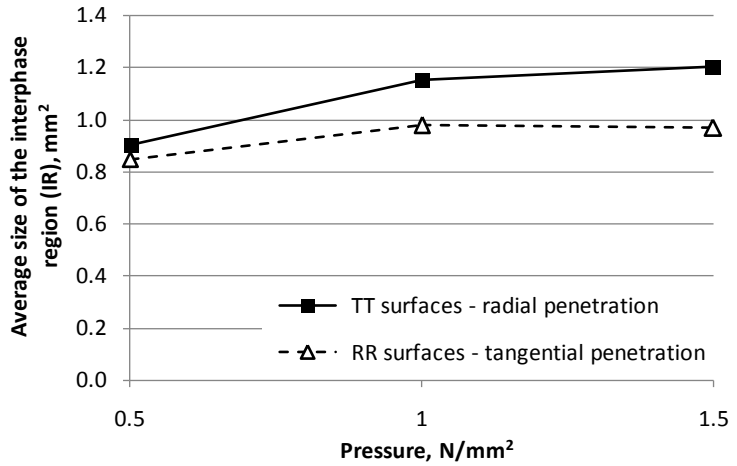


Figure 5. *Average size of the interphase region (IR) (mm²) for poplar and UF resin I as a function of the specific pressure during the press process*

The Average sum of filled lumens and rays within the interphase (A) decreases slightly with higher specific pressures applied during the press process; only the tangential penetration shows statistically significant differences (Figure 6).

For the two lower pressures no difference is given between the two penetration directions; the slightly lower value for A for tangential penetration at the highest pressure is not significantly secured.

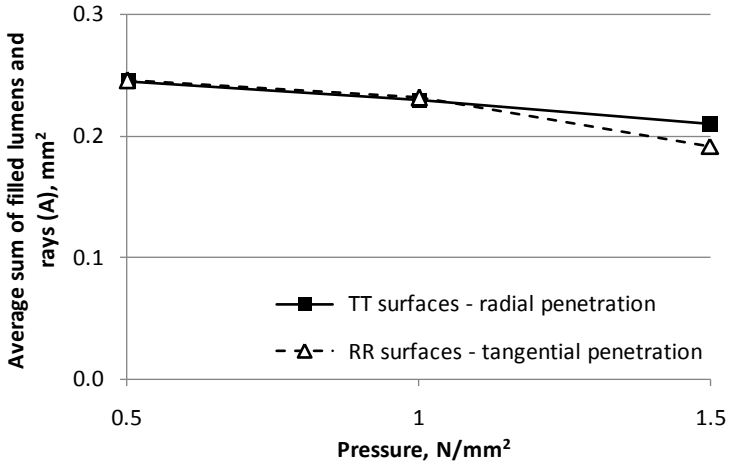


Figure 6. *Average sum of filled lumens and rays within the interphase (A) (mm²) for poplar and UF resin I as a function of the specific pressure during the press process*

The reason for the decrease of A with higher pressure is not fully clear; on the one side the anatomical structure of poplar wood elements has to be taken into consideration; especially the transport vessels have wide lumens and relatively thin walls; this enables a relatively higher penetration of adhesive. It is also the case that many of the transport vessels are only partially filled with the adhesive. Under higher pressure such vessels are quite easily compressed and thus decreased in volume; due to the wide original lumens this will not necessarily already really prevents the penetration of the adhesive. The change in the lumen can also slightly falsify the determination of A, not being able always to clearly distinguish between fully and only partially filled lumens.

Another effect will be that due to the applied pressure some stronger flow and even squeezing out of the adhesive in the bond line can occur.

The Filled interphase region (FIR) describes the proportion of the filled cells within the interphase; as the thickness of the interphase increases with higher specific pressure applied during the press process, FIR decreases (Figure 7). The amount of resin penetrating does not increase even at higher pressure, but the penetration depth and with this the thickness of the interphase increases; this means that the penetrated resin is more distributed within the most upper wood layer.

Statistical difference is only given between the two lower pressures for the tangential direction and between the two higher pressures for the radial direction. No statistically significant difference between the two penetration directions exits at all applied pressure levels.

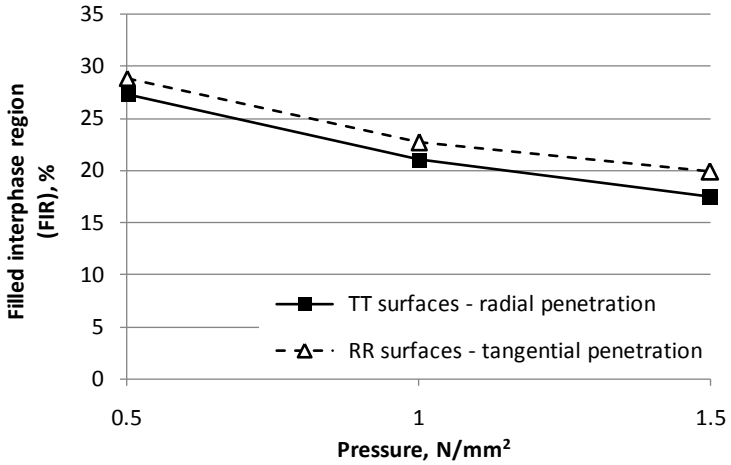


Figure 7. *Filled interphase region (FIR) (%) for poplar and UF resin I as a function of the specific pressure during the press process*

3.3. Shear strength of bond produced at different pressures during the press cycle

Table 3 summarizes the various shear strengths measured when preparing the joints at different specific pressures during the press cycle.

Table 3: *Summary of shear strengths for joints prepared at various pressures during the press cycle*

Poplar UF I	Pressure	Shear strength	Standard deviation		Wood failure	
	(N/mm²)	(N/mm²)	(N/mm²)	(%)	(%)	mm
TT	0.5	6.8	1.1	17	77	0.63
	1.0	7.7	0.9	12	75	1.2
	1.5	7.2	0.8	12	86	2.5
RR	0.5	4.6	0.7	15	83	1.9
	1.0	6.8	0.8	12	81	1.5
	1.5	5.5	0.5	8	91	1.8

TT: two tangential surfaces bonded (radial penetration)
RR: two radial surfaces bonded (tangential penetration)

The shear strengths is influenced by the applied pressure; increasing the pressure from 0.5 N/mm² to 1.0 N/mm² gives a significant increase in shear strength for tangential penetration; increase in radial penetration is less and also not statistically secured (Figure 8). Further increased pressure during the production of the joints, however, did not yield in better shear strength, but decrease in shear strength was observed. The highest values of the shear strength for both, TT and RR samples, hence were obtained with the medium pressure level of 1.0 N/mm².

The shear strengths between tangential surfaces (= radial direction of penetration) is always higher than for radial surfaces (= tangential direction of penetration) with statistically secured difference at the lowest and at the highest pressure level and showing the big influence of the bonding surface (direction of penetration).

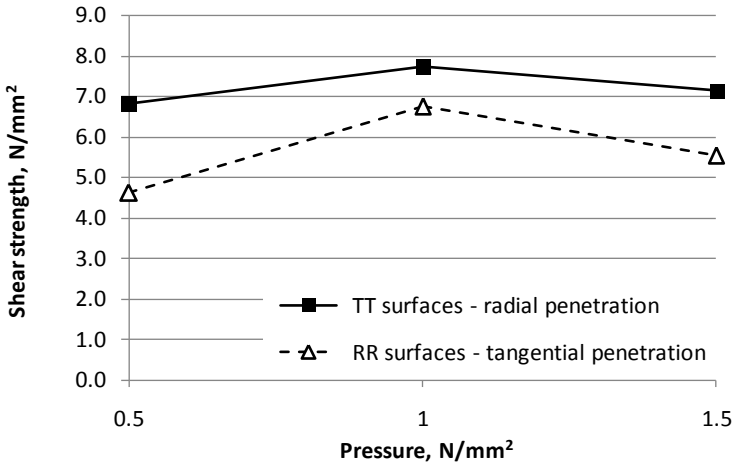


Figure 8. *Shear strength of joints made from poplar and UF resin UF I as a function of the specific pressure during the press process; results are shown for radial penetration (TT surfaces bonded) and for tangential penetration (RR surfaces bonded)*

The increase might be caused by several factors, like better contact between the wood surfaces, giving thinner bond line; also the fortification of the interphase might help in bond strength, as this was assumed as a consequence of the deeper penetration of the resin into the wood tissue (Gavrilovic-Grmusa 2012a). The lowest pressure obviously has not provided an appropriate level of penetration and interlocking, whereas the highest pressure can have already negative influence on the wood

strength; the interphase region does not increase further due to higher maximum penetration depth, but the proportion of filled lumens in the interphase decreases significantly. Additional the changes in the wood structure under high pressure, in combination with moisture (from the applied resin) and the press temperature may have induced already mechanical damages at the interphase bonding region, representing a certain degree of in situ mechanical weak boundary layer and resulting in lower shear strength.

However, measuring shear strengths always is linked to the influence of the wood failure. Per definition a “good” wood joint should show a failure zone in the adjacent wood and not in the interphase or even in the bond line itself. Weakening the wood structure close to the bond line, however, will drive the failure zone into the interphase, where these changes in the wood structure have occurred.

Proportion of wood failure is high in all investigated cases. For the two lower pressures more or less the same values are given (but slightly higher for tangential penetration); for the highest pressure level the wood failure increases for both directions (again slightly higher for the tangential direction). This is an interesting effect, because the shear strengths are lower for both directions at the highest pressure level compared to the maximum shear strength at the medium level; this means that shear strengths and proportion of wood failure do not correlate. This might have two reasons: (i) the wood failures are high anyhow, so small differences in the original wood structure can cause the variation in shear strength; (ii) at the highest pressure already a certain deterioration of the wood structure has happened; this means the wood failure has increased whereas the shear strength did not increase but even slightly decrease.

The average thickness of the wood failure increases for the radial penetration with increased pressure, similar as the higher pressure also had caused the increase in average and maximum penetration depth. For the tangential penetration this effect is not clearly seen. In both cases, however, the average thickness of the wood failure is in the same order of magnitude as the thickness of the interphase. This at least means that penetration heavily affects shear strength as well as wood failure.

4. CONCLUSIONS

Higher pressure applied during the press cycle increases the ability of the resin for penetration deeper into the wood tissue. However this effect levels out at a certain pressure.

The bond strength, measured as shear strength of the bonded joints, increases at moderate pressures but decreases again at high pressure. This can already be caused by the partial deterioration of the wood tissue itself due to the crushing and compressing of wood cells under the impact of pressure, temperature and high moisture content in the interphase.

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The Authors' Addresses:

D.Sc. Ivana Gavrilović-Grmuša
Assistant Professor, University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: ivana.grmusa@sfb.bg.ac.rs

D.Sc. Manfred Dunky
Lecturer and Universitaetsdozent
Institute of Wood Science and Technology,
University of Natural Resources and Applied Life Sciences,
A 1190, Vienna, Austria and
Manager for Research and Application Technology,
Kronospan Lampertswalde, D-01561 Lampertswalde, GERMANY

Prof.Dr.Sc. Milanka Djiporović-Momčilović
Full Professor, University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: milanka.djiporovic@sfb.bg.ac.rs

D.Sc. Mladjan Popović
Assistant Professor, University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: mladjan.popovic@sfb.bg.ac.rs

B.Sc. Jasmina Popović
Assistant, University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: jasmina.popovic@sfb.bg.ac.rs

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WOOD INDUSTRY COMPETITIVENESS OF THE REPUBLIC OF MACEDONIA

Mira Stankevik Shumanska, Zhivka Meloska, Violeta Efremovska, Goran Zlateski

Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje
e-mail: stankevik@fdtme.ukim.edu.mk; meloska@fdtme.ukim.edu.mk;
efremovska@fdtme.ukim.edu.mk; zlateski@fdtme.ukim.edu.mk

ABSTRACT

On the production competitiveness affecting a number of factors. One of the important factor is certainly the trade balance of production. In this paper will be analyzed balance for separate groups of wood industry products for the period of 2008-2012, based on data and nomenclature of the State Statistical Office of the Republic of Macedonia. The trade balance of wood industry products in the analyzed period has a negative trend in both primary production and the production of furniture. More important trading partners of the Republic of Macedonia in the trade of products of primary production and the production of furniture are the immediate neighborhood countries (Serbia, Kosovo, Croatia and Greece), as well as Germany, Italy, Turkey and others.

Key words: competitiveness, wood industry, exports, imports, trade balance, trading partners

1. INTRODUCTION

Competitiveness is one of the driving factors of the growing trends in the world economy. It shows the ability of national economies for equal competition with the competition on the domestic and foreign markets, as well as integration into global trade and financial flows.

Increasing competitiveness is of particular importance for the development of the country. Perceptions about development possibilities suggest that the promotion of competitiveness is a basic prerequisite for efficient management, increased development and rising living standards of the population.

The competitive ability represents: having satisfied market, local competition and state regulation of market competition. Competition is not an abstract size but each time associated with a given market and expresses its specifications.

Competitive products produce competitive enterprises. Such an enterprise is one that has a real ability and potential (in management and execution) to study, design, construct, manufacture and distribute products whose price and non-price properties more effectively meet the complex requirements of customers compared to the same or analogous products of competitors.

Macedonian wood industry traditionally is important as to satisfy the domestic market and also for export. Macedonian products processing industry, and therefore the wood industry is exposed to strong world competition is particularly pronounced with the involvement of our country in world global processes, with the signing of the Stabilization and Association Agreement (between Macedonia and EU) and the accession of the Republic of Macedonia in WTO (World Trade Organization).

2. SUBJECT AND AN AIM OF THE RESEARCH

The subject of the research of this paper is to analyze the competitiveness of the Republic of Macedonia with regard to the production of wood and wood products and furniture production.

Competitiveness is analyzed in terms of trade in these two sectors. Further it is analyzed the trade balance and the countries exporting and importing of the separate products from the manufacture of wood and wood products and furniture production.

Analyzes are based on data obtained from publications of the State Statistical Office of Macedonia. The publications are in foreign trade - Commodity exchange Republic of Macedonia abroad (2008-2012).

Trade and the balance are analyzed according to the National Classification of Activities NACE Rev. 2, and exports and imports by countries are according to the classification of products by SITC (Standard International Trade Classification).

An aim of this research is to review trends in trade as in the production of wood and wood products and in manufacture of furniture, and thus to determine the competitiveness of these industries in the markets in the immediate neighborhood and beyond.

3. RESULTS AND DISCUSSION

As we have underlined before, there are several ways to measure the competitiveness of a country in terms of markets in the region, but is most widely used as trade and trade balance.

In further chapters we will analyze the results achieved in export and import activities for the period 2008 - 2012 and realized trade balance of Republic of Macedonia given value in 000 US dollars.

3.1. Export - import by activities

Export of wood industry products is shown in Table 1. It is shown the total export of the Republic of Macedonia and the total export of the products and its structure by activities of the wood industry.

Table 1. *Export of wood industry products (in 000 US dollars)*

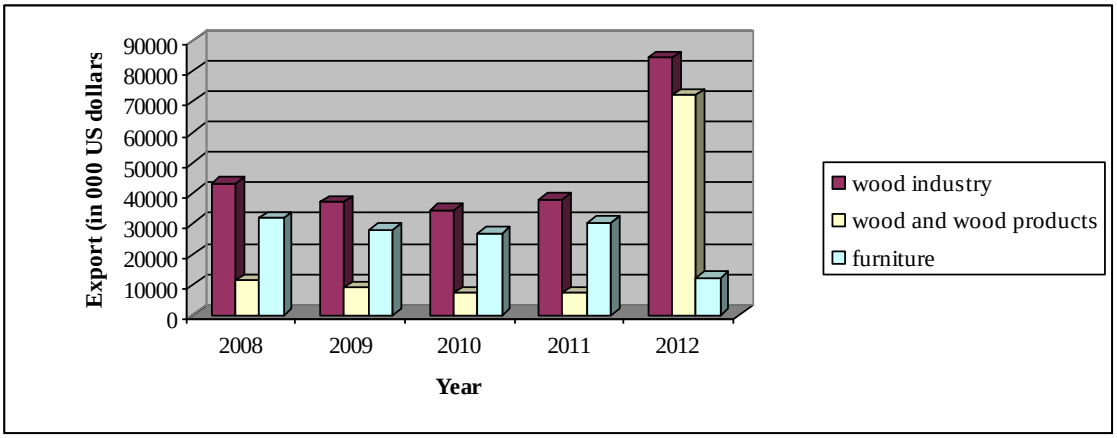
	Total	**Wood industry**	**Wood and wood products**	**Furniture**
2008	3990642	43257	11459	31798
2009	2708488	37188	9240	27948
2010	3351429	34417	7479	26938
2011	4478313	37985	7438	30547
2012	4015403	84309	72032	12277
Average	**3708855**	**47431**	**21530**	**25902**
AAR	**0,2**	**18,2**	**58,3**	**-21,2**
Participation (average in %)		**100**	**45**	**55**

Source: State Statistical Office of the Republic of Macedonia, Publications - stock exchange of the Republic of Macedonia abroad (2008 - 2012), own calculations

Export of activity of wood and wood products is characterized by decrease or increase from year to year, in the analyzed period. Besides variations for the total period is calculated annual average rate (AAR) of growth from 58.3%. In the analyzed period was amounted the average value of exports from 21530000 US dollars.

The export of products from furniture activity can be said that has variable dynamics in the period 2008-2012. AAR has calculated decline and was -21.2%. For the analyzed period, the export of furniture production has an average value in the amount of 25902000 US dollars.

The Figure 1 shows the dynamics of exports wood industry products, total and structure, according to the Classification by activities.



Source: State Statistical Office of the Republic of Macedonia, Publications - stock exchange of the Republic of Macedonia abroad (2008 - 2012), own calculations

Figure 1. *Export dynamics of wood industry products*

Given the dynamics of the exports movement by separate activities of production, total exports of wood industry products in the studied period tends to increase average annual rate of 18.2%.

Regarding the average participation in the total export of wood industry products in the country, for the analyzed period, the production of wood and wood products was represented by 45% and production of furniture had greater representation of 55% (Table 1).

Imports of wood industry products for the period 2008 - 2012 is shown in Table 2. It is analyzed the total imports of the products and its structure by activities of the wood industry. In order to show the participation of imported wood industry products it is given and total import of products in the country.

Table 2. *Import of wood industry products (in 000 US dollars)*

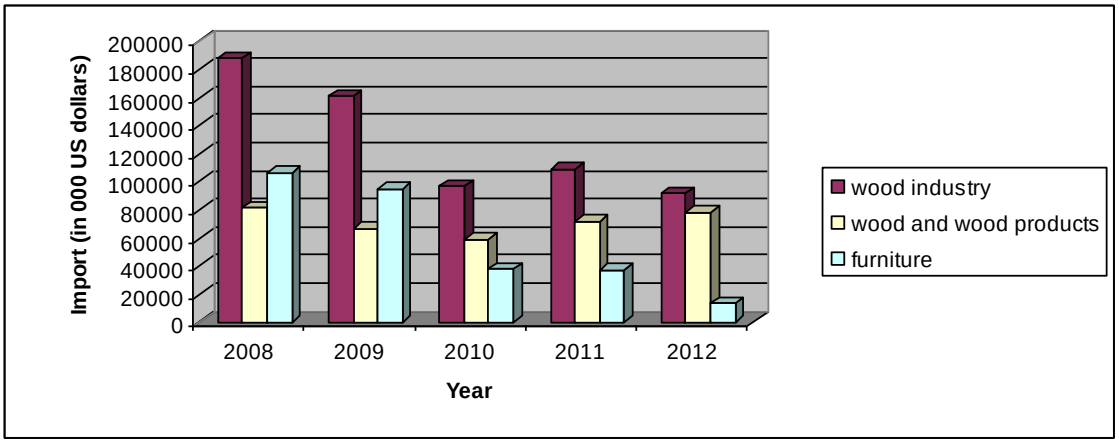
	Total	**Wood industry**	**Wood and wood products**	**Furniture**
2008	6882653	187750	81154	106596
2009	5072821	161045	66431	94614
2010	5474485	96690	58913	37777
2011	7027162	109177	71958	37219
2012	6522388	91916	78281	13635
Average	**6195902**	**129316**	**71347**	**57968**
AAR	**-1,3**	**-16,3**	**-0,9**	**-40,2**
Participation (average in %)		**100**	**55**	**45**

Source: State Statistical Office of the Republic of Macedonia, Publications - stock exchange of the Republic of Macedonia abroad (2008 - 2012), own calculations

The data in Table 2 for the import of wood industry products in the period 2008-2012, we can see that an import of wood and wood products tends to decrease. For the total period is calculated AAR of growth from -0.9%. Average for all imports amounted to 71347000 US dollars.

The tendency of continuous decline in imports has the import of furniture, where the average rate of decline per year is -40.2%. The average value of imports in the analyzed period amounted to 57968000 US dollars and is less than the average imports of wood and wood products.

Figure 2 show a dynamics of imports of wood industry products, total and by activities according to the Classification by activities.



Source: State Statistical Office of the Republic of Macedonia, Publications - stock exchange of the Republic of Macedonia abroad (2008 - 2012), own calculations

***Figure 2**. Import dynamics of wood industry products*

Considering the trend of decline in imports in both sectors of production, the expectation is the same type tendency to have and a total import of wood industry products. The average rate of decline of total imports is -16.3% in the given period.

The average participation of imports of wood and wood products in the total import of wood industry products accounted for 55%, while imports of furniture is lower at 45% for the period 2008 - 2012 (Table 2).

The products from the wood industry participated with about 2.1% of the total import of the Republic of Macedonia for an analyzed period.

3.2. Trade balance of the wood industry production

Based on the analyzed data on exports and imports, in separate sectors of manufacturing and total wood industry was made and their balance for the period 2008 - 2012.

The balance of exports and imports in the production of wood and wood products is given in Figure 3 for the period 2008 - 2012.

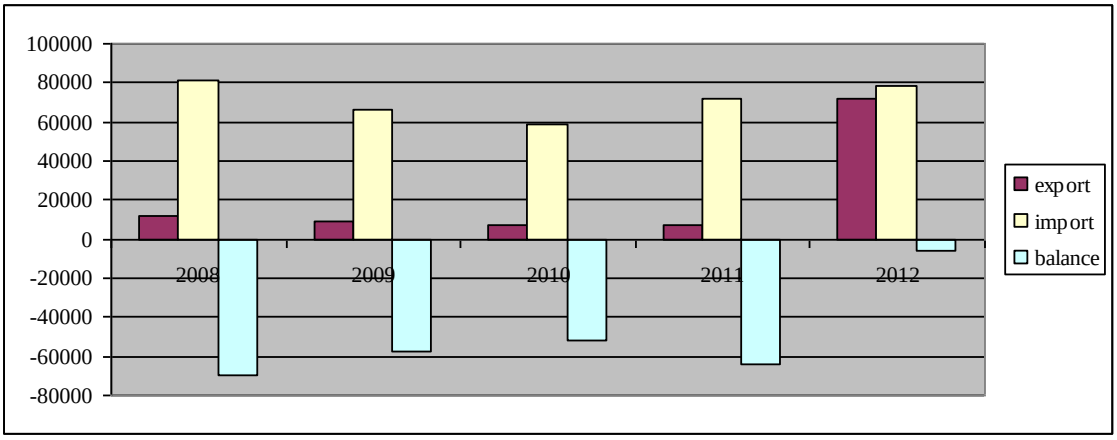


***Figure 3.** Trade balance in production of wood and wood products*

The data in Figure 3 shows that trade balance of wood and wood products production has a negative value over the examined period.

The balance of exports and imports in furniture production is shown in Figure 4 for a given period. Here, the trade balance retains the negative trend during the entire period studied.

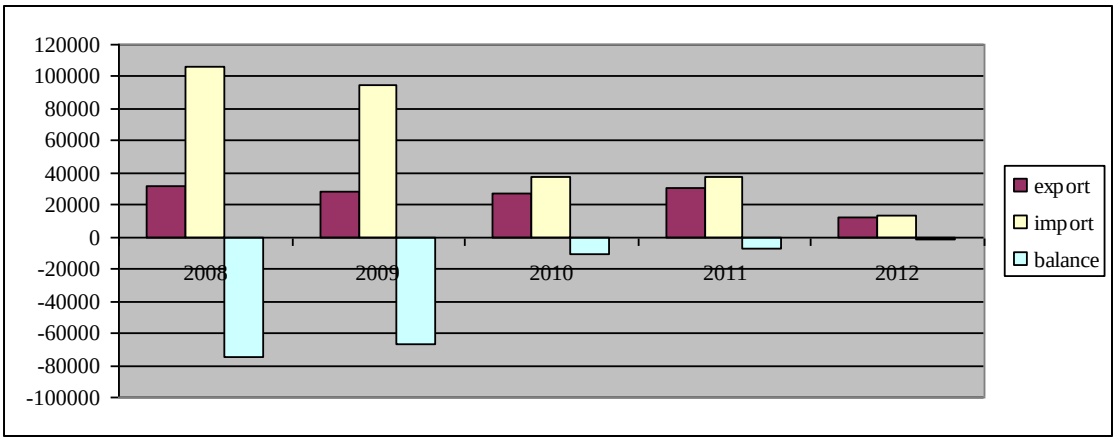


Figure 4. *Trade balance in furniture production*

As a result balance of exports and imports in separate activities of wood industry production and total balance of the wood industry is a negative in all years of the analyzed period (Figure 5). Negative balance is particularly emphasized in first years of the period (2008, 2009 and 2010) and at the end it decreases.

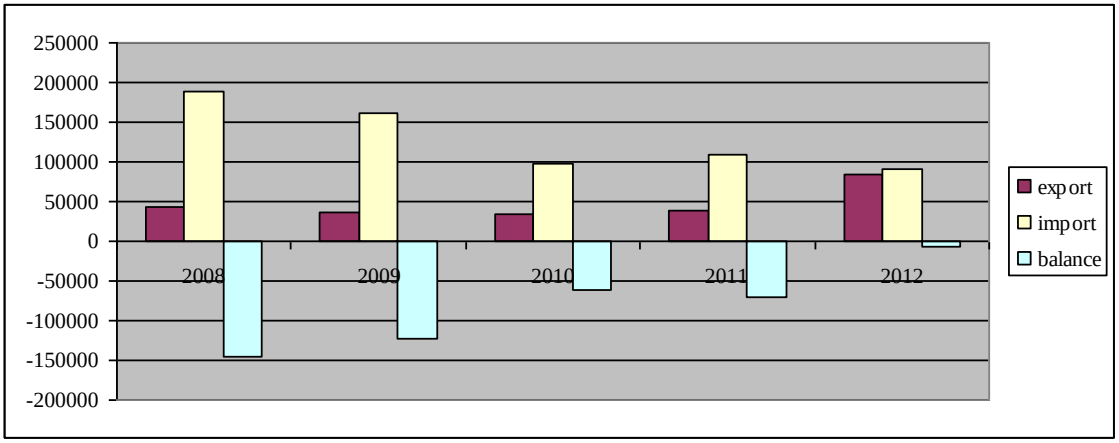


Figure 5. *Trade balance in the wood industry*

4. MAJOR EXPORTING AND IMPORTING COUNTRIES OF THE WOOD INDUSTRY PRODUCTS

Data for major countries that are exported and imported of the wood industry products in the Republic of Macedonia are obtained from publications of the State Statistical Office. It was analyzed the period 2010 - 2012.

Enterprises of the Republic of Macedonia most exported to the region Kosovo, Serbia and Croatia and the EU countries Germany, Greece, Italy and the Netherlands in the analyzed period. Exports of wood industry products consist mainly of exports to other seats with wooden frames and wooden furniture for bedrooms and exported and doors and windows and other wood species processed length with the thickness of 6 mm.

Macedonian largest importer of products from wood industry in the region is Kosovo with amount from 6.335 million US $ in the period 2010 – 2012. The value of exports to Serbia amounted to 4.404 million US $ and Croatia from 3.831 million US $. From other countries with which Macedonia has developed trade links and belong to the wider environment is Germany where exports accounted for 6.982 million US $.

The import of wood industry products mostly come from regional countries such as Bulgaria, Serbia and Slovenia, and in a remarkable volume from Turkey and China in the period 2010 - 2012. On the other hand lower volume of imports is noticed from Croatia, Greece, Italy, Germany and Austria.

Import of wood industry products is characterized by a broader assortment unlike exports. Mostly imported are particle boards, MDF wooden boards, other wooden furniture, bedrooms, other seats with wooden frames, wood of coniferous species sawn lengthwise, of a thickness exceeding 6 mm, doors and windows and other wood products.

The biggest trading partner of the Republic of Macedonia on imports of wood industry products is Bulgaria with total amount from 31.389 million US $ in the given period. In terms of representation of the imported products dominated particle boards and wood of coniferous species sawn lengthwise, of a thickness exceeding 6 mm.

The second largest trading partner to import wood industry products is Serbia which is realized import of 20.957 million US $ in the analyzed period. The structure of imports has the dominant particle board, followed by other seats with wooden frames, wooden furniture for bedrooms and other wooden furniture.

Import of products of wood industry in Slovenia has a value of 4.475 million US $. Most are imported doors and windows, other wooden furniture and wood of coniferous species sawn lengthwise, of a thickness exceeding 6 mm.

Turkey and China represent major exporters of wood industry products in Macedonia in the period 2010 - 2012. Imports from Turkey amounted to 19.749 million US $, which were mostly imported MDF wooden boards, particle boards and other wood furniture. The import structure from China dominated with MDF wooden boards and particle board. Total imports from China amounted to 7.548 million US $.

According to the total volume of trade of the wood industry products Republic of Macedonia most traded with Serbia, Croatia, Slovenia, Germany and Greece. With all these trade partners Republic of Macedonia has a deficit in trade.

5. DISCUSSION AND CONCLUSIONS

The analysis of foreign trade, i.e. exports and imports and the trade balance as a measuring instrument for the competitiveness of products of wood industry in the period 2008 - 2012 year show that:

Export in the production of wood and wood products tends to increase and export in furniture production declines. As a result of this tendency in export activities, the total export of wood industry products from the Republic of Macedonia tends to mildly increase in the analyzed period.

The import in the production of wood and wood products declines, while imports in the furniture production also decreases with increasing frequency. Based on the decrease in imports in both sectors of production and the total import of wood industry products in the Republic of Macedonia tends to decline in a given period.

The participation of the two sectors of production in total exports and imports of the wood industry products is almost equally annual average for the period 2008 - 2012.

Considering the balance of exports and imports in separate sectors, the overall balance of the wood industry has a negative sign in all the years of the period. This means that the value of imports was significantly greater than the value of exports of the wood industry products. The negative balance confirms the lack of competitiveness of wood industry products of the Republic of Macedonia to the external market.

In order to overcome the existing situation should be increased export value of furniture in volume, as a final product with a competitive price in the market, also to import raw materials at favorable prices for domestic production. The furniture as a final export target certainly more cost will improve the trade balance in the wood products industry.

The biggest trade partners to export of wood industry products from the Republic of Macedonia are neighboring countries Kosovo, Serbia and Croatia in the period 2010 - 2012 year. The most exported other seats with wooden frames and wooden furniture for bedrooms. Due to the still modest

Macedonian wood industry quality products, their export is restricted to the region where international quality standards of the products are not fully implemented.

Major trading partners to import wood industry products in the Republic of Macedonia are Bulgaria, Serbia and Slovenia in analyzed period. Imports are characterized by a wider range unlike exports. Mostly imported particle boards, MDF wooden boards, other wooden furniture, bedrooms, other seats with wooden frames, wood of coniferous species sawn lengthwise, of a thickness exceeding 6 mm, doors and windows and other wood products.

According to the total volume of trade of the wood industry products of the Republic of Macedonia in terms of exporting and importing countries is realized deficit in the balance of trade.The problems faced by the Macedonian producers of wood industry in exports are uninformed and lack the education necessary for full participation in foreign markets. Above all it involves lack of information on the conditions and possibilities to export our products abroad, access to new markets, necessary documents, possible barriers and other information necessary for organized markets worldwide.

The final goal should be to achieve better export performance through quality and price of the final products, which would mean a positive effect on the trade balance and greater competitiveness of the wood industry products of the Republic of Macedonia.

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The Authors' Addresses:

Mira Stankevik
Associate Professor, PhD,
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje,Republic of MACEDONIA
e-mail: stankevik@fdtme.ukim.edu.mk

Zhivka Meloska
Full professor, PhD,
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: meloska@fdtme.ukim.edu.mk

Violeta Efremovska
Full professor, PhD,
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: efremovska@fdtme.ukim.edu.mk

Goran Zlateski
Full professor, PhD,
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: zlateski@fdtme.ukim.edu.mk

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STRENGTH ANALYSIS OF A SHAFT OF TWO-SIDED CIRCULAR SAW FOR CROSS-CUTTING BY THE FINITE ELEMENT METHOD

Nelly Staneva, Slavcho Sokolovski

University of Forestry, Faculty of Forest Industry, Sofia, Bulgaria,
e-mail:nelly_staneva@yahoo.com; slav_sokolovski @abv.com

ABSTRACT

A strength analysis of the shaft with two bearing supports from the basic mechanism of a woodworking machine for two-sided edging of details for wooden pallets and packaging is carried out. The static analysis of the 3D saw shaft model is carried out by the method of finite elements (FEM) with Autodesk Inventor Professional®. The 3D model of the circular saw shaft is generated with all elements of the real shaft – keyslot, thread, grooves for clip ring, centre holes, chamfers, filets, and etc. The shaft loading and restrictions are simulated by FEM with taking into account of physical and mechanical properties of the shaft material. The distribution of stresses, strains, displacements and factor of safety are obtained, visualized in the 3D saw shaft model of the circular saw shaft and analyzed.

Key words: circular saw, shaft, woodworking, strength analysis, CAD/CAE, FEM

1. INTRODUCTION

A two-sided edging circular woodworking machine has been proposed for edging of details for wooden pallets and packaging. It is described in detail in Sokolovski, Staneva, Panchev, 2015. This woodworking machine consists of two circular cutting mechanisms, a mechanism for conveying transfer of the sizing pieces with manual loading, unloading and stacking of the parts, and a mechanism for horizontal translation of the circular cutting mechanisms to obtain the details of the desired length – Figure 1.

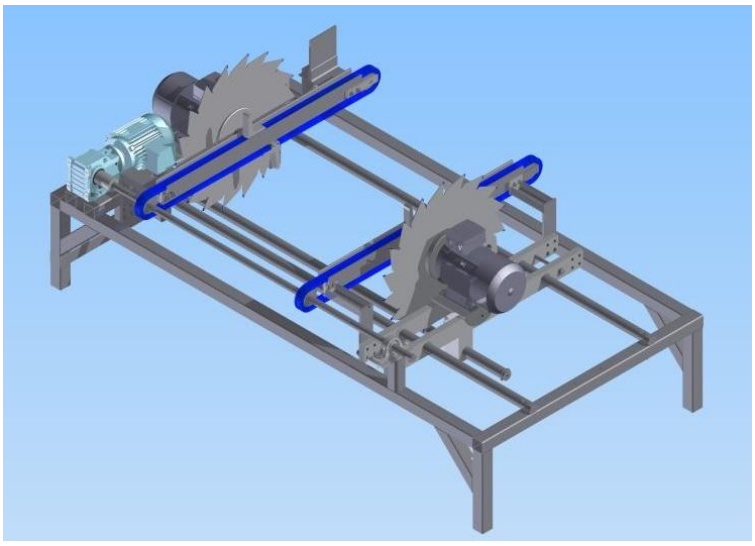

Figure 1. *Woodworking machine for two-sided edging of details for wooden pallet*

The main mechanism of this machine is the circular cutting mechanism, presented on Figure 2. It consists of two identical three-phase motors **4**: AT112 type M2 with following characteristics: power N = 4 kW; speed n = 2860 min^{-1}; efficiency η = 0,83. A circular blade **1,** model 5381-20*WZ* profile *BA*, production of ZMM "Plana", Smolyan, is attached by clamping flanges **2** on the shaft **3** of the motor. It is selected after the necessary calculations with the following parameters: diameter of the saw blade D = 450 mm; width of sawing b = 4 mm; thickness s = 2,8 mm; number of teeth z = 72; rear corner α = 15°; front corner γ = 10°.

The main kinematic features of this cutting mechanism were also determined (Sokolovski, Staneva, Panchev, 2015): cutting speed v = 67,36 m.s^{-1} satisfying values for the factory, both softwood and hardwood; cutting height: h_{min} = 0,022 m and h_{max} = 0,145 m; feed rate: u_{max} = 0,15 m.s^{-1} and u_{min} = 0,092 m.s^{-1}.

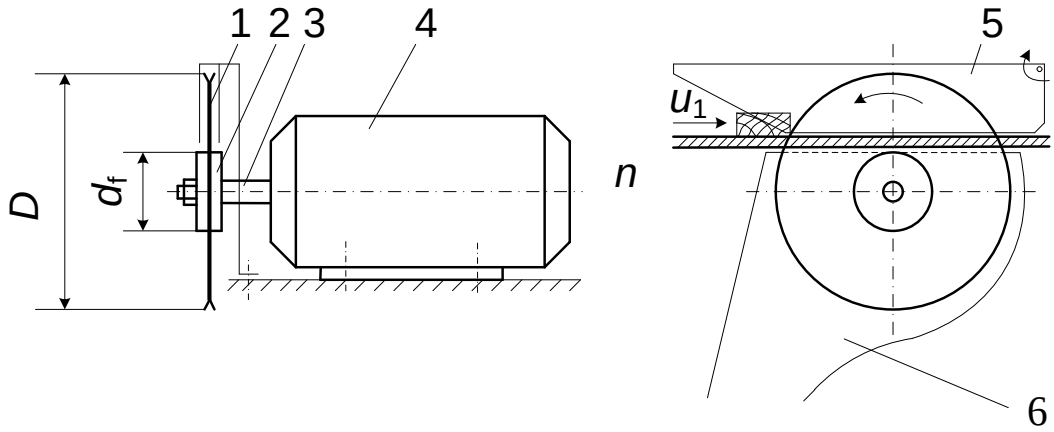

Figure 2. *Scheme of circular cutting mechanism*

The working shafts of the circular woodworking machines operate with relatively high cutting speeds and in bad-case conditions - dusty environment and shock loads, which induces different dynamics processes. This complicates the operation of cutting mechanisms and bearings. That is way its correct calculations are very important.

Some authors already use the modern methods and approaches for study and calculation of the of cutting shafts of woodworking machines: Wasielewski and Orlowski (2006) have used a static approach, Orlowski and Ochrymiuk, (2007) have used the method of fracture mechanics, Chaitanya and Kaladhar (2013), Marta and Corduta (2010), Michna and Svoren (2007) have used finite element anasysis, Gok et.al., 2013 have used failure analysis.

It is established that the finite element method (FEM) is the most frequent applied in calculating and in predicting the stress and strain in solid bodies.

The object of this study is caring out of a static analysis of the circular shaft of a woodworking machine for two-sided edging of details for wooden pallets by the method of finite elements (FEM).

2. METHODS

2.1. 3D modeling of the circular saw shaft and calculation scheme.

3D model of circular shaft of woodworking machine for two-sided edging of details was created with all elements of the real shaft by means of the modulus “Shaft Generator” of CAD/CAE system Autodesk Inventor Professional® (Sokolovski, Staneva, 2015).

The circular shaft is with two bearing supports and console saw blade. Loading conditions were defined in the previous publication (Sokolovski, Staneva, 2015) according to the loading scheme, presented on Figure 3. The characteristics longitudes of the shaft are: l_1=50 mm, l_2=246 mm and l_3=40 mm and diameters: d_C = 28 mm, d_A = d_B = 30 mm and d_D = 40 mm.

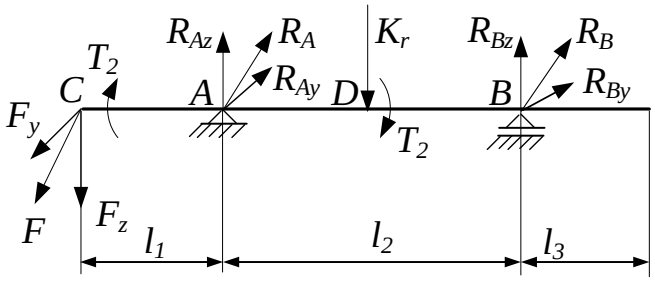

Figure 3. *Scheme of loading*

2.2 Static analysis

The static analysis of the circular shaft 3D model was performed by the method of finite elements (FEM) with the CAD/CAE system Autodesk Inventor Professional®. The sequence of this analysis is shown on Figure 4.

First, the shaft material characteristics of steel C45 BDS EN 10083-2: 2006 were input in the program: modulus of elasticity $E = 2{,}07.10^{11}$ N.m^{-2}, modulus of rigidity $G = 7{,}78.10^{10}$ N.m^{-2}, density 7860 kg/m^3, Poisson’s ratio 0,33; yield strength $Re = 430.10^6$ N.m^{-2}; tensile strength $Rm = 650.10^6$ N.m^{-2}.

Second, the constraints of the shaft in the 3D model were set: Fixed Constraint:2 in bearing support “*A”* and Pin Constrant:1 (axial free) in bearing support “*B*” – Figure 3 and Figure 4.

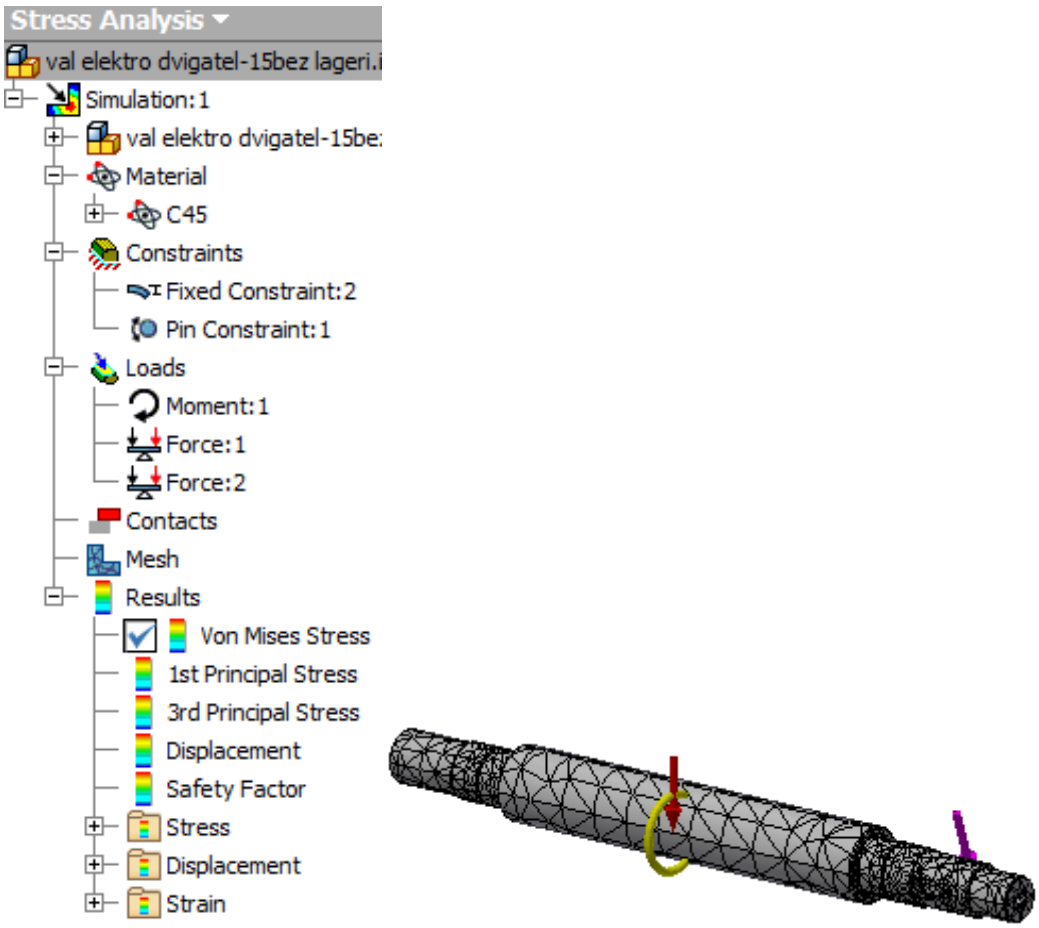

Figure 4. *Sequence of static analysis of the shaft 3D model*

Third, the loads were input in the program as calculated in (Sokolovski, Staneva, 2015):

Torque, $T_2 = 12$ N.m; Components of cutting force: F_y = 71 N – total force acted in the horizontal plane xy and F_z = 206 N – total force acted in the vertical plane xz. Force of motor rotor Kr = 730 N, including magnetic force of rotor and mass force of the rotor and shaft.

The following characteristics of the finite elements mesh were set: curved mesh elements; 13604 number of elements and 21670 number of nodes; average element size 0,1; minimum element size 0,2; grading factor 1,5; maximum turn angle 60 deg. For the solver the following was set: maximum number of h refinements 3; stop criteria 10%; h refinements threshold 0,95.

3. RESULTS AND DISCUSSION

Some of the results from the static analysis are represented on Figure 5 to Figure 9. In order to understand where deformation is occurring an exaggeration effect is provided with “Adjust Displacement Display” – Adjusted x 1 (www.autodesk.com).

The distribution of equivalent von-Mises stresses and 1st principal stresses in the circular shaft 3D model is represented on Fig.5. The maximum values of $31{,}78.10^6$ N.m^{-2} and $44{,}16.\ 10^6$ N.m^{-2} were received near to the bearing shoulder “*A*”. In the same section of the shaft the maximal stress “XX” was received – Figure 6.

On Figure 7 the distribution of resultant equivalent strains and “YY” strains is presented. Maximum equivalent strain 0,000147 and maximum “YY” strain 0,000019 are received in the same places where the stresses are maximum – near to the shaft bearing shoulder “*A*”. The maximum equivalent strain 0,000147 is lower than the allowable strain for shafts:

$$[f]\ /l \leq (0{,}0002 \div 0{,}0003).$$

The distribution of Safety Factor is shown on Figure 8. The program calculates the factor of safety as the ratio of the maximum allowable stress to the maximum von-Misses stress when using Yield Strength as a Yield Limit:

$$\text{Factor of Safety (FOS)} = \sigma_{\text{limit}} / \sigma_{\text{vonMises}}$$

A minimum Safety Factor of 13,56 was received near to the bearing support “*A*”.

The distribution of resultant displacements in the shaft 3D models is represented on the right of Figure 8. Maximum resultant displacement 0,00206 mm was received in the section where saw blade is assembled. In the same place the maximum X-displacement 0,00048 mm was localized – Figure 9. The maximum Z-displacement 0,00065 mm was received in the end of the shaft on the side of saw blade – Figure 9.

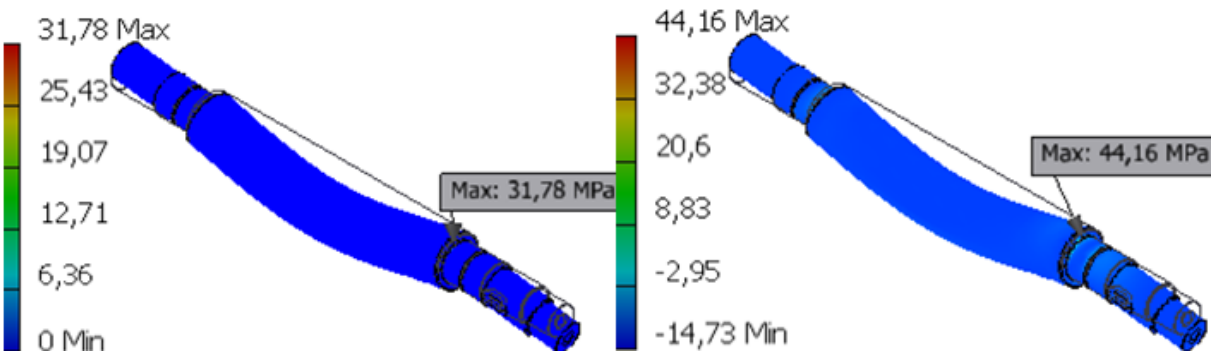

Figure 5. *Distribution of von-Misses and 1st principal stresses*

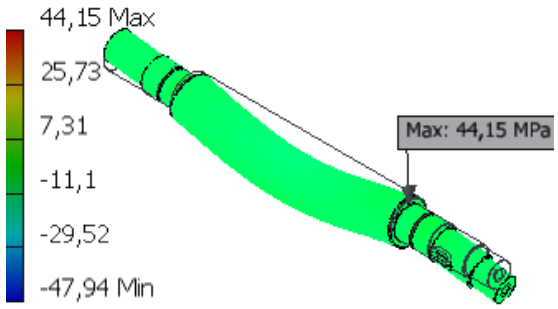

Figure 6. *Distribution of stresses “XX”*

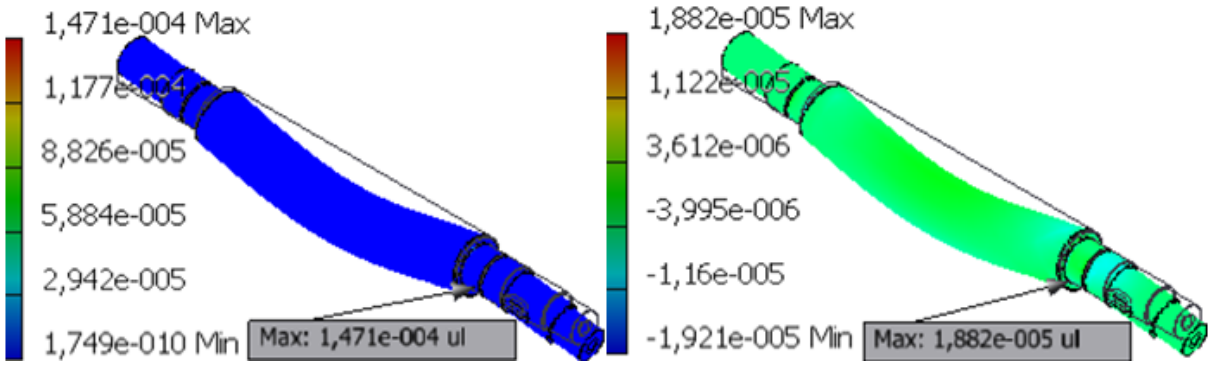

Figure 7. *Distribution of equivalent strain and “YY” strain*

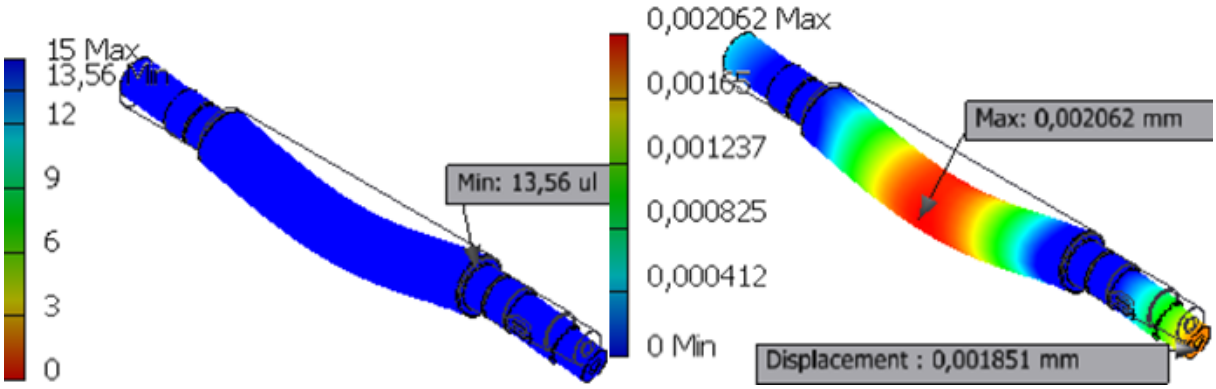

Figure 8. *Distribution of Safety factor and resultant displacements*

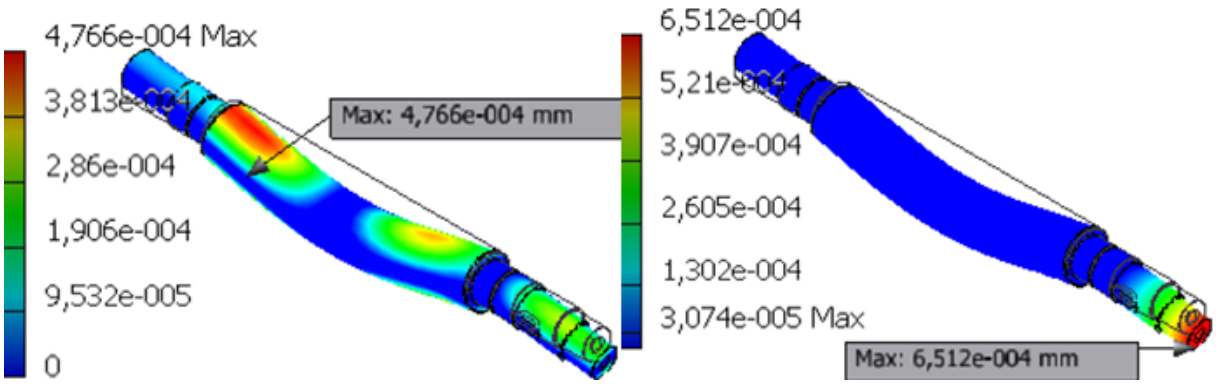

Figure 9. *Distribution of X-displacements and Z-displacements*

4. CONCLUSIONS

3D results of von Misses stresses and equivalent strains distribution in the circular shaft 3D model are received by FEM. The maximum values of these parameters are localized near to the bearing support “*A*”. The maximum resultant displacements are localized in the section of rotor force applying and in the end of the shaft where the saw blade is fixed. The factor of safety is not under the 1 for no one finite element, i.e. there is no danger of shaft failure.

The static analysis results of the circular shaft must be taken into account in designing of new woodworking machines.

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The Authors' Addresses:

Nelly Staneva, Assoc. Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: nelly_staneva@yahoo.com

Slavcho Sokolovski, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: slav_sokolovski@abv.com

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CALCULATION OF THE TOTAL ENERGY CONSUMPTION NEEDED FOR DEFROSTING AND THE FOLLOWING HEATING OF FROZEN WOOD CHIPS

Nencho Deliiski[1], Veselin Brezin[1], Izabela Radkova[1], Anton Geffert[2], Jarmila Geffertova[2]

[1]University of Forestry, Faculty of Forest Industry, Sofia, Bulgaria
e-mail: deliiski@netbg.com, brezin@abv.bg, izabelarad@abv.bg
[2]Technical University in Zvolen, Faculty of Wood Science and Technology, Zvolen, Slovakia
e-mail: geffert@tuzvo.sk, geffertova@tuzvo.sk

ABSTRACT

An engineering approach for the calculation of the specific mass energy consumption, which is needed for defrosting and the following heating of the frozen wood chips above the hydroscopic range, $q_{\text{total}}^{\text{m/t}}$, has been suggested. Equations for easy calculation of $q_{\text{total}}^{\text{m/t}}$ have been derived, depending on the wood moisture content u, on the fiber saturation points of the wood species at 20 °C and at –2 °C (i.e. at 293.15 K and at 271.15 K), $u_{\text{fsp}}^{293.15}$ and $u_{\text{fsp}}^{271.15}$respectively, on the initial chips' temperature, T_0 , and on the final temperature of the defrosted and heated chips, T_1.

For the calculation of the $q_{\text{total}}^{\text{m/t}}$ according to the suggested approach and equations a software program has been prepared in MS Excel 2010. With the help of the program calculations have been carried out for the determination of the energy consumption $q_{\text{total}}^{\text{m/t}}$, which is needed for defrosting and following heating of oak, acacia, beech, and poplar frozen chips with moisture content in the range from u = 0.4 kg·kg^{-1} to u = 1.0 kg·kg^{-1}, initial temperature t_0 = –40 °C, t_0 = –30 °C, t_0 = –20 °C, and t_0 = –10 °C until reaching of the chips‘ mass temperature of t_1 = 100 °C at the end of the heating.

Key words: frozen wood chips, defrosting, heating, specific mass energy consumption

1. INTRODUCTION

The possibility for the calculation of the energy consumption, which is needed for the heating of frozen wood chips until the starting of the chemical reaction during their cooking in the production of cellulose is of certain scientific and practical interest (Deliiski, Geffert, Geffertova 2014). Such possibility is of interest also for the calculation of the energy needed for the heating of frozen wood chips in the beginning of their drying when the chips are used as a fuel or for the production of briquettes, pellets, or particle boards (Yosifov 1989, 2005).

The aim of the present work is to suggest an engineering approach for the calculation of the specific mass energy consumption for the defrosting and the following heating of wood chips, which contain both frozen bound and free water.

2. MATERIAL AND METHODS

2.1. Theoretical basis for the calculation of the energy consumption for defrosting and the following heating of the wood chips

It is known that the specific volume energy consumption for the heating of 1 m^3 of solid materials with an initial mass temperature T_0 to a given mass temperature T_1 is determined using the equation (Chudinov 1968, Deliiski 2013a, 2013b)

$$q^{\text{v/m3}} = \frac{c \cdot \rho \cdot (T_1 - T_0)}{3.6 \cdot 10^6}. \quad (1)$$

The multiplier $3.6 \cdot 10^6$ in the denominator of eq. (1) ensures that the values of q are obtained in $kWh \cdot m^{-3}$, instead of in $J \cdot m^{-3}$.

After dividing the right part of eq. (1) by the wood density ρ, the following equation for the determination of the specific mass energy consumption for the heating of 1 kg is obtained:

$$q^{\text{m/kg}} = \frac{c \cdot (T_1 - T_0)}{3.6 \cdot 10^6}. \quad (2)$$

For the practical needs it is more convenient to determine the specific mass energy consumption q in $kWh \cdot t^{-1}$ (i.e. for the heating of 1 ton of wood chips) according to the equation

$$q^{\text{m/t}} = \frac{c \cdot (T_1 - T_0)}{3.6 \cdot 10^3}. \quad (3)$$

The total specific mass energy consumption, $q_{\text{total}}^{\text{m/t}}$, which is needed for the defrosting and the following heating of the wood chips, can be calculated according to the equation (Deliiski 2013a)

$$q_{\text{total}}^{\text{m/t}} = q_{\text{dfr}}^{\text{m/t}} + q_{\text{heat}}^{\text{m/t}}. \quad (4)$$

2.2. Calculation of the specific mass energy consumption for defrosting of the wood chips

The moisture content of the subjected to defrosting wood chips in the practice usually is above the fiber saturation point. This means that the chips contain the maximum possible amount of bound water for the given wood specie and chips contain free water, too.

Consequently, the specific mass energy for defrosting of the wood chips, which contain both frozen bound and free water, $q_{\text{dfr}}^{\text{m/t}}$, can be calculated according to the following equation (Deliiski 2013a):

$$q_{\text{dfr}}^{\text{m/t}} = q_{\text{dfr-bwm}}^{\text{m/t}} + q_{\text{bwm}}^{\text{m/t}} + q_{\text{dfr-fw}}^{\text{m/t}} + q_{\text{fw}}^{\text{m/t}}. \quad (5)$$

It has been determined, using the studies in Chudinov (1968), that the melting of the frozen bound water in the wood takes place gradually in the entire range from the initial temperature of the frozen wood $t_0 < -2\ ^{\text{o}}\text{C}$ (i.e. $T_0 < 271.15\ \text{K}$) until the reaching of the temperature $t_{\text{dfr-bwm}} = -2\ ^{\text{o}}\text{C}$ (i.e. $T_{\text{dfr-bwm}} = 271.15\ \text{K}$).

This means that based on eq. (3), the ***specific mass energy consumption for the heating of the wood chips until melting of the maximum possible amount of frozen bound water in them*** can be calculated according to the following equation (Deliiski *et. al.* 2014c):

$$q_{\text{dfr-bwm}}^{\text{m/t}} = \frac{c_{\text{dfr-bwm}}}{3.6 \cdot 10^3}(271.5 - T_0), \quad (6)$$

where the specific heat capacity of the wood with maximum possible amount frozen bound water in it, $c_{\mathrm{fr}}^{\mathrm{bwm}}$, can be calculated according to the equation given in (Deliiski 2011, 2013a).

Analogously, the *specific mass energy consumption for the melting of the maximum possible amount of frozen bound water in the chips* can be calculated according to the following equation (Deliiski *et. al*. 2014d):

$$q_{\mathrm{bwm}}^{\mathrm{m/t}} = \frac{c_{\mathrm{bwm}}}{3.6 \cdot 10^3}\left(271.15 - T_0\right) \;\; @ \;\; u > u_{\mathrm{fsp}}^{271.15} \;\&\;\; 213.15 \;\mathrm{K} \le T_0 \le 271.15 \;\mathrm{K}, \tag{7}$$

where the specific heat capacity of the maximum possible amount of frozen bound water in the chips, c_{bwm}, can be calculated according to the equation given in (Deliiski 2013a).

It has been determined that the melting of the frozen free water in the wood takes place in the temperature range between –2 °C and –1 °C, i.e. between 271.15 K and 272.15 K (Chudinov 1968). Based on this fact, the following equation for the calculation of the ***specific mass energy for the melting of the frozen free water in the wood chips*** has been derived (Deliiski *et. al*. 2014a):

$$q_{\mathrm{fw}}^{\mathrm{m/t}} = \frac{c_{\mathrm{fw}}}{3.6 \cdot 10^3} = 92.7778 \;\; \frac{u - u_{\mathrm{fsp}}^{293.15} - 0.022}{1 + u} \;\; @ \;\; u > u_{\mathrm{fsp}}^{271.15} \;\&\; 271.15\mathrm{K} \le T \le 272.15\mathrm{K}. \tag{8}$$

Because of the circumstance that in the range $271.15 \;\mathrm{K} \le T \le 272.15 \;\mathrm{K}$ there in no more frozen bound water in the chips, the ***specific mass energy consumption for the heating of the wood chips*** in this range ***until melting of the frozen free water in them*** can be calculated according to the following equation (Deliiski *et. al*. 2014b):

$$q_{\mathrm{dfr-fw}}^{\mathrm{m/t}} = \frac{c_{\mathrm{dfr-fw}}}{3.6 \cdot 10^3}, \tag{9}$$

where the specific heat capacity of the wood with only frozen free water in it can be calculated according to the equation given in (Deliiski 2013a).

2.3. Calculation of the specific mass energy consumption for heating of the defrosted wood chips

The specific mass energy, which is needed for the heating of the fully defrosted (i.e. non-frozen) wood chips above the hygroscopic range from the temperature 272.15 K (i.e. –1 °C) to the reaching of the desired mass temperature T_1 > 272.15 K, $q_{\mathrm{heat}}^{\mathrm{m/t}}$, can be calculated according to the following equation (Deliiski 2013a):

$$q_{\mathrm{heat}}^{\mathrm{m/t}} = \frac{\dfrac{2862u + 555}{1 + u} + \dfrac{5.49u + 2.95}{1 + u}\left(\dfrac{271.15 + T_1}{2}\right) + \dfrac{0.0036}{1 + u}\left(\dfrac{271.15 + T_1}{2}\right)^2}{3.6 \cdot 10^3}\left(T_1 - 272.15\right). \tag{10}$$

3. RESULTS

For the solution of eqs. (4) ÷ (15) a program in the calculation environment of MS Excel 2010 has been created (refer to http://www.gcflearnfree.org/excel2010).

With the help of the program, the change in the energy $q_{\mathrm{total}}^{\mathrm{m/t}}$ and its components depending on $T_0 = \mathrm{var}$ and on $u = \mathrm{var}$ above the hygroscopic range have been calculated for frequently used in the production of chips oak wood (*Quercus petraea* Libl.), acacia wood (*Robinia pseudoacacia* J.), beech wood (*Fagus silvatica* L), and poplar wood (*Populus nigra* L.).

For the calculations, standardized values of the fiber saturation point at 20 °C derived in the literature for the studied wood species have been used, namely: $u_{\mathrm{fsp}}^{293.15} = 0.29$ kg·kg^{-1} for oak wood, $u_{\mathrm{fsp}}^{293.15} = 0.30$ kg·kg^{-1} for acacia wood, $u_{\mathrm{fsp}}^{293.15} = 0.31$ kg·kg^{-1} for beech wood, and $u_{\mathrm{fsp}}^{293.15} = 0.35$ kg·kg^{-1} for poplar wood (Nikolov and Videlov 1987, Videlov 2003, Deliiski 2013a). The influence of the initial wood temperature and of the wood moisture content on $q_{\mathrm{total}}^{\mathrm{m/t}}$ have been studied for chips containing ice in the ranges $0.4\ \mathrm{kg \cdot kg^{-1}} \le u \le 1.0\ \mathrm{kg \cdot kg^{-1}}$ and $233.15\ \mathrm{K} \le T_0 \le 263.15\ \mathrm{K}$ (i.e. $-40\ ^{\mathrm{o}}\mathrm{C} \le t_0 \le -10\ ^{\mathrm{o}}\mathrm{C}$).

The calculated according to eq. (5) change in $q_{\mathrm{dfr}}^{\mathrm{m/t}} = f(u, t_0)$ at $t_0 = -10$ °C, $t_0 = -20$ °C, $t_0 = -30$ °C, and $t_0 = -40$ °C is shown on Figure 1.

The calculated according to eq. (10) change in $q_{\mathrm{heat}}^{\mathrm{m/t}} = f(u)$ at $T_1 = 373.15$ K (i.e at $t_1 = 100$ °C) is shown on Figure 2. According to eq. (10) the energy $q_{\mathrm{heatr}}^{\mathrm{m/t}}$ does not depend on t_0 and on the wood specie.

The calculated according to eq. (4) change in $q_{\mathrm{total}}^{\mathrm{m/t}} = f(u, t_0)$ at $t_0 = -10$ °C, $t_0 = -20$ °C, $t_0 = -30$ °C, $t_0 = -40$ °C, and $t_1 = 100$ °C is shown on Figure 3.

4. DISCUSSION

The analysis of the obtained results, a part of which were presented above, leads to the following conclusions:

1. The components $q_{\mathrm{dfr\text{-}bwm}}^{\mathrm{m/t}}$ and $q_{\mathrm{bwm}}^{\mathrm{m/t}}$ of the energy $q_{\mathrm{total}}^{\mathrm{m/t}}$ depend on the initial temperature t_0 of the wood chips, but the components $q_{\mathrm{dfr\text{-}fw}}^{\mathrm{m/t}}$, $q_{\mathrm{fw}}^{\mathrm{m/t}}$, and $q_{\mathrm{heat}}^{\mathrm{m/t}}$ do not depend on t_0. Only the component $q_{\mathrm{heat}}^{\mathrm{m/t}}$ of $q_{\mathrm{total}}^{\mathrm{m/t}}$ depends on the desired mass temperature t_1 of the defrosted and after that heated chips.

2. All components of $q_{\mathrm{total}}^{\mathrm{m/t}}$, except $q_{\mathrm{dfr\text{-}fw}}^{\mathrm{m/t}}$ and $q_{\mathrm{heat}}^{\mathrm{m/t}}$, depend on the wood specie.

3. The increase in u causes a non-linear increase in $q_{\mathrm{dfr}}^{\mathrm{m/t}}$ and $q_{\mathrm{total}}^{\mathrm{m/t}}$ due to the increasing of the amount of frozen free water in the more moist wood.

4. The increase of u from $u = 0.4\ \mathrm{kg \cdot kg^{-1}}$ to $u = 1.0\ \mathrm{kg \cdot kg^{-1}}$ at $t_0 = -20$ °C causes an increase in $q_{\mathrm{dfr}}^{\mathrm{m/t}}$ as follows:

- for oak wood: from 25.88 kWh·t^{-1} to 50.11 kWh·t^{-1}, i.e. by 1.93 times;
- for acacia wood: from 25.73 kWh·t^{-1} to 50.01 kWh·t^{-1}, i.e. by 1.94 times;
- for beech wood: from 25.58 kWh·t^{-1} to 49.91 kWh·t^{-1}, i.e. by 1.95 times;
- for poplar wood: from 24.97 kWh·t^{-1} to 49.49 kWh·t^{-1}, i.e. by 1.98 times.

5. The increase of u from $u = 0.4\ \mathrm{kg \cdot kg^{-1}}$ to $u = 1.0\ \mathrm{kg \cdot kg^{-1}}$ at $t_0 = -20$ °C and $t_1 = 100$ °C causes a non-linear increase in $q_{\mathrm{total}}^{\mathrm{m/t}}$ by 1.41 times for all studied wood species, as follows:

- for oak wood: from 100.73 kWh·t^{-1} to 141.50 kWh·t^{-1};
- for acacia wood: from 100.57 kWh·t^{-1} to 141.40 kWh·t^{-1};
- for beech wood: from 100.42 kWh·t^{-1} to 141.30 kWh·t^{-1};
- for poplar wood: from 99.82 kWh·t^{-1} to 140.88 kWh·t^{-1}.

6. The fiber saturation point $u_{\mathrm{fsp}}^{293.15}$ causes the following contradictory change in $q_{\mathrm{dfr}}^{\mathrm{m/t}}$ and $q_{\mathrm{total}}^{\mathrm{m/t}}$, depending on T_0:

- in the range 243.15 K < T_0 < 271.15 K (i.e. at −30 °C < t_0 < −2 °C) the increase of $u_{\mathrm{fsp}}^{293.15}$ causes a larger decrease in $q_{\mathrm{dfr}}^{\mathrm{m/t}}$ and $q_{\mathrm{total}}^{\mathrm{m/t}}$ the more T_0 is larger than 243.15 K;
- at $T_0 \approx 243.15$ K (i.e. at $t_0 \approx -30$ °C) the increase of $u_{\mathrm{fsp}}^{293.15}$ does not influence $q_{\mathrm{dfr}}^{\mathrm{m/t}}$ and $q_{\mathrm{total}}^{\mathrm{m/t}}$;

• in the range 233.15 K < T_0 < 243.15 K (i.e. at −40 °C < t_0 < −30 °C) the increase of $u_{\mathrm{fsp}}^{293.15}$ causes a larger increase in $q_{\mathrm{dfr}}^{\mathrm{m/t}}$ and $q_{\mathrm{total}}^{\mathrm{m/t}}$ the more T_0 is lower then 243.15 K.

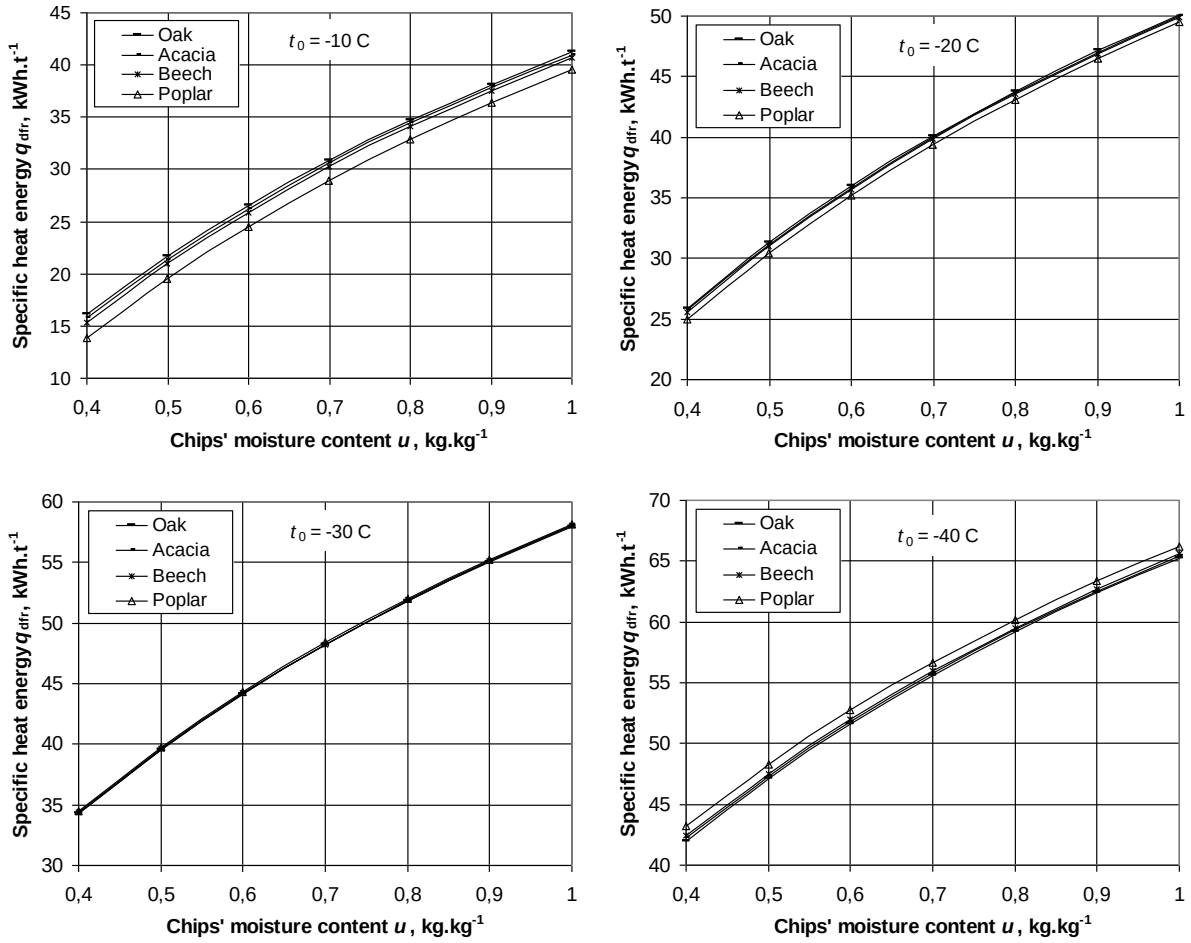

Figure 1. *Change in* $q_{\mathrm{dfr}}^{\mathrm{m/t}}$ *of subjected to defrosting oak, acacia, beech, and poplar chips, depending on u and* t_0

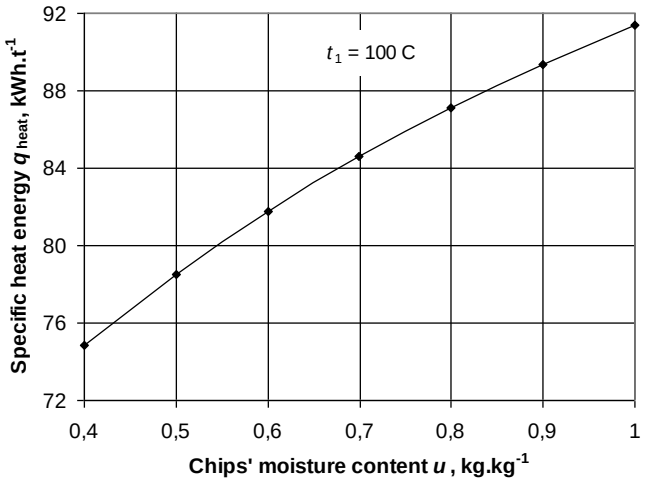

Figure 2. *Change in* $q_{\mathrm{heat}}^{\mathrm{m/t}}$ *of subjected to heating defrosted chips from all wood species until reaching of* t_1 *= 100 °C, depending on u*

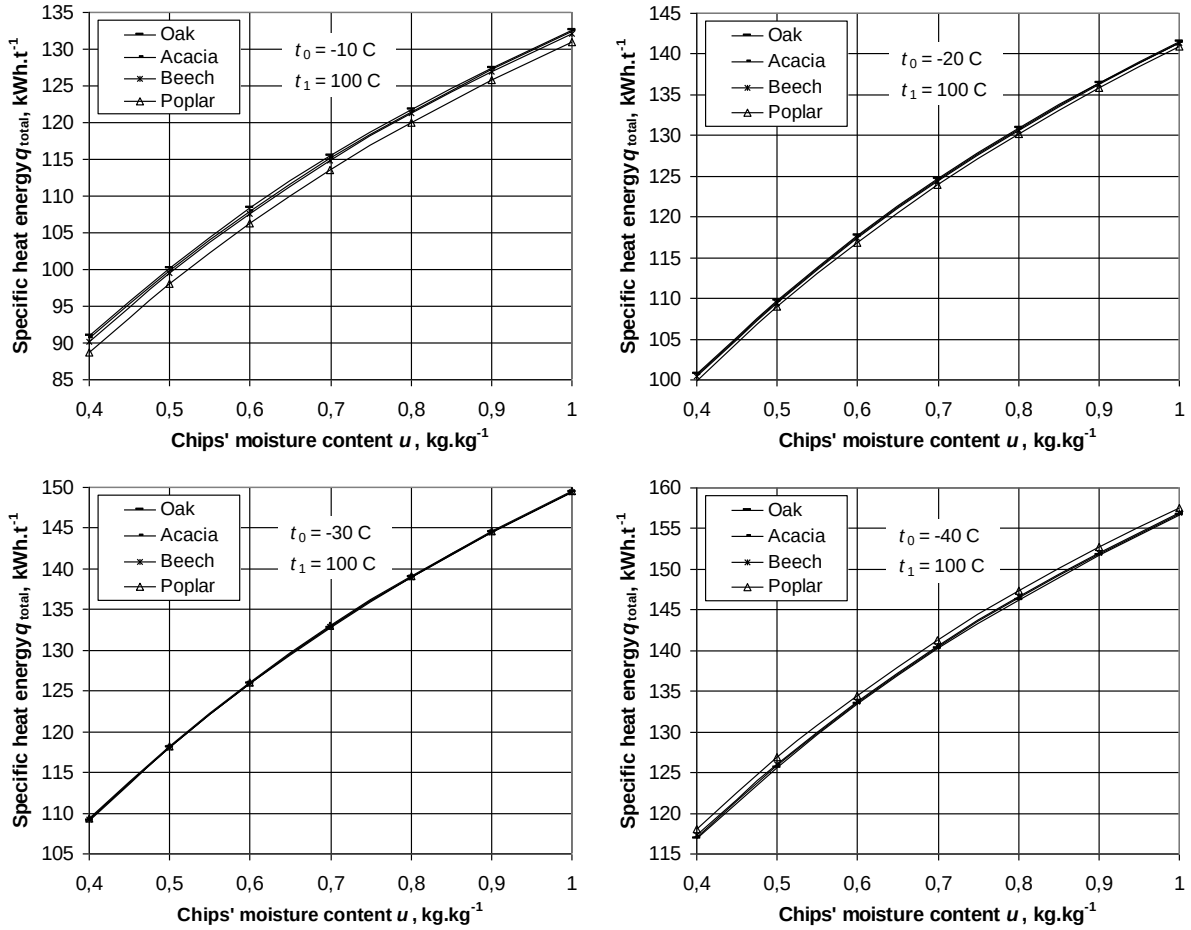

Figure 3. *Change in* $q_{\text{total}}^{\text{m/t}}$ *of subjected to defrosting and the following heating at* t_1 *= 100* ^{o}*C oak, acacia, beech, and poplar chips, depending on u and* t_0

5. CONCLUSIONS

The present paper describes the suggested by the authors engineering approach for the calculation of the total specific mass energy consumption $q_{\text{total}}^{\text{m/t}}$ for defrosting and the following heating of the wood chips, which contain both frozen bound and free water. Equations for the easy calculation of $q_{\text{total}}^{\text{m/t}}$ have been presented, depending on u, $u_{\text{fsp}}^{271.15}$, $u_{\text{fsp}}^{293.15}$, T_0 and T_1.

For the calculation of the $q_{\text{total}}^{\text{m/t}}$ according to the suggested approach a software program has been prepared in MS Excel 2010. With the help of the program, calculations have been carried out for the determination of $q_{\text{total}}^{\text{m/t}}$ and its components $q_{\text{dfr-bwm}}^{\text{m/t}}$, $q_{\text{bwm}}^{\text{m/t}}$, $q_{\text{dfr-fw}}^{\text{m/t}}$, $q_{\text{fw}}^{\text{m/t}}$, and $q_{\text{heat}}^{\text{m/t}}$ for oak, acacia, beech, and poplar frozen chips with moisture content in the range from u = 0.4 kg·kg^{-1} to u = 1.0 kg·kg^{-1}, initial temperature t_0 = –40 ^{o}C, t_0 = –30 ^{o}C, t_0 = –20 ^{o}C, and t_0 = –10 ^{o}C until reaching of the final chips‘ mass temperature of t_1 = 100 ^{o}C.

The obtained results show that $q_{\text{total}}^{\text{m/t}}$ increases non-linearly with an increase of the chips’ moisture content u. When u of the frozen chips with t_0 = –20 ^{o}C increases from 0.4 kg·kg^{-1} to 1.0 kg·kg^{-1} the value of $q_{\text{total}}^{\text{m/t}}$ increases from 100.5 kWh·t^{-1} to 141.5 kWh·t^{-1}, i.e. by about 1.41 for all studied wood species.

It must be noted that the components $q^{m/t}_{dfr\text{-}bwm}$ and $q^{m/t}_{bwm}$ of the energy $q^{m/t}_{total}$ depend on the initial chips' temperature t_0, but the components $q^{m/t}_{dfr\text{-}fw}$, $q^{m/t}_{fw}$, and $q^{m/t}_{heat}$ do not depend on t_0. All components of $q^{m/t}_{total}$, except $q^{m/t}_{dfr\text{-}fw}$ and $q^{m/t}_{heat}$, depend on the wood specie. Only the component $q^{m/t}_{heat}$ of $q^{m/t}_{total}$ depends on the desired mass temperature t_1 of the defrosted and after that heated chips.

The increase of the standard value of fiber saturation point of the wood, $u^{293.15}_{fsp}$, causes a contradictory change in $q^{m/t}_{total}$, depending on T_0: $q^{m/t}_{total}$ decreases when 243.15 K < T_0 < 271.15 K and $q^{m/t}_{total}$ increases at T_0< 243.15 K. The reason for this are the different degrees and directions of the influence of u on the separate components of $q^{m/t}_{total}$.

The obtained results can be used for a science-based determination of the energy consumption for defrosting and heating of wood chips in the production of cellulose, briquettes, pellets or particle boards. They are also of specific importance for the optimization of the technology and of the model-based automatic control (Deliiski 2003, Hadjiiski 2003) of the chips' defrosting and heating processes.

Symbols

c = specific heat capacity ($J \cdot kg^{-1} \cdot K^{-1}$)
exp = exponent
q = specific mass energy consumption ($kWh \cdot t^{-1}$) or specific volume energy consumption ($kWh \cdot m^{-3}$)
t = temperature (^oC): $t = T - 273.15$
T = temperature (K): $T = t + 273.15$
u = moisture content ($kg \cdot kg^{-1}$): $u = W/100$
W = moisture content (%): $W = 100u$
ρ = density ($kg \cdot m^{-3}$)
& = and simultaneously with this
@ = at

Subscripts and superscripts:

Bw = bound water
bwm = maximum possible amount of bound water (for the specific heat capacity of this water in frozen state in the wood chips or for the energy needed for the melting of this water)
dfr = defrosting (of the wood chips)
dfr-bwm = for the energy needed for heating of the chips until melting of the maximum possible amount of frozen bound water in them
dfr-fw = for the energy needed for heating of the chips until melting of the frozen free water in them
fw = free water (for the specific heat capacity of the frozen free water in the wood chips or for the energy needed for melting of this water)
fsp = fiber saturation point of the wood specie
heat = heating (for the specific heat capacity of the non-frozen wood chips or for the energy needed for the heating of the defrosted chips)
m/kg = mass (for the specific mass energy consumption in $kWh \cdot kg^{-1}$)
m/t = mass (for the specific mass energy consumption in $kWh \cdot t^{-1}$)
total = total (for the energy needed for defrosting and following heating of the wood chips)
v/m3 = volume (for the specific volume energy consumption in $kWh \cdot m^{-3}$)
0 = initial (for the average mass temperature of the chips at the beginning of the defrosting)
1 = end (for the average mass temperature of the chips at the end of the defrosting and heating)
271.15 = at 271.15 K, i.e. at –2 ^oC (for the temperature, at which the melting of the frozen free water in the wood chips has been completed or for the calculated value of the wood fiber saturation point of the wood specie at this temperature)
272.15 = at 272.15 K, i.e. at –1 ^oC (for the temperature, at which the melting of the frozen bound water in the wood chips has been completed or for the calculated value of the wood fiber saturation point of the wood specie at this temperature)
293.15= at 293.15 K, i.e. at 20 ^oC (for the standard value of the fiber saturation point of wood specie)

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The Authors’ Addresses:

Nencho Deliiski, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: deliiski@netbg.com

Veselin Brezin, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: brezin@abv.bg

Izabela Radkova, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: izabelarad@abv.bg

Anton Geffert, Professor, PhD,
University of Forestry,
Technical University, Faculty of Wood Science and Technology,
Ul. T.G. Masarika 2117/24, 969 53 Zvolen, SLOVAKIA
e-mail: geffert@tuzvo.sk

Jarmila Geffertova, Professor, PhD,
University of Forestry,
Technical University, Faculty of Wood Science and Technology,
Ul. T.G. Masarika 2117/24, 969 53 Zvolen, SLOVAKIA
e-mail: geffertova @tuzvo.sk

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COMPUTATION OF THE TOTAL SPECIFIC ENERGY CONSUMPTION FOR UNILATERAL HEATING OF FLAT SPRUCE DETAILS BEFORE THEIR BENDING

Nencho Deliiski[1], Neno Trichkov[1], Dimitar Angelski[1], Ladislav Dzurenda[2]

[1]University of Forestry, Faculty of Forest Industry, Sofia, Bulgaria
e-mail: deliiski@netbg.com, nenotr@abv.bg, d.angelski@gmail.com
[2]Technical University in Zvolen, Faculty of Wood Science and Technology, Zvolen, Slovakia
e-mail: ladislav.dzurenda@tuzvo.sk

ABSTRACT

A numerical approach for the computation of the total specific energy consumption, q_{total}, which is needed for unilateral heating of 1 m^2 of flat wood details aimed at their plasticizing in the production of curved outside parts for corpses of stringed music instruments, has been suggested. The energy q_{total} consists of two components: energy needed for heating of the wood itself, q_w, and energy needed for the covering of the heat emission from the non-heated side of the wood details, q_e, i.e. $q_{total}= q_w+q_e$.

The suggested approach is based on the integration of the solutions of a linear model for the calculation of the non-stationary 1D temperature distribution along the thickness of subjected to unilateral heating flat wood details, which was created and solved earlier by the authors.

For the numerical solution of the model and for simultaneous determination of the specific energies q_w, q_e, and q_{total} a software program has been prepared, which has been input in the calculation environment of Visual Fortran Professional.

Using the program, computations were carried out for the determination of the change in the specific energies q_w, q_e, and q_{total}, which are consumed by spruce details with an initial temperature of 20 ^oC, moisture content of 0.15 $kg \cdot kg^{-1}$, and thicknesses of 6 mm, 8 mm, and 10 mm during their 10 min unilateral heating at temperatures of the heating metal band of 120 ^oC and of the surrounding air of 20 ^oC. The obtained results are graphically presented and analyzed.

Key words: spruce details, unilateral heating, plasticizing, bending, specific energy consumption

1. INTRODUCTION

An important component of the technologies for production of curved wood details is their plasticizing up to the stage that allows their faultless bending. The duration of the heating process and the energy consumption for the unilateral heating of the details aimed at their plasticizing before bending depends on many factors: wood specie, thickness and moisture content of the details, temperatures of the heating medium and of the surrounding air, desired degree of plasticizing, etc. (Chudinov 1968, Taylor 2001, Trebula and Klement 2002, Videlov 2003, Pervan 2009, Angelski 2010, Deliiski and Dzurenda 2010, Gaff and Prokein 2011).

Unilateral heating is applied, for example, in the production of curved outside parts for the corpses of string music instruments, so that they are plasticized before bending. In the practice, those details are with thicknesses between 5 mm and 10 mm and with about 15% moisture content. The technology for plasticizing of such details usually uses an equipment with a metal band, electrically heated up to the temperature in the range 100 ºC ÷ 150 ºC.

In the specialized literature information about the energy consumption needed for the unilateral heating of wood details was given only by the authors (Deliiski *et. al.* 2014). In the cited publication an approach for the calculation of the specific energy consumption needed only for the heating of the

wood itself in kWh.m^{-3} was presented and there is no information about the energy needed for the covering of the heat emission from the non-heated side of the wood details.

For the practical needs it is more convenient to determine the total energy consumption for unilateral heating of flat details in kWh.m^{-2} instead in kWh.m^{-3}.

The aim of the present work is to suggest a numerical approach for the computation of the total specific energy consumption (in kWh.m^{-2}), which is needed for unilateral heating of flat wood details aimed at their plasticizing in the production of curved outside parts for corpses of stringed music instruments. The approach has to be based on the integration of the solutions of a linear model for the calculation of the non-stationary 1D temperature distribution along the thickness of subjected to unilateral heating flat wood details, which was created earlier by the authors.

2. MATERIAL AND METHODS

2.1. Modelling of the heat distribution in flat wood details during their unilateral heating

When the width and length of the wood details exceed their thickness by at least 3 and 5 times respectively, then the calculation of the change in the temperature only along the thickness of the details in the center of their flat side during the unilateral heating (i.e. along the coordinate *x*, which coincides with the details' thickness *h*) can be carried out with the help of the following linear 1D mathematical model (Deliiski 2003):

$$\frac{\partial T(x,\tau)}{\partial \tau} = a\frac{\partial^2 T(x,\tau)}{\partial x^2} \tag{1}$$

with an initial condition

$$T(x,0) = T_0 \tag{2}$$

and the following boundary conditions:

• from the side of the details' heating – at prescribed surface temperature, which is equal to the temperature of the heating metal band T_m:

$$T(0,\tau) = T_m(\tau)\,; \tag{3}$$

• from the opposite non-heated side of the details – at convective heat exchange between the details' surface and the surrounding air environment

$$\frac{\partial T(X,\tau)}{\partial x} = -\frac{\alpha(\tau)}{\lambda_s(\tau)}\left[T_a(\tau) - T_s(\tau)\right]\,. \tag{4}$$

For practical usage of eqs. (1) and (4) it is needed to have mathematical descriptions of the wood temperature conductivity cross sectional to the fibers, a_c, of the wood thermal conductivity, $\lambda_c = \lambda_s$, and of the heat transfer coefficient between the details' surface at their non-heated side and the surrounding air, α. For this purpose the mathematical description of *a* and λ given in (Deliiski 2003, 2011, 2013b) can be used.

The calculation of the heat transfer coefficient α can be carried out with the help of the following equation, which has been suggested by Chudinov (1968) for the cases of cooling of horizontally situated wood rectangular surfaces in atmospheric conditions of free convection:

$$\alpha = 3.256\left[T_s(\tau) - T_a(\tau)\right]^{0.25}. \tag{5}$$

According to eq. (3), the temperature at the details' surface being in contact with the heating metal band is equal to the temperature of the metal band T_m due to the extremely high coefficient of heat transfer between the band and the wood during their very close contact.

2.2. Modelling of the total specific energy consumption for unilateral heating of wood details

The total specific energy consumption for unilateral heating of wood details, q_{total}, consists of two components:

- energy needed for heating of the wood itself, q_{w};
- energy needed for covering of the heat emission from the non-heated side of the wood details, q_{e}.

This means that the energy q_{total} can be calculated according to the following equation:

$$q_{\text{total}} = q_{\text{w}} + q_{\text{e}}\,. \tag{6}$$

2.2.1. Modelling of the specific energy consumption for heating of the wood itself

It is known that the specific energy consumption for the heating of 1 m^3 of solid materials with an initial mass temperature T_0 to a given average mass temperature T_{avg} is determined using the equation (Deliiski, 2003, 2013b)

$$q = \frac{c \cdot \rho \cdot \left(T_{\text{avg}} - T_0\right)}{3.6 \cdot 10^6}\,. \tag{7}$$

After multiplying the right part of eq. (7) with the detail's thickness h the following equation for the determination of the specific mass energy consumption needed for the heating of 1 m^2 of the subjected to unilateral heating wood details, q_{w}, is obtained:

$$q_{\text{w}} = \frac{c \cdot \rho \cdot h \cdot \left(T_{\text{avg}} - T_0\right)}{3.6 \cdot 10^6}, \tag{8}$$

where

$$T_{\text{avg}} = \frac{1}{h}\int_{(h)} T(x,\tau)\mathrm{d}h \tag{9}$$

and according to Chudinov (1968) and Deliiski (2013a)

$$\rho = \rho_{\text{b}}\,\frac{1+u}{1-\dfrac{S_{\text{v}}}{100}\left(u_{\text{fsp}}^{293.15}-u\right)} \quad @ \quad u \le u_{\text{fsp}}. \tag{10}$$

The multiplier $3.6 \cdot 10^6$ in the denominator of eq. (8) ensures that the values of q_{w} are obtained in kWh·m^{-2}, instead of in J·m^{-2}.

For practical usage of eq. (8) it is needed to have mathematical descriptions of the specific heat capacity of the non-frozen wood, c. Such descriptions are given in (Deliiski 2003, 2011, 2013b) and in Deliiski and Dzurenda 2010).

2.2.2. Modelling of the specific energy consumption for covering of the heat emission from the non-heated side of the wood details

The change in the specific energy consumption q_{e}, (for 1 m^2 of the details' surface) which is needed for covering of the heat emission from the non-heated side of the wood details into the surrounding air environment during time of $\Delta\tau$, can be calculated according to the following equation (Deliiski 2003, Deliiski *et. al*. 2014a):

$$\Delta q_{\text{e}} = \frac{\alpha(\tau)\Delta\tau}{3.6 \cdot 10^6}\left[T_{\text{s}}(\tau) - T_{\text{a}}(\tau)\right]. \tag{11}$$

The specific energy consumption needed for the covering of the emission from 1 m^2 surface of the details during their unilateral heating with duration of $\tau_p = N.\Delta\tau$ is equal to

$$q_e = \sum_{i=1}^{N} \Delta q_{ei} \,. \tag{12}$$

3. RESULTS

For the numerical solution of the above presented mathematical models aimed at usage of the suggested approach for the calculation of q_{total} a software program was prepared in FORTRAN, which was input in the developed by Microsoft calculation environment of Visual Fortran Professional.

With the help of the program, as examples, computations have been made for the determination of the total specific energy consumption, which is needed for unilateral heating of non-frozen spruce (*Picea Abies Karst*) details with thicknesses of h = 6 mm, h = 8 mm, h = 10 mm, initial wood temperature of t_0 = 20 °C, wood moisture content of u = 0.15 kg·kg^{-1}, basic density ρ_b = 380 kg.m^{-3}, and volume shrinkage 11.4% during their 10 min heating at t_m = 120 °C and at t_a = 20 °C.

The solution of the model and the computations of q_{total} have been done with the average arithmetic values for the temperature range 20 °C ≤ t ≤ 120 °C of the spruce temperature conductivity cross-sectional to the fibers a_c = 2.7627·10^{-7} m^2.s^{-1} and of the spruce thermal conductivity cross-sectional to the fibers $\lambda_c = \lambda_s$ = 0.2745 W·m^{-1}·K^{-1}, which have been obtained using the mathematical descriptions of a_c, and λ_c, depending on the temperature and wood moisture content (Deliiski 2003, 2011, 2013b).Simultaneously with the solution of the 1D model, calculations of t_{avg} and also of q_w, q_e, and q_{total} have been carried out, using the value of the density ρ = 445.64 kg.m^{-3}. This value of ρ is calculated according to eq. (10) for spruce wood with u = 0.15 kg·kg^{-1}, $u_{fsp}^{293.15} = 0.32\ \text{kg}\cdot\text{kg}^{-1}$, ρ_b = 380 kg·m^{-3}, and volume shrinkage S_v = 11.4% (Videlov, 2003). The value of c was calculated according to the mathematical description of the specific heat capacity of the wood in the hygroscopic range given in (Deliiski, 2003, 2011, 20013b). Because of the almost linear dependence of c on t the average arithmetic values of c = 2218 J·kg^{-1}·K^{-1} for the studied temperature range 20 °C ≤ t ≤ 120 °C were used during the solution of eq. (8). The left part of Figure 1 presents the temperature change calculated by the model in 4 equidistant from one another characteristic points along the thickness of the detail with h = 8 mm during its unilateral heating. The coordinates of those points are shown in the legend of the figure. The right part of this figure shows the change in t_{avg} of the details during their heating, depending on h. Figure 2 and 3 present the calculated change of q_w, q_e, and q_{total} during the unilateral heating of the spruce details with studied thicknesses.

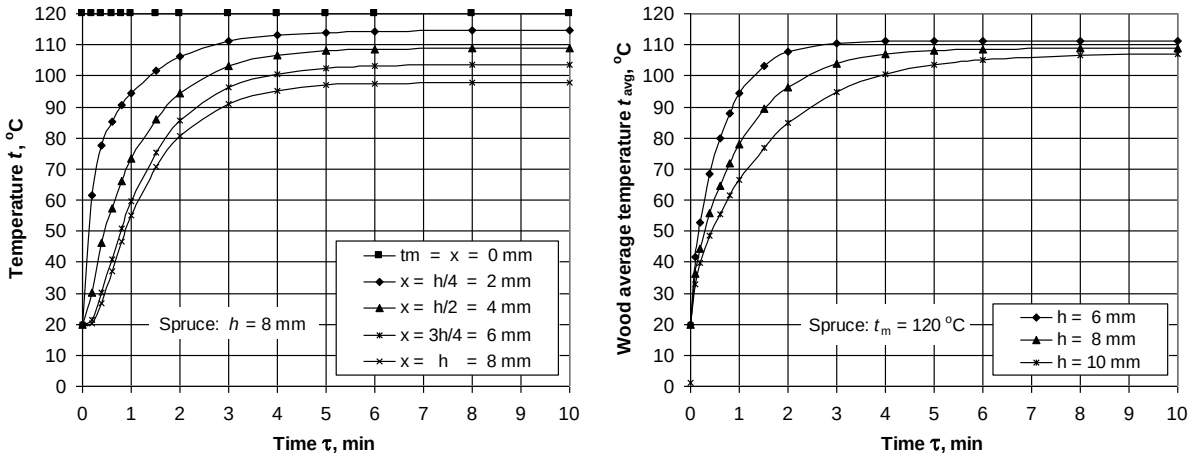

Figure 1. *Change in t along the detail's thickness of h = 8 mm (left) and in t_{avg} (right) of spruce details with t_0 = 20 °C, u = 0.15 kg.kg^{-1}, h = 6 mm, h = 8 mm, and h = 10 mm during their unilateral heating at t_m = 120 °C and at t_a = 20 °C*

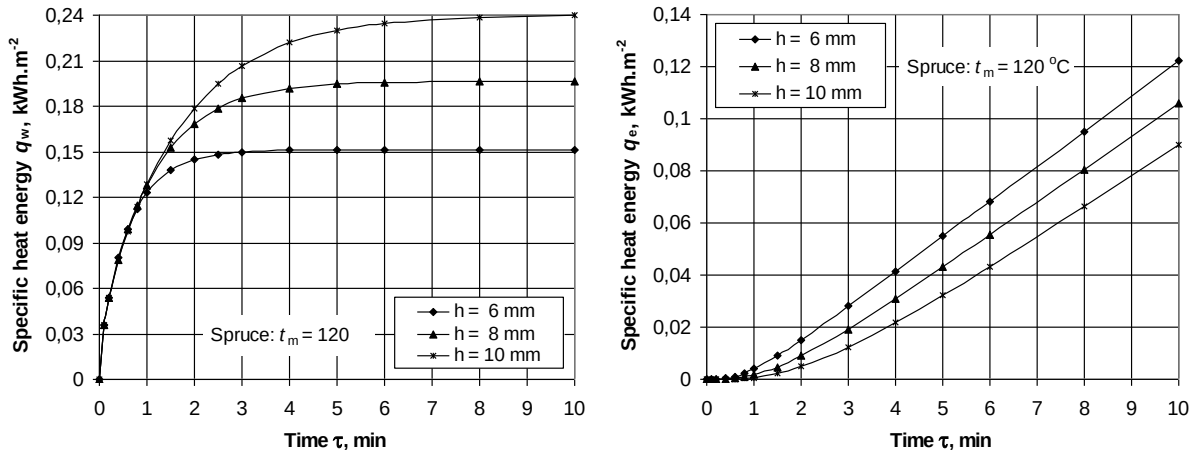

Figure. 2. *Change in q_w (left) and q_e (right) for spruce details with t_0 = 20 °C and u = 0.15 kg.kg^{-1}, during their unilateral heating at t_m = 120 °C and t_a = 20 °C, depending on h*

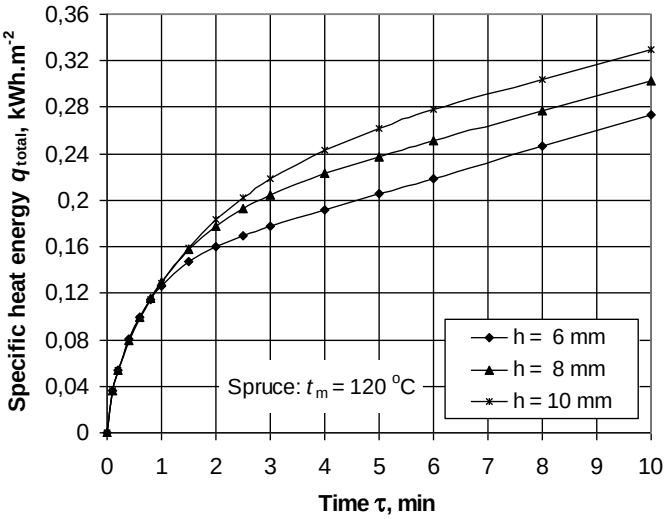

Figure. 3. *Change in q_{total} for spruce details with t_0 = 20 °C and u = 0.15 kg.kg^{-1}, during their unilateral heating at t_m = 120 °C and t_a = 20 °C, depending on h*

4. DISCUSSION

The analysis of the obtained results, a part of which were presented above, leads to the following conclusions:

1. The increasing of the total specific energy consumption, q_{total}, during the unilateral heating of the wood details goes on according to a curvilinear dependence, which passes into a linear dependence when a stationary temperature distribution along the thickness of the details occurs.

2. The slope of the linear sections of the dependences $q_{total} = f(\tau)$ slightly decreases with an increase of the details' thickness, *h*.

3. The specific energy consumption q_{total} at constant other conditions depends proportionally on the duration of the details' heating and is inversely proportional to *h*. For example, after 5 min and 10 min unilateral heating of the spruce details with studied thicknesses, the energy consumption q_{total} reaches the following values:

- for *h* = 6 mm: q_{total} = 0.2056 kWh.m^{-2} and q_{total} = 0.2730 kWh.m^{-2} respectively;
- for *h* = 8 mm: q_{total} = 0.2377 kWh.m^{-2} and q_{total} = 0.3022 kWh.m^{-2} respectively;
- for *h* = 10 mm: q_{total} = 0.2624 kWh.m^{-2} and q_{total} = 0.3296 kWh.m^{-2} respectively.

4. CONCLUSIONS

The present paper describes a numerical approach for the computation of the total specific energy consumption (in kWh.m^{-2}), q_{total}, which is needed for the unilateral heating of flat wood details aimed at their plasticizing in the production of curved outside parts for corpses of stringed music instruments. The approach is based on the integration of the solutions of a linear mathematical model for the calculation of the non-stationary 1D temperature distribution along the thickness of subjected to unilateral heating flat wood details.

The energy consumption q_{total} is a sum of two components: energy needed for heating of the wood itself, q_w, and energy needed for covering of the heat emission from the non-heated side of the wood details, q_e.

For the numerical solution of the model aimed at the usage of the suggested approach a software program has been prepared, which has been input in the calculation environment of Visual Fortran Professional. As examples, computations have been carried out for the determination of the change in the total specific energy, which is consumed by spruce details with an initial temperature of 20 ^{o}C, moisture content of 0.15 kg.kg^{-1}, and thicknesses of 6 mm, 8 mm, and 10 mm during their 10 min unilateral heating at temperatures of the heating metal band 120 ^{o}C and of the surrounding air 20 ^{o}C.

The obtained results show that during the unilateral heating of the details the increasing in the total specific energy q_{total} goes on according to complex curves. The values of q_{total} increasingly depend on the duration of the details' heating and decreasingly depend on h. The results also show that by increasing the heating time the curves of q_{total} gradually approach asymptotically to the straight lines, when at given values of h, t_m, and t_a a stationary temperature distribution along the thickness of the subjected to unilateral heating wood details occurs. For example, when spruce details with t_0 = 20 ^{o}C and u = 0.15 kg.kg^{-1} are subjected to unilateral heating at t_m = 120 ^{o}C and t_a = 20 ^{o}C, the energy consumption q_{total} reaches the following values after 10 min heating: q_{total} = 0.2730 kWh.m^{-2} for h = 6 mm, q_{total} = 0.3022 kWh.m^{-2} for h = 8 mm, and q_{total} = 0.3296 kWh.m^{-2} for h = 10 mm.

The obtained results can be used for a science-based determination of the energy consumption, which is needed for unilateral heating of flat wood details aimed at their plasticizing before bending in the production of curved details for different applications in the furniture and other industries. They are also of specific importance for the optimization of the technology and of the model-based automatic control (Deliiski 2003, Hadjiski 2003, Deliiski and Dzurenda 2010) of the heating process of details before their bending.

Symbols

a = temperature conductivity (m^2·s^{-1})
c = specific heat capacity (J·kg^{-1}·K^{-1})
h = thickness (m)
N = number of the steps on the τ-coordinate using which the model was solved
q = specific energy consumption (kWh·m^{-2})
S = wood shrinkage (%)
T = temperature (^{o}C): $t = T - 273.15$
T = temperature (K): $T = t + 273.15$
u = moisture content (kg·kg^{-1}): $u = W/100$
W = moisture content (%): $W = 100u$
x = coordinate along the thickness of the details: $0 \le x \le X = h$
α = heat transfer coefficient (W·m^{-2}·K^{-1})
λ = thermal conductivity (W·m^{-1}·K^{-1})
ρ= density (kg·m^{-3})
τ = time (s)
Δx = step on the x-coordinate of the model, which coincides with the thickness of the subjected to heating wood details (m)
$\Delta\tau$ = step on the τ-coordinate for solution of the model, i.e. interval between time levels (s)
Δq = change of q for time equal to $\Delta\tau$, kWh·m^{-2}
@ = at

Subscripts and superscripts:

a = air (for the temperature of the air near the non-heated side of the wood details)
avg = average (for the average mass temperature of the details at given moment of their unilateral heating or for the average arithmetic values of the thermo physical characteristics of wood)
b = basic (for density, based on dry mass divided by green volume)
c = cross-sectional to the fibers (for the values of the thermo physical characteristics of wood)
e = emission (for the energy needed for covering of the heat emission from the details)
fsp = fiber saturation point of the wood
m = medium (for the temperature of the heating metal band used for unilateral heating)
p = process
s = surface (for the non-heated surface of the wood details)
total = total (for the energy needed both for heating of the wood itself and for the covering of the heat emission from the details)
v = volume (for the wood shrinkage)
w = wood (for the energy needed for heating of the wood itself)
0 = initial (for the average mass temperature of the details at the beginning of the heating or for the time level at the beginning of the model’s solution)
293.15 = at 293.15 K, i.e. at 20 ^{o}C (for the standard values of the wood fiber saturation point)

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The Authors' Addresses:

Nencho Deliiski, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: deliiski@netbg.com

Neno Trichkov, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: nenotr@abv.bg

Dimitar Angelski, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: d.angelski@gmail.com

Ladislav Dzurenda, Professor, PhD,
University of Forestry,
Technical University, Faculty of Wood Science and Technology,
Ul. T.G. Masarika 2117/24, 969 53 Zvolen, SLOVAKIA
e-mail: ladislav.dzurenda@tuzvo.sk

UDC (UDK): 674.815:539.166

THE INFLUENCE OF CONTROLLED GAMMA RAY EXPOSITION UPON CHEMICAL STRUCTURE CHANGES OF THE SEVERAL WOOD-BASED COMPOSITES USING THE FTIR SPECTRA

Srđan Svrzić, Marija Mandić

University of Belgrade, Faculty of Forestry,,
Department of Wood Processing Kneza Višeslava 1, Belgrade,
email: svrza@ptt.rs, marija.mandic@sfb.bg.ac.rs

ABSTRACT

The results in change of chemical structure, presented, relate to utilisation of irradiation phenomena (by controlled gamma rays) and to better understanding some machining, mechanical and chemical properties of chosen samples of wood-based composites, already established. The properties studied included power consumed in cutting, bending stress at break, MOE in bending, moisture contents and free formaldehyde emission. There are strong indications of in-depth structural changes induced by irradiation, shown by differences between magnitudes of the effects generally associated with moisture contents, etc. The irradiation treatment seems to be favourable regarding power consumed in cutting, at a price of decreasing bending stress at break values. Finally, ever-increasing importance of the environmental effects seems to recommend irradiation of MDF and particleboard in view of decreased free formaldehyde emission, opposite to the cases of hardboard (although less expressed) and plywood.

The FTIR spectra provided in this research shows characteristic transmittance peaks in all chemical groups associated with wood polymers (cellulose and lignin) and also with ones distinctive for formaldehyde. However, using the statistic for comparison spectra for treated and control samples an alteration was noticed which refers to the spectral region characteristic to hydrogen bonded OH groups. It was observed that the changes took places in the case of all studied composites, but not even in the relative amount and direction.

Key words: gamma irradiation, plywood, particleboard, MDF, hardboard, FTIR spectrometry

1. INTRODUCTION

Many of the modification methods have been developed for a more profitable usage of commercially available and widely used wood products. The procedures such as acetylating, impregnation, coating and plasma treatment are commonly used for improving the targeted properties of wood and wood based composites. The use of different types of irradiation for the free surface activation, thus raising its energy, is well known procedure in adhesion theory (Albano et al 2002; Svrzić and Todorović 2011). The pre-treatment of wood fibres and particles with the gamma radiation (or some other energy sufficient radiation) improves all the mechanical properties of corresponding wood-based composites (Djiporović 2007). However, the negative aspect of the gamma ray implementation is its destructive impact upon the structural integrity of the subject exposed to it. Previous researches have determined the optimum dose of absorbed radiation from ^{60}Co (all in gamma spectrum scope) at about 10 kGy, which provides minor structural changes but sufficient alterations in chemical structure of wood-based composites: plywood, particleboard, MDF and hardboard.

The chemical structure has been investigated using FTIR spectrometry by comparing the IR absorption graphs for non-treated and gamma ray treated samples of the plywood, particleboard, MDF and hardboard, proving the change, mainly in the number of free hydroxyl groups. The same trend has

been noticed for all four groups of boards. It was assumed according to previous works that such absorbed quantity of radiation would not significantly change the mechanical properties of the investigated materials (Todorović et al 2006) and yet increase the free surface energy for other applications, such as coating.

In terms of the energy of impact particles the plasma modification method is the most similar to the gamma ray treatment. Previous researches (Svrzic and Todorović 2011) indicate that the nitrogen glow discharge plasma treatment improves moisture sorption resilience, simultaneously influencing an increase in dielectric properties. The effect of etching has not been noticed and detected mass loss has been associated with secondary vacuum drying. Since the energy of the gamma radiation from ^{60}Co has higher values, it was expected that the mass loss would be significantly higher. Also, the alterations in structure and chemical composition were expected to occur throughout the bulk of the treated samples and not just superficially.

In the work of Aoki et al. (1977) it was found that controlled doses of gamma rays do not significantly affect the specific gravity, degree of crystallinity, thermal softening temperature, tension strength and torsion strength of wood and cellulose. The implemented doses were about 100 KGy. No results about the structural and chemical changes were presented.

Wood particle treatment with a source of ^{60}Co 10 kGy gamma radiation is a well known surface modifier method. The elevating free surface energy of the wood particle (Djiporović et al., 1996) slightly increases the number of active chemical groups responsible for interaction with polypropylene matrix and increases the tensile strength of polypropylene (PP) composites.

The irradiated energy is considered to be an accelerating factor in the curing ability of different resins, such as polypropylene in multiphase polymer systems, predominantly increasing its mechanical properties (Czvikovsky, 2003). The applied doses were significantly higher than 10 kGy, reaching the values of 175 kGy. Such high dose may be induced in the material preparation phase of the production process, but applied on a final product the effects may lead to its deterioration. According to Czvikovsky (2003) the negative effects of radiation upon a polymer (resin and wood), or its favourable effects if degradation is controlled, are associated with a diminishing molar mass of natural polymers, e.g. cellulose, natural rubber, etc., and the reuse of (cross-linked) polymers after degradative recycling.

According to Todorovic, et al. (1996), the applied dose of 10 kGy slightly influences the mechanical properties of wood based polymers involved, decreasing the bending strength and power consumption during bend saw cutting.

The investigation of the chemical composition by IR spectrometry is a common method of instrumental chemical analysis. On the basis of the above it was possible to monitor the change of the chemical structure of treated materials resulting from gamma ray implementation. The fact that very little is known about the chemical alterations in the structure of wood-based composites influenced by gamma radiation treatment makes this research qualitatively new.

2. METERIALS AND METHODS

Under current market conditions, there is a great diversity of available wood-based composites, similar to the ones investigated in this study. A large number of manufacturers, a variety of technological processes, origin and qualities of raw material used in manufacturing and various types of adhesives do not allow the proper selection of composites representative to their type. To annul all of these factors and provide the random sampling character to the material selection phase, commercially available samples were collected from the Laboratory for Testing of wood-based composites at Faculty of Forestry, Belgrade University, without specifying the manufacturer and origin. The only considered board parameters were: the urea-formaldehyde adhesive type, conventional three-layered 16 mm particle board, 12 mm MDF board, 6 mm three-layer plywood and 3 mm hardboard.

The irradiation of samples of wood-based composites was performed in the radiation industrial sterilization unit at the Institute of Nuclear Energy "Vinča", Belgrade, Serbia. The radioactive isotope ^{60}Co was used as a source of ionizing radiation, and the absorbed dose was 10 kGy. The radiation unit utilises wet storage of the radiation source (^{60}CO), preventing the radiation leak. When operating, the

source is allowing uniform irradiation of samples placed in appropriate containers. The whole process is computer controlled with multiple-circuit anti-accident protection.

The FTIR analysis of the samples was carried out in the laboratory of the Department of Organic Chemistry, Faculty of Technology, University of Belgrade.

The samples, previously crushed and then pulverized in a micro mill, were tested on at infrared spectrophotometer Bomem MB 100. Figures 1 and 2 show the layout of IR Bomem MB 100.

Figure 1. *BOMEM MB 100 spectrometer*

Figure 2. *Experimental layout*

The material, pulverized on a micro mill, was mixed with KBr (potassium bromide) and placed in a mould to form pastilles (tiles). The masses of pulverized boards and KBr were measured on electrical analytic scale with the accuracy of 1/10000 of a gram. For the purpose of spectroscopy it was of the greatest importance that the constant mass ratios of constituents were maintained for all pastilles prepared. The mould was inserted into the press and exposed to a pressure of 20 MPa for 2-3 minutes for homogenization of the pastilles. The resulting transparent plate thickness was about 0,5 mm and a diameter of 15 mm.

The FTIR spectrophotometry analysis can provide so much information about the structure of molecules in such a short time, and with such a small amount of the sample as no other method. In the same time data acquired only indicates the direction of the changes that have occurred, yet not giving the precise quantitative analysis. In order to explain the other physical and mechanical alterations (Todorović et al 2006) obtained IR spectra could be proved as sufficient evidence. However the similar analysis were conducted (Fabiyi et al 2008) for the purpose of wood plastic high density polypropylene (HDPE) and polypropylene (PP) composites, weathering examinations, for determination of C−O and C=C groups.

Wood as natural polymeric material composed of cellulose, lignin and extractives shows absorption in the spectral regions characteristic for O−H, C−H, C=O, C−O groups at different band positions depending upon specific assignment of them. According to Pandley 1999, absorption for string hydrogen bonded O−H appears at around 3400 cm^{-1} and at 2900 cm^{-1} for C−H. Absorption for C=O and C=C occur at around 1740 cm^{-1} and 1510 cm^{-1}, respectively. Absorption bands below 1460 cm^{-1} in so called finger print region are complex originates from various vibration modes in carbohydrates and lignin (Faix and Böttcher 1992).

The UF matrix as another constituent of examined wood based panels was investigated by means of FTIR (Zorba et al 2008). It presents thermosetting polymers obtained from two-step process comprising of the methylolation and condensation stage. The urea molecules are bonded with methylene ether bridges ($-CH_2-O-CH_2-$) and methylene bridges ($-CH_2-$). The expected absorption peaks ranges from 1189 to 1170 cm^{-1} and from 1483,68 to 1445,09 cm^{-1}, respectively (Stuart 2004).
Special attention was paid to the eventual change in the number hydrogen bonded O−H groups. They originate from cellulose chains and they are responsible for water binding capacity, influencing other properties of wood and wood-based materials such as examined composites. For that reason it was

necessary to know the moisture content of examined samples. The moisture content for composites observed is shown in Table 1.

Table 1. *Moisture content for control and treated samples of Plywood, Hardboard, MDF and Particleboard*

Moisture content MC (%)	Plywood	Hardboard	MDF	Particleboard
Control	8,2710	7,3321	8,5818	12,0373
Treated	8,2961	7,5471	8,6797	7,4309

3. RESULTS AND DISCUSSION

The results of infrared spectrophotometer are given in the form of graphics. Y axe contains wavelength values of the infrared part of the spectrum, and permeability (transmittance) values on the ordinate as a percentage.

All figures presented in this paragraph show the original spectra subjected to computer processing.

IR spectrum should be analyzed in the scope of wavelengths below 7,7 μm, known as the “area of functional groups”. This particular area indicates presence of OH, NH, C=O and C≡C groups. The other important region of IR spectrum ranges from 7,7 to 11 μm and it is defined as “finger print” area, characteristic for the investigated material.

The peaks of the figures represent parts of the spectrum where wavelengths allowed for intense permeability. These peaks are places to which particular attention should be paid in further analysis. For this study, extremely important were the spectral ranges of small wavelengths, because they were subjected to the most evident changes. The software package for Bomem MB 100 spectrophotometer has the ability to capture and statistically analyze the selected area of the spectrum, which was previously visually inspected for characteristic changes. Below are given the spectrums and values calculated for each of the spectra.

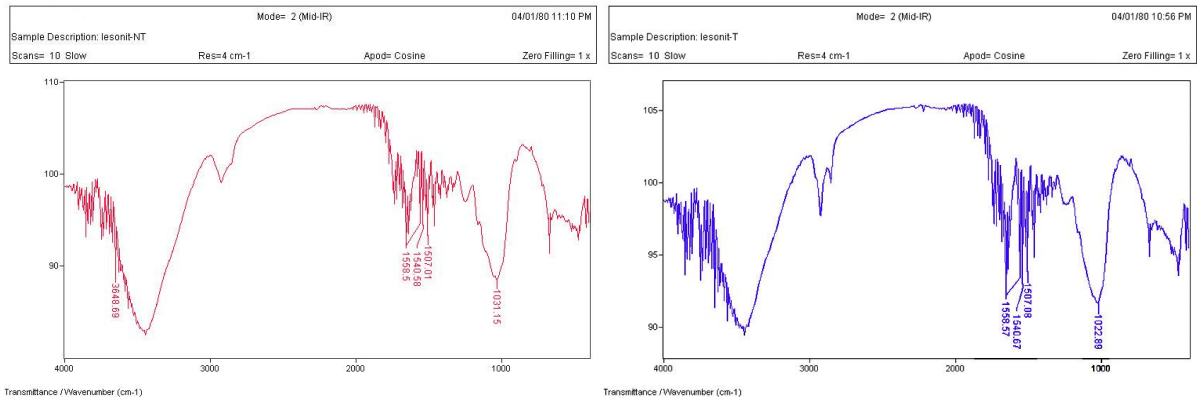

Figure 3. *Untreated (NT) and treated (T) hardboard absorption spectrums*

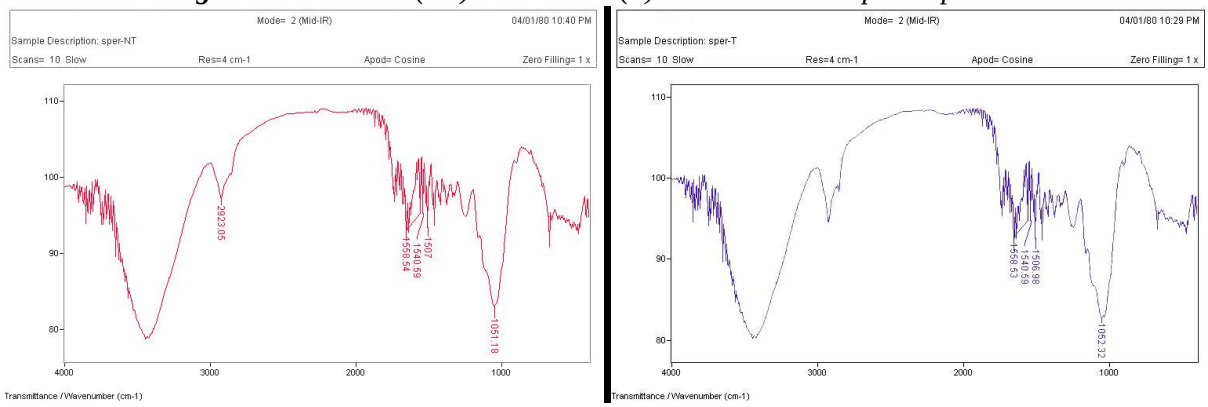

Figure 4. *Untreated (NT) and treated (T) plywood absorption spectrums*

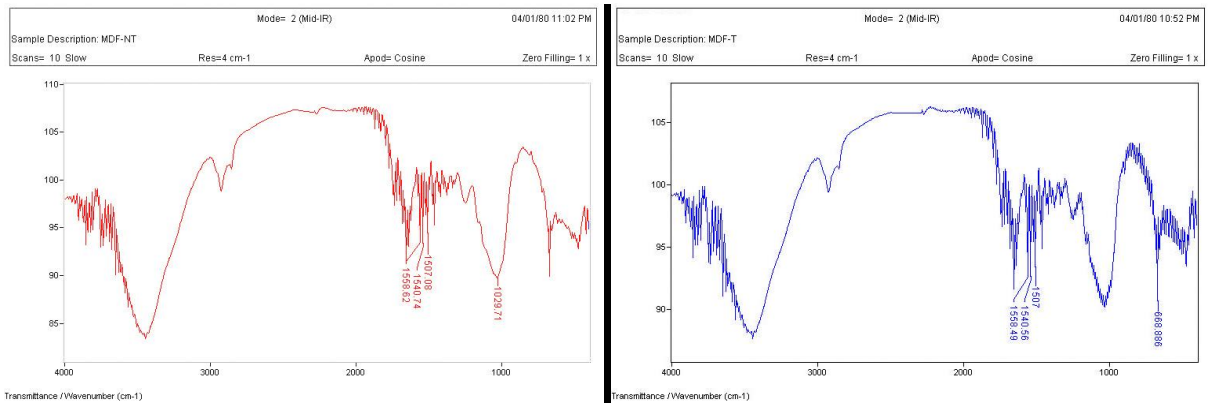

Figure 5. *Untreated (NT) and treated (T) MDF absorption spectrums*

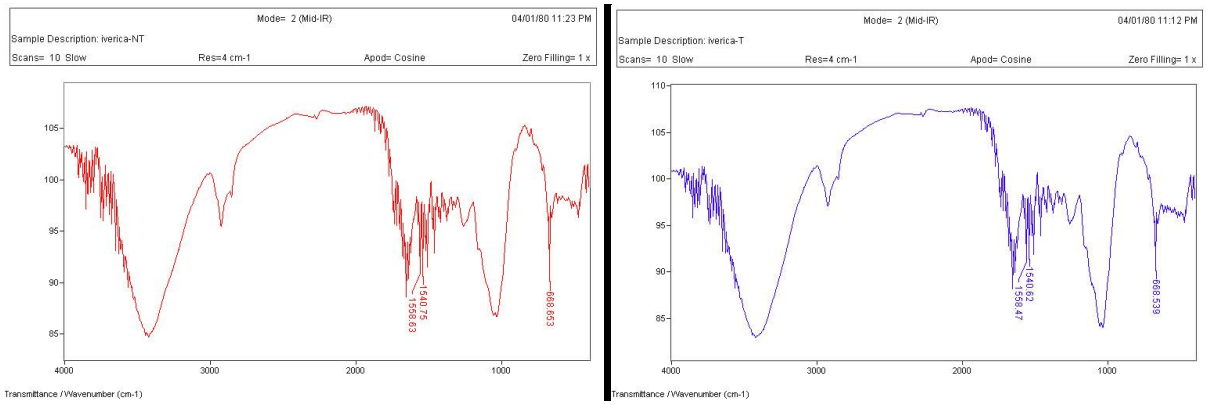

Figure 6*. Untreated (NT) and treated (T) particleboard absorption spectrums*

Test results are presented in Figures 3 to 6. The figures show spectra for each individual wood-based composite, providing the opportunity to compare the values of the absorbed IR spectra for the control and treated samples. The figures representing the control and treated samples have different colors for an easy spotting of differences. Statistical data are also given.

Table 2. *Statistical data for IR spectrometry of control and treated wood based composite samples for wave number characteristic for intermolecular hydrogen bonds in dimeric associations*

Hardboard - control	**Hardboard - treated**
Integration Region Left edge: 3787.89 Right edge: 29297.35 Data points: 405 Area: 4057.46 Height: 11.0777 y Max: 89.4935 Peak Position At Y Maximum: 3446.54 Centre of Mass: 3446.18 Peak Width At half Height: 499.05 midpoint: 3520.62 Peak Z Values Mean: -5.35304 Median: -5398 Std. Deviation: 3.40939	Integration Region Left edge: 3813.8 Right edge: 29297.35 Data points: 406 Area: 6803.01 Height: 18.0088 y Max: 82.5452 Peak Position At Y Maximum: 3446.54 Centre of Mass: 3446.15 Peak Width At half Height: 414.688 midpoint: 3453.66 Peak Z Values Mean: -8.68785 Median: -8.71772 Std. Deviation: 5.79297
Plywood - control	**Plywood - treated**
Integration Region Left edge: 3839.47 Right edge: 2927.35 Data points: 409 Area: 8335.6 Height: 21.8117 y Max: 78.7651 Peak Position	Integration Region Left edge: 3832.93 Right edge: 2940.43 Data points: 411 Area: 8001.57 Height: 20.483 y Max: 80.1948 Peak Position

At Y Maximum: 3446.54 Centre of Mass: 3445.91 Peak Width At half Height: 392.949 midpoint: 3425.41 Peak Z Values Mean-10.5668: Median: -10.7143 Std. Deviation: 7.25732	At Y Maximum: 3446.54 Centre of Mass: 3445.96 Peak Width At half Height: 392.949 midpoint: 3447.64 Peak Z Values Mean: Median -10.0934: -10.5614 Std. Deviation: 6.87832
MDF - control	**MDF - treated**
Integration Region Left edge: 3852.3 Right edge: 2946.72 Data points: 411 Area: 6267.39 Height: 17.0587 y Max: 83.4193 Peak Position At Y Maximum: 3446.54 Centre of Mass: 3446.2 Peak Width At half Height: 414.996 midpoint: 3465.8 Peak Z Values Mean: -7.90654 Median: -7.56559 Std. Deviation: 5.47052	Integration Region Left edge: 3878.21 Right edge: 2946.72 Data points: 413 Area: 5032.33 Height: 13.1496 y Max: 87.6537 Peak Position At Y Maximum: 3446.54 Centre of Mass: 3446.11 Peak Width At half Height: 399.374 midpoint: 3453.03 Peak Z Values Mean: -6.31699 Median: -6.22408 Std. Deviation: 4.1721
Particleboard - control	**Particleboard - treated**
Integration Region Left edge: 3858.84 Right edge: 2953.26 Data points: 411 Area: 6768.95 Height: 17.3165 y Max: 84.7122 Peak Position At Y Maximum: 3421.47 Centre of Mass: 3421.57 Peak Width At half Height: 429.187 midpoint: 3443.01 Peak Z Values Mean: -8.53927 Median: -8.74785 Std. Deviation: 5.54193	Integration Region Left edge: 3839.47 Right edge: 2940.43 Data points: 409 Area: 7200.72 Height: 18.2902 y Max: 82.9706 Peak Position At Y Maximum: 3421.47 Centre of Mass: 3421.12 Peak Width At half Height: 424.707 midpoint: 3425.27 Peak Z Values Mean: -9.12789 Median: -9.08474 Std. Deviation: 6.04187

It is important to note that the software provided by the device Bomem MB has a possibility to extract and statistically process a specific spectrum area distinguished by visual inspection.

For comparative analysis of the IR spectra of the control and treated particleboard, changes in the transmittance spectra were noticed, and those changes occurred at shorter wavelengths (4000 cm^{-1} to 1298,7 cm^{-1}). Therefore, the specific area was isolated.

The spectra, for particleboard, obtained clearly indicate resemblance with those presented with the results for particleboard presented by Zorba et al 2004.

The finger print region remained unchanged for all treated and untreated samples, with characteristic peaks at about 1030 and 668 cm^{-1}. In the scope of wave lengths near 2919 cm^{-1}, characteristic for C−H groups (Pandey 1998), on spectra presented as picks at about 2922 to 2993 cm^{-1}, no changes were detected for both treated and control specimens.

In the spectral area ranging from 1653 to 1636 cm^{-1} the characteristic spectral bends 1653, 1647 and 1636 cm^{-1} remained unchanged for all examined types, both treated and control, of wood-based composites. Due to the Stuart 2004 and Pandey 1998 this bands can be attributed to hydrogen bonded urea carbonyl C=O group.

The existence of free hydroxyl groups was identified, i.e. valence vibration characteristic of intermolecular hydrogen bonds in dimeric associations. As expected from previous researches (Faix and Böttcher 1992) transmittance occurred in spectral regions about 3400 cm^{-1}. In the case of the control sample particleboard, OH groups occurred at wavelengths of 3418,88 cm^{-1} and the maximum transmittance was 84,7122%. For the samples of treated particleboard, OH groups were identified in

the 3420,59 cm^{-1}, with a maximum permeability of 82,9706%. After comparing the data, it was noticed that the effects of treatment reduced permeability to 2,06%, indicating that the sample reduced the number of hydroxyl groups. This change could have very important implications for other properties. A smaller number of free hydroxyl groups should mean that they are engaged in a chemical reaction with the same or other functional groups, which leads to less active sites for water binding (decrease of hygroscopicity), strengthening the bonds of the wood-plastic matrix, improving mechanical properties and binding the residual formaldehyde, i.e. decreasing the secondary emissions of formaldehyde. When analyzing the spectra of the control and the treated particleboard, it was noticed that there has been a shift in the wavelength at which the OH groups occur, but the change was very small in absolute terms, 1,71 cm^{-1} or 0,05% as a proportion, yet not overcoming wave length domain characteristic for intermolecular hydrogen bonds.

Figure 5 (a, b) shows a comparison of the spectra for the control and treated MDF. As in the case of plywood, the change in the characteristic spectrum of the free hydroxyl groups was identified. The wavelengths of 3451,09 cm^{-1} for the control and 3444,55 cm^{-1} for treated and maximum transmittance of 83,4193% and 87,6537% were observed. Increasing the maximum transmittance by 5,07% in relative terms, leads to the conclusion that an increase in the number of free hydroxyl groups occurred. An absolute change of the wavelength at which the free hydroxyl groups were identified was 6,54 cm^{-1}, and the relative rate of change was 0,19%. A small change in wavelength still remains in the domain of intermolecular dimeric hydrogen bond association’s characteristic of the free hydroxyl groups.

As in the previous two cases, significant changes in transmittance spectra occurred in the area of shorter wavelengths of the spectrum, when the control and the treated plywood samples were compared. Identified vibrations are typical for the presence of free hydroxyl groups. In the control plywood, free OH groups appeared at the wavelengths of 3446,24 cm^{-1}, i.e. a maximum transmittance permeability of 78,7651%. The IR analysis of treated plywood lead to the wavelength of 3446,53 cm^{-1} and a maximum transmittance of 80,1948%. A comparison of these results suggested that the treatment have increased permeability for 1,81% in relative terms, i.e. that there was an increase in the number of free hydroxyl groups. A change in the wavelength at which the free hydroxyl groups were identified was 0,29 cm^{-1} in the absolute, and 0,008% in relative terms, with a positive sign.

When the IR spectra for the control and treated hardboard were compared, similar observations were made as in the previous case. Again, there was an increased presence of free hydroxyl groups of the treated samples compared to the control ones. This fact illustrates the maximum transmittance of the control sample, which amounts to 82,5452%, while the maximum permeability of the treated sample was 89,4935%, with absolute increase of 6,9483% or 8,42% for relative changes. The wavelengths at which the observed free hydroxyl groups took place were 3444,55 cm^{-1} for the control sample, and 3438,26 cm^{-1} for the treated sample. The absolute change in the wavelength of the infrared spectrum for observed free hydroxyl groups is 6,29 cm^{-1}, and the relative change amounted to 0,18% in the negative sense.

In general it can be said that the treatment led to a reduction of free hydroxyl groups, only in the case of particleboard, while in all other cases it increased their presence, which is shown by the values above for the maximum measured transmittance.

The effect of mass loss was not noticed. The weight of samples before and after gamma ray irradiation remained unchanged. The effect of etching as a prominent characteristic of plasma treatment did not occur during the radiation treatment.

4. CONCLUSIONS

The implemented IR spectrometry proved suitable to explain the changes in chemical structure of the examined materials, initiated by the radiation treatment. The chemical composition was slightly changed and that became obvious when the obtained IR spectra were compared, predominantly in the area typical of free hydroxyl groups. The chemical structure of observed materials categorized as wood-plastic composites is abundant in hydroxyl groups, which are either bound or free. The fact that is proved by this research is the increased presence of free hydroxyl groups, although not for all materials. An increased level of their presence is evident for hardboard, MDF and plywood, with the relative change of 8,42%, 5,07% and 1,81%, respectively. The preceding paragraphs have already described destructive effects of gamma radiation on the observed wood-based composites, and in that

sense this change in chemical structure has complete meaning. However, in the particleboard, the reduction in the number of free hydroxyl groups after treatment amounted to about 2.09%. This data, in terms of other results, could be explained as the outcome from lowered level of moisture content of particleboard samples after irradiation. However, the observed reduced hygroscopicity noticed only for particleboard (which comes predominantly from the chemical structure rich in hydroxyl groups) could be of great importance for some further research (Todorovic et al 1996). Although the mechanical, machining and dielectric properties of treated wood-based composite deteriorated compared to those of the untreated ones (Todorović et al 1996), chemical structure was changed such that hydroxyl groups were closed for the moisture from the air. The reason for this probably lies in the recombination of broken and re-established chemical bonds. These connections may be weaker, by the energy required for their break and hence reductions in the specific cutting force and bending strength occur.

Acknowledgements:

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The Authors' Addresses:

Dr Srđan Svrzić, assistant professor;
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade
e-mail: svrza@ptt.rs

Phd. Marija Mandić, teaching assistant,
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade
e-mail: marija.mandic@sfb.bg.ac.rs

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VERIFICATION CALCULATIONS OF THE SHAFT OF TWO-SIDED CIRCULAR SAW FOR CROSS CUTTING OF PACKING TIMBER WITH CAD/CAE

Slavcho Sokolovski, Nelly Staneva

University of Forestry, Faculty of Forest Industry, Sofia, Bulgaria,
e-mail: slav_sokolovski@abv.com; nelly_staneva@yahoo.com

ABSTRACT

Verification calculations of the shaft from the basic mechanism of a woodworking machine for two-sided edging of details for wooden pallets and packaging are carried out. The saw shaft is 3D modeled with modul “Shaft Generator” of the CAD/CAE system Autodesk Inventor Professional® with all elements of the real shaft – keyslot, thread, grooves for clip ring, centre holes, chamfers, filets, and etc. The material - carbon steel grade C45, restrains and preliminary calculated loads – torque, cutting forces and motor rotor force are set. The values and graphics data for reaction forces, bending moments, bending stresses, shear stresses, torsion stresses, reduced stresses and deflections are received and analyzed. The distribution of the ideal shaft diameter along its length for the given loads is presented.

Key words: circular saw, shaft, woodworking, verification calculations, CAD/CAE

1. INTRODUCTION

The global economic crisis has affected many companies in the woodworking industry, offering wooden building materials. The demand for wood packaging remains relatively stable. Therefore, many small businesses switch production to the manufacture of wooden pallets, since from a technological point of view is possible to use the same machines.

In the manufacture of wooden packaging the set of the exact size in length by cutting across the most often performed of circular cross-cutting machines with manual feed and one cutting tool. More appropriate is to set the right length to it at the beginning of the technological process, before or after the first operation slitting. Thus with a flick of the cutting mechanism is set exact length of the preform, which will be produced several finished products.

Both technological and economic point of view for accomplishment of these operations a two-sided edging circular woodworking machine is proposed and constructed. It is described in detail in Sokolovski, Staneva, Panchev, 2015 - Figure 1. By means of a mechanism for horizontal translation of the cutting mechanism the desired length of the finished parts is set, which is the distance between the two circular saws. Both motors of mechanisms for cutting are turned on and then geared motor of feeding mechanism is turned on. Processed parts one by one are placed manually over the rails, one of the foreheads of the details touches the positioning rail. So positioned detail is engaged by two parallel moving thumbs which carry the feed movement. The finished piece is taken manually and placed on pallets with ready details.

This woodworking machine consists of two circular cutting mechanisms, a mechanism for conveying transfer of the sizing pieces with manual loading, unloading and stacking of the parts, and a mechanism for horizontal translation of the cutting mechanisms to obtain the details of the desired length.

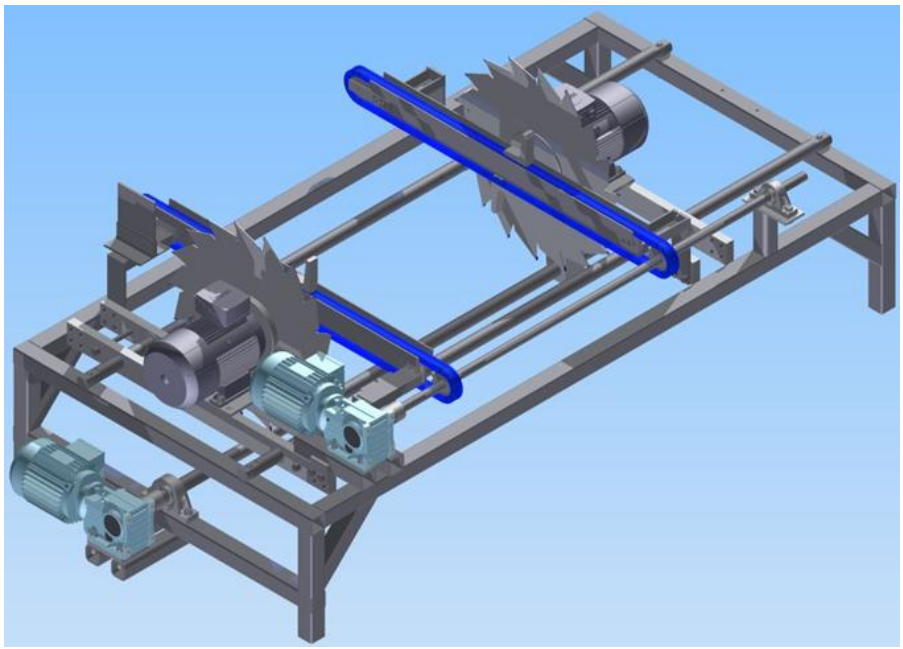

Figure 1. *Two-sided edging circular saw machine*

Main mechanism of this machine is the circular cutting mechanism, presented in more detail on Figure 2. It consists of two identical three-phase motors **4**: AT112 type *M*2, selected from a catalog by cutting power P_p^{max} = 3080W with following characteristics: power N = 4 kW; speed n = 2860 min^{-1}; efficiency η = 0,83. A saw blade **1** model 5381-20WZ profile BA, production of ZMM "Plana", Smolyan, is attached by clamping flanges **2** on shaft **3** of the motor. It is selected after the necessary calculations with the following parameters: diameter of the saw blade D = 450 mm; width of sawing b = 4 mm; thickness s = 2,8 mm; number of teeth z = 72; rear corner α = 15°; front corner γ = 10°.

The main kinematic features of this cutting mechanism are determined: cutting speed v = 67,36 $m.s^{-1}$ satisfying values for the factory, both softwood and hardwood; cutting height: h_{min} = 0,022 m and h_{max} = 0,145 m; feed rate: u_{max} = 0,15 $m.s^{-1}$ and u_{min} = 0,092 $m.s^{-1}$ (Sokolovski, Staneva, Panchev, 2015).

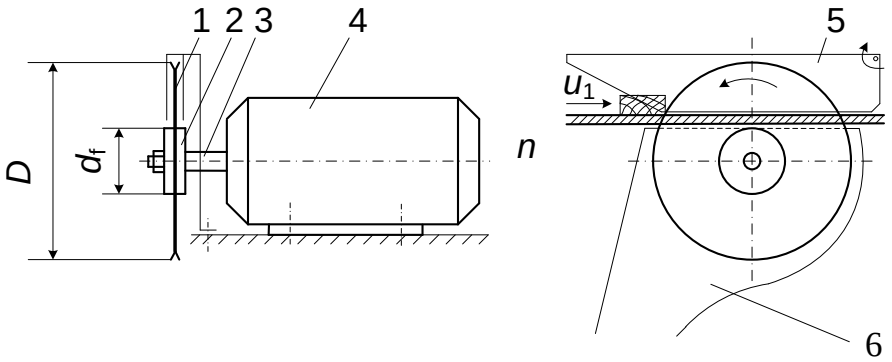

Figure 2. *Scheme of circular cutting mechanism*

The purpose of the study is carrying out of verification calculations of static strength of the shaft of the cutting mechanism of two-sided edging circular saw with the help of a CAD/CAE system.

In recent years, the use of advanced CAD/CAE systems for engineering calculations and analyzes allow the calculation of static strength to be automated, which reduces the cost and time taken.

2. METHODS

2.1. Calculation of cutting forces

In the place of the mounting of the saw blade, the shaft of the cutting mechanism is loaded with the tangential *P* and the normal *R* component of cutting force, the force of gravity of the flanges and circular saw F_f and centrifugal force of the unbalanced masses *C*, shown in Figure 3 (Filipov, 1967). Since the forces acting on the shaft in different planes, they decompose in two components acting in mutually perpendicular planes - horizontal *xy* and vertical *xz*.

Average tangential cutting force *P*, and its components P_z and P_y, are determined:

$$P = \frac{1000.N.\eta}{\upsilon} = \frac{1000.4.0{,}83}{67{,}36} = 50 \text{ N},$$

$$P_z = P.\sin\theta = 50.0{,}755 = 38 \text{ N},$$

$$P_y = P.\cos\theta = 50.0{,}66 = 33 \text{ N},$$

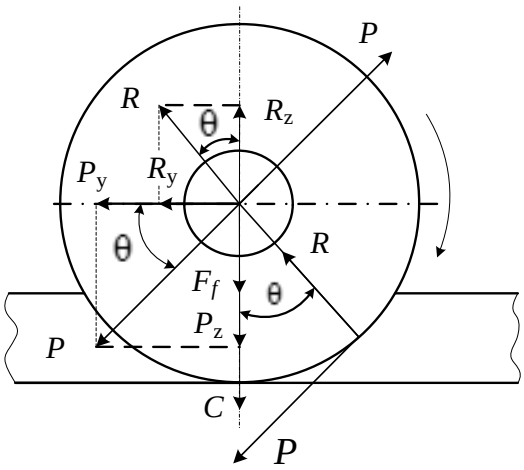

Figure 3. *Scheme of acted forces from circular blade*

where $\upsilon = \pi.D.n = \frac{\pi.D.n}{100060} = \frac{3{,}14.450.2860}{100060} = 67{,}36$ m/s is the speed of cutting,

$\theta = arccos\frac{2a+h}{D} = \frac{2.75+150}{450} = 49{,}04°$ – average kinematic angle congregation,

$a = \frac{D}{2} - (h+5) = 225 - 145 - 5 = 75$ mm.

The normal component of cutting force *R* and its components R_z *and* R_y are determined:

$$R = m.P = 1.49{,}29 = 50 \text{ N},$$

where *m* is a factor considering dull teeth. For sharp teeth *m* = 0,5, and for dulled teeth *m* = 1.

$$R_z = R.\cos\theta = 33 \text{ N},$$

$$R_y = R.\sin\theta = 38 \text{ N}.$$

The total force acted in the vertical plane F_z is:

$$F_z = P_z - R_z + F_f + C = 38 - 33 + 130 + 71 = 206 \text{ N},$$

where $F_f = 130$ N is the mass force of the flanges and saw blade, N;

$C = \sqrt{P^2 + R^2} = \sqrt{50^2 + 50^2} = 71$ N - centrifugal force of the unbalanced masses /It is accepted to be equal of cutting force/.

The total force acted in the horizontal plane F_y is:

$$F_y = P_y + R_y = 71 \text{ N}.$$

2.2. 3D modeling of the circular saw shaft

In order to carry out of verification calculations of the shaft first a 3D model was created with CAD/CAE system Autodesk Inventor Professional®. The shaft is preliminary calculated for pointed above conditions. The shaft with two bearing supports and console saw blade was 3D modeled: characteristic longitudes of the shaft are: l_1=50 mm (distance from the middle point of circular blade to the middle of the nearest bearing support), l_2=246 mm (span) and l_3=40 mm (distance from the middle of the other bearing support to the fen middle section). The shaft diameters are: thread M24 x2 HL on the side of the saw disk, supports 1 and 2 - 30 mm, maximal diameter - 40 mm (Figure 4) and (Figure 5).

The 3D model of the shaft is created with the modulus “Shaft Generator” of the program Autodesk Inventor Professional ® section by section. For every section “Shaft Generator” gives opportunities for creation of all elements of the real shaft (Figure 4) – keyway, thread, grooves for retaining ring, center holes, chamfers, filets, etc. The sequence of creation of the 3D model of the shaft is shown on Figure 4.

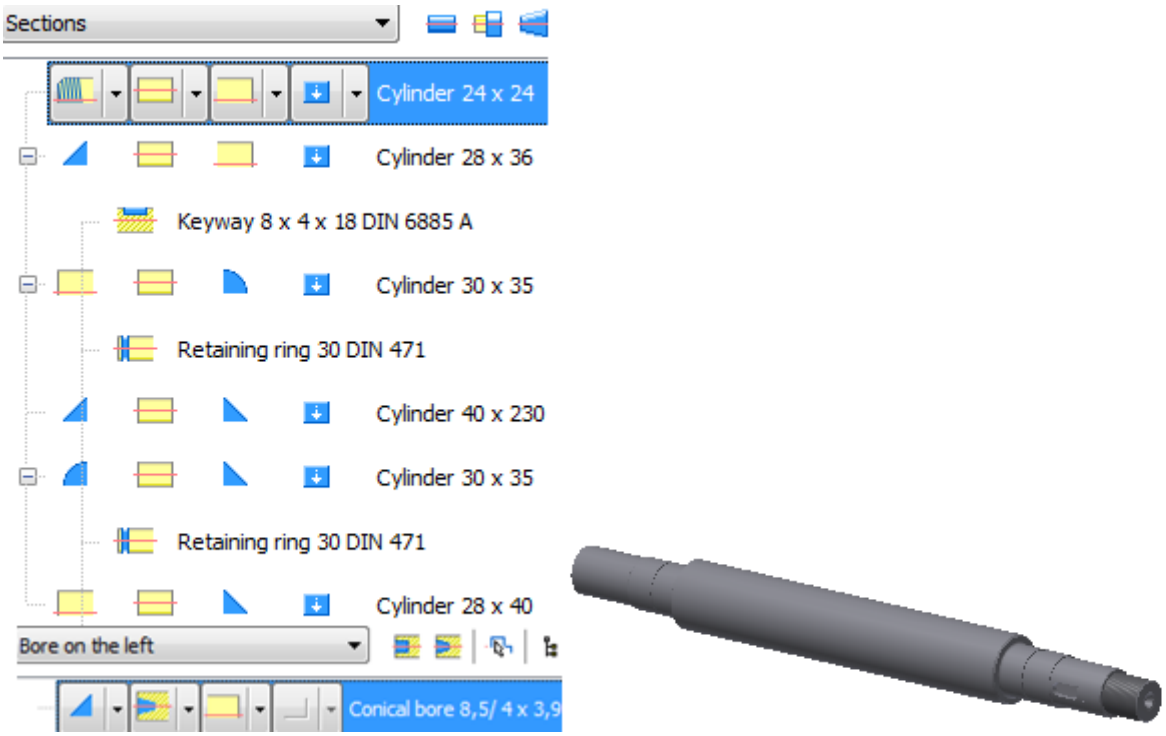

Figure 4. *Sequence of creation of the shaft 3D model*

2.3. Controlling calculations of the shaft

Controlling calculations of the 3D model of the shaft for circular saw were carried out with “Shaft Generator” of CAD/CAE system Autodesk Inventor®.

First, the shaft material characteristics of steel C45 BDS EN 10083-2:2006 were input in the program – Figure 5: modulus of elasticity, shear modulus, density, yield strength Re = 300.10^6 N.m^{-2}.

Second, the restrains were set: support 1 (on the side of circular blade) – fixed and support 2 – free (Figure 5).

The shaft is horizontal and is loaded with a torque and forces according as pointed on Figure 5 and calculated as mentioned above. The following forces have been set in the modulus “Shaft Generator” (Figure 5):

Torque, $T_2 = 9554\frac{N.\eta}{n} = 12$ N.m; $T_1 = -12$ N.m.

where N = 4 kW is the power of the motor; η =0,83 – efficiency of the motor; n = 2860 min^{-1} – the motor speed.

Cutting force F_1 with its components:

- F_{1y} = 71 N – total force acted in the horizontal plane xy;
- F_{1z} = 206 N – total force acted in the vertical plane xz.

Force of motor rotor F_2= Km +f_b.G = 730 N, determined according to (Perel, 1983),

where *Km* is magnetic force of the rotor: *Km=2.Dr.Lr= 480* N (*Dr* – rotor diameter, cm and *Lr* – rotor width, cm);

G = 25kg – mass force of the rotor;

f_b = 10 - dynamic coefficient, considering motor imbalance.

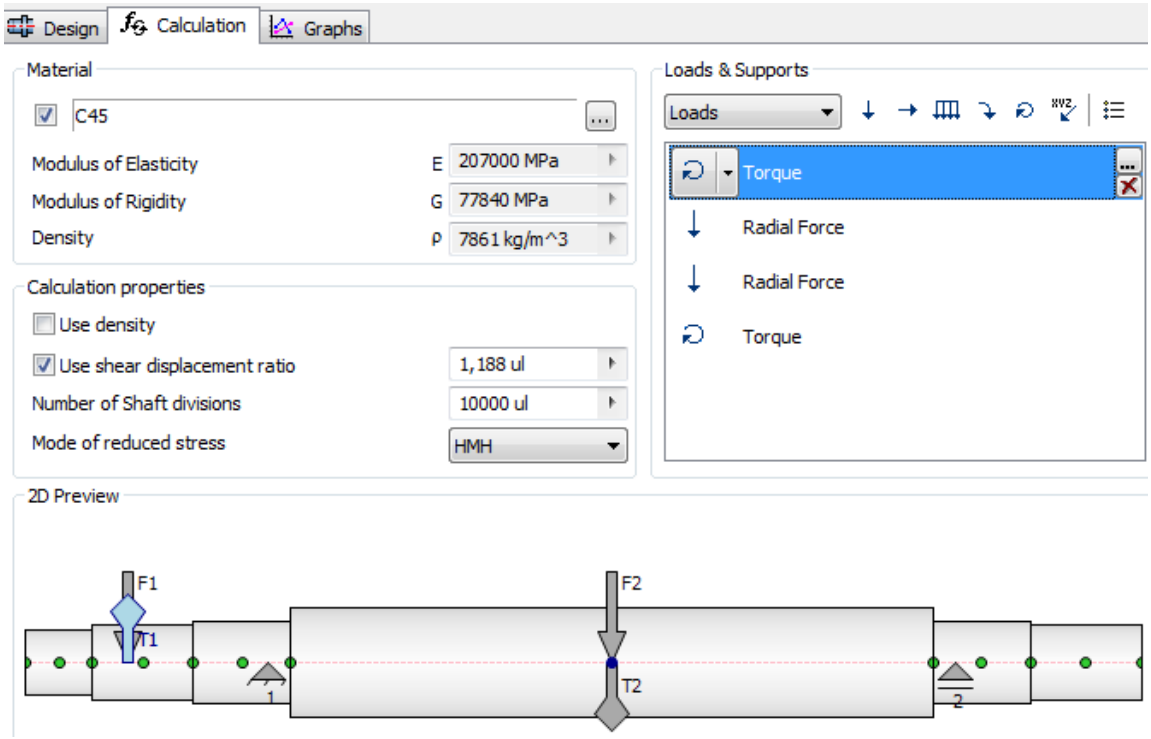

Figure 5. *Calculation scheme of the shaft 3D model*

3. RESULTS AND DISCUSSION

As a results of verification calculations the values and graphics data for reaction forces,bending moments, shear stresses, bending stresses, equivalent stresses and deflections were received and are graphically presented on Fig. 6 to Fig.16.

The calculated resultant reaction forces in support 1 and 2 are shown on Figure 6, reaction forces in the vertical plane YZ and in the horizontal plane XZ are shown on the Figure 7 and Figure 8 correspondingly.

The graphs of the resultant bending moment and bending moment XZ are shown on Figure 9 and Figure 10. The maximal resultant moment of 39,79 N.m was calculated in the place where the rotor force F_2 (Figure 5) was applied. Resultant bending moment at support 1 is 10 N.m.

In the same point the maximal resultant deflection was received – 13,91 μm (Figure 11). Провисването при десния лагер е около 7 μm.

The resultant bending stress of 6,33MPa was calculated in section where force of rotor motor was applied – Figure 12. Resultant bending stress at support 1 is 4 MPa.

The maximal torsion stress of 2,78 MPa was received in the section of saw blade mounting – Figure 13. The maximal resultant shear stress of 0,58 MPa was received in the section of support 1 – Figure 14.

The reduced stresses are presented on Figure 15. The program calculates reduced (equivalent) stress by the energy criterion of von Misses (“maximal shear-strain-energy”), known in the literature and in program as “HMH” criterion:

$$\sigma_{red} = \sqrt{(\sigma_B + \sigma_T)^2 + \alpha(\tau^2 + \tau_S^2)},$$

where σ_B is bending stress, $\sigma_T = 0$ – tension stress, τ – torsion stress, τ_S – shear stress, $\alpha = 3$ for mode HMH.

The maximal reduced stress of 6,56 MPa was received in section where force of rotor motor has been applied. In the section of support 1 the second maximal reduced stress was received of 5,8 MPa, where the resultant bending stress has also second maximal value of 4,2 MPa.

The program offers a diagram of distribution of “ideal diameter” along the shaft length for given loading – Figure 16. In the most loaded shaft section an ideal diameter of 20,31 mm was received, which is less than the real shaft diameter in this section – 40 mm. The diameter of supports 1 and 2 are 14,8 and 18 mm, which are less than the real ones – 30 mm. The shaft diameter in the place of mounting of circular disk is 13 mm, which is also less than the real one – 28 mm.

4. CONCLUSIONS

3D model of the circular shaft of a woodworking machine for two-sided edging of details for wooden pallets and packaging is created with CAD/CAE system in order to carry out of verification calculations of static strength. The results for bending moments, bending stresses, shear stresses, torsion stresses, reduced stresses, deflections and “ideal shaft diameter” show that the most endangered sections of the shaft are these of applying of rotor force, cutting force and the section of bearing support on the side of the saw blade.

More detailed data for the static strength of circular shaft have been received with the help of the CAD/CAE system /shear stresses, torsion stresses, reduced stresses, “ideal shaft diameter”/ in comparison with the conventional control calculations of a shaft. Created 3D model of this circular shaft gives opportunity to carry out of further analyses by the method of finite elements.

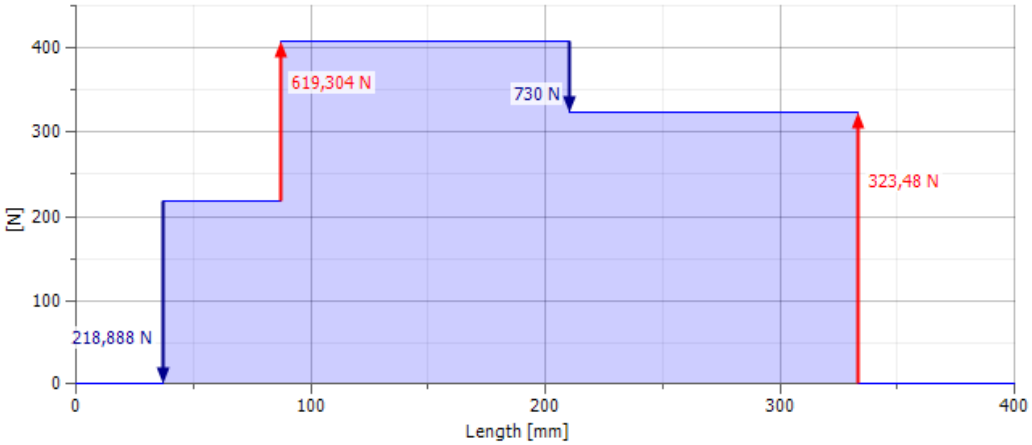

Figure 6. *Chart of the resultant shear forces*

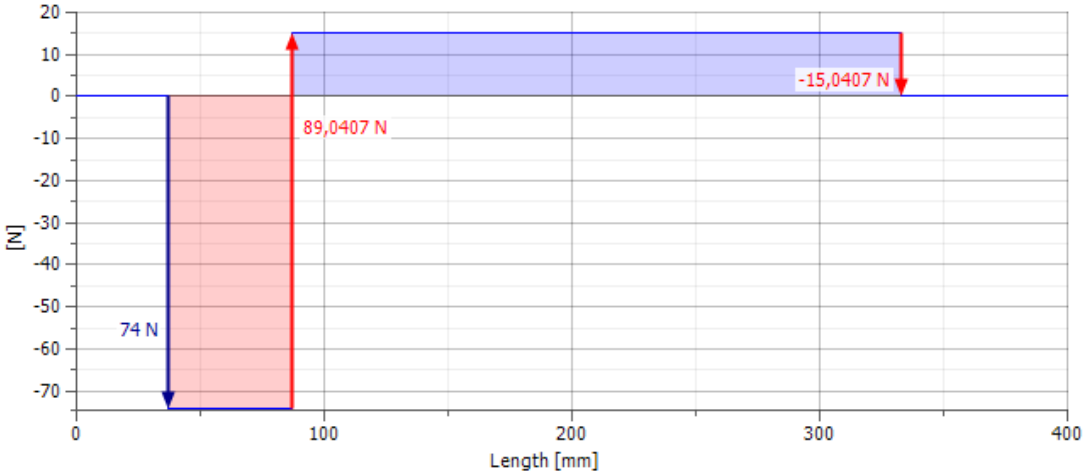

Figure 7. *Chart of the shear forces - YZ Plane*

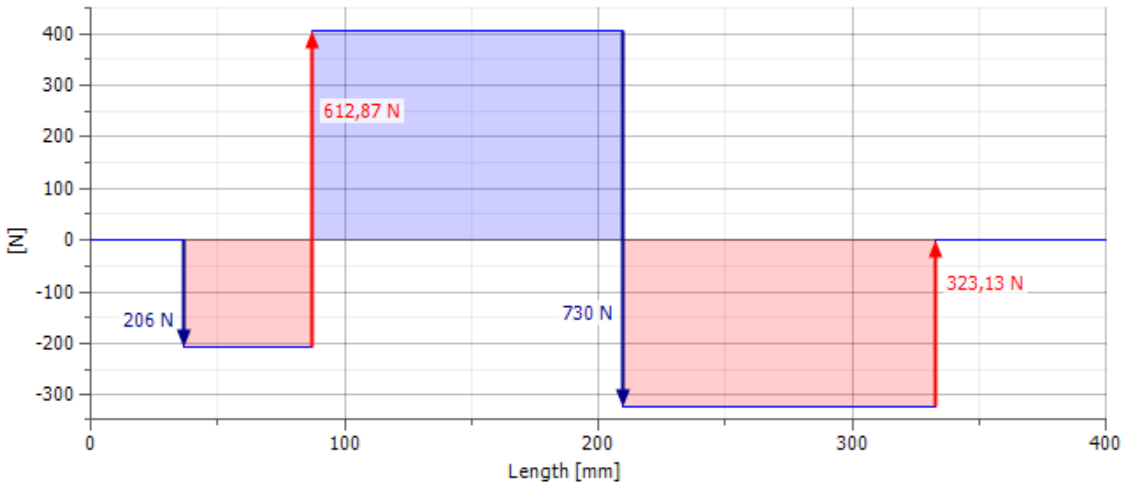

Figure 8. *Chart of the shear forces - XZ Plane*

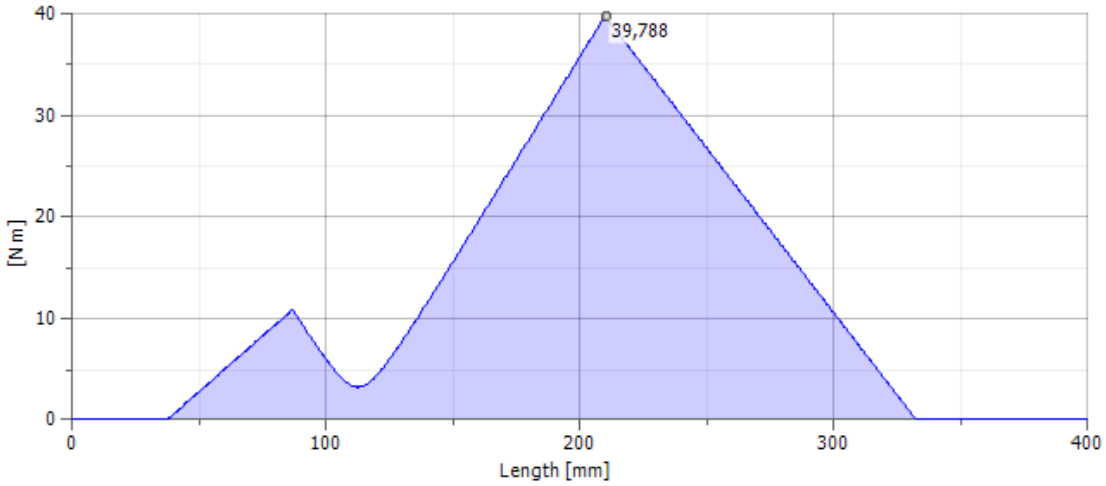

Figure 9. *Chart of resultant bending moment*

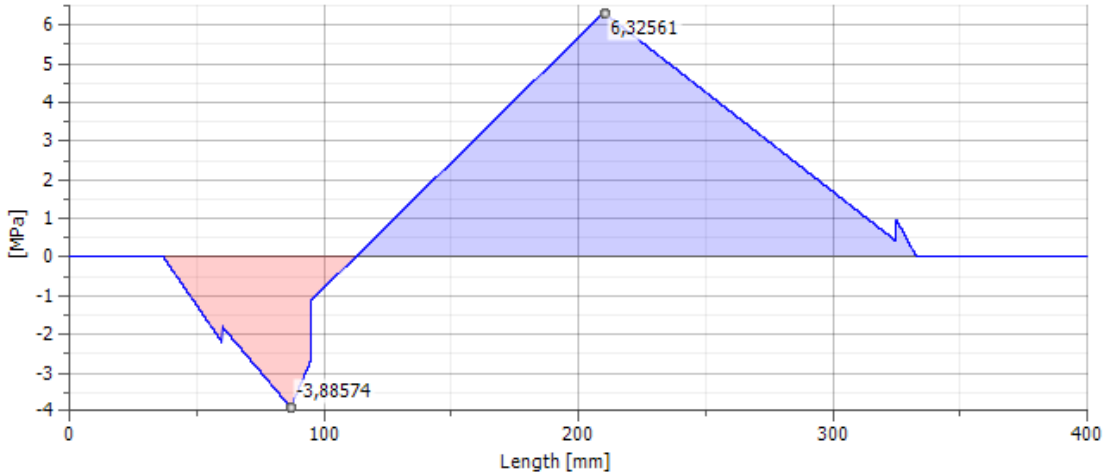

Figure 10. *Chart of bending moment XZ*

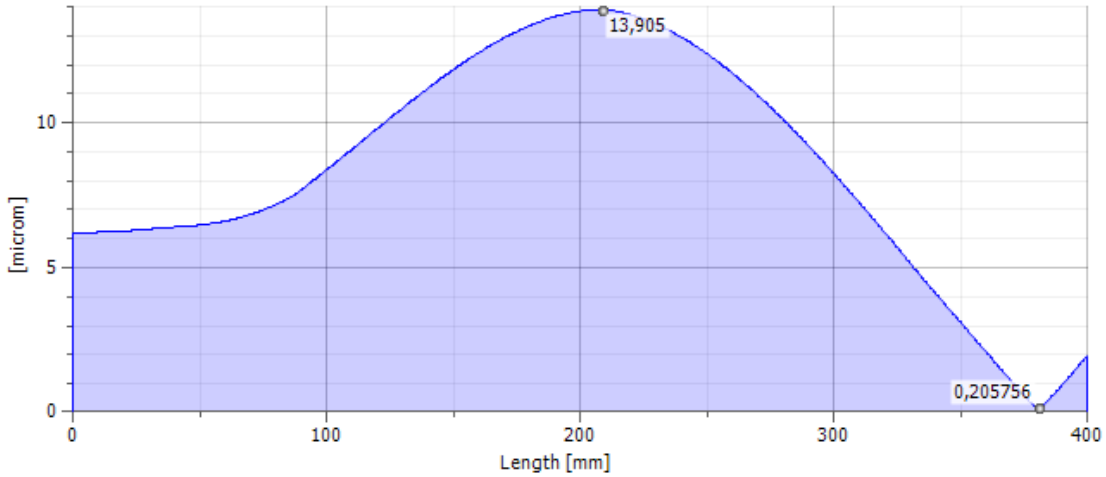

Figure 11. *Chart of resultant deflection*

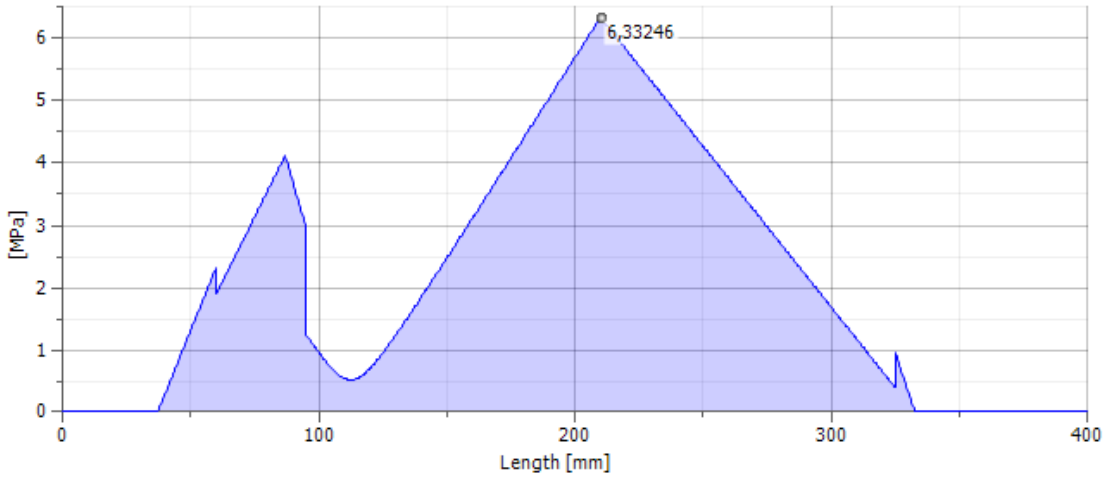

Figure 12. *Chart of resultant bending stress*

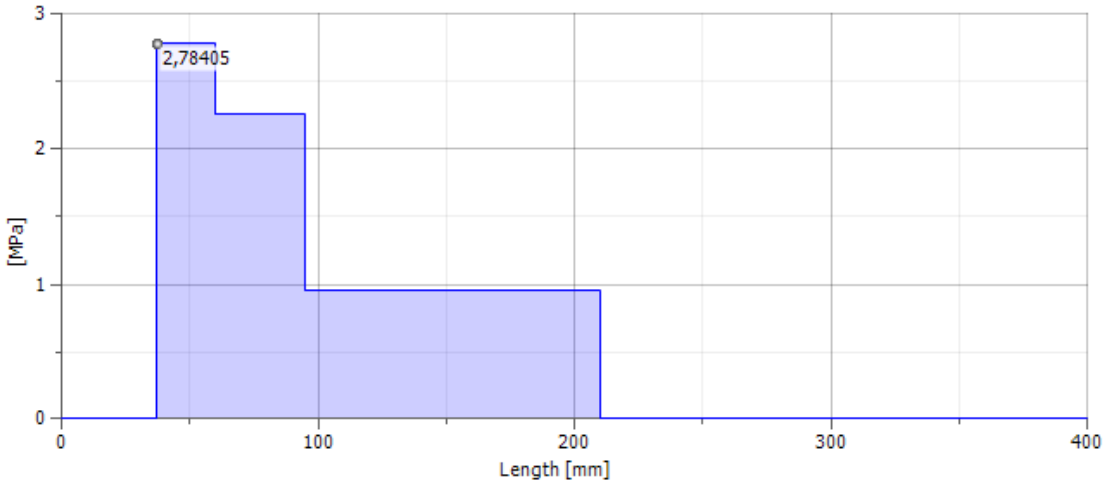

Figure 13. *Chart of torsion stress*

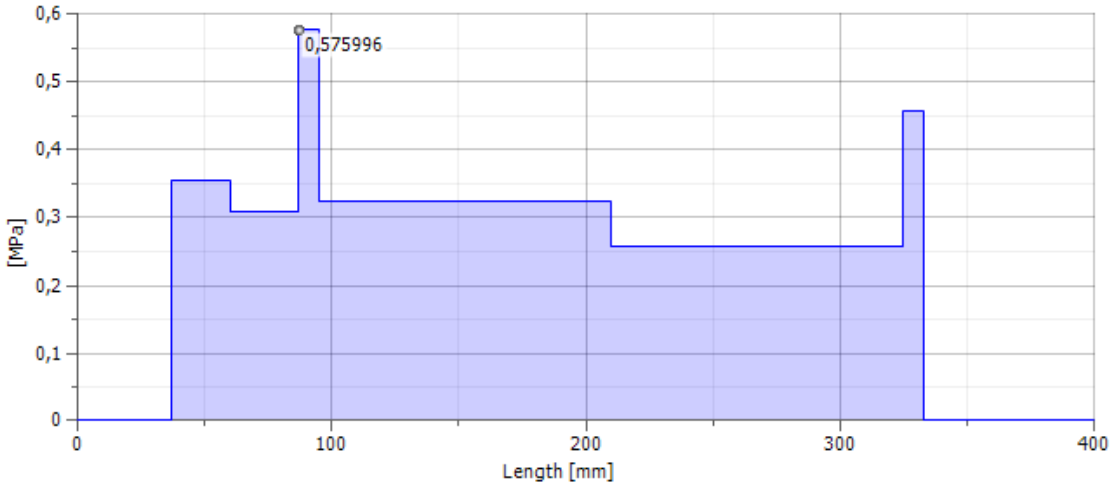

Figure 14*. Chart of shear stress*

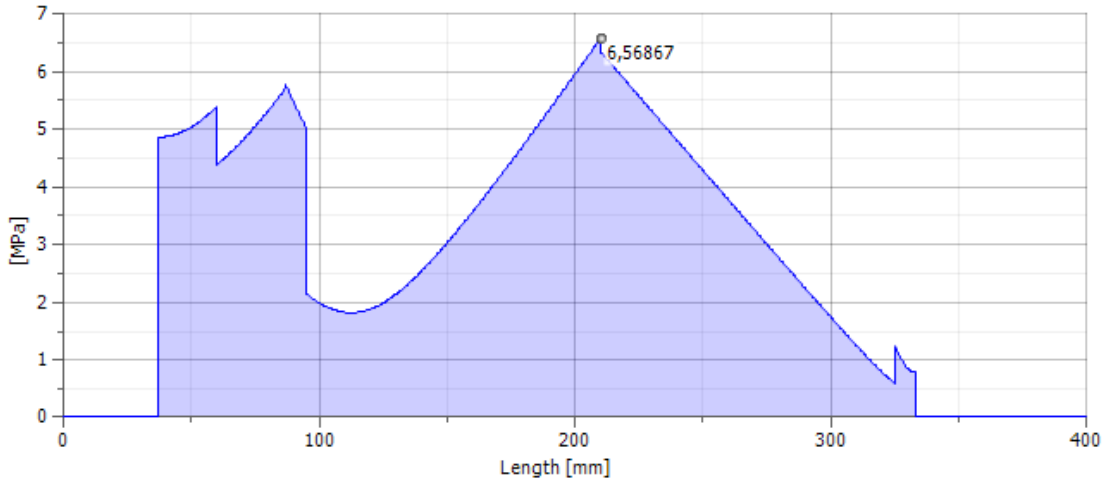

Figure 15. *Chart of reduced stress*

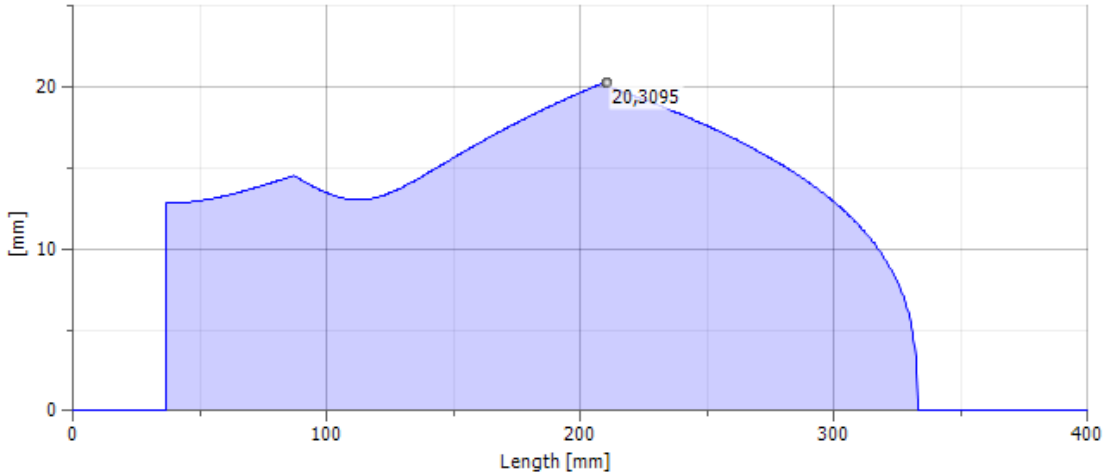

Figure 16. *Chart of ideal diameter*

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The Authors’ Addresses:

Slavcho Sokolovski, Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: slav_sokolovski@abv.com

Nelly Staneva, Assoc. Professor, PhD,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: nelly_staneva@yahoo.com

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EUROPEAN WOOD FLOORING MARKET – CURRENT SITUATION AND TRENDS

Slavica Petrović

University of Belgrade, Faculty of Forestry, Belgrade, Serbia,
e-mail: slavica.petrovic@sfb.bg.ac.rs

ABSTRACT

The paper presents results of researching wood flooring market in the FEP countries in the period 2007-2014 and special attention is paid to the analysis of market characteristics in the period after the recession which certain member states had experienced. Apart from the stated, the research also included certain South East European countries since they place a part of their wood flooring production onto the markets of the FEP countries.

Key words: wood flooring, production, wood species, consumption, import, export

1. INTRODUCTION

Wood flooring has a long tradition of use and owing to its good mechanical, insulating and esthetical characteristics, it is used both in residential and commercial and public facilities. Consumers can choose among three wood flooring types, namely solid wood parquet (including ship decking, classic parquet and lamparquet), mosaic and multilayer parquet.[4] Owing to various kinds of surface processing, dimensions, quality class and parquet colour which depends on wood species which it is produced from, it has a wide product range. Previous several years, flooring made of thermally treated wood has become quite popular, which are used in rooms with higher humidity such as saunas, or in open air next to the pools and in the gardens. However, beside good characteristics, long life, easy maintenance, wood flooring has been losing its share on the European wood flooring market and European producers have been facing numerous problems. Recession, experienced by certain European counties in previous years, which has impacted the reduction of construction activities and drop of wood flooring consumption at the same time, has largely influenced the destabilization of this market.

2. MATERIAL AND METHOD OF WORK

Analysis of the European wood flooring market for the purpose of identifying the biggest producers and consumers of this product type has been done based on the data taken from The European Federation of Parquet (FEP) reports[5]. Timeline established for this analysis covered the period 2007-2013, which is a sufficiently long period for understanding the situation and trends of the activities on the analyzed market. Analysis of the biggest importers and the countries which are the most significant for supplying the biggest consumers of wood flooring in Europe has been carried out based on the data taken from the EUROSTAT database. Timeline covering the period 2007-2014 has been formed for the purpose of this analysis.

[4] On the market in Serbia, the terms wood flooring and parquet are synonyms, while on certain markets in Europe, such as German, it is usual to use the term parquet and on the market in Great Britain it is usual to use wood flooring.

[5] FEP member states are: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Norway, Switzerland, Italy, Hungary, Poland, Netherlands, Sweden, Romania and Spain.

For the purpose of researching wood flooring markets in certain European countries, as well as the countries on other continents, general scientific methods were used, such as the methods of analysis, namely functional, genetic and comparative analysis, and the methods of generalization, induction and deduction.

Functional analysis is used for establishing the relation, links and interdependences existing within the scope of research, namely primarily within the FEP wood flooring market as well as the links and relationships with certain counties worldwide significant for its functioning. Generic analysis is used in the paper for the purpose of discovering the reasons why FEP market is in such a condition nowadays and comparative analysis is used for comparing adequate activities analyzed in the paper. Methods of generalization, induction and deduction are used for the purpose of drawing certain conclusions about the current situation on FEP's wood flooring market.

3. RESEARCH RESULTS

3.1. Wood flooring production in FEP countries

Analysis of wood flooring market in FEP countries shows that record production of 100.3 million m^2 realized in 2007 wasn't reached even seven years later (FEP, 2014). Moreover, production in 2013 was 33.2% less than in 2007 (Figure 1). In the analyzed period, consumption of wood flooring in FEP countries has similar trend and in 2013 it was 26.3% less than in 2007 when it reached 112.2 million m^2 (FEP, 2014). According to the first estimates, FEP market did not get stabilized in 2014 either, however it is estimated that consumption of wood flooring dropped by 3.8% to 79.5 million m^2, while even higher drop rate is estimated for the production **(**Global Flooring Alliance, 2015)**.**[6] The trend of analyzed activities is particularly concerning because of the fact that production and consumption realized in 2014 were smaller than the production and consumption realized in 2009, when the impact of recession was the most expressed.

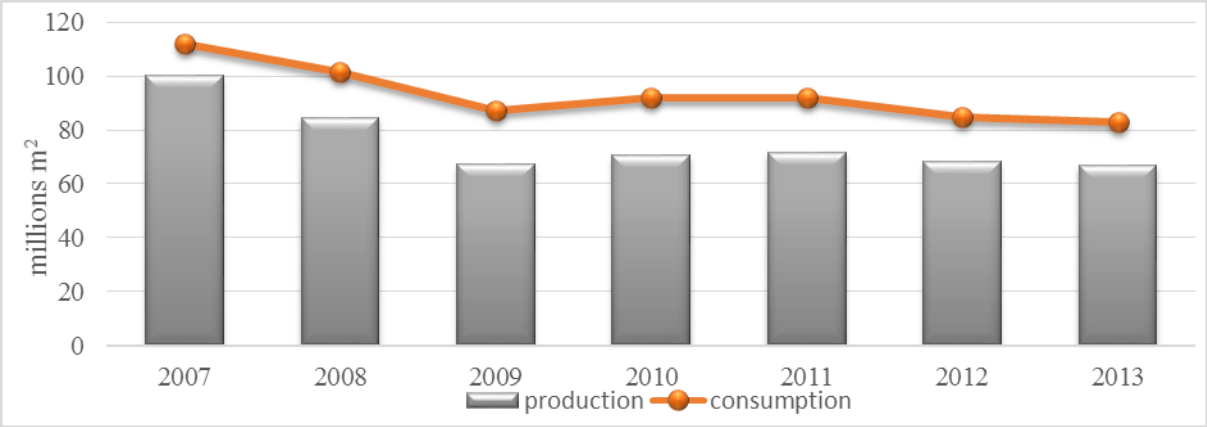

Figure 1. *Production and consumption of wood flooring in FEP countries in the period 2007-2013 (Petrović, S., 2010; FEP Reports, 2009-2014)*

Analysis of production by countries shows that in the period 2008-2009, all biggest FEP producers of wood flooring reduced their production and after that, the fastest recovery from recession occurred in Poland, France and Austria. These three countries were the only countries which managed to increase their production in the period 2010-2013, in particular Poland by 6.6%, France by 6.0% and Austria by 4.0% (Figure 2). However, among these countries, Poland is the only country which realized continuous increase of production, while the production in Austria and France first increased and then slightly dropped in 2012 and 2013. Cluster of Nordic countries,[7] Sweden and Italy also managed to increase their production in the period 2010-2011, however they couldn't keep this trend

[6] Official data about production and consumption of wood flooring in FEP countries in 2014 will be published in June 2015.
[7] Denmark/Finland/Norway.

in the period 2012-2013. The biggest drop of production in the period 2010-2013 of 46.5% was marked in the countries of Nordic Cluster, while Italy faced the drop of 22.4%, and Sweden 6.1%. After the increase of 9.9% in 2010, Germany decreased its production by 5.6% in the period until 2013. The most difficult situation during the analyzed period by far was in Spain, where the negative trend of production started in 2008 and continued until 2013, where production dropped by 54.4%, or from 10.1 million m^2 in 2007 to 4.6 million m^2 in 2013 (Petrović, S., 2010; FEP, 2008-2013).[8]

Poland reached the leading position in 2008 by putting Sweden back, and kept it until 2013 when it produced 13.3 million m^2 of wood flooring. The same year, Germany was the second biggest producer in FEP with 10.4 million m^2, followed by Sweden with 8.8 million m^2, Austria with 8.3 million m^2 and France with 6.9 million m^2 (FEP, 2014).

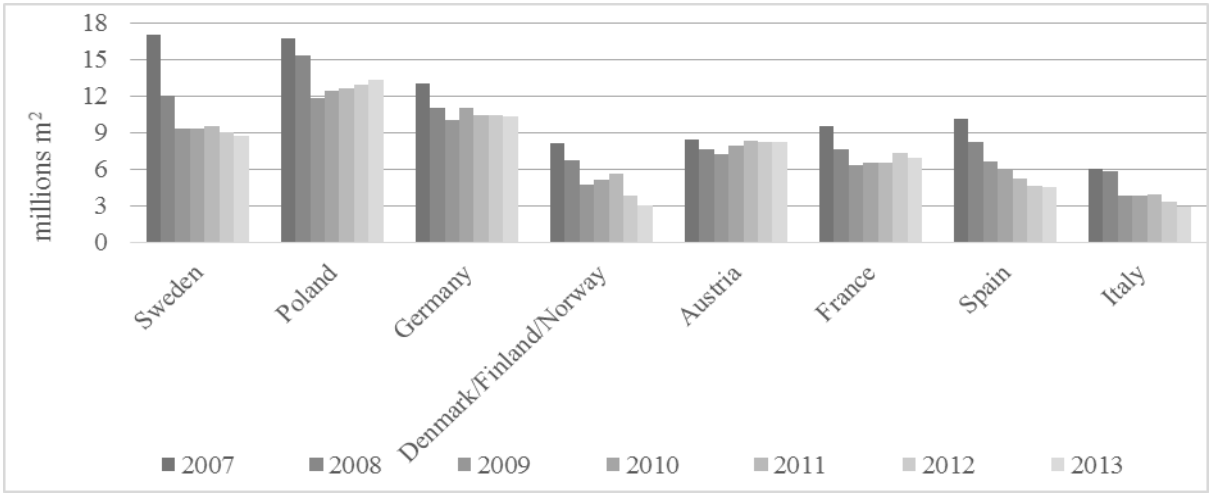

Figure 2. *Biggest producers of wood flooring in FEP countries in the period 2007-2013 (Petrović, S., 2010; FEP Reports, 2007-2014)*

In FEP countries, multilayer parquet is produced most, and in 2013 it participated with 78% in the total production, while solid wood parquet (including classic parquet, ship decking and lamparquet) participated with 20% and mosaic parquet participated with 2%. Wood flooring is mostly made of oak and its participation in the production of flooring increased from 50.3%, which was the situation in 2005, to 70.9% in 2013 (Petrović, S., 2007; FEP, 2014). At the same time, the participation of beech dropped from 9.4% in 2005, when it was the second most important for flooring production, to 4.6% in 2013. Instead of beech, tropical wood species took the second position in 2013 with the share of 5.8%. However, the use of tropical wood species for flooring production in FEP countries significantly decreased after 2005. Italy and Poland are the exceptions, where tropical wood species participated with 30% and 19% respectively in flooring production in 2013 (Petrović, S., 2010; FEP, 2014a).

3.2. Wood flooring consumption in FEP countries

Unlike production, consumption of wood flooring in FEP countries in the period 2007-2013 is characterized by less oscillations. In the analyzed period, Switzerland is the only country which increased consumption by 36.9% to 6.4 million m^2 in 2013, while in all other countries it decreased (Figure 3). Again, the situation was the most difficult in Spain where, due to constant drop, consumption of wood flooring decreased by 68.9%, i.e. from 18 million m^2 in 2007 to 5.6 million m^2 in 2013. The situation was similar in Italy and Poland as well, where the consumption dropped by 42.1% and 33.8% respectively in the period 2007-2013. Cluster of Nordic countries, Sweden, Austria, France and Germany managed to stop the negative trend of consumption during 2010, however they could not keep the trend of increase until 2013. Consumption in the Cluster of Nordic countries of 7.5 million m^2 in 2013 was 24.2% lower compared to 2007, in Sweden this rate was 12.6% and in Austria

[8] Data for the production of wood flooring by FEP countries for 2014 were not available at the time when this paper was written. Data on production and consumption in FEP countries are usually published during the month of June of the current year for the previous year.

it was 11.6%. France had lower drop rate in the same period amounting to 7.2% and with 11.6 million m^2 in 2013 it was the second biggest consumer in the FEP. Germany had the smallest drop of consumption in the period 2007-2013 of 4.5% and with 19.8 million m^2 in 2013 it was the biggest FEP consumer of wood flooring (Petrović, S., 2010; FEP, 2009-2014).[9]

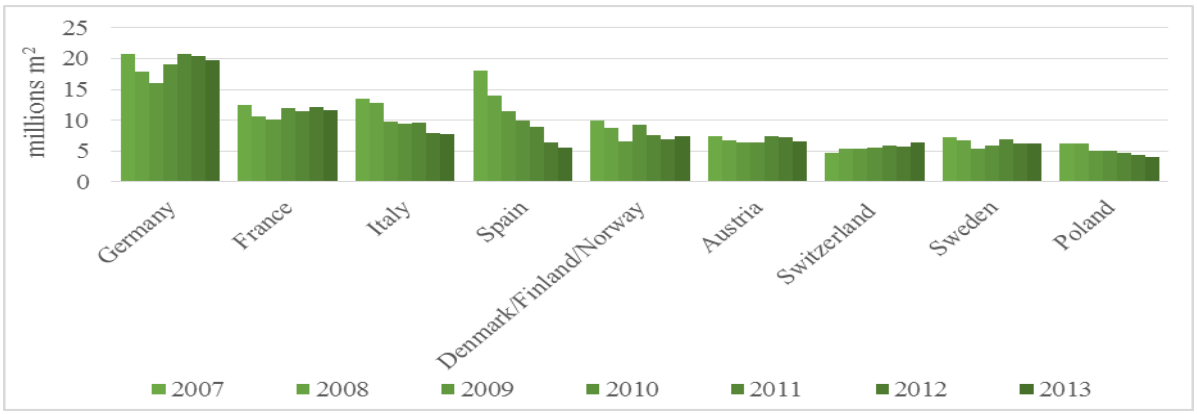

Figure 3. *Biggest consumers of wood flooring in FEP countries in the period 2007-2013 (Petrović, S., 2010; FEP Reports, 2009-2014)*

3.3. Supply of FEP market with wood flooring

Since FEP countries are bigger consumers than producers, they import wood flooring more than they export it. In the period 2007-2014, the value of wood flooring import of FEP countries decreased by 4.9% to 1.13 billion € (EUROSTAT, 2015) (Figure 4).[10] Supply of FEP market with wood flooring can be analyzed on the level of internal trade realized among member countries and foreign trade realized with all other countries worldwide. Results of researching FEP market show that its member countries are the most significant suppliers of this market. During all the years of the analyzed period 2007-2014, the value of trade among member countries was higher than the value of import from other countries worldwide. Comparative analysis of the relationship of trade among FEP countries and import from other countries worldwide in the period 2007-2014 indicates that it ranged in the interval 66.8%:33.2%, which was in 2007, to 61%:29% in 2010. In 2014, trade among member countries represented 62.1% of the total value of import, while 37.9% was the import from other countries worldwide.

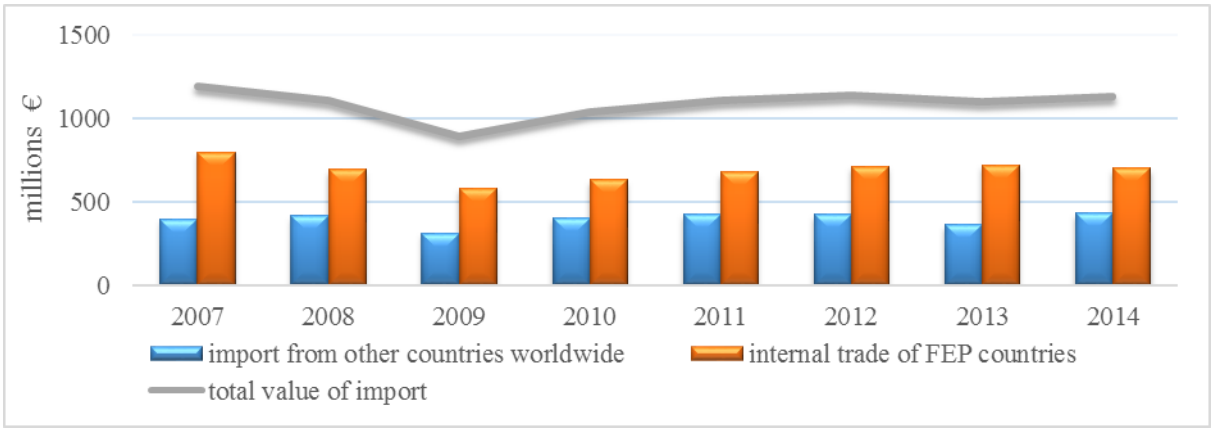

Figure 4. *Foreign and domestic trade of FEP countries in the period 2007-2014 (EUROSTAT, 2015)*

Among member countries, Poland, Sweden and Austria had the most significant role in supplying FEP market. Import of FEP member countries from these three countries represented 53.3% of the

[9] Results of first conducted analyses show that consumption in Sweden increased in 2014, while it dropped in Italy and France, and it was stable in Germany and Austria.
[10] Given data do not contain import value of Switzerland and Norway from the countries outside the EU-28.

total trade among the member countries in 2014, which is 1.6% less than in 2007. The value of import of FEP countries from Austria and Sweden in 2014 was 20.1% and 15.1% less respectively compared to 2007, while import value from Poland increased by 12.6%.

The most significant foreign trade partners from FEP countries are the countries on the Asian continent, primarily China, while Malaysia, Indonesia, Vietnam and Thailand have significantly lower importance. The value of import from these four countries in 2014 represented 60% of the value of import from other countries worldwide. Significance of China as a supplier with wood flooring of FEP market is increasing year after year. It is proven by the fact that in the period 2007-2014, import value of wood flooring from China increased by 26.9%, namely from 170 million € in 2007 to 215.7 million € in 2014 (EUROSTAT, 2015) (Figure 5).[11] In the same period, import value from Malaysia and Indonesia dropped by 30.8% and 67.1% respectively, from Thailand it dropped 6.6 times, while import from Vietnam increased 3.5 times. Apart from Vietnam wherefrom solid wood parquet is mostly imported, multilayer parquet is imported most from other countries and import of mosaic parquet is the lowest.

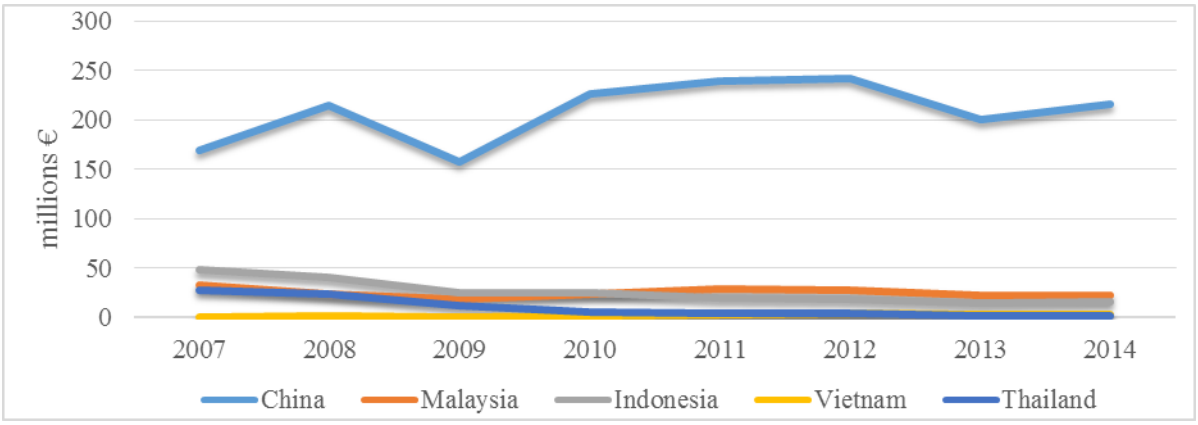

Figure 5. *Import of wood flooring from Asian countries in the period 2007-2014 (EUROSTAT, 2015)*

In the period 2007-2014, import value of multilayer parquet from China increased by 41.1%, while the import value of solid wood parquet dropped by 30.7% and of mosaic parquet by 52.3% (Figure 6). In the structure of import value from China in 2014, multilayer parquet had the share of 89.4%, solid wood parquet had the share of 10.5% and mosaic parquet had the share of 0.1% (EUROSTAT, 2015).

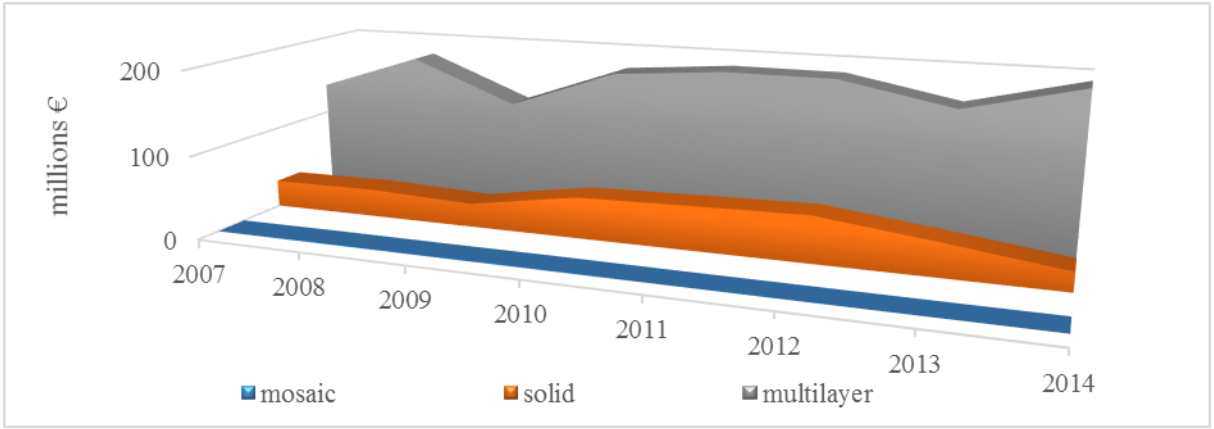

Figure 6. *Structure of wood flooring import from China in FEP countries in the period 2007-2014 (EUROSTAT, 2015)*

[11] Given data do not contain import value of Switzerland and Norway.

Among other countries worldwide significant for supplying FEP market with wood flooring, Lithuania, Ukraine and Russia can be highlighted, while United Kingdom is of lower importance (Figure 7).[12] Import value of FEP member from these four abovementioned countries represented 19.7% of the value of import from other countries worldwide in 2014. In this group of countries, Lithuania should be highlighted in particular, the import from which constantly increased during the analyzed period. In the period 2007-2014, import value from this country increased 4.3 times to 52 milion €, while in the same period the import from Ukraine increased 4.8 times to 23.7 million € and import from Russia increased 5.6 times to 6.1 million €. Brazil used to belong to this group, however during the analyzed period import from this country dropped from 24.2 million euro, which was in 2007, to 0.9 million euro in 2014 and this is the reason why it lost its function in supplying the FEP market.

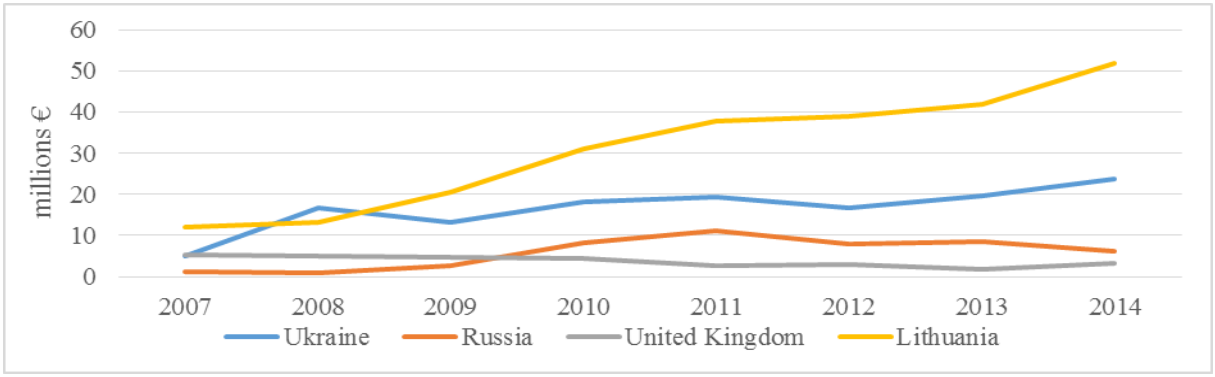

Figure 7. *European countries significant for supplying FEP market in the period 2007-2014 (EUROSTAT, 2015)*

Significance of South East European countries for supplying FEP market with wood flooring started decreasing in previous years since in the period 2007-2014 import value from these countries dropped by 20.7%. Import value of FEP countries from the countries in this region represented 5.8% of the total import from other countries worldwide in 2014.[13] Croatia has the biggest significance among SEE countries for the FEP market although import from this county decreased by 22.5% to 18.7 million € in the period 2007-2014. Significance of Serbia, Slovenia, Bosnia and Herzegovina is significantly lower, and the import from Serbia was 2.5 million € in 2014[14] (EUROSTAT, 2015) (Figure 8). The main reason for such market situation is the fact that countries which are not a part of FEP member community are the most significant export markets for Serbia. Export from other SEE countries, namely Albania, Macedonia and Montenegro into FEP countries was sporadic and without continuity during the analyzed period, which is the reason why they are not presented on the graph. Switzerland, Italy, Denmark, Germany and Austria import most from the SEE countries, and import of these countries in 2014 represented 74% of the total import of FEP countries from the SEE region.

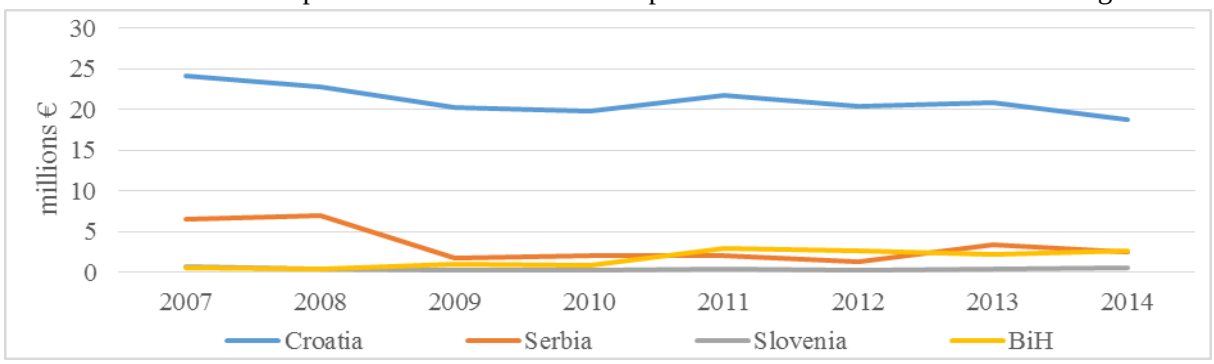

Figure 8. *Import of wood flooring of FEP countries from SEE countries in the period 2007-2014 (EUROSTAT, 2015)*

[12] Given data do not contain import value of Switzerland and Norway from Russia and Ukraine.
[13] In the determination of import value, trade between Serbia and Bosnia and Herzegovina on one side and Switzerland and Norway on the other was not analyzed.
[14] Import of Switzerland from Serbia was not analyzed.

3.4. Biggest countries importers in the FEP

The following countries have the biggest difference between consumption and production, which makes them the biggest FEP importers: Germany, Switzerland, Sweden, Norway and Belgium (Figure 9). In 2014, Germany imported wood flooring in the value of 244.5 million €, Switzerland imported in the value of 133.7 million €, Sweden imported in the value of 117.3 million €, Norway imported in the value of 104.2 million € and Belgium imported in the value of 87.1 million € (EUROSTAT, 2015).[15]

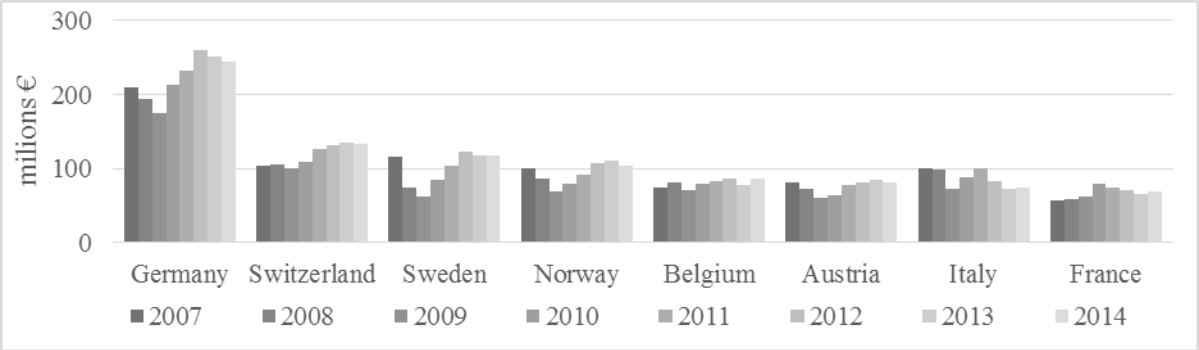

Figure 9. *The biggest importers of wood flooring in the period 2007-2014 (EUROSTAT,* 2015)

Germany meets the needs of its market to a large extent by importing flooring from other FEP member countries, primarily from Austria followed by Poland. In 2014, value of import from FEP member countries represented 65.8% of the total import value, while the value of import from China was 14.9%.

Flooring from China is mostly imported by Belgium and the Netherlands, primarily multilayer parquet. In the structure of the value of flooring import in Belgium in 2014, import from China represented 59.5%. In the period 2007-2014, Belgium imported wood flooring from China in the total value of 378.4 million € and the Netherlands imported in the value of 275.8 million €, while Italy took the third position with 241.8 million € and Germany was the fourth with 198.4 million €. FEP member countries have the greatest significance for supplying the markets of other biggest consumers (EUROSTAT, 2015).

4. DISCUSSION

After the recession experienced by certain European countries in the period 2008-2009, recovery of FEP wood flooring market goes significantly slower than it was expected. Record high values of production and consumption realized in 2007 weren’t reached seven years later yet. Such market situation results from various speed of getting out of the recession by certain member countries as well as the fact that some of them are still under the impact of the crisis. Spain is facing the most difficult situation, where production and consumption of wood flooring during all the years of the analyzed period constantly decreased.

Reasons for the reduction of wood flooring production in FEP countries should also be searched in the price of raw material for its production, as well as in the cost price of produced m^2 of wood flooring which includes other factors apart from the price of raw material. For many years, flooring is produced most from oak, the price of raw material for which is higher compared to beech or similar species. The fact is that flooring production in FEP countries is decreasing and that China is gaining higher significance for supplying this market. Presently, there are more than 2,300 factories for wood flooring production in China[16], and in 2013 their production reached the level of 689 million m^2, which is 14.6% more than in 2012 (Huidian Research, 2014). Only in 2013, 44.5 million m^2 of parquet

[15] Value of import for Switzerland and Norway refers only to the EU-28 countries and does not contain data on the value of import from other countries in the world.

[16] In China, wood flooring is considered to include parquet, laminate flooring, bamboo flooring, cork flooring and engineered solid wood flooring.

was sold in China (Research In China, 2014). However, although the import of multilayer parquet from China is increasing, FEP countries are still the most significant for the supply of own market.

The reduction of wood flooring consumption was mostly influenced by the drop of construction activities, which occurred due to the recession. Countries which decreased wood flooring consumption the most in the analyzed period also faced the biggest drop rates of construction activities. Thus, construction of new residential facilities in Denmark dropped by 70% in the period 2006-2013, while the construction of new facilities (of various purposes) in Italy dropped by 44% in the period 2006-2012. In Spain, activities in construction sector dropped by 23% only in 2013 compared to 2012, when the drop of 30.8% was marked compared to 2011.

Condition on the FEP wood flooring market during the previous years was certainly contributed by competitive products, primarily laminate flooring whose production and consumption intensively increased during the previous years. The fact that the share of laminate flooring on the European market increased from 12.7% in 2004 to 14.3% in 2010, while the share of wood flooring increased from 5.1% to 5.6% in the same period, goes in favor of the aforesaid (Global Wood Trade Network, 2013). In 2014 only, European producers of laminate flooring sold the total of 465 million m^2 of this flooring, 390 million m^2 of which was in Europe and the remaining 75 million m^2 was in the countries of North, South America and Asia (Global Flooring Alliance, 2015). Germany with 69 million m^2 was the biggest consumer of laminate flooring in Europe in 2014, followed by France with 39 million m^2, Poland with 27 million m^2, the Netherlands with 17 million m^2 and Spain with 14 million m^2. Apart from Poland, all the stated countries belong to the group of the biggest consumers of wood flooring in FEP, which clearly indicates the pressure of laminate flooring competition which these countries are facing. Unlike European countries, consumption of laminate flooring in Canada in 2014 was on the level of 11 million m^2 and in the USA it was 30 million m^2 (Global Flooring Alliance, 2015).

5. CONCLUSION

Although wood flooring is characterized by numerous advantages the most significant of which are environmental characteristics, anti-allergic properties, warm and natural feeling, good mechanical and insulating properties, European market of this product type has been destabilized for a longer period of years already, and the recovery is slow. Record high values of production and consumption realized in 2007 have not been reached even seven years later. Slow recovery from the recession of certain FEP member countries, decreased construction activities as its consequence, price of raw material, as well as the cost prices of final product are just some of the reasons for such a condition on wood flooring market in Europe. Beside the stated, flooring producers in Europe are also struggling with tough competition of producers from China, whose products are characterized by lower prices compared to the flooring produced in Europe. Although the producers from Europe publicly point to their consumers that the quality of flooring produced in China is lower than the quality of flooring they produce, import of FEP countries from China increased in the period 2007-2014 by 26.9%, i.e. from 170 million € in 2007 to 215.7 million € in 2014.

Another reason for slow recovery of wood flooring market in previous years is the impact of competitive products, primarily laminate flooring, whose production and consumption are constantly increasing.

Results of production and consumption analysis show that the biggest producers of flooring in the FEP are Poland, Germany, Sweden, Austria and France, while the biggest consumers are Germany, France, Italy, cluster of Nordic countries and Austria. Since they have the biggest difference between consumption and production, the biggest importers in the FEP are: Germany, Switzerland, Sweden, Norway and Belgium. Belgium and the Netherlands import from China the most, while other FEP countries are the most significant for supplying the market of other consumers. However, regardless of numerous problems which FEP flooring market faces, its member countries still have the most significant function in supplying this market, primarily Poland, Sweden and Austria. Among other countries worldwide which are not FEP member countries, countries on the Asian continent are the most significant for supplying its market with wood flooring, primarily China, and to a less extent Indonesia, Malaysia, Vietnam and Thailand. Value of import from these countries represented 60% of the value of FEP import from all other countries worldwide which are not FEP member countries in 2014. Among other countries worldwide significant for the supply of FEP market, Lithuania and

Ukraine can be highlighted, while the significance of the SEE countries has decreased for the last several years. Among the SEE countries, Croatia exports the most to the market of FEP member countries.

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The Author's address:

dr Slavica Petrovic, assistant professor
University of Belgrade, Faculty of Forestry
Kneza Viseslava 1, 11030 Belgrade, SERBIA
tel: +381 11 3053 912
e-mail: slavica.petrovic@sfb.bg.ac.rs

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BENDING PROPERTIES OF COMPOSITE WOOD-BASED PANELS

Violeta Jakimovska Popovska, Borche Iliev, Mitko Nacevski

Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje
e-mail: jakimovska@fdtme.ukim.edu.mk; iliev@fdtme.ukim.edu.mk;
nacevski@fdtme.ukim.edu.mk

ABSTRACT

The research presented in this paper includes the study of bending properties of composite wood based panels.

For this purpose, four experimental models of composite wood based panels were made. The models were made with combination of single-layer particle boards and constructive peeled beech and black pine veneers. One additional model of single-layer particleboard was made as control model.

The modeling is made on the basis of changing the number and type of the veneers used for particleboard overlay.

Water-soluble phenol-formaldehyde resin was used as panel binder.

The bending strength and modulus of elasticity in bending of the experimental composite panels were tested in two directions, parallel and perpendicular to the face grain.

The research results showed that the tested composite panels meet the defined values of bending properties in accordance with the requirements of the standard for structural wood-based panels for use in construction. The different veneer species and different number of veneer sheets in panel structure gives opportunities for production of panels with different strength characteristics.

Key words: composite wood-based panels, particleboard, veneer, beech, black pine, phenol-formaldehyde resin, bending strength, modulus of elasticity in bending

1. INTRODUCTION

Composite wood-based panels made from particleboard core faced with decorative veneers or plastic laminates so far have been used in furniture production, primary as non-structural components. When these kind of composite wood-based panels are made with peeled constructive veneers for particleboard overlay, possibility for production of structural panels is created. The composite wood-based panels can be used in structural application in construction. These panels combine structural efficiency with favorable manufacturing cost (Biblis and Chiu 1974). Utilization of lower quality wood raw material also is an advantage of production of composite wood-based panels.

The researches in the area of structural wood-based panels are directed to creating possibilities for production of stable panels that will meet the requirements in modern construction. One part of the researches in this field concerns the production of combined or composite wood-based panels that should replace the standard plywood which are mainly used in construction. Similar composite panels made from various core and face materials were studied by many researchers (Hse 1976; Biblis and Mangalousis 1983; Biblis 1985; Chow et al. 1986; Dimeski et al. 1996 and 1997; Miljkovic et al. 1997; Mihajolva et al. 2005; Iliev et al. 1994, 2000, 2005, 2010).

Norvydas and Minelga (2006) studied the changes of the properties of overlaid particleboards depending on the number of the veneer layers used for particleboard overlay. Study of the effect of thermally compressed veneers for production of overlaid particleboard for structural application was

conducted by Buyuksari (2012). Study for improving the water resistance properties of composite panels was also conducted (Hse et al. 2012).

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For the realization of the research four models of experimental composite wood-based panels were made. The composite panels were made by combining single-layer particleboard with thickness of 16 mm as core layer and peeled beech and black pine veneers as surface layers. Two of the composite models were made with single beech/black pine veneer overlay on both sides with thickness of 3,2 mm and the other two models were faced on both sides with two-ply cross-laminated beech/black pine veneers with thickness of 1,5 and 3,2 mm.

One model of experimental single-layer particleboard without veneer overlay was made as control model.

The single-layer particleboard is made from beech particles mixed of equal weight ratios of particles for core and surface layer for production of standard three-layer particleboards. The following ratios of particle fractions were used: 0/2,5 mm (25 %), 2,5/0,63 mm (59 %), 0,63/0,36 mm (8 %), 0,36/0,16 mm (5 %) and 0,6/0,07 mm (3 %).

Water solution of phenol-formaldehyde resin was used as an adhesive for particle bonding. The resin had the following characteristics: color – light red; density at 20°C – 1,25 g/cm^3; dry matters – 48%; content of free phenol – 0 %; viscosity by Ford at 20°C – 155 s; pH value – 11,0; resin curing time at 150°C – 20÷35 s. For production of single-layer particleboards, phenol formaldehyde resin with 13 % dry matters content on dry wood basis was used modified with epoxy resin with 5 % dry content. Aluminum sulfate $Al_2(SO_4)_3$×18H2O with dry content of 1 % was used as catalyst.

The particleboard were pressed under specific pressure of 25 kg/cm^2 (6 minutes under specific pressure of 25 kg/cm^2, 4 minutes under 12,5 kg/cm^2 and 4 minutes under 6 kg/cm^2) at temperature of 190°C for time of 14 minutes. The panels were made with dimensions of 550×550 mm^2 and thickness of 16 mm.

The veneers were bonded on the core layer (particleboard) with the same resin that was used for particle bonding, but without modifier. Wheat flour was used as filler and 20 % solution of NaOH as catalyst. The binder was applied in quantity of 180 g/m^2 on both sides on the particleboards in those models faced with one veneer sheet and on both sides on the inner veneers with thickness of 3,2 mm in the models that were double-faced with two veneer sheets.

The composite panels (overlaid particleboards) were made in a hot press under specific pressure of 15 kg/cm^2 at temperature of 155°C for time of 8 minutes for single-overlay panels and 10 minutes for panels made with two-ply cross-laminated veneers.

Dimensions of the composite panels were 540×540 mm^2. The moisture content of the panels was 10 %.

According to this methodology four models of composite panels were made and one control model of particleboard:

- Model A: composite water-resistant panel made with single-veneer overlay on both sides with beech peeled veneers with thickness of 3,2 mm (panel thickness of 21 mm; density of 770,51 kg/m^3);
- Model B: composite water-resistant panel made with two-ply cross-laminated beech peeled veneers with thickness of 1,5 and 3,2 mm on both sides (panel thickness of 24 mm; density of 777,06 kg/m^3);
- Model C: composite water-resistant panel made with single-veneer overlay on both sides with black pine peeled veneers with thickness of 3,2 mm (panel thickness of 21 mm; density of 765,71 kg/m^3);
- Model D: composite water-resistant panel made with two-ply cross-laminated black pine peeled veneers with thickness of 1,5 and 3,2 mm on both sides (panel thickness of 23 mm; density of 771,31 kg/m^3);
- Model K (control model): single-layer particle board with thickness of 16 mm and density of 741,56 kg/m^3.

The configuration of panels’ structure is shown on Figure 1.

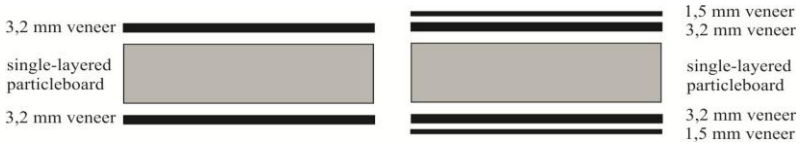

Figure 1. *Pattern of the structure of combined panels*

The bending strength and modulus of elasticity in bending of experimental models were tested according to MKS EN 310. These properties were tested in two directions, i.e., parallel and perpendicular to the face grain of the surface veneers used for panel overlay. The modulus of elasticity in bending was determinate at maximum load.

The obtained data were statistically analyzed. One way ANOVA (analysis of variance) was used to determinate the significance of the effect of type of the panel overlay on the bending properties of the composite panels. Shapiro-Wilk test for normality of the obtained data was applied and Levene’s test for homogeneity of variances was applied. Tukey’s test was applied to evaluate the statistical significance between mean values of the properties of different panel models.

Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

3. RESULTS AND DISCUSSION

The test results of the bending strength and modulus of elasticity in bending parallel and perpendicular to the face grain of the panel are shown in Tables 1, 2, 3 and 4.

The values of the bending strength parallel to the face grain of models A and C (single veneer overlay panels) are within similar limits, as well as the values of models B and D (panels with two-ply cross-laminated veneers). The mean values of bending strength in models A and C are higher for 17,52 to 25,03 % compared to the mean values in models B and D. The control model of a single-layer particleboard (model K) has the lowest value of this property. Overlaying the particleboard with single veneers increase the bending strength up to 3,8 times compared to non-overlay particleboard (control model K). The analysis of variance of the obtained data for bending strength parallel to the face grain (ANOVA: F (4; 25) = 107,48; p=0,000) showed that the differences between the mean value of this property of at least two models are statistically significant. The conducted post-hoc Tukey’s test for multiple comparison between models showed that there are statistically significant differences in the mean value of this property of models A and C compared to models B and D. The differences in the mean values of bending strength between model A and model C, as well as between model B and model D are not statistically significant, which means that the wood specie used for veneer production does not have significant impact on bending strength parallel to the face grain of the composite panels when the overlay is made with the same number of veneers. Model A has higher value of bending strength parallel to the face grain for 6 % compared to model C, while models B and D have almost equal mean values of this property. The statistically significant differences in the mean values between models A and B, as well as between models C and D showed that the number of the veneers used for particleboard overlay significantly affect the bending strength of composite panels. The differences in the mean values between the control model and all composite models are statistically significant. This means that overlaying the single-layer particleboard with constructive peeled veneers on both sides of the panel have significant impact on the bending strength parallel to the face grain.

The highest mean value of modulus of elasticity in bending parallel to the face grain of the panel is achieved in model A. The single veneer overlay panels (models A and C) have higher values compared to the combined models with two-ply cross-laminated veneers (models B and D), whereas the model A has higher mean value for 161,7 % compared to model B, while model C has higher value compared to model D for 30,4 %. With the exception of model A, the control model K has higher mean value of this property compared to all other composite models. The lower values of the composite models with two-ply cross-laminated veneers compared to the single veneer overlay panels can be attributed to horizontal shear failure. This is so far known in the research of composite panels (Hse et al., 2012).

The analysis of variance of the obtained data for the modulus of elasticity in bending parallel to the face grain (ANOVA: F (4; 25) = 43,97; p=0,000) showed that the differences between the mean

value of this property of at least two models are statistically significant. The conducted post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences between all composite models, which means that the wood species used for veneer production, as well as the number of the veneers used for particleboard overlay have significant impact on modulus of elasticity in bending parallel to the face grain of composite panels. There were not statistically significant differences between the control model K and model A, as well as between model K and model C, which means that overlaying the particleboard with one veneer sheet on both sides of the panel does not cause significant impact on the values of this property. The differences in the mean values of the control model K and composite models B and D are statistically significant.

Overlaying the particleboard with single beech veneers on both sides of the panels increase the modulus of elasticity in bending for about 15 % compared to the non-overlay particleboard.

Table 1. *Statistical data for bending strength parallel to the face grain of the experimental panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std. Deviation	Std. Error
		[N/mm^2]	[N/mm^2]	[N/mm^2]	Lower Bound	Upper Bound	[N/mm^2]	[N/mm^2]
A	6	87,27[a]	80,35	97,93	80,83	93,72	6,14	2,51
B	6	69,80[b]	59,76	83,02	60,93	78,67	8,46	3,45
C	6	82,36[a]	77,57	86,09	79,14	85,57	3,06	1,25
D	6	70,08[b]	60,02	78,09	62,08	78,08	7,62	3,11
K	6	22,60[c]	19,56	26,51	19,79	25,39	2,67	1,09

The mean values with the same letters are not significantly different at 0,05 probability level

Table 2. *Statistical data for modulus of elasticity in bending parallel to the face grain of the experimental panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std. Deviation	Std. Error
		[N/mm^2]	[N/mm^2]	[N/mm^2]	Lower Bound	Upper Bound	[N/mm^2]	[N/mm^2]
A	6	22449,60[a]	19440,00	24831,61	20026,41	24872,80	2309,05	942,66
B	6	8577,64[b]	7135,82	10377,34	7428,56	9726,73	1094,95	447,01
C	6	16301,42[c]	14073,63	20765,20	13762,79	18840,05	2419,04	987,57
D	6	12496,22[d]	10754,41	15194,26	10561,00	14431,45	1844,06	752,84
K	6	19427,78[a,c]	15458,07	21472,73	17127,17	21728,38	2192,23	894,97

The mean values with the same letters are not significantly different at 0,05 probability level

Table 3*. Statistical data for bending strength perpendicular to the face grain of the experimental panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std. Deviation	Std. Error
		[N/mm^2]	[N/mm^2]	[N/mm^2]	Lower Bound	Upper Bound	[N/mm^2]	[N/mm^2]
A	6	19,66[a]	16,57	21,73	19,14	22,09	1,80	0,74
B	6	67,25[b]	63,02	70,46	17,77	21,55	2,58	1,06
C	6	20,52[a]	18,89	22,59	64,54	69,97	1,56	0,64
D	6	64,19[b]	58,97	73,33	18,89	22,15	5,77	2,36
K	6	20,61[a]	18,41	22,50	58,13	70,25	1,41	0,57

The mean values with the same letters are not significantly different at 0,05 probability level

Table 4. *Statistical data for modulus of elasticity in bending perpendicular to the face grain of the experimental panels*

Model	***N***	***Mean***	***Min***	***Max***	***95% Confidence Interval for Mean***		***Std. Deviation***	***Std. Error***
		[N/mm^2]	***[N/mm^2]***	***[N/mm^2]***	***Lower Bound***	***Upper Bound***	***[N/mm^2]***	***[N/mm^2]***
A	6	3827,24 [a]	3001,24	4425,16	3248,15	4406,33	551,81	225,27
B	6	11469,35 [b]	10496,09	12152,45	10772,18	12166,52	664,33	271,21
C	6	4416,75 [a]	4044,46	5019,30	4057,60	4775,90	342,23	139,72
D	6	12869,49 [b]	11108,30	15377,44	11252,21	14486,77	1541,10	629,15
K	6	18861,98 [c]	17073,74	21822,55	16849,73	20874,23	1917,46	782,80

The mean values with the same letters are not significantly different at 0,05 probability level.

The analysis of variance of the obtained data and post-hoc Tukey’s test for bending strength (ANOVA: F(4;25) = 390,90; p=0,000) and modulus of elasticity in bending perpendicular to the face grain (ANOVA: F (4;25) =171,14; p=0,000) showed that the there are statistically significant differences in the mean values of these properties between single-veneer overlay panels and panels with two-ply cross-laminated veneers. The mean values of these properties in composite models with two-ply cross-laminated veneers (B and D) are higher compared to the single veneer overlay panels (A and C), whereas the model B has higher mean value of bending strength for 242,1 % compared to model A, while model D has higher value compared to model C for 212,8 %. The mean value of the modulus of elasticity in bending in model B is higher compared to those one in model A for 199,7 %, while the mean value of this property in model D is higher compared to model C for 191,4 %.

The differences in the mean values of bending strength and modulus of elasticity in bending perpendicular to the face grain between model A and model C, as well as between model B and model D are not statistically significant, which means that the wood species (beech or black pine) used for veneer production dos not significantly affect these properties when the overlay is made with the same number of veneers.

There are no statistically significant differences in the mean values of the bending strength perpendicular to the face grain of the control model and single veneer overlay panels (A and C). The mean value of the control model of single-layer particleboard is within the limits of the values of these composite panels.

Overlaying the particleboard with two-ply cross-laminated veneers increases the bending strength perpendicular to the face grain up to 3,3 times compared to non-overlay particleboard (control model).

The differences in the mean values of the modulus of elasticity in bending perpendicular to the face grain of the control model K and all composite models are statistically significant.

Composite panels made with two-ply cross-laminated veneers have similar values of bending strength parallel and perpendicular to the face grain which demonstrate the advantage of cross-laminated veneers on the panel surface. This advantage is also seen in higher values of modulus of elasticity in bending perpendicular to the face grain of the composite panels made with two-ply cross-laminated veneers in comparison with the single-veneer overlay panels. The single-veneer overlay panels have significantly lower values of bending strength and modulus of elasticity in bending perpendicular to the face grain compared to the values obtained when the panels were stressed parallel to the grain direction.

The obtained values of bending strength and modulus of elasticity in bending of the experimental panels are within the limits of the values for these properties listed in available literature. Hse et al. (2012) gives the values of 58,85 N/mm^2 and 25,29 N/mm^2 for bending strength parallel to the face grain of single veneer overlay particleboard (pine veneer thickness of 3,2 mm) and particleboard with two-ply cross-laminated veneers (2×3,2 mm), respectively. The same authors for this property in cross-grain direction give the values of 5,6 N/mm^2 for single veneer overlay particleboard and 23,63 N/mm^2 for particleboard with two-ply cross-laminated veneers. The values of the modulus of elasticity in bending parallel to the face grain were 7157 N/mm^2 for single veneer overlay particleboard and 5551 N/mm^2 for particleboard with two-ply cross-laminated veneers. In cross-grain direction of the same panels the authors gives the values of 1188 and 3378 N/mm^2.

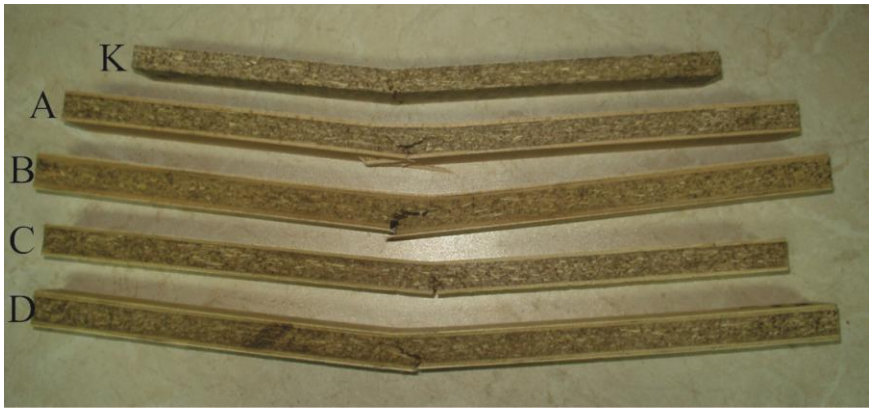

Figure 2. *Failure mode of the test specimens of the experimental panels*

Buyuksari (2012) gives the values within the limits of 47,3 to 51,8 N/mm^2 and 4869 to 5641 N/mm^2 for bending strength and modulus of elasticity in bending parallel to the face grain of particleboard overlaid on both sides with beech veneers with thickness of 1,5 mm. That study showed that the bending strength and modulus of elasticity in bending were increased for 318 % and 157 % respectively, compared to unlaminated particleboard. Borysiuk et al. (2011) for particleboard overlaid with 1,4 mm pine veneers gives the values of 49,1 and 6506 N/mm^2 for bending strength and modulus of elasticity in bending parallel to the face grain, respectively. The same author gives the values of 13 and 1520 N/mm^2 respectively for bending strength and modulus of elasticity in bending perpendicular to the face grain of the panel. Application of veneers to outer layers increased the bending strength and modulus of elasticity in bending in major axis around 65 ÷ 72 % with simultaneous decrease in minor axis by around 23 ÷ 30 % (Borysiuk et al. 2011).

Norvydas and Minelga (2006) give the values within the limits of 30 and 52,2 N/mm^2 for bending strength and 2592 to 3528 N/mm^2 for modulus of elasticity in bending of composite panels made from particleboard overlaid with different number of layers of sliced mahogany veneers. The highest values were achieved in panels overlaid with 5 layers of veneers (3 mm thickness).

Iliev (2000) gives the values within the limits of 47,31 to 83,08 N/mm^2 for bending strength parallel to the face grain of composite panels made from particleboard with single veneer overlay and values within the limits of 35,03 to 59,85 N/mm^2 for bending strength of composite panels with two-ply cross-laminated veneers. The same author gives the values within the limits of 5132 to 6590 N/mm^2 for modulus of elasticity in bending parallel to the face grain of single-veneer overlay panel and values within the limits of 2140 to 4899 N/mm^2 for modulus of elasticity in bending of panels with two-ply cross-laminated veneers.

Miljković et al. (1997) for composite panel made from particleboard with single-pine veneer overlay gives the value of 32,72 N/mm^2. Dimeski et al. (1996) gives the values of 32,88 N/mm^2 and 31,31 N/mm^2 for bending strength of combined panels made with single beech veneer overly and panels with two-ply cross-laminated veneers, respectively. Iliev (1994) gives the values of 8223 N/mm^2 and 8046 N/mm^2 for modulus of elasticity in bending of composite panels made from particleboard overlaid with beech and black pine veneers, respectively.

The obtained values of bending strength and modulus of elasticity in bending of experimental panels exceed the minimal values for load-bearing particleboard for structural application defined in the standard EN 312. For thickness class of 20÷25 mm the defined values for bending strength of load-bearing particleboards range from 13 to 18,5 N/mm^2 depend on the particleboard type. The values of modulus of elasticity in bending for the same thickness class range from 1900 to 2900 N/mm^2.

4. CONCLUSIONS

On the basis of the conducted research it can be concluded that the production of composite wood-based panels made with peeled constructive veneers for particleboard overlay give the possibility for production of panels for structural application in construction.

The wood specie used for veneer production (beech or black pine) does not have significant impact on bending strength of the composite panels when the overlay is made with the same number of veneers, but the number of the veneers used for particleboard overlay significantly affects this property. Overlaying the particleboard with single veneers increase the bending strength parallel to the face grain up to 3,8 times compared to non-overlay particleboard.

The highest mean value of bending strength and modulus of elasticity in bending parallel to the face grain of the panel is achieved in single-beech veneer overlay composite model.

The wood species used for veneer production, as well as the number of the veneers used for particleboard overlay have significant impact on modulus of elasticity in bending parallel to the face grain of composite panels. Overlaying the particleboard with one veneer sheet on both sides of the panel does not cause significant differences in the mean values of this property between these composite models and the non-overlaid particleboard.

The wood species (beech or black pine) used for veneer production dos not significantly affect the bending strength and modulus of elasticity in bending perpendicular to the face grain of the composite panels when the overlay is made with the same number of veneers. Overlaying the particleboard with two-ply cross-laminated veneers increases the bending strength perpendicular to the face grain up to 3,3 times compared to non-overlay particleboard.

The advantage of cross-laminated veneers on the panel surface is demonstrate by the similar values of bending strength parallel and perpendicular to the face grain of these composite panels. The advantage is also seen in higher values of modulus of elasticity in bending perpendicular to the face grain of the composite panels made with two-ply cross-laminated veneers in comparison with the single-veneer overlay panels.

The obtained values of bending strength and modulus of elasticity in bending of experimental panels exceed the minimal values for load-bearing particleboard for structural application defined in the standard EN 312.

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The Authors' Addresses:

Dr Violeta Jakimovska Popovska, Docent
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: jakimovska@fdtme.ukim.edu.mk

Dr Borche Iliev, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: iliev@fdtme.ukim.edu.mk

Dr Mitko Nacevski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: nacevski@fdtme.ukim.edu.mk

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NAIL WITHDRAWAL RESISTANCE OF COMPOSITE WOOD-BASED PANELS

Violeta Jakimovska Popovska, Borche Iliev, Goran Zlateski

Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje
e-mail: jakimovska@fdtme.ukim.edu.mk; iliev@fdtme.ukim.edu.mk;
zlateski@fdtme.ukim.edu.mk

ABSTRACT

The paper elaborates the nail withdrawal resistance of composite water-resistant wood-based panels for use in construction. Three experimental panels were made by combining particleboards and constructive peeled veneers of beech, pine and poplar with thickness of 3,2 mm. The core layer of composite panels was made of single-layer particleboard with thickness of 16 mm. Particleboards were overlaid on both sides with the veneers.

Water-soluble phenol-formaldehyde resin was used for particle bonding and veneering.

The results from the research showed that the different veneer species used for particleboard overlay significantly impact the nail withdrawal resistance perpendicular to the plain of the composite panels.

According to the obtained values of the nail withdrawal resistance, the composite panels can be used in construction.

Key words: composite wood-based panels, particleboard, veneer, beech, black pine, poplar, phenol formaldehyde resin, nail withdrawal resistance

1. INTRODUCTION

The researches in the field of wood-based panels are directed to finding methods and technical-technological solutions for production of stable panels with high physical and mechanical properties that can meet the requirements of the modern construction.

One type of wood-based panels for use in construction is composite wood-based panels, which represent a composition of particleboard and veneers. Many authors have done researches of this kind of composite wood-based panels (Buyuksari 2012; Dimeski et al. 1996 and 1997; Hse et al. 2012; Iliev et al. 2000, 2005, 2006, 2010; Jakimovska Popovska et al. 2014; Miljkovic et al. 1997; Mihajolva et al. 2005; Norvydas and Minelga 2006).

Some of the researches concern the dimensional stability of the panels under water impact (Iliev 2006; Jakimovska Popovska et al. 2014; Mihajolva et al. 2005). Possibilities for improving the water resistance properties of composite panels were investigated by Hse et al. 2012.

The impact of the number of the veneers on composite panel’s properties was investigated by Iliev (2000) and Norvydas and Minelga (2006).

Beside other physical and mechanical properties of composite wood-based panels important for panels use in construction, the nail withdrawal resistance is also an important property that can shows the behavior of the assemblies of this kind of wood-based panels made with nails.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For the realization of the research three experimental composite wood-based panels were made. These panels were made by combining single-layered particleboard and peeled beech, black pine and

poplar veneers. The core layer of combined panels represents a single-layer particleboard with thickness of 16 mm which is overlaid on both sides with beech/black pine/poplar veneers with thickness of 3,2 mm.

The single-layered particleboards were made from beech particles. Water solution of phenol-formaldehyde resin was used as an adhesive for particle bonding. The resin has the following characteristics: color – light red; density at 20°C – 1,22 g/cm^3; dry matters – 50,43%; content of free phenol – 0,30%; viscosity by Ford at 20°C – 195 s; pH value – 11,0; resin curing time – 97 s. For production of single-layered particleboards, a pure phenol formaldehyde resin with 16 % dry matters content on dry wood basis was used. The mixture of particles for production of single-layered particleboards is obtained with mixing of equal weight ratios of particles for core and surface layer.

The particleboard pressing was made according to the following technological parameters: specific pressure of 25 kg/cm^2 (19 minutes under maximal specific pressure of 25 kg/cm^2 and 10 minutes under pressure of 12,5 kg/cm^2), pressing temperature of 155°C and pressing time of 30 minutes. The particleboards were made with dimensions of 560×455 mm^2 and thickness of 16 mm.

The particleboard overlay was made with beech, black pine and poplar veneers with thickness of 3,2 mm. The orientation of the veneers was parallel to the longitudinal axis of the particleboard. A water-soluble phenol-formaldehyde resin with the following characteristics was used for veneer bonding: color – light red; density at 20°C – 1,201 g/cm^3; dry matters – 48,85%; content of free phenol – 0,21%; viscosity by Ford at 20°C – 165 s; pH value – 11,12; resin curing time (120°C) – 108 s. Wheat flour was used as filler and 15 % water solution of $Ca(OH)_2$ as catalyst. The binder was applied on both sides of the particleboards in quantity of 180 g/m^2.

The veneering was made in a hot press using the following parameters: specific pressure of 15 kg/cm^2, pressing temperature of 155°C and pressing time of 20 minutes.

The composite panels were overlaid with phenol-formaldehyde resin impregnated paper during the hot pressing process. The produced panels have dimensions of 545×435 mm^2, with thickness from 20,41 to 20,68 mm depending on the model and moisture content of 8,5 %.

According to this methodology three models of composite wood-based panels were made:

- Model A: water-resistant composite panel made of particleboard core layer and face layers of beech peeled veneers overlaid with phenol-formaldehyde resin impregnated paper;
- Model B: water-resistant composite panel made of particleboard core layer and face layers of black pine peeled veneers overlaid with phenol-formaldehyde resin impregnated paper;
- Model C: water-resistant composite panel made of particleboard core layer and face layers of poplar peeled veneers overlaid with phenol-formaldehyde resin impregnated paper.

The configuration of panels’ structure is shown on Figure 1.

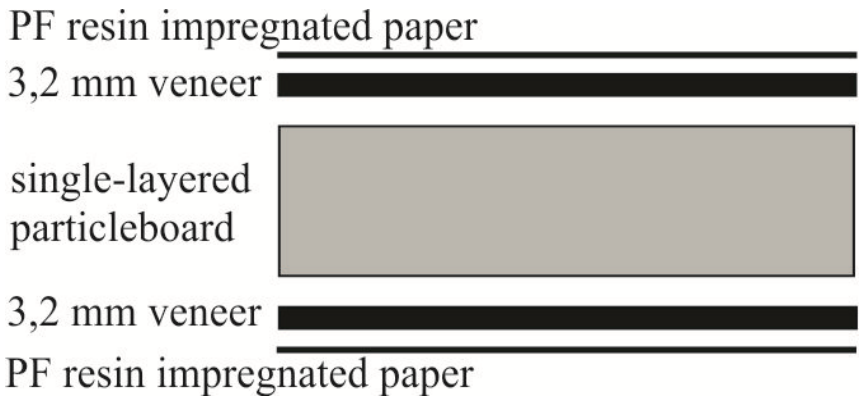

Figure 1. *Pattern of the structure of composite panels*

The nail withdrawal resistance of composite panels was tested according to MKS D.C8.111/82. This property was tested in two directions: perpendicular to the plane of the panel, i.e., when the nail was driven in the surface of the panel and in plain of the panel (the nail was driven in panel’s edge).

Nine test specimens of each model were made with dimensions of 100×50×d mm. Nails with diameter of 2 mm and length of 45 mm were used for these tests. When the nails were driven in to the surface of the panel, the free length of the nail above the surface of the test specimen was 4/10 of nail's length, while when the nails were driven in to the edge of the panel, the depth of the nail driving into the test specimen was 1,2×d. Because of the limited number of the test specimens, the same test specimens were used for testing the withdrawal resistance in both direction of the panel, so one nail was driven in to the surface of the test specimen and two nails in to the edge of the specimen.

The tests were performed on universal testing machine, measuring the maximal force of withdrawal.

The specific nail withdrawal resistance perpendicular to the plane of the panel was calculated using the following equation:

$$K_{\perp}=\frac{F}{d\times\pi\times d_1}\ [\mathrm{N/mm^2}],$$

where F is maximal force of nail withdrawal [N], d is diameter of the nails [mm] and d_1 is the thickness of the panel.

The specific nail withdrawal resistance parallel to the plane of the panel was calculated using the following equation:

$$K_{\parallel}=\frac{F}{d\times\pi\times l}\ [\mathrm{N/mm^2}],$$

where F is maximal force of nail withdrawal [N]; d is diameter of the nails [mm] and l is the depth of driving of the nail in to the panel's edge.

The obtained data were statistically analyzed. One way ANOVA (analysis of variance) was used to determinate the significance of the effect of veneer type on panel's nail withdrawal resistance perpendicular to the plane of the panel. Shapiro-Wilk test for normality of the obtained data was applied and Levene's test for homogeneity of variances was applied. Tukey's test was applied to evaluate the statistical significance between mean values of the property of composite panels with different veneer type (different panel models).

Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

3. RESULTS AND DISCUSSION

The analysis of variance of the obtained data for the nail withdrawal resistance perpendicular to the plain of the panel (ANOVA: F (2; 24)=13,196; p=0,000) showed that the differences between the mean value of this property of at least two models are statistically significant, which means that the wood species used for particleboard overlay has significant impact on this property. The conducted post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences in the mean value of this property between models C and the other two composite models. The differences in the mean values of nail withdrawal resistance perpendicular to the plain of the panel between model A and model B are not statistically significant.

The highest mean value of this property is achieved in composite model that is overlaid with beech veneers, while the lowest value is achieved in model made with poplar veneers. These values correspond with the values of the density of the composite models (Table 1).

The ANOVA (F(2,24)=17,177; p=0,000) and Tukey's test for the density of the composite panels also showed that there is statistical differences in the density of the composite model made with poplar veneers and models made with beech and black pine veneers.

The analysis of variance of the obtained data for the nail withdrawal resistance parallel to the plain of the panel (ANOVA: F (2; 24)=1,408; p=0,264) showed that there are no statistically significant differences between the mean values of this property of all composite models. This was expected due to the fact that all composite models are made with the same core layer of single-layer particleboard, i.e., in all models the nail withdrawal resistance parallel to the plain of the panel is tested in the particleboard core layer, which is the same in all models.

Table 1. *Statistical data for density of the composite panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std. Deviation	Std. Error
		kg/m³	kg/m³	kg/m³	Lower Bound	Upper Bound	kg/m³	kg/m³
A	9	728,00[a]	699,00	755,00	715,48	740,52	16,29	5,43
B	9	721,.22[a]	663,00	757,00	696,52	745,92	32,13	10,71
C	9	661,67[b]	627,00	703,00	639,98	683,36	28,22	9,41

The mean values with the same letters are not significantly different at 0,05 probability level

Table 2. *Statistical data for nail withdrawal resistance perpendicular to the plain of the composite panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std, Deviation	Std, Error
		N/mm²	N/mm²	N/mm²	Lower Bound	Upper Bound	N/mm²	N/mm²
A	9	5,49[a]	4,64	6,64	4,92	6,05	0,73	0,24
B	9	5,11[a]	4,61	5,68	4,83	5,39	0,36	0,12
C	9	4,29[b]	3,57	4,64	4,04	4,53	0,32	0,11

The mean values with the same letters are not significantly different at 0,05 probability level

Table 3. *Statistical data for nail withdrawal resistance parallel to the plain of the composite panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std, Deviation	Std, Error
		N/mm²	N/mm²	N/mm²	Lower Bound	Upper Bound	N/mm²	N/mm²
A	9	2,86	2,49	3,82	2,49	3,22	0,48	0,16
B	9	2,59	2,29	3,02	2,42	2,76	0,22	0,07
C	9	2,56	2,07	3,66	2,19	2,93	0,48	0,16

There are no statistically significant differences between the mean values at 0,05 probability level

The test specimens for determination of nail withdrawal resistance are shown on Figures 2 and 3.

The obtained values of nail withdrawal resistance of the experimental composite panels are within the limits of the values listed in the literature from the similar researches. Iliev (2000) gives the values in the limits of 4,39 to 5,62 N/mm^2 for nail withdrawal resistance perpendicular to the plain of the composite panels made with two-ply cross-laminated beech veneers and values in the limits of 4,68 and 5,56 N/mm^2 for the composite panels made with single beech veneer overlay. Miljković et al. (1997) give the value of 4,72 N/mm^2 for nail withdrawal resistance perpendicular to the plain of the composite panel made with two-ply cross-laminated black pine veneers.

For the nail withdrawal resistance parallel to the plain of the panel Iliev (2000) gives the values within the limits of 3,55 to 4,12 N/mm^2 for composite panels made with single beech veneer overlay and values within the limits of 2,70 to 3,91 N/mm^2 for composite panels made with two-ply cross-laminated beech veneers. Dimeski et al. (1997) give the value of 4,04 N/mm^2 for nail withdrawal resistance parallel to the plain of the composite panels with two-ply cross-laminated poplar veneers.

Miljković (1991) defined the values within the limits of 2,4 to 3,6 N/mm^2 for the nail withdrawal resistance perpendicular to the plain of the particleboard panel and the values within the limits of 1,2 to 1,8 N/mm^2 for the nail withdrawal resistance parallel to the plain of the particleboard panel. The obtained values for this property of the experimental composite wood-based panels exceed these values.

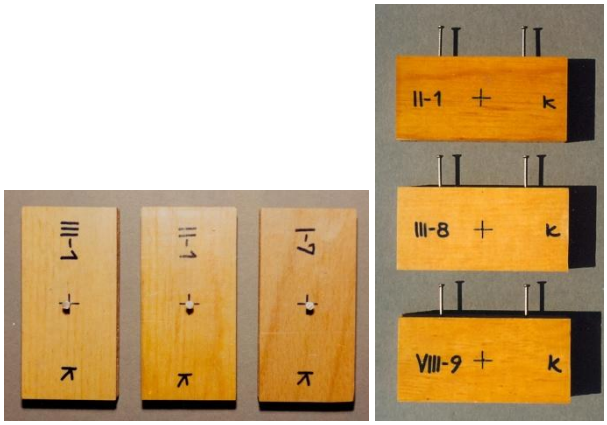

Figure 2. *Test specimens for determination of nail withdrawal resistance of composite panels*

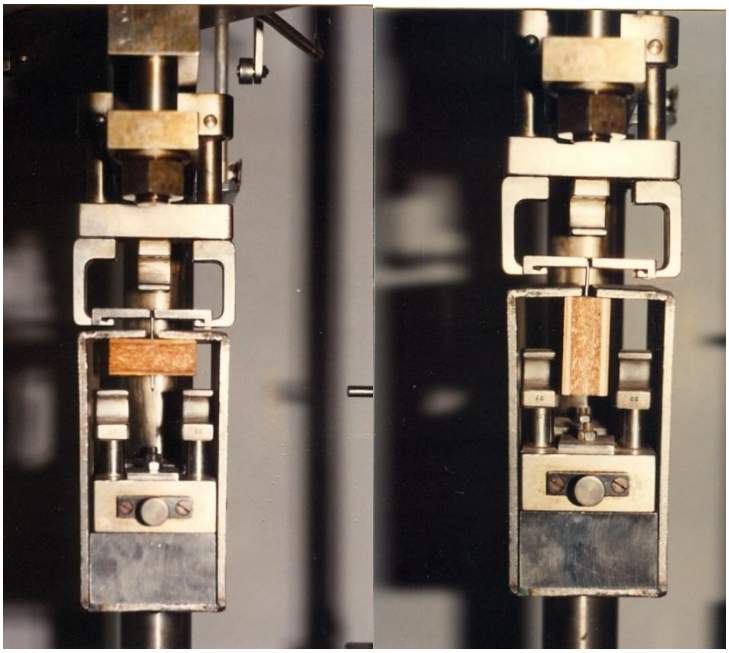

Figure 3. *Tests for determination of nail withdrawal resistance of composite panels*

4. CONCLUSIONS

On the basis of the obtained results from the conducted research, following conclusions can be drawn:

- The obtained results for the nail withdrawal resistance of the experimental panels showed that the composite wood-based panels made with peeled constructive veneers for particleboard overlay are adequate for structural application in construction.
- The wood specie used for veneer production (beech, black pine or poplar) has significant impact on wood species used for particleboard overlay has significant impact on the values of nail withdrawal resistance perpendicular to the plain of the composite wood-based panels. The highest mean value of this property is achieved in composite model made with beech veneer overlay, which is in accordance with the highest value of the density of this model.
- According to the obtained values of the nail withdrawal resistance, the composite panels can be used in construction.

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The Authors' Addresses:

Dr Violeta Jakimovska Popovska, Docent
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: jakimovska@fdtme.ukim.edu.mk

Dr Borche Iliev, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: iliev@fdtme.ukim.edu.mk

Dr Goran Zlateski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: zlateski@fdtme.ukim.edu.mk

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INFLUENCE OF HEAT TREATMENT ON WATER ADSORPTION OF BEECH WOOD

Ranko Popadić, Branko Kolin, Goran Milić, Nebojša Todorović

University of Belgrade, Faculty of Forestry,
Department of Technology, Management and Design of Furniture and Wood Products,
Belgrade, Republic of Serbia
e-mail: ranko.popadic@sfb.bg.ac.rs; branko.kolin@sfb.bg.ac.rs;
goran.milic@sfb.bg.ac.rs; nebojsa.todorovic @sfb.bg.ac.rs;

ABSTRACT

The paper shows the adsorption, and the radial and tangential swelling of heat-treated beech sapwood and red heartwood. Heat treatment lasted for 4 hours, with temperatures of 170 °C, 190 °C, and 210 °C. All the samples were oven-dried and then exposed to a climate of saturated air (RH = 100%) during 325 days. The results indicate that the adsorption and swelling of beech timber are decreased with an increase of temperature of heat treatment. The speed of adsorption and swelling was greatest in the beginning, and then had a slow decline. After three months, the values were around 90% of the final values, and after six months, both of these processes were finished. Concerning hygroscopicity and swelling, red heartwood had properties that were equal to or better than sapwood.

Key words: beech, heat treatment, red heartwood, adsorption, swelling

1. INTRODUCTION

Thermal treatment is a process in which high temperatures are applied on wood in order to decrease its hygroscopicity (Milić et al. 2013). Also, this process increases wood’s resistance toward fungi and insects (Kotilainen 2000, Sailer et al. 2000), it influences its color (Todorović et al. 2012), but also somewhat reduces its mechanical properties (Todorović et al. 2010, Popadić et al. 2010). There are various schedules of thermal treatment. The temperatures used are 150-260 °C (Kotilainen 2000), and the effects of the process are also influenced by its duration. Heat treated wood is used in conditions of frequent humidity changes in environment, outdoors, and in indoor spaces with increased air humidity (swimming pools, saunas, etc.). Use of beech wood is not recommended for such environments. Although it has good mechanical properties, beech is not the best choice here because of its high values of shrinking and swelling, its tendency toward changing its shape and form, and its low durability (resistance to fungi). Apart from the aforementioned, beech wood has a tendency toward developing red heartwood. Sawmill products with red heartwood have a lower value because of their different (reddish) color and the possible presence of fungi (Karadžić 1981), even though they are otherwise equal to products made out of sapwood (Šoškić and Skakić, 1995).

The goal of this paper is to compare the hygroscopicity of heat treated and untreated beech wood, and those of sapwood and red heartwood. In this way, the knowledge is widened about influences of heat treatment on decrease of hygroscopicity of beech timber, and about its potentially bigger spectrum of use. This especially applies to the red heartwood as the lower-valued wood, considering that, according to Todorović et al. (2012), color difference between sapwood and red heartwood is diminished after heat treatment.

2. MATERIAL AND METHODS

The material used in this research was obtained from Goč mountain in Serbia. Beech (*Fagus mosesiaca L.*) logs with a relevant quantity of red heartwood were cut and radial boards were taken for research. These boards were then processed to separate sapwood from red heartwood. Control boards from sapwood and red heartwood were extracted, and other boards were subjected to the heat treatment.

Heat treatment was conducted in a laboratory chamber ($1m^3$, ± 1 °C sensitivity) for heat treatment filled with water vapor. Applied were the usual schedules for beech in industrial conditions, that are used in “Tarket doo” company in Bačka Palanka, Serbia. Samples were treated with temperatures of 170, 190 and 210 °C during 4 hours. After the treatment, all the samples were conditioned during 8 weeks at temperature of 23 °C and air humidity of 50%.

Samples for examining hygroscopicity and swelling were made out of the control and the heat treated boards. Dimensions of samples were 20x20x20 mm, with edges parallel to anatomic directions of wood (radial, tangential and axial). Eight groups of 15 samples were formed. Four groups were made from sapwood and other four were made from red heartwood. One in each of these four was control (from untreated wood), and other three were to be used for different temperatures of treatment (170, 190 i 210 ^{0}C).

After this, all samples were oven-dried in a laboratory kiln (at 103±2 ^{0}C). Their masses and dimensions were measured, and they were placed in an atmosphere of saturated humid air (above water) for the process of adsorption to be followed (Figure 1). Adsorption was followed in these conditions, at room temperature (21-25 °C) during 325 days. Mass was measured on laboratory scales with 0.01 g precision, and dimensions were measured with a caliper with 0.01 mm precision.

Figure 1. *Plastic container for samples conditioning at RH 100%*

To calculate the moisture content of specimens we used standard formula:

$$\mathbf{MC} = \frac{\mathbf{m_v} - \mathbf{m_0}}{\mathbf{m_0}} \cdot \mathbf{100[\%]}$$

where:
MC – moisture content (%)
m_v – mass of wet sample (g)
m_0 – mass of oven-dry sample (g)

Linear swellings in radial and tangential directions were calculated according to the formula:

$$\mathbf{S_{r(t)}} = \frac{\mathbf{D_V} - \mathbf{D_0}}{\mathbf{D_0}} \cdot \mathbf{100[\%]}$$

with:

S_r – radial swelling [%]
S_t – tangential swelling [%]
D_V – radial (tangential) dimension of wet sample [mm]
D_0 – radial (tangential) dimension of oven-dry sample
Swelling coefficients were calculated according to the formula:

$$k_{s\left(\frac{r}{t}\right)} = \frac{S_t}{MC_{max}} \left[\frac{\%\ of\ swelling}{\%\ of\ moisture}\right]$$

with:
k_s – swelling coefficient in radial (tangential) direction
S_t – total swelling in radial (tangential) direction [%]
MC_{max} – maximal moisture content achieved [%]

All obtained data was statistically processed in the software SPSS 13.0. Significance of differences between treatments were tested by ANOVA, using the Tukey HSD post hoc test.

3. RESULTS AND DISCUSSION

Maximal moisture content (MC_f) that the samples reached after 325 days in the environment of saturated humid air is shown in Table 1.

Table 1. *Moisture content of samples after 325 days of adsorption*

	Sapwood				Red heartwood			
	control	170^{0}C	190^{0}C	210^{0}C	control	170^{0}C	190^{0}C	210^{0}C
MC_f (%)	29.38	25.34	21.06	15.90	29.77	25.68	19.51	15.27

The table shows that, as expected, the highest level of adsorption was reached by the untreated beech wood, and the values were in accordance with data for beech wood from this part of Europe (Šoškić 1986). With an increase of temperature of treatment, the adsorption decreased ($F=279.092$; $p<0.01$), while the differences in moisture contents of sapwood and red heartwood were mostly insignificant, except with the treatment at 190 °C.

Figure 2 shows the timeline of adsorption in saturated humid air (RH=100%) in applied heat treatments.

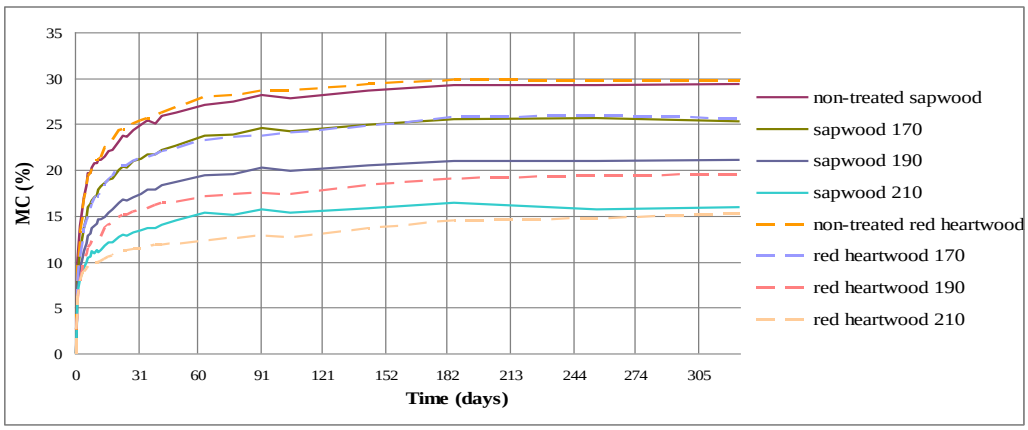

Figure 2. *Timeline of changes in moisture content of untreated and heat-treated sapwood and red heartwood in saturated humid air (RH=100%)*

The figure shows that all the samples behaved equivalently. Adsorption speed was highest in the first several days and was reduced afterwards. A similar behavior was also reported by Šoškić et al. (1995). There were no differences between sapwood and red heartwood of untreated samples and samples treated at 170 °C. At higher temperatures (190 °C and 210 °C) red heartwood had a somewhat slower adsorption, and also a lower final moisture content.

Figure 3 shows radial swelling in correlation with the applied treatment.

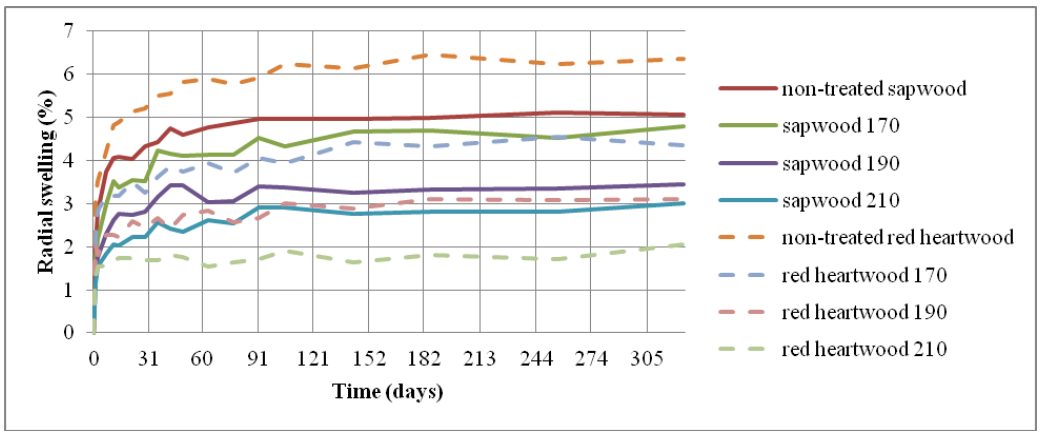

Figure 3. *Timeline of radial swelling of untreated and heat treated beech sapwood and red heartwood in saturated humid air (RH=100%)*

The trend of speed of radial swelling was similar to the trend of change in moisture content. Figure 3 shows that, control samples excluded, sapwood swelled more in the radial direction than red heartwood did. As with the speed of adsorption, the heat treatment had a positive influence, i.e. radial swelling was reduced with an increase of temperature.

ANOVA shows that there were significant differences between treatments ($F=32,941$; $p<0,01$). The post-hoc analysis indicates that there are four similar groups. Highest values of radial swelling were recorded in untreated red heartwood – 6.36%. They were somewhat higher than those reported by Šoškić (1986) – 5.80, and Šoškić and Skakić (1995) – between 4.93 and 5.91%. Red heartwood treated at 210 °C had the lowest radial swelling (2.05%). Between these two values were two groups without significant differences in radial swelling. The one group comprises untreated sapwood ($S_r=5.10\%$), and sapwood ($S_r=4.79\%$) and red heartwood ($S_r=4.36\%$) treated at 170 °C. The other group comprises sapwood ($S_r=3.45\%$) and red heartwood ($S_r=3.10\%$) treated at 190 °C, and sapwood treated at 210 °C ($S_r=3.00\%$).

Figure 4 shows tangential swelling of beech sapwood and red heartwood in correlation with the applied treatment.

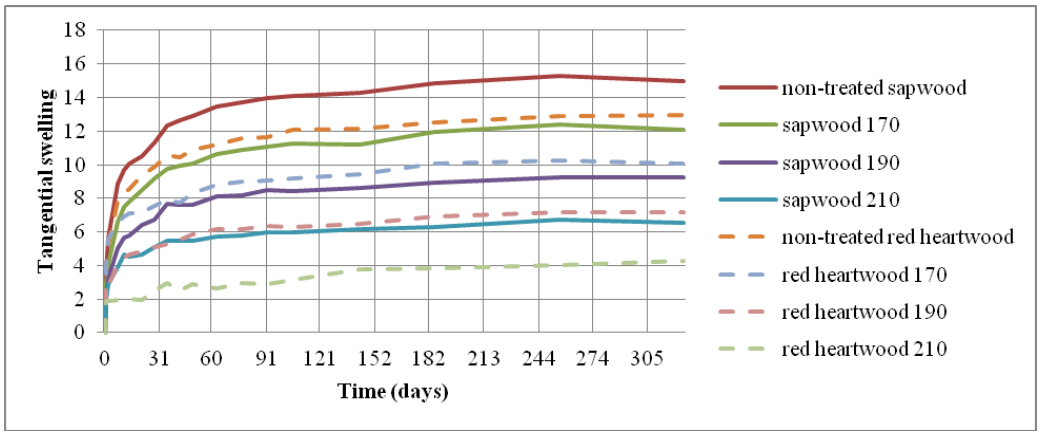

Figure 4. *Timeline of tangential swelling of untreated and heat treated beech sapwood and red heartwood in saturated air (RH=100%)*

Tangential swelling also follows MC change, with speed being reduced afterwards. Sapwood swelled more than red heartwood, and the intensity of heat treatment also influenced the decrease of tangential swelling.

The statistical analysis confirmed significant differences in tangential swelling by treatment ($F=94.864$; $p<0.01$). The post-hoc analysis showed that all the heat treatments were significantly different between each other. Also, in each treatment there were significant differences between sapwood and red heartwood. Untreated sapwood swelled the most – 14.99% which is about 3% higher than reported by Šoškić (1986) – 11.80%, and Šoškić and Skakić (1995) – between 11.30 and 12.79%. Red heartwood treated at 210 °C swelled the least – 4.29%. However, there were no significant differences between the following: untreated red heartwood ($S_t=12.98\%$) and sapwood treated at 170 °C ($S_t=12.10\%$); red heartwood treated at 170 °C ($S_t=10.06\%$) and sapwood treated at 190 °C ($S_t=9.28\%$); red heartwood treated at 190 °C ($S_t=7.19\%$) and sapwood treated at 210 °C ($S_t=6.54\%$). This indicates that approximately equal tangential swelling can be expected after certain treatments of red heartwood and treatments of sapwood that are respectively more severe by one step.

Figures 2, 3, and 4 show that adsorption and swelling in saturated humid air had similar behaviors. These processes both had the greatest speed during the first several days, with the speed decreasing later. About 90% of total values were achieved in the first three months and, 6 months into the process, both adsorption and swelling were finished. There were, however, some minor differences. While the adsorption was steady, and the curves illustrating it were level, the swelling (especially in the radial direction) was oscillating, and so were its respective curves. This phenomenon was present in the first three months of the process and was probably a consequence of the fact that the humid air was adsorbed in wood but was not directly in the walls of anatomic elements, but rather in cell lumens. Thus, moisture content of the samples was increased without an increase in their dimensions.

Coefficients of swelling (amount of swelling within MC change of 1%) are indicators that can be used to determine if the intensity of heat treatment affects the swelling only in the measure in which hygroscopicity is changed, or if heat treatment also affects the amount of unitary swelling. Table 2 shows coefficients of swelling in radial and tangential directions in examined treatments.

Table 2. *Coefficients of swelling in radial and tangential directions*

	Sapwood				False heartwood			
	control	170^0C	190^0C	210^0C	control	170^0C	190^0C	210^0C
Coefficient of swelling in radial direction (%)	0.173	0.189	0.164	0.190	0.214	0.165	0.159	0.139
Coefficient of swelling in tangential direction (%)	0.511	0.477	0.440	0.413	0.437	0.404	0.372	0.294

Although these results indicate that sapwood swells more than red heartwood, and that the intensity of treatment may reduce the coefficient of swelling, this cannot be fully asserted due to high data variation. Statistical analysis of these data indicates that there were significant differences in coefficients of swelling in tangential direction ($F=13.839$, $p<0.01$) and these are primarily a consequence of differences in coefficients of swelling that untreated sapwood and red heartwood treated at 210 °C had, compared to the rest of the samples. Significant differences in coefficients of swelling in radial direction ($F=3.944$; $p<0.01$) are solely a consequence of the difference in coefficients of swelling between untreated red heartwood and the rest of the samples – that did not differ among themselves.

4. CONLUSIONS

The results of examination of adsorption during 325 days in saturated humid air lead to these conclusions:

- heat treated beech timber adsorbed less water than untreated does. Intensity of heat treatment affected the adsorption level, and no differences between sapwood and red heartwood were proved;
- radial swelling decreased with the increase of the temperature of heat treatment. Although the values of radial swelling of red heartwood were nominally lower as compared to sapwood, these differences were not statistically significant;
- tangential swelling decreased with the increase of temperature of heat treatment. Red heartwood swelled less than sapwood in tangential direction;
- trends of speed of adsorption and swelling in saturated humid air (RH=100%) were very similar. The highest speed of these processes was recorded in the first several days, and it slowly decreased afterwards. About 90% of total values of adsorption and swelling were achieved in the first three months, and six months into the examination both processes were completely finished;
- analysis of coefficient of swelling indicated that sapwood swelled more than red heartwood did (especially in tangential direction) and that the intensity of treatment influenced the swelling coefficients, but this was not statistically proved due to a high data variation;
- heat treated, red heartwood proved to be equal or better than sapwood, considering hygroscopicity and swelling. Thus, the expectation was confirmed that a new field of use of this sawmill product could be opened, especially considering its price that is significantly lower than that of sapwood.

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The Authors' Addresses:

Dr. Ranko Popadić
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: ranko.popadic@sfb.bg.ac.rs

Dr. Branko Kolin
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: branko.kolin@sfb.bg.ac.rs

Dr. Goran Milić
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: goran.milic@sfb.bg.ac.rs

Dr. Nebojša Todorović
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: nebojsa.todorovic@sfb.bg.ac.rs

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ANTIC EFFECT FILMFORMING TECHNOLOGIES ON FURNITURE SURFACES

**Panayot Panayotov, Zhivko Georgiev, Yancho Genchev,
Dimitar Angelski, Vasil Merdjanov**

*University of Forestry, Faculty of Wood Industry
10 Kliment Ohridski Bulv.,1756 Sofia, Bulgaria
e-mail: ppanayotov@mail.bg*

ABSTRACT

This study is about filmforming technologies for receiving antic effects. In this case the effects are named: *crackle; white pore and black pore.* It is made on kitchen furniture doors and test samples of oak veneered MDF boards. They are received by using stains, PU and NC basecoats and topcoats. It is determinate the adhesion on tested samples according to BDS 13088 and BDS EN ISO 4624, [1,2]. The received values are more than need about longtime exploitation.

Key words: furniture, antic effects, coats, adhesion

1. INTRODUCTION

The modern progress in technologies is allowing us to create more comfortable interior with new, qualitative materials. It was made an analysis about modern influence in furniture sale. There were demarcated two basic directions: “the new”, characterized with extremely clear lines; sharp lines; straight corners; maximum simple, practical design and the “the old”-nostalgia back to the past: rounded shapes; delicate colors; floral motives [4]. More and more people are interested in this style: our dynamic lifestyle is making us to turn back to the calmness, to the home comfort, which physically can be felt with the furnishing. The furniture which looks old has the same quality and character as the new one, but looks different. It was made with false impression of antiquity with effects, made by different forming coatings [2, 3]. The analysis was made and it was established that the most common effects are used for creating antique effects: effect “old paint”, effect “crackle’ and effect “white pores” and etc. [3, 4]. These effects can be made with completely technologies methods, in following the technical order. It doesn’t eliminate hand work, for example cleaning the corners with soft pressure with sandpaper [9]. This is an example, showing that the technology order of operation and the duration are very important. It should be conformable with the materials, which are used and the technologies of forming for maximum stage of reiteration and to avoid defects. Another sight of the problem is to use modern materials like MDF to reduce the price and make technologies simpler. The using of veneered MDF is a step in this direction. Oak veneer gave us more ability to make these effects, because it has open pore structure.

2. MATERIALS AND WORK EXPERIMENTAL METHODS

About effect achievement are use oak veneered MDF with thickness 18 mm. There were made 12 samples about each of different series with the following sizes 18x50x300 mm and furniture aggregate (furniture doors) for visual effects with sizes 18x200x360 mm.

The effects are marked with following index: “white crackle”(WC), “grey crackle”(GC), “black pore”(BP), “white pore“(WP), “sanded coating”(SC) , “white grey”(WG). The used materials are produced by MILESI - Italy and they are presents in Table 1.

Table 1. *Used materials to achieve effects*

N	Product code	Characteristic of products
1	LBA 42	Clear PU sealer. It is mixed with 50% LBN (hardener). Mixture pot life 3 hours.
2	LBR 30	White PU basecoat. It is mixed with 50% LBN(hardener). Mixture pot life 3 hours.
3	LBR 30 RAL 7038	Grey PU basecoat. It is mixed with 50% LBN(hardener). Mixture pot life 3 hours.
4	LGA 24	Clear PU deep matt topcoat. It is mixed with 50% LBN(hardener). Mixture pot life 3 hours.
5	LEC-400	Fast drying clear nitrocellulose selfsealer with 90 gloss.
6	Crackle	Special produced crackle effect topcoat. The crackles measurement depends of thinner quantities. It is thinner for PU and vary of 10-30%.
7	CQT 10	Solvent borne white patina.
8	CQT 19	Solvent borne black patina.

The steps to achieve the effects are explained in table 2. The all coating systems are made after preliminary sanding with sandpaper with grits № 120 and № 180 after that. The application was made with conventional gun “SATA 500” equipped with nozzle 1.8 mm.

Table 2. *Technological steps*

Effect	Priming	Sanding	Special effect	topcoat
WC	LBR 30 (180 g/m²)	Sandpaper with grit № 320 after 6 hours	LEC-400(150 g/m²) after 40 min. Crackle (100g/m²). Drying time 4 hours.	LGA 24 (120 g/m²)
GC	LBR 30 grey (180 g/m²)	Sandpaper with grit № 320 after 6 hours	LEC-400(150 g/m²) after 40 min. Crackle (100 g/m²) 4 hours	LGA 24 (120 g/m²)
WP	LBA 42 (90 g/m²)	Sandpaper with grit № 320 after 2 hours	CQT 10 (90 g/m²) thinned with 50% acetone; after 1hours sanding with metal wool.	LGA 24 (120 g/m²)
BP	LBA 42 (90 g/m²)	Sandpaper with grit № 320 after 2 hours.	CQT 19 (90 g/m²) thinned with 50% acetone; after 1hours sanding with metal wool.	LGA 24 (120 g/m²)
SC	LBA 42 (90 g/m²)	Sandpaper with grit № 320 after 2 hours	LBR 30 (100 g/m²) ; drying 6 hours; machine sanding with paper grit 320.	LGA 24 (120 g/m²)
WG	LBR 30 grey (180 g/m²)	Sandpaper with grit № 320 after 6 hours	CQT 10 (90 g/m²) thinned with 50% acetone; after 1hours sanding with metal wool.	LGA 24 (120 g/m²)

There were made measuring of the mass in liquid state and dry state for calculating the expense and coverless. The coat thickness was determinate in following equation:

$$\delta_{сф} = \frac{P.c}{100.\rho}, [\mu m] \qquad (1)$$

where: P – coating expense, g/m^2; c – dry containing, %; ρ – coating density, kg/l

It was made for every layer and calculates after that the total dry thickness about effect. To measure the quality of the formed coatings with antique effects the adhesion was measured. The adhesion was measured using the method of wresting metal stamp and it was determinate the vision of

destruction [1,2,3]. After completely drying of the varnish, the samples have been conditioned in indoor conditions and the metal stamps are glued to the surface with cyanogen acrylate glue Locktite, made by Loctite-Ireland in license of Henkel-Germany. After 72h is determinate the power of wresting on universal examine machine FU – 1000 using the aggregate, showed on Figure 1. The adhesion was calculated on the equation (2):

$$\sigma = 0{,}032.F, \left[N/mm^2\right] \quad (2)$$

where: F- disintegrate force in kg

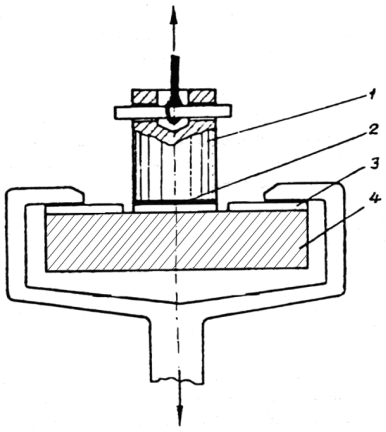

Figure 1. *Aggregate for determinate the adhesion of formed coating to the wood: 1-metal stamp; 2 – adhesive layer; 3 – final coating; 4 – sample;*

3. RESULTS AND DISCUSSION

The received effects are similar and reproduced the same effect in different colors. The photos are presented in Figure 2. The crackles are interest effect, which is result of differences in chemical nature between different layers. The strongest of the effect depends of quantity of thinner. The veneer has also effect on crackles. The oak veneer has open pore structure and it depends on effect.

Figure 2. *“White Cracle “effect (WC) aggregate in left; “Grey Crackle”(GC) aggregate in right*

The second type of effect are effects with patinas. The most important to receive a good patinas effect is to have wood with open pore. About these effect achievment is important to block patina between two layers, sealer and topcoat. The sealer must be clear and with low pore hiding power. The another important thing is drying time of patina, it must be minimum 30min. The photos are present in Figure 3. Another idea is to use color basecoat instead patina and reproduce the same effect. The photos are present on Figure 4.

Figure 3. *“Black pore “effect (BP) aggregate in left; “White pore” effect (WP) aggregate in right*

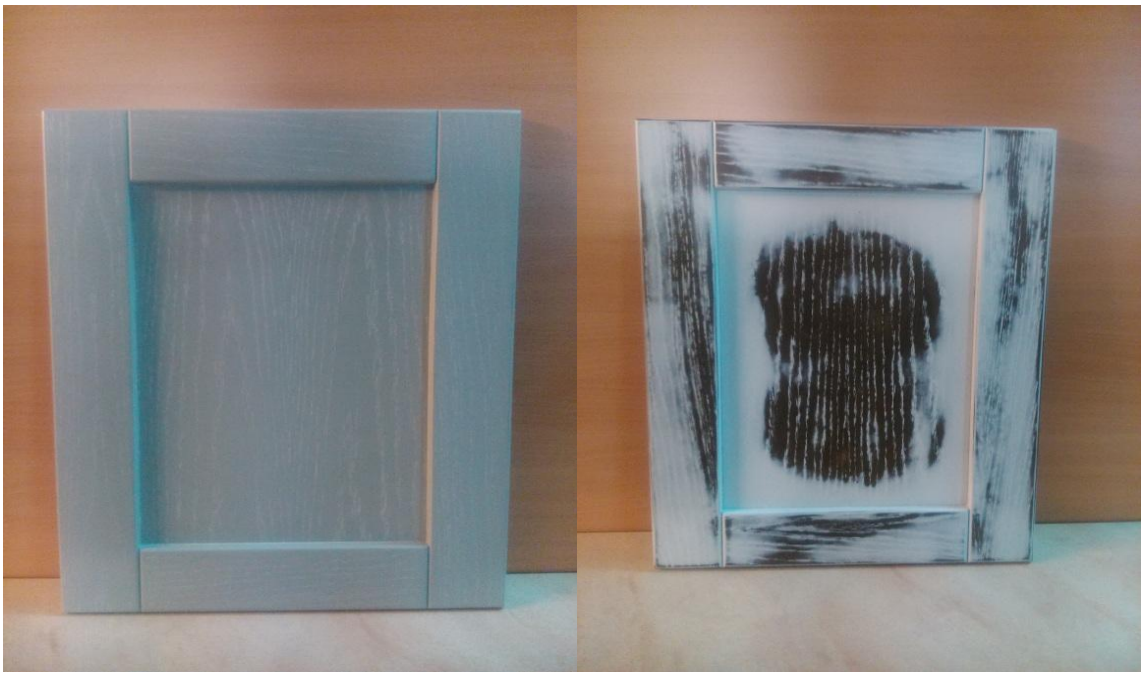

Figure 4. *“White grey “effect (WG) aggregate in left; “Sanded coating” effect (SC) aggregate in right*

In paralel of filmforming on furniture aggregate are also produced samples with the same effects. On these samples are determinate the total film thickness and adhesion. The ¯results are present in Table 3.

Table 3. *Adhesion and description of the destruction*

Series	Thickness of total dry film µm	Variation index				Prevalent character of destruction [%]
		Minimum adhesion σ_a [N/mm^2]	Maximum adhesion σ_a [N/mm^2]	Average adhesion σ_a [N/mm^2]	Eror ± [N/mm^2]	
WC	151	1.050	1.520	1.285	0.062	60%DWS
GC	151	1.070	1.472	1.271	0.026	60%DWS
WP	63	1.142	1.961	1.552	0.071	80%DWS
BP	63	1.205	1.729	1.467	0.053	80%DWS
WG	86	1.163	1.587	1.375	0.061	90%DWS
SC	63	0.987	1.582	1.284	0.069	90%DWS

Description: *WC – effect “white crackle” ; GC – effect “ grey crackle”; WP – effect “white pore”; BP – effect “black pore” ; WG – effect “white grey”; SC – effect “sanded coating”; X- average adhesion; Er- average error; DWS – destruction between wood and basecoat.*

The film thickness of the different series varies in large range. The crackle effect is received in fat layer coating; it is twice than obviously systems and came from thick layer NC intermediate coat.

The received results about adhesion show that similar coating has similar behavior. The best results about adhesion have series WP and BP with patinas effects, but the all results are relative.

4. CONCLUSION

The created coatings show variants for making effects, imparting antique effects on the furniture. Their technology guaranties their multiplicity repeat. The variety of colors is improved by use of patinas and that’s make the effect more interesting. The adhesion has low values, but it was expected. Created effects are modern and sale prospecting.

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The Authors' Addresses:

University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: ppanayotov@mail.bg

UDC (UDK): 674.028.9

INFLUENCE OF DIFFERENT CHEMICAL TREATMENTS OF THE NARROW-LEAVED ASH (*Fraxinus angustifolia* Vahl. ssp. *Pannonica* Soo & Simon) ON THE LAP SHEAR STRENGTH

Jasmina Popović, Milanka Djiporović-Momčilović, Mladjan Popović, Ivana Gavrilović-Grmuša

University of Belgrade - Faculty of Forestry,Belgrade, Serbia
e-mail: jasmina.popovic@sfb.bg.ac.rs; milanka.djiporovic@sfb.bg.ac.rs; mladjan.popovic@sfb.bg.ac.rs; ivana.grmusa@sfb.bg.ac.rs;

ABSTRACT

Chemical composition of wood is considered to be the one of the important factors which affects the bonding quality between the wood and the adhesive. The application of different treatments may change the chemical composition of wood in different degree, which in turn may result in the changes of other wood properties. This paper presents the evaluation of the shear strength of the lap joint on the samples of the Narrow-leaved ash treated with water and with various solutions of acetic acid (0.03, 0.06 and 0.09 g/g). Both, the water and the acetic acid treatments, were performed at the temperatures of 100 ^{o}C and 120 ^{o}C. The influence of the treatments has been evaluated by comparing the shear strength of the control series (non-treated samples) with the series of treated samples. The urea formaldehyde (UF) adhesive was used as a bonding agent. The significant change in the shear strength was noticed only for the treatment with the highest addition of acetic acid (0.09 g/g) and at the treatment temperature of 100 ^{o}C. This treatment has lowered the shear strength for the 14.8 %. All other treatments did not show the effect on the shear strength in lap joint for Narrow leaved ash samples.

Key words: water and acetic acid treatment, ash wood, shear strength, urea-formaldehyde resin

1. INTRODUCTION

The adhesion process with wood as an adherent is highly complex due to the both morphological and chemical features of the wood structure. In order to form the bond, the adhesive needs to wet the wood surface and to penetrate into the wood tissue; and even into the wood cell walls (Frihart, 2007). A suitable degree of penetration into the wood is very important for creating a good bond and this depends on the adhesive and the wood, as well as on the bonding conditions. Besides the characteristics of the adhesive itself, there are other factors which affect the wetting and adhesive penetration, such as: surface energy, size of the capillaries and cavities, i.e. porosity and the permeability of the wood as adherent (Frihart, 2005).

The interaction between the wood and the adhesive is very important for the strength and durability of the adhesive bond (Frihart, 2005) and this is obtained by the formation of chemical bonds and by the mechanical interlocking (Frihart, 2007). From the chemical aspect, the bonds between the adhesive and the wood forms due to the molecular interactions, such as the van der Waals forces, dipole-dipole interactions and hydrogen bonds. Due to the presence of the high number of hydroxyl groups in the main wood components (cellulose, hemicelluloses and lignin), the hydrogen bonds are dominant (Frihart, 2005). On the other hand, the mechanical aspect of the adhesion considers the adhesive penetration into the wood (Frihart, 2007). Due to the specific structure of wood it also presents an important and necessary factor for good adhesion (Frihart, 2006).

Having in mind the significance of the panel products, which includes the plywood, oriented strand board (OSB), fiberboard and particleboard, we can understand the interest of the researchers to find out the means of improving their properties. The strength of these products crucially depends on the quality of the bond formation between the wood and the adhesive during their production. In the production of such products the urea-formaldehyde resin presents one of the most common adhesive systems, due to its favorable characteristics (Frihart, 2005).

Besides the application of pretreatments of wood during the bio-ethanol production (Zhang and Lynd, 2004, Mosier et al, 2005, Gaspar, Kalman, Reczey, 2007, Taherzadeh and Karimi, 2007, Hendriks and Zeeman, 2009, Kumar et al, 2009,) or craft pulping (Yoon and Heiningen, 2008, Al-Dajani and Tschirner, 2008, Al-Dajani et al, 2009), the growing interest of researchers is directed toward the application of pre-treatments in order to improve certain aspects of wood, such as the hydrophilic properties or dimensional stability (Hosseinaei *et al*, 2011a, Paredes *et al*, 2008, Oliveira *et al*, 2010; Blankenhorn *et al*, 1989, Nicholls, Blankenhorn, Labosky, 1991). Water extraction of hemicelluloses results in a decrease in the number of OH groups, which results in the decrease in water adsorption and improves the dimensional stability of treated wood samples (Hosseinaei *et al*, 2011a). Also, due to the loss of hemicelluloses, the relative ratio of lignin and other hydrophobic components in treated samples is increasing, which may be the reason of its increased hydrophobic character (Lu et al, 2003, Hosseinaei et al, 2011b). In addition, the recorded decrease of the surface energy of water treated samples suggests that the polarity of the wood surface is decreased after the extraction (Zhang et al, 2011).

Due to the changes mentioned above, it could be expected that the treatments have influenced in the changes of the adhesion process. Šernek et al (2008) have found the changes in the adhesive distribution across the surface, as well as in the penetration into the structure of modified wood, due to the increased hydrophobic character of wood after the thermal treatment.

The hydroxyl groups in wood presents the potential sites for the formation of hydrogen bonds with the adhesive (River, Vick, Gillespie, 1991). Hence, the decrease in the number of hydroxyl groups in the water treated samples, besides the decrease in hygroscopicity, has an influence in decrease of the shear strength in the lap joint, as well as the increase in the wood failure of treated samples (Mirzaei, Mohebby, Tasooji, 2012). The decrease in the number of accessible OH groups (Tjeerdsma and Militz, 2005) decreases the number of the bonds formed between wood and adhesive (Mirzaei, Mohebby, Tasooji, 2012).

Numerous studies are conducted in order to apply pretreatments during the manufacturing of wood based composite materials, such as MDF, OSB or particleboards (Li et al, 2011, McConnell and Shi, 2011, Hosseinaei et al, 2011b, Pelaez-Samaniego et al, 2014). Decrease in the mechanical properties of wood plastic composites based on wood fibers treated with the oxalic acid have been addressed to the chemical changes in the cell wall as a consequence of the hemicelluloses extraction, which has brought to the decrease in compatibility between treated wood fibers and UF adhesive (Winandy, Stark, Horn, 2008, Li et al, 2011). The improvement of the mechanical properties of the panels based on the water treated eucalyptus particles has been explained by the removal of the extractives from wood, which may retard the curing reaction of UF adhesive (Pan et al, 2007). After the water treatment, the pH value is lowered, i.e. the acidity of the wood is increased which had the favorable effects on the interaction between the UF adhesive and treated particles (Pan et al, 2007, Mirzaei, Mohebby, Tasooji, 2012).

This work presents the research on the pretreatment influence on the shear strength in lap joint of the Narrow-leafed ash samples boned with the UF adhesive. The pretreatments were performed on two different temperatures and consisted of water treatment and the treatments with the acetic acid solutions.

2. MATERIALS AND METHODS

The samples of the 72 years old Narrow-leaved Ash (*Fraxinus angustifolia* Vahl. ssp. *Pannonica* Soo & Simon) were taken from the 5 different height zones of the log. The test panel samples were cut into dimensions of 5 x 20 x 150 mm, at tangential, radial and axial direction, respectively, and sorted into 9 test series: the 8 treatment series and one control series. Each test series consisted of 13 pairs of panel samples, representing the equal distribution of pairs throughout the log.

The treatments with distilled water and with the acetic acid aqueous solutions were performed in the glycol heater with 6 rotating autoclaves. Treatment temperatures were 100 °C and 120 °C; the ratio of liquid to dry wood was 5:1 (the water already present in the air dried samples was taken into account for the calculation) and the duration of each treatment was 60 min. The addition of acetic acid (glacial) (CH_3COOH) (99.5 %) was 0.03, 0.06 and 0.09 g/g wood dry mass.

After the treatment, wood panel samples were washed with distilled water upon reaching the neutral pH value and consequently air dried and conditioned at 20 ± 2 °C and at the relative humidity of 65 %, according to EN 205. Finally, the mass loss was determined for all of the treated samples.

The UF adhesive "Lendur 730F" (Nafta Petrochem, Lendava, Slovenia) was used to bond the sample panels. The addition of ammonium sulphate as a hardener was 3 % (per adhesive dry mass). The concentration of the aqueous solution of hardener was adjusted in order to achieve 54.45 % of the UF adhesive dry content.

Two wood panels were bonded with the adhesive load of 200 g/m^2 applied onto one of the surfaces and then pressed in a hydraulic press at 128 °C and 1 MPa for 13 minutes. Bonded test samples were conditioned at 20 ± 2°C and 65 ± 5 %, according to the requirements of EN 205.

The tensile shear tests were performed using hydraulic test machine (ZWICK, Germany) with a measuring scale of 50 kN and with the testing speed of 10 mm/min in tensile mode. The shear area (20 × 10 mm) was examined to determine the proportion of wood failure and the thickness of the wood layer in the wood failure area. Statistical analysis was based on the single factor ANOVA test, at the confidence level of 95 %.

3. RESULTS AND DISCUSSION

All of the applied treatments have influenced in the loss of wood mass in the range between the 0.67 % do 2.15 % (Figure 1). The loss of wood mass has occurred during both, water and acetic acid treatments as a consequence of the extractives dissolving in reaction mixtures and hydrolysis of the structural wood components, primarily the hemicelluloses (Lu et al, 2003).

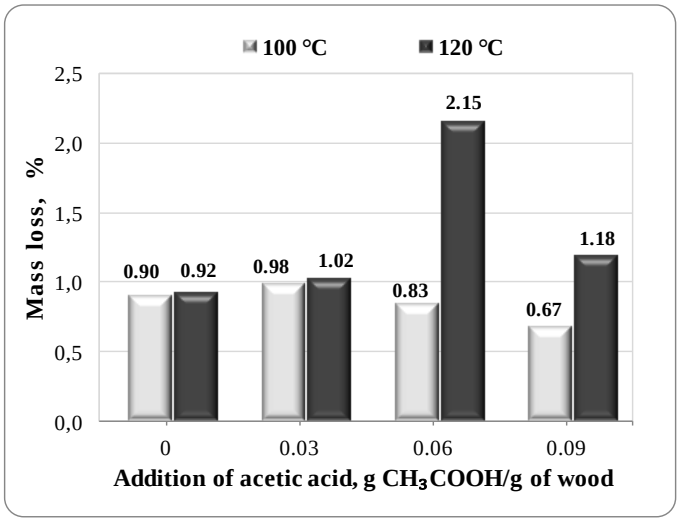

Figure 1. *The mass loss of Narrow-leaved Ash during treatments*

The Figure 1 shows that the mass loss of Narrow-leaved Ash samples during water treatments, for both of the applied treatment temperatures, was approximately the same (0.90 % and 0.92 %).

On the other hand, the treatment temperatures showed different trends of the mass loss of the wood samples treated with the acetic acid. For the treatments at 100 °C, the mass loss of wood has decreased from 0.98 % to 0.67 % with the increase of the acetic acid concentration (Figure 1). This was not expected since the Lu et al (2003) have established that the mass loss of sugi-sapwood, treated during 1 h at the room temperature (25 °C), increases from 1.20 % to 1.97 % with the increase in the acetic acid concentration from 3 % to 30 %. However, by analyzing the intensity changes on the carbonyl peak of the FTIR spectra of beech and pine samples during the hydrothermal treatment,

Tjeerdsma and Militz (2005) found the occurrence of the acetyl groups cleavage during the first step, which results in the formation of certain acids, mostly the acetic acid. During the next treatment step, the reaction of esterification takes place between the present acids and the hydroxyl groups of wood, i.e. lignin (Tjeerdsma and Militz, 2005). On the basis of the results of Tjeerdsma and Militz (2005) it could be expected that the presence of the acetic acid in treatment solutions has brought to the reactions of esterification in the Narrow-leaved Ash samples during the applied treatments. This may explain the lower mass loss at the higher concentrations of the acetic acid solutions. The mass of the Narrow-leaved Ash samples have been decreasing during the treatment due to dissolving and hydrolysis of wood compounds, while the formation of new ester groups has the opposite effect. The rate of such reactions which occurred in the reaction systems simultaneously, was depending on the treatment conditions (temperature and the acetic acid concentration), which resulted in the lowest mass loss of the sample of 0.67 % at the highest addition of acetic acid (0.09 g/g) and at the treatment temperature of 100 ^{o}C.

At the same concentration of acetic acid, the samples treated at the 120 ^{o}C have showed the higher values of the mass loss in regard to the samples treated at 100 ^{o}C. Such results suggest that the reactions of decomposition of compounds in the wood tissue have been more intense at the higher treatment temperature. Accordingly, the highest mass loss of 2.15 % was noticed for the samples treated with the 0.06 g/g of acetic acid at the temperature of 120 ^{o}C.

Having in mind that the treatments has changed the composition of samples, indicated by the mass loss of the treated samples (Figure 1), it could be expected that the adhesion properties of treated Narrow-leaved Ash wood has also been changed.

The Figure 2 shows the values of the shear strength (a) and the wood failure surface (b) of the samples treated with water and with the aqueous solutions of acetic acid (0.03, 0.06 and 0.09 g/g), and for both treatment temperatures (100 ^{o}C and 120 ^{o}C).

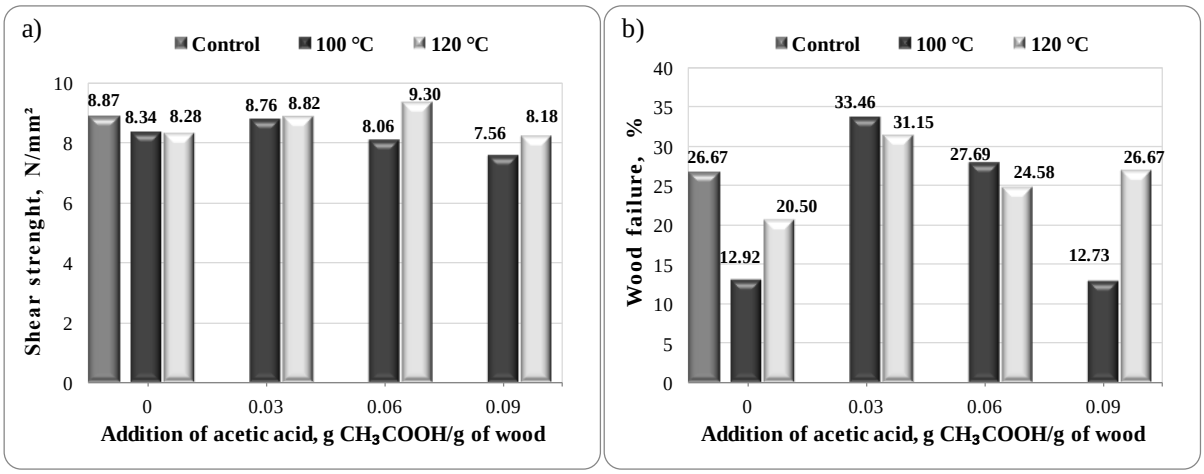

Figure 2. *Shear strength in lap joint (a) and the wood failure surface (b) of the treated and the control Narrow-leaved Ash samples*

The Figure 2 shows that the most of the treated samples had lower shear strength in regard to the control sample group (8,87 N/mm^2). It is interesting to notice that there is a similar trend in behavior of the samples from the aspects of mass loss (Fig. 1) and the shear strength values (Figure 2).

The shear strength values of the samples treated with water at the 100 ^{o}C and 120 ^{o}C (8.34 and 8.28 N/mm^2, respectively) have not been significantly changed in regard to the non-treated samples (Table 1).

The shear strength of the samples treated at 100 ^{o}C has decrease from 8.56 to 7.56 N/mm^2, with the increase in the acetic acid addition from 0.03 to 0.09 g/g. This complies with the assumption that the lower mass loss, occurred at the higher acetic acid addition, is the consequence of the reaction of esterification. Due to the substitution of OH groups with the ester (acetyl) groups, there is a relatively smaller number of the potential sites left for the formation of bonds between the wood and he adhesive (Mirzaei, Mohebby, Tasooji, 2012), which may result in the lower adhesion strength. Acetyl groups

can also form the hydrogen bonds with hydrogen donors, but these bonds are weaker than the bonds formed by the hydroxyl groups (Frihart, 2006).

Table 1. *Statistical comparison of the control and the treated sample groups (ANOVA)*

Treatment temperatures	**100 °C**			**120 °C**		
Between Groups	*F*	*P-value*	*F crit*	*F*	*P-value*	*F crit*
Control/ Water	0.7084	0.4090	4.3009	0.7964	0.3833	4.3808
*Control /0.03 g CH_3COOH /g o.d.w.**	0.0423	0.8390	4.3009	0.0042	0.9490	4.3009
*Control /0.06 g CH_3COOH /g o.d.w.**	1.7351	0.2007	4.2793	0.3064	0.5854	4.3009
*Control /0.09 g CH_3COOH /g o.d.w.**	5.4785**	0.0292	4.3247	0.7755	0.3895	4.3808

** oven dry wood*
***denotes a statistically significant difference at the confidence level of 95 %*

In comparison to the control sample group, the most of the shear strength values of the samples treated with the acetic acid solutions have not be changed significantly (Table 1). The exception is the sample group treated with the acetic acid addition of 0.09 g/g at the temperature of 100 °C, having the significantly lower shear strength (7.56 N/mm^2) in regard to the control sample group (Table 1), but also in regard to the other treated sample groups. The same sample group showed the lowest mass loss of 0.67 % (Figure 1).

The samples treated at the 120 °C have also shown a decreasing trend in the shear strength values with the increase in the acetic acid addition. The exception is the sample group treated with 0.06 g/g of acetic acid, which resulted in the highest shear strength value of 9.30 N/mm^2. Having in mind that the same samples also had the highest mass loss during treatment (2.15 %) it could be assumed that their porosity and permeability have been increased in regard to the other sample groups. This could improve the adhesive penetration into the wood tissue and could increase the ratio of the mechanical adhesion in these samples, leading to an increased adhesive bond strength which has resulted in the higher shear strength values.

In comparison to the control samples, the wood failure surface (Figure 2b) has been decreased more considerably for the samples treated with water (12.92 %) and with acetic acid addition of 0.09 g/g (12.73 %) at the treatment temperature of 100 °C.

4. CONCLUSIONS

The mass loss of treated samples ranges from 0.67 % to 2.15 %. The decrease in the mass loss with the increase of the acetic acid concentration at the treatment temperature of 100 °C can be explained by the occurrence of the reactions of esterification, during which the rate of these reactions increases with the increase of the treatment concentrations of the acetic acid solution.

The shear strength of the treated wood samples has not been significantly changed in regard to the control samples and also follows the trend of the mass loss values. The exceptions is the sample group with the lowest mass loss of 0.67 %, treated with the acetic acid solution of 0.09 g/g and at the treatment temperature of 100 °C. Its shear strength (7.56 N/mm^2) was the lowest in comparison to both the control sample group and the other treated sample groups. The same sample group has the wood failure surface of 12.73 %, which was two times lower in comparison to the control samples.

It could be concluded that the water treatments and the acetic acid treatments at 100 °C and 120 °C have not shown the significant effects on the formation of the adhesive bond between the treated samples and the UF adhesive. Hence, there should be no major problems for the application of such treatments in the production of wood based composite materials.

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The Authors' Addresses:

B.Sc. Jasmina Popović
Assistant, University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: jasmina.popovic@sfb.bg.ac.rs

Prof. Dr.Sc. Milanka Djiporović-Momčilović
Full Professor, University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: milanka.djiporovic@sfb.bg.ac.rs

D.Sc. Mladjan Popović
Assistant Professor, University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: mladjan.popovic@sfb.bg.ac.rs

D.Sc. Ivana Gavrilović-Grmuša
Assistant Professor , University of Belgrade,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: ivana.grmusa@sfb.bg.ac.rs

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INVESTIGATION OF THE FORCED TORSIONAL VIBRATIONS IN THE SAW UNIT OF A KIND OF CIRCULAR SAWS. PART I: MECHANIC-MATHEMATICAL MODEL

Georgi Vukov[1], Zhivko Gochev[2], Valentin Slavov[3]

[1,2] University of Forestry in Sofia, R. Bulgaria, Faculty of Forest Industry,
[3] University of Chemical Technology and Metallurgy in Sofia, R. Bulgaria.
Department of Physics-Mathematical and Technical Sciences
e-mail: georgiv@abv.bg; zhivkog@yahoo.com; valslav@abv.bg

ABSTRACT

Investigation of the forced torsional vibrations in the saw unit of a kind of circular saws. Part I: Mechanic-mathematical model. A model for investigation of the forced torsional vibrations of the circular’s saw unit is presented in this study. The mechanic-mathematical model for investigation of the torsional vibrations of this kind of a circular saw, developed by the authors, allows lots of simulative studies. The model presents features in the construction and operation of the circular machines. This model takes into account the characteristics of the interaction between the cutting tool and work piece. The model also gives possibilities for modeling and analysis of the effects of a number of defects. The results of the investigation can be used as a base for making some recommendations concerning the increase of reliability of the circular machines as well as the accuracy and quality of their production. Numerical investigations and analysis of the survey results is the subject of the next part of this work.

Key words: circular saws, modeling, torsional vibrations

1. INTRODUCTION

One of the main tasks, imposed by the modern wood engineering practice, is conducting reasonable steps to reduce the level of vibration and noise accompanying the work of contemporary circular machines. This task is determined by the increasingly high demands on the parameters of the equipment for the wood industry. The discovery of the causes and the level rise of vibration and noise demand understanding the essence of phenomena which are specific to a particular machine and its individual elements. This requires studies where the machine can be considered as a mechanical vibration system with some known characteristics (Amirouchef F., 2006, Veits V. at al., 1971).

The main aim is to reduce the level of vibration and noise. This aim requires the formulation of specific measures and ways to influence the vibration system. This in turn demands the introduction of specific requirements for the construction and operation of its elements. The mechanical-mathematical modeling of the machine is very important to achieve this aim (Coutinho M., 2001). The compilation and analysis of the equations describing the vibration of the elements of the circular machine are of a particular interest. Some research as well as some recommendations to the construction and its operation can be made on the base of these equations.

The proposed work presents a study of the forced torsional vibrations in a class of circular machines, widely used in practice (Filipov G., 1977, Obreshkov P., 1996). Figure 1 shows a circular machine and a scheme of this circular machine. The electric motor is presented by 1, 2 is the belt drive, 3 – the work table, 4 – the main shaft, 5 – the machine’s body, 6 – the carriage, 7 – the treated detail, 8 – the circular saw with the flanges and the nut of the main shaft.

Figure 2 shows the unit saw of the circular machine which is investigated in this study.

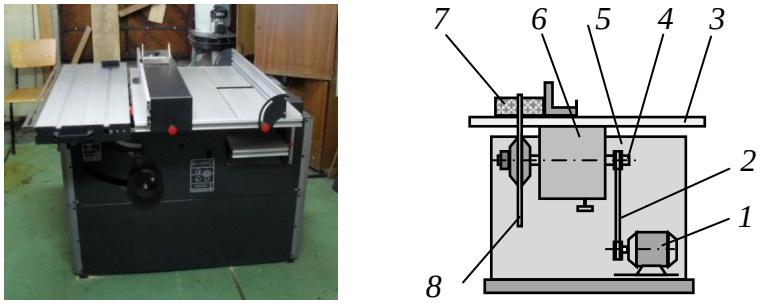

Figure 1. *Circular Machine*
1 – Electric Motor, 2 – Belt Gear, 3 – Work Table, 4 – Main Shaft,
5 – Machine's Body, 6 – Carriage, 7 – Treated Detail, 8 – Circular Saw.

Figure 2. *Unit saw of the circular machine*

The special features in the modeling of circular machines are examined in some previous work of the authors (VUKOV *at al.*, 2010, 2012). It is made some numerical investigations of the natural frequencies and mode shapes of the circular's saw unit. Some based recommendations for the avoidance of resonant regimes are formed on the basis of this study. It is connected with the increase of reliability of the machine as well as with the accuracy and quality of the production.

2. MECHANIC-MATHEMATICAL MODEL

An original mechanic-mathematical model for investigation of the dynamical processes and vibrations in the saw unit of a kind of circular saws is built. It is shown on the Figure 3. This model includes four discrete mass connected with three massless elastic elements. φ_i, $i = 1, 2, 3, 4$ are the angles of the rotation of the corresponding rotor. The elasticity coefficients of the electric motor's shaft, the belt and the main shaft are taken into account. The elasticity angular coefficient of the electric motor's shaft is marked with c_1, and this one of the main shaft – with c_3 (*N.m/rad*). The elasticity linear coefficients of the two parts of the belt between the belt puller are c_{23} and c_{32} (*N/m*). The damping coefficients are marked with *b* and respective indices. The applied moments M_i on the disks are shown too.

The others symbols marked on Figure 3 are:

d_1, d_3 – diameters of the electric motor's shaft and main shaft (m);

l_1, l_3 – computing length of the electric motor's shaft and main shaft (m);

r_2, r_3 – radius of the belt pullers on the electric motor's shaft and main shaft (m);

G – modulus of shearing.

The reduced mass inertia moments ($kg \cdot m^2$) render in account:

J_1 – the mass inertia moment of the electric motor's rotor;

J_2 – the mass inertia moment of the belt puller on the electric motor's shaft;

J_3 – the mass inertia moment of the belt puller on the main shaft;

J_4 – the mass inertia moment of the circular saw.

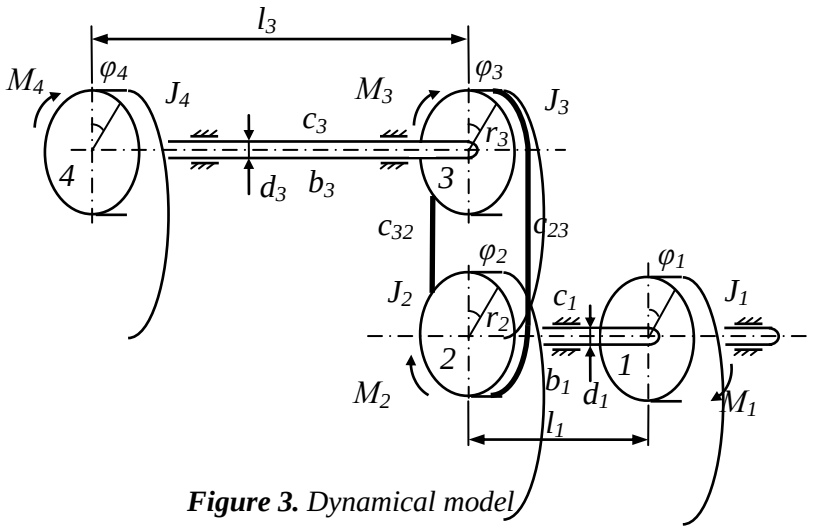

Figure 3. *Dynamical model*

The investigation of the vibrations of the circular's unit saw requires formulation and solution of the differential equations which describe these processes. Therefore, it is used the matrix mechanics (Angelov I., Slavov V., 2010)

The mechanic-mathematical model is done by using the applied engineer program (Mathematica). It is developed an algorithm for formulation of the matrixes which describe the mass-inertial properties and the elastic properties of the mechanical system. The differential equations which describe the free vibrations are deduced by using the Lagrange's method.

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right)-\frac{\partial T}{\partial q}=-\frac{\partial L}{\partial q}-\frac{\partial F}{\partial \dot{q}}+Q, \tag{1}$$

where q_i are the generalized coordinates, T and L are respectively the kinetic and the potential energy of the multibody systems, F is dissipative function, Q is the vector of the generalized forces.

The vector of the generalized coordinates is

$$\mathbf{q}=\left[\varphi_1 \quad \varphi_2 \quad \varphi_3 \quad \varphi_4\right]^T. \tag{2}$$

The kinetic energy of the mechanical system is obtained as a sum of the kinetic energy of the four basic bodies (the electric motor's rotor, the belt puller on the electric motor's shaft, the belt puller on the main shaft, circular saw)

$$T=\frac{1}{2}I_1.\dot{\varphi}_1{}^2+\frac{1}{2}I_2.\dot{\varphi}_2{}^2+\frac{1}{2}I_3.\dot{\varphi}_3{}^2+\frac{1}{2}I_4.\dot{\varphi}_4{}^2. \tag{3}$$

The potential energy of the mechanical system is obtained as a sum of the potential energies received from the deformations of the electric motor's shaft, the belt and the main shaft

$$\begin{aligned}L=&\frac{1}{2}c_1.(\varphi_1-\varphi_2)^2+\frac{1}{2}c_{23}.(r_2.\varphi_2-r_3.\varphi_3)^2+\\&+\frac{1}{2}c_{32}.(r_3.\varphi_3-r_2.\varphi_2)^2+\frac{1}{2}c_3.(\varphi_3-\varphi_4)^2\end{aligned}. \tag{4}$$

The dissipative function is

$$F = \frac{1}{2} b_1 . (\dot{\varphi}_1 - \dot{\varphi}_2)^2 + \frac{1}{2} b_{23} . (r_2 . \dot{\varphi}_2 - r_3 . \dot{\varphi}_3)^2 + \\ + \frac{1}{2} b_{32} . (r_3 . \dot{\varphi}_3 - r_2 . \dot{\varphi}_2)^2 + \frac{1}{2} b_3 . (\dot{\varphi}_3 - \dot{\varphi}_4)^2 . \quad (5)$$

The vector of the generalized loads includes all torsional moments, applied on the rotors. It is

$$\mathbf{Q} = \begin{bmatrix} M_1 & -M_2 & -M_3 & -M_4 \end{bmatrix}^T , \quad (6)$$

where:
M_1 is the moment of the electric motor,
M_2 and M_3 – moments of the belt pullers from their interaction with the belt,
M_4 – the concentrated moment of the circular saw, which is formed when the circular machine works.

This method supposes receiving a system of parametric differential equations which describe the forced torsional vibrations of the circular's saw unit. They are

$$\mathbf{M} . \ddot{\mathbf{q}} + \mathbf{B} . \dot{\mathbf{q}} + \mathbf{C} . \mathbf{q} = \mathbf{Q} . \quad (7)$$

The matrix, which characterizes the mass-inertial properties of the mechanical system, is (numerical values are given in $kg.m^2$)

$$\mathbf{M} = \left[a_{ij} \right], \qquad a_{ij} = \frac{\partial^2 T}{\partial \dot{q}_i . \partial \dot{q}_j},$$

$$\mathbf{M} = \begin{bmatrix} J_1 & 0 & 0 & 0 \\ 0 & J_2 & 0 & 0 \\ 0 & 0 & J_3 & 0 \\ 0 & 0 & 0 & J_4 \end{bmatrix} = \begin{bmatrix} 0{,}001018 & 0 & 0 & 0 \\ 0 & 0{,}000018 & 0 & 0 \\ 0 & 0 & 0{,}000003 & 0 \\ 0 & 0 & 0 & 0{,}011325 \end{bmatrix} . \quad (8)$$

The matrix, which characterizes the elastic properties of the mechanical system, is (numerical values are given in $\frac{N.m}{rad}$)

$$\mathbf{C} = \left[c_{ij} \right], \qquad c_{ij} = \frac{\partial^2 L}{\partial q_i . \partial q_j},$$

$$\mathbf{C} = \begin{bmatrix} c_1 & -c_1 & 0 & 0 \\ -c_1 & c_1 + c_{23} . r_2^{\,2} + c_{32} . r_2^{\,2} & -c_{23} . r_2 . r_3 - c_{32} . r_2 . r_3 & 0 \\ 0 & -c_{23} . r_2 . r_3 - c_{32} . r_2 . r_3 & c_3 + c_{23} . r_3^{\,2} + c_{32} . r_3^{\,2} & -c_3 \\ 0 & 0 & -c_3 & c_3 \end{bmatrix} = \quad (9)$$

$$= \begin{bmatrix} 13004{,}7 & -13004{,}7 & 0 & 0 \\ -13004{,}7 & 13311{,}9 & -172{,}8 & 0 \\ 0 & -172{,}8 & 9320{,}36 & -9223{,}16 \\ 0 & 0 & -9223{,}16 & 9223{,}16 \end{bmatrix} .$$

The matrix, which characterizes the damping properties of the mechanical system, is (numerical values are given in $\frac{N.m.s}{rad}$)

$$\mathbf{B} = \left[b_{ij}\right], \qquad b_{ij} = \frac{\partial^2 F}{\partial \dot{q}_i . \partial \dot{q}_j},$$

$$\mathbf{B} = \begin{bmatrix} b_1 & -b_1 & 0 & 0 \\ -b_1 & b_1 + b_{23}.r_2{}^2 + b_{32}.r_2{}^2 & -b_{23}.r_2.r_3 - b_{32}.r_2.r_3 & 0 \\ 0 & -b_{23}.r_2.r_3 - b_{32}.r_2.r_3 & b_3 + b_{23}.r_3{}^2 + b_{32}.r_3{}^2 & -b_3 \\ 0 & 0 & -b_3 & b_3 \end{bmatrix} = \tag{10}$$

$$= \begin{bmatrix} 5 & -5 & 0 & 0 \\ -5 & 5{,}00102 & -0{,}000576 & 0 \\ 0 & -0{,}000576 & 5{,}00032 & -5 \\ 0 & 0 & -5 & 5 \end{bmatrix}.$$

The general solutions of the system of differential equations (7) in the harmonious appearance of disturbing forces and initial conditions $t = 0$, $q(0) = q_0$, $\dot{q}(0) = \dot{q}_0$, written in matrix form are

$$q(t) = \sum_{r=1}^{4} \frac{2}{g_r^2 + h_r^2} [\mathbf{G}_r \mathbf{M} \dot{q}(0) + (-\alpha_r \mathbf{G}_r \mathbf{M} + \beta_r \mathbf{H}_r \mathbf{M} + \mathbf{G}_r \mathbf{B}) q(0)] . e^{-\alpha_r t} . \cos \beta_r t +$$

$$+ \sum_{r=1}^{4} \frac{2}{g_r^2 + h_r^2} [\mathbf{H}_r . \mathbf{M} . \dot{q}(0) + (-\alpha_r . \mathbf{H}_r . \mathbf{M} - \beta_r . \mathbf{G}_r . \mathbf{M} + \mathbf{H}_r . \mathbf{B}) . q(0)] . e^{-\alpha_r t} . \sin \beta_r t + \tag{11}$$

$$+ \mathrm{Re}\{ \sum_{k=0}^{n} \sum_{r=1}^{4} \frac{2}{g_r^2 + h_r^2} \frac{\alpha_r . \mathbf{G}_r + \beta_r . \mathbf{H}_r + i.k.\Omega . \mathbf{G}_r}{\omega_r^2 - k^2 . \Omega^2 + i.2.k.\sigma_r . \omega_r . \Omega} \mathbf{Q} . e^{ik\Omega t} \}$$

where:
M, B and C are respectivly the matrix of the mass-inertial, damping and elastic properties of the mechanical system,
Q – vector of the generalized loads,

$$g_r = -2\alpha_r \left(\mathbf{V}_r^T . \mathbf{M} . \mathbf{V}_r - \mathbf{W}_r^T . \mathbf{M} . \mathbf{W}_r \right) - 4\beta_r \mathbf{V}_r^T . \mathbf{M} . \mathbf{W}_r + \mathbf{V}_r^T . \mathbf{B} . \mathbf{V}_r - \mathbf{W}_r^T . \mathbf{B} . \mathbf{W}_r ;$$

$$h_r = 2\beta_r \left(\mathbf{V}_r^T . \mathbf{M} . \mathbf{V}_r - \mathbf{W}_r^T . \mathbf{M} . \mathbf{W}_r \right) - 4\alpha_r \mathbf{V}_r^T . \mathbf{M} . \mathbf{W}_r + 2\mathbf{V}_r^T . \mathbf{B} . \mathbf{W}_r ;$$

$$\mathbf{G}_r = g_r \mathbf{L}_r + h_r \mathbf{R}_r ; \quad \mathbf{L}_r = \mathbf{V}_r . \mathbf{V}_r^T - \mathbf{W}_r . \mathbf{W}_r^T ;$$

$$\mathbf{H}_r = h_r \mathbf{L}_r - g_r \mathbf{R}_r ; \quad \mathbf{R}_r = \mathbf{V}_r . \mathbf{W}_r^T + \mathbf{W}_r . \mathbf{V}_r^T .$$

V – modal matrix,

W – the matrix of the imaginary part of the natural vectors of the damping system,

$p_r = -\alpha_r \pm i\beta_r$ – natural values,

$u_r = v_r \pm i w_r$ – natural vectors,

$\alpha_r = \sigma_r . \omega_r \quad ; \quad \beta_r = \omega_r \sqrt{1 - \sigma_r^2}$,

σ_r – relative damping coefficient,

α_r – damping coefficient,

β_r – frequency of free damping vibration,

w_r – the imaginary part of the natural vector caused by dampening system,

v_r , ω_r – natural modes and natural frequencies of the non damping system.

As a result, a system of differential equations describing the torsional vibrations of the studied mechanical system is derived by using the proposed method.

3. CONCLUSIONS

The work presents an original mechanical mathematical model of class circular machines for testing the vibration behavior of this type of machines. The model allows conducting a number of simulation studies. These studies examine the modeling and analyzing the work of the machine in different operating regimes. The model allows investigating the passing dynamic processes, seeking and analyzing the causes of high-level vibration and noise. An additional possibility is to model and study the effects of a number of arisen defects. The numerical investigations and analysis of the survey results are presented in the next part of this work.

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The Authors' Addresses:

University of Forestry, Faculty of Forest Industry,
10 Kl.Ohridski Blvd., 1756 Sofia, BULGARIA

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INVESTIGATION OF THE FORCED TORSIONAL VIBRATIONS IN THE SAW UNIT OF A KIND OF CIRCULAR SAWS. PART II: NUMERICAL INVESTIGATIONS

Georgi Vukov[1], Zhivko Gochev[2], Valentin Slavov[3]

[1,2] University of Forestry in Sofia, R. Bulgaria, Faculty of Forest Industry,
[3] University of Chemical Technology and Metallurgy in Sofia, R. Bulgaria.
Department of Physics-Mathematical and Technical Sciences
e-mail: georgiv@abv.bg; zhivkog@yahoo.com; valslav@abv.bg

ABSTRACT

Investigation of the forced torsional vibrations in the saw unit of a kind of circular saws. Part II: Numerical investigations. The proposed study presents a numerical investigation of the forced torsional vibrations in the saw unit of a class of circular machines. The investigation is done on the base of the authors developed adequate mechanic – mathematical model for the examination of torsional vibrations of this class of a circular machine. The model is given in the first part of the proposed study. The natural frequencies and mode shapes of the studied saw unit are determined. The free damped vibrations of the mechanism are investigated and analyzed. Some investigations of the forced vibrations of the cutting mechanism, due to the presence of defects in the drive electric motor, are conducted. The amplitude-frequency characteristics of the system are obtained. The results of the study can be considered as a basis for the formation of specific recommendations. These recommendations aim improving the reliability of the machine and the accuracy and quality of the production process. The results are important for the vibrocontrol of circular machines and they are of unquestionable benefit in conducting vibration analysis of the system.
Key words: circular saws, modeling, torsional vibrations

2. INTRODUCTION

The first part of the proposed work presents an original mechanical mathematical model of a class of circular machines for testing the vibration behavior of the saw unit of this type of machinery. It is possible to conduct a number of simulation studies using this model. The aim of simulation studies is to model and analyze the performance of the circular’s saw unit of the machine, taking into account all the peculiarities of its construction. The model allows investigating the running dynamic processes, seeking and analyzing the causes of high-level vibration and noise. The researches in this direction are associated with the rapid development of vibration analysis and control of the machines. Therefore, it is imposed additional, in-depth studies of the vibration behavior of the machine both in normal operation and in the occurrence and development of a wide range of faults. The discovery of the causes for rising and increasing the vibration and noise level requires understanding the essence of phenomena which are specific to a particular machine and its individual components (Amirouche F., 2006, Veits V. at al., 1971). This demands studies in which the machine can be considered as a mechanical vibrating system with known characteristics (Vukov at al., 2010, 2012). The approaches and methods of the theory of vibrations are used in the study.

3. RESEARCH OBJECTIVE

This part of the proposed work shows methodological succession and results of numerical studies of torsional vibrations in the saw unit of a class of circular machines. First, it is determined the natural

frequencies and the mode shapes of this mechanical system. Then it is examined and analyzed the free damped vibrations of the mechanism. The researches continue with the investigation of the forced vibrations of the saw unit due to the presence of a fault in the drive electric motor. The amplitude-frequency characteristics are plotted too. Some conclusions and based recommendations are formed on the base of the obtained results. They aim to improve the machine's work and make the organization of its vibrocontrol easier.

The elements of the circular's saw unit are modeled in this study by using the applied engineer program Solid Works. The mass, elastic and geometrical characteristics of the circular's elements are shown in the Table 1.

Table 1. *Machine data*

J_1 – inertia moment of the electric motor's rotor (kg·m^2)	0, 001018
J_2 – inertia moment of the belt puller *2* (kg·m^2)	0, 000018
J_3 – inertia moment of the belt puller *3* (kg·m^2)	0, 000003
J_4 – inertia moment of the circular saw	0, 011325
c_1 – stiffness of the electric motor's shaft (Nm/rad)	13004, 7·
c_2 – stiffness of the main shaft (Nm/rad)	9223,16
c_{23} – stiffness of the belt (N/m)	$6.\cdot 10^5$
c_{32} – stiffness of the belt (N/m)	$6.\cdot 10^5$
d_1 – diameter of the electric motor's shaft (mm)	17
d_3 – diameter of the main shaft (mm)	17
r_2 – radius of the belt puller *2* (mm)	16
r_3 – radius of the belt puller *3* (mm)	9
l_1 – distance between the belt puller *2* and the electric motor (mm)	50
l_3 – distance between the circular saw and the belt puller *3* (mm)	70,5
M_1 – moment of the electric motor (N.m)	8,5
M_{11} – additional moment of the electric motor (N.m)	4
M_{12} – additional moment of the electric motor (N.m)	4
M_2 – moment of the belt puller *2* (N.m)	0,2
M_3 – moment of the belt puller *3* (N.m)	0,15
M_4 – moment of the circular saw (N.m)	3,03
G – modulus of shearing (Pa)	$7,93.10^{10}$
Ω – frequency of rotation (s^{-1})	46,82

The calculations are done with help of the applied engineer program Mathematica. The natural frequencies [s^{-1}] (and in [min^{-1}]) are

55747,9, 27419, 543,377, 0 (532353; 261832; 5188,86; 0).

A vector of mode shapes $\mathbf{v_r}$ corresponds to each own frequency ω_r . This vector sets the ratio between the amplitudes of the vibrations (Angelov I., Slavov V., 2010). The components of the vectors define the matrix of mode vectors (modal matrix). This matrix for the system under consideration is

$$\begin{bmatrix} -0{,}000016751\,9 & 0{,}00405865 & -0{,}999992 & 0{,}000262117 \\ 0{,}0172781 & -0{,}999553 & -0{,}0244133 & 0{,}000026474\,9 \\ 0{,}714645 & 0{,}698128 & -0{,}0234281 & -0{,}0367525 \\ 0{,}346667 & 0{,}346667 & 0{,}616297 & 0{,}616297 \end{bmatrix}.$$

The obtained results are graphically illustrated in Figures 1, 2, 3 and 4. The figure shows the relative amplitudes of vibration of the different natural frequencies in the respective generalized coordinates

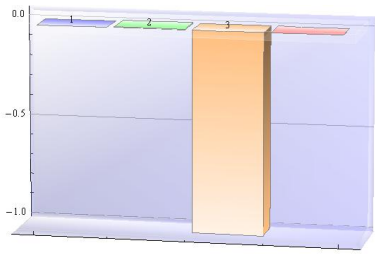

Figure 1

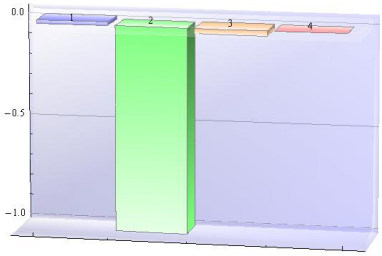

Figure 2

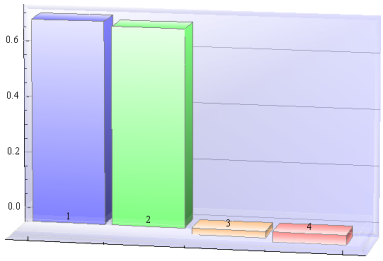

Figure 3

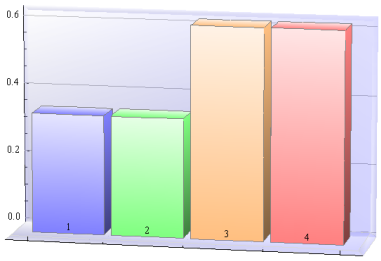

Figure 4

4. FREE DAMPED VIBRATIONS

Some investigations of free damped vibrations of a circular saw unit are done on the base of the developed mechanical mathematical model. The damping properties of the elements of the mechanism are noticed in the first part of the study. The results are illustrated in Figures 5, 6, 7 and 8. These figures show the graphs illustrating the damping vibrations of the individual elements of the mechanism – the rotor of the electric motor, the two belt pulleys and the circular saw.

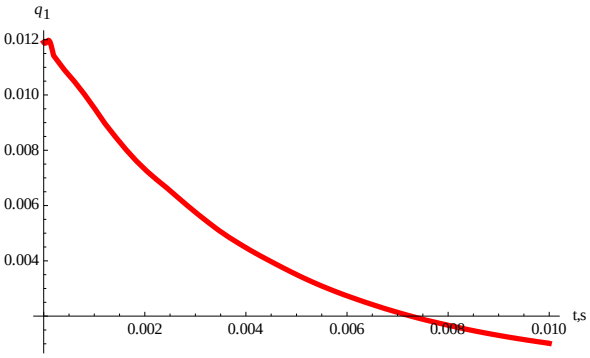

Figure 5

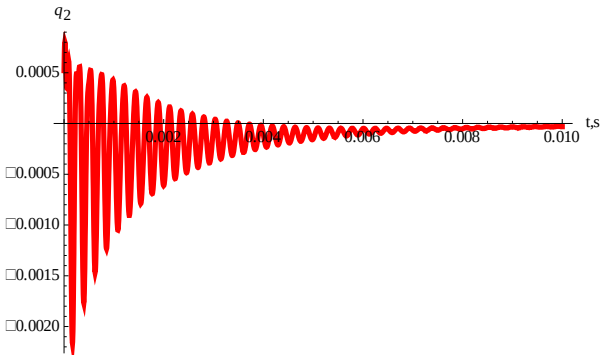

Figure 6

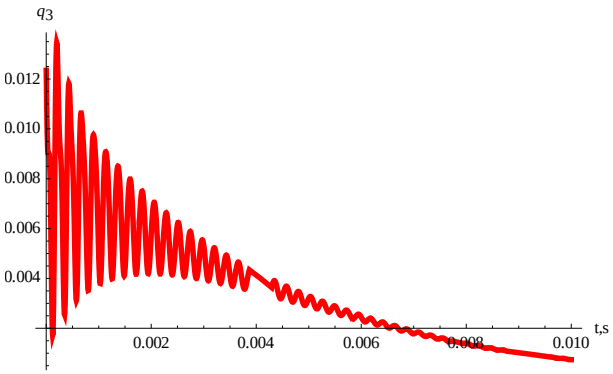

Figure 7

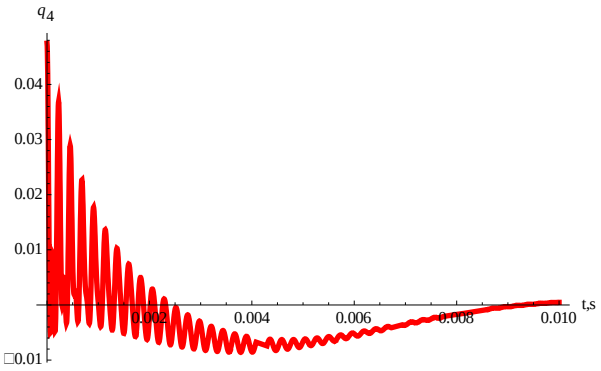

Figure 8

Figures show relatively rapid damping for all elements of the mechanism. Analysis of the resultant graph shows that the rotor of the electric motor performs damping non periodic motion. The motions of the two belt pulleys and the circular saw is damping periodic. Moreover, exactly the circular saw has the highest level of vibrations and it takes its equilibrium position the most slowly.

5. FORCED VIBRATIONS

The forced vibrations of a circular saw unit are investigated by using the developed mechanical mathematical model. Forced vibrations due to the presence of a fault in the drive electric motor are studied. It is known (Stevens D., 2007) that the deviation of the correct shape of the stator and the unbalance of the rotor lead to the occurrence of a variable air space e between the rotor and the stator during operation of the electric motor. The uniformity of rotation is disturbed as a result of these faults. Thus poliharmonic torsional vibrations and radial vibrations are raised. However, the greatest amplitude has the harmonic with frequency equal to the frequency of rotation, and the harmonic with frequency equal to doubled frequency of rotation. This fact is render in account in the study and two components that have the type $M_{11}sin\Omega t$ and $M_{12}sin2\Omega t$ are added to the electric motor moment M_1. The concentrated moment on circular saw M_4, which is formed during the work of machine, is also accounted. Similarly it is taken into consideration the moments M_2 and M_3 on pulleys from their interaction with the belt. The results are illustrated in Figures 9, 10, 11 and 12. These figures show the graphs of the forced vibrations of the individual elements of the mechanism.

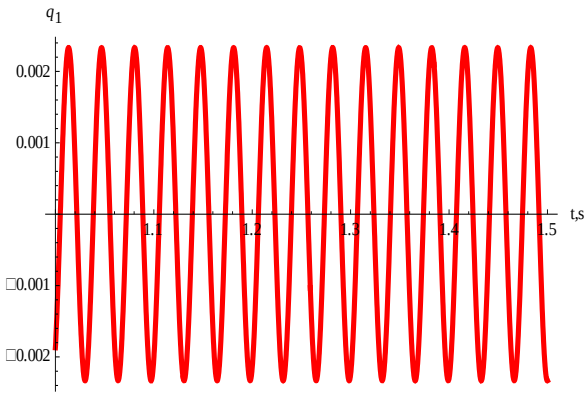

Figure 9

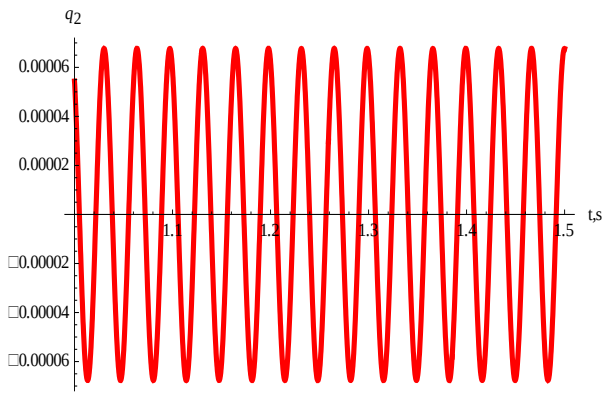

Figure 10

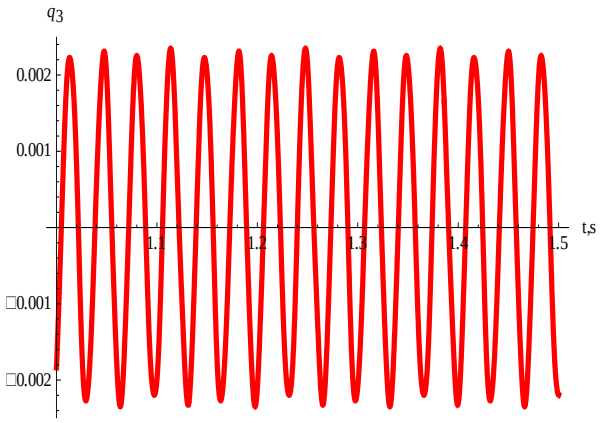

Figure 11

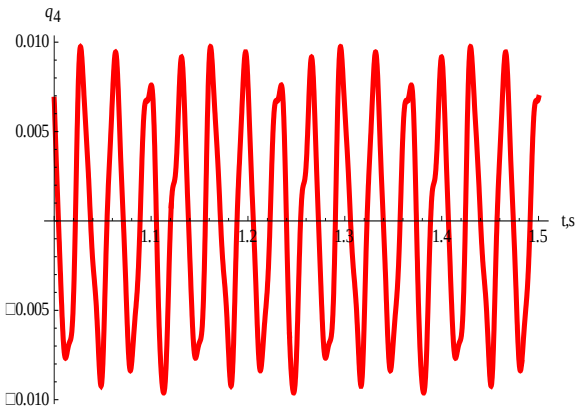

Figure 12

Some conclusions are imposed from the above figures. The amplitudes of forced vibrations of the rotor of the electric motor and belt pulley 3 are of the same order, but there are additional harmonics of the vibrations of pulley 3. The amplitudes of forced vibrations of the belt pulley 2 are much smaller than those of the other elements. The biggest amplitudes of forced vibrations are of a circular saw.

However, those vibrations are poliharmonic. Analysis of the results shows that the great influence of the examined type of vibrations is on the circular saw. This inevitably affects the quality and accuracy of the proceeding product. The recommendation for monitoring the technical status of the drive electric motor to ensure product quality is imposed.

6. AMPLITUDE FREQUENCY CHARACTERISTICS

The mechanic – mathematical model built and developed by the authors allows obtaining the amplitude-frequency characteristics of the saw unit of a circular machine. These characteristics are made and are shown in Figures 13, 14, 15 and 16.

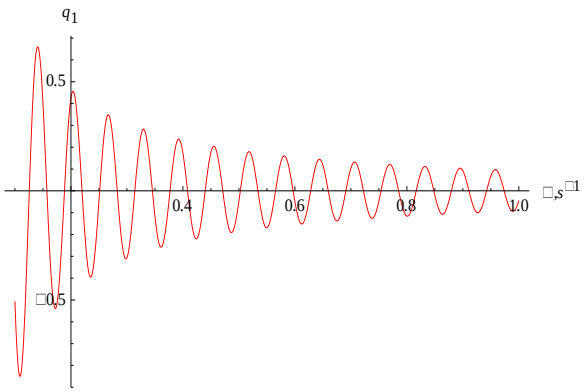

Figure 13

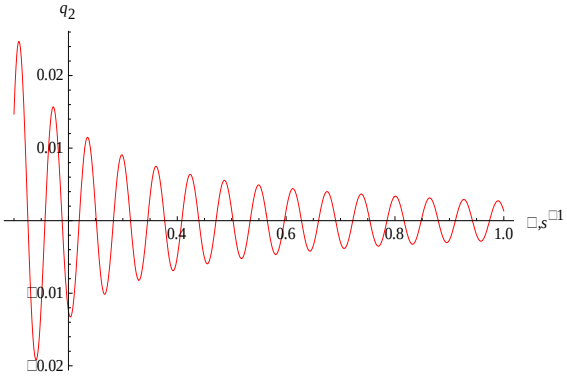

Figure 14

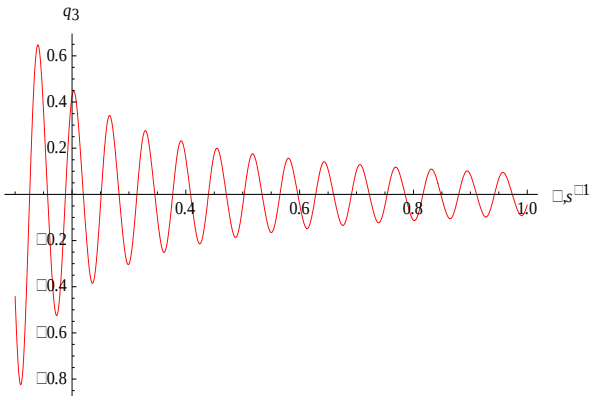

Figure 15

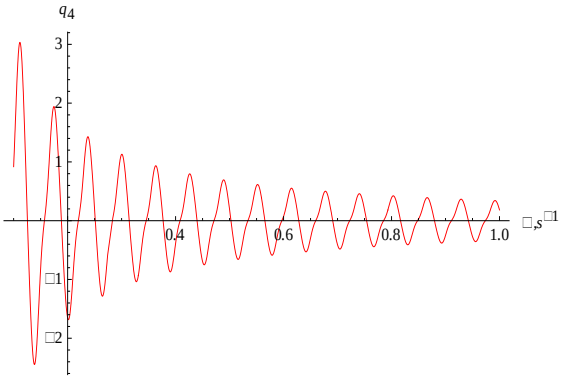

Figure 16

The obtained graphs clearly show that there are torsional vibrations with large amplitudes in the transient regimes attached to starting and stopping of the machine. These amplitudes are strongly reduced at approaching the range of the angular work speed of the machine. This confirms the importance of rapid passing of the transient regimes for the limiting of the machine’s work at high-level vibration and noise.

7. CONCLUSIONS

The study presents the results of the implementation of numerical investigations with original mechanical mathematical model of the saw unit of the circular machine. The vibration behavior of the saw unit is studied. Its natural frequencies and mode shapes are determined. The free damped vibrations of the mechanism are investigated and analyzed. The researches continue with the investigation of the forced vibrations of the saw unit due to the presence of a fault in the drive electric

motor. The amplitude-frequency characteristics are plotted too. All obtained results make it possible to analyze the dynamic processes in the machine. This analysis is the base for the formation of specific recommendations aimed at improving the reliability of the machine, as well as the accuracy and quality of the production. The results of this study have a purpose and they are especially useful for conducting a vibration control of the circular machines.

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The Authors' Addresses:

University of Forestry,
Faculty of Forest Industry,
10 Kl.Ohridski Blvd., 1756 Sofia, BULGARIA

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THE SUCCESSFULNESS OF SAWMILLING SMALL-SIZED ROUNDWOOD IN CROATIAPART I - SWEET CHESTNUT (*CASTANEA SATIVA* MILL.)

Josip Ištvanić, Alan Antonović, Krešimir Greger

University of Zagreb, Republic of Croatia
Wood Technology Department, Faculty of Forestry,
e-mail: jistvanic@sumfak.hr; aantonovic@sumfak.hr; kgreger@sumfak.hr

ABSTRACT

This research is focused on small-sized roundwood yield factors of Sweet Chestnut (*Castanea sativa* Mill.). 60 piecess Small-Sized Roundwood were classified in groups according to diameter 15 to 24 cm and sawed by live sawing technique into unedged sawn boards with nominal thickness of 25 mm. All sawn boards were processed into dimension stocks and raw parquet staves by rip-cross sawing.

Volume yield of the Small-Sized Roundwood processing into dimension stocks and raw parquet staves was in the range 16.7 % to 41.4 %.

Quality yield coefficient of the roundwood processing into dimension stocks and raw parquet staves was in the range of 0.34977 to 0.87923 or 255.33 EUR/m^3 to 641.84 EUR/m^3 of dimension stocks and raw parquet staves. Log value yield coefficient was in the range 0.06950 to 0.17253 or 50.74 EUR/m^3 to 245.15 EUR/m^3 of the Small-Sized Roundwood.

The results indicate a possibility of rational processing of the researched Sweet Chestnut Small-Sized Roundwood in sawmills.

Key words: Sweet Chestnut (*Castanea sativa* Mill.), low quality and small-sized roundwood, sawmilling production, dimension stock, raw parquet staves, log volume yield, quality yield, log value yield

1. INTRODUCTION

Sustainable lack of standard sawmilling logs makes sawmills fully utilize their capacities by processing round wood of smaller dimensions, so called small diameter roundwood. In such sawmill raw material diameter dimensions are smaller than prescribed by the norm, as well as the quality. The diameters of small diameter roundwood amounts from 15 to 24 cm and length is 2 m and over.

In addition to small diameter roundwood as a feedstock a high-quality stacked wood in the form of roundwood or split wood can be classified (pitt wood, pulpwood, fuelwood and wood for chopped board wood panels). However, this kind of raw material is rarely used in large industrial sawmills due to their small dimensions and shapes and special sawmill technological base, and profitability of such problematic sawmill processing (Ištvanić 2003).

In one of the first studies on small wood in industrial manufacture in this region authors (Janković et al. 1964) have first attempted to clarify the concept and definition of round wood of small dimensions in our setting. As one of the important characteristics of this wood is considered to be:

- that it is produced in the forest,
- that they are of small size and irregular shape,
- that the assortments of this group have high cost of cutting and transport in relation to their commercial value.

As a source of supply with such round timber the following come into account: coppice and scrub forest; young stand which are obtained by cleaning and thinning described wood; old stand where during the cutting of old and large trees, tree branches and top trees are obtained; stands from poor habitats on the border of forest vegetation where trees do not reach large dimensions, and all stands where small sized wood is obtained by regular cutting as the excess in making normal technical forestry products.

Deciduous wood with diameter less than 7 cm represents an extremely small material with high operating costs, and as such represents a special category of small dimension wood among deciduous wood. It can be used primarily in the production of cellulose and chipped wood boards, and more recently as a raw material for the exploitation of wood chips, which is used in power plants for the production of heat and electricity.

Deciduous wood with diameter of 7-14 cm has lower operating costs than the wood with diameter less than 7 cm, and more than wood with diameter of 15 to 25 cm. This wood is mainly used for cellulose, chipped wood boards, however it can be used for mechanical processing by sawing.

Deciduous wood with diameter of 15-25 cm as small dimension wood has relatively low operating costs, and can be used in addition to the already mentioned in the first two categories in mechanical treatment by sawing, cutting and stay log peeling. Often this group of round wood is 1 m long. This is justified by irregular axial form of roundwood or large curvature, and a smaller length gives larger logs straightness or suitability for mechanical processing of wood. The length can be greater for the purpose of rationalization of forest exploitation.

Brežnjak et al. (1978) state that logs of small dimensions are arriving as a feedstock to the sawmills around the world, and they will arrive even more in the future. Due to our circumstances, small roundwood can be defined as roundwood that cannot be economically processed on standard lines for larger diameter logs or by methods and technology applied for such logs. The quality of sawn wood obtained from small-diameter roundwood (younger trees) due to higher content of juvenile wood is worse than the quality of sawn boards obtained from logs of larger diameters. It seems that the smaller diameter logs of deciduous trees can economically be used (with regard to other conditions) to produce sawn board for packaging, palette material, raw parquet staves and furniture components. Characteristics of technology on which such raw materials could be cost-effective processed should be: great effect, narrow saw kerf, high sawing accuracy, great finesse of the sawn surface, complex integral raw yield and small investment. One of the important features for economical processing is a sufficient quantity of raw material for the utilization of one product line capacity.

By analysing the problem of processing such sawmill raw material of coniferous and broadleaved trees, it is understood that it must enable the production of the desired product at least by its dimensions and quality. As essential elements of quality, straightness and a small decrease in log taper are listed. Also it is considered that in sawmill processing volume yield is not crucial and important as it is with standard roundwood.

Nikolić et al. (1977) found that the volume yield in sawmill processing of beech wood of 1 m length in dimension stock and raw parquet staves is around 36 %. There by, the form of split wood has very little effect on increasing the percentage of utilization while larger and more regular forms normally have a higher rate of utilization. Sawing roundwood requires almost 20% more time than the processing of split wood, half logs and quarter of logs due to inappropriate forms of raw materials for processing. Increase of efficiency, performance and rationalisation of production should be sought in the regularity of split wood making and in properly selected dimensions of sawmill products that will be manufactured from such raw materials.

Zubčević (1973, 1983) dealt with the issue of mechanical treatment, that is sawing of so-called non-standard beech roundwood and wood shakes. It is stated that specialised practice of that period implies roundwood of 2-3 m length or more and a diameter less than 20 cm, that is roundwood less than 2 m length and a diameter greater than 20 cm under that term. According to the author, the average volume utilization of small sized beech roundwood of 1 m length and a diameter of 10-25 cm in the preparation of dimension stock and raw parquet staves amounted to 32-51 %. The share of raw parquet staves in sawn wood products from logs of 10-19 cm diameter was 42-72 %. It was found that

with the insured placement of sawmill products, profitability of processing non-standard roundwood and technical split wood depends on:

- dimensions and quality of the raw material in relation to the volume and qualitative yield,
- structure of finished sawmill products,
- choice of primary and secondary machines,
- the choice of the technological process.

Gregić (1969) conducted a study of yield of oak small sized roundwood with 20 to 24 cm diameter and of logs with 30 to 34 cm diameter. Reached volume yield was in the range from 20 to 30% with a large proportion of the raw parquet staves, which was to be expected for this type of sawmill raw material.

This research was complemented by Prka (1973) who examined volume yield and profitability of sawmill processing of oak small sized roundwood with diameter from 16 to 24 cm. Logs were sorted according to quality criteria for I. and II. class sawlogs. Overall, the results of this study showed that the processing of these logs takes place on the verge of profitability primarily because of low productivity, incompatibility of prices sawmill raw materials and products and the incorrect application of (classical) sawmill technology.

Two years later Prka (1975) repeated the research of profitability of sawmill processing of oak small sized roundwood of the same diameter and quality. This time along with raw parquet staves, sawn dimension stock were made. These results showed satisfactory business results in relation to previous research. Reached volume yield of roundwood was 25 to 30 %. It can be concluded that from certain log quality and certain log diameter, only certain sawmill products can be produced, deciding from the standpoint of quality, assortment and dimensions.

Prka (1978) has researched the impact of quality and diameter of oak logs on yield in the production of sawn elements and parquet staves. Saw logs of I, II. and III. class were sawn into three classes of log diameters. It was concluded that volume yield significantly depends on the diameter and class quality of oak logs. The size of log diameter has a greater impact on yield if only the elements are made, and not raw parquet staves. It was found that the value of logs yield increases with increasing of diameter and quality. In addition, better class quality of logs has a greater positive meaning for value recovery, if it is perceived through total production, not only through the production of elements.

Herak (1984) researched sawing oak small sized roundwood of 16 to 24 cm diameter, quality consistent to I. class sawlogs, and achieved volume yield of roundwood of 30 %.

Serrano and Cassens (2000) showed the structure of the volume yield at intended sawmill processing of small diameter roundwood to wood dimension stock for pallets. Where 47 % was used for dimension stock, 15 % was bark, and 14 % sawdust. From total quantity of elements for pallets, 13% were pure quality elements that could be used for production of finger joint boards which would increase the efficiency of production.

Stewart et al. (2004) dealt with the issue of investment in appropriate technologies for processing small diameter roundwood. The simulation model showed that the cost-effectiveness is possible only if it is invested in existing plants.

2. AIM OF RESEARCH

Following global trends, even in the 60s of the twentieth century, the investigation begun which predicted the importance small sized roundwood will have as one form of sawmill raw material in areas like Croatia. At the end of the 70s of the twentieth century, research has resulted in the project at the Faculty of Forestry, University of Zagreb called Rational processing of low-quality roundwood.

Today, the importance of small sized roundwood as raw material for processing at Croatian sawmills is even greater. Exploring new areas of application and placement, and the rationalization of the processing of this raw material in the present conditions is a necessity, because the discrepancy between annual cut possibility in Croatian Forests and Croatian sawmill capacity has been increasing, while at the same time the quality of sawmill raw material and average diameter (dimensions) are declining.

Thanks to these projects of sawmill small sized roundwood processing in the world, but also in Croatian context, there are a lot of written scientific and technical papers. It should be noted that the

local papers were mostly limited to research of the most common tree species in Croatian forests, such as oak and beech.

When we talk about less represented wood species in the Croatian forests then we refer to species whose share in our growing stock is smaller but not negligible, and as such are less processed in sawmills. From deciduous trees we can mention maple, black locust, common maple, elm, hornbeam, alder, willow, common walnut and black walnut, wild cherry, wild pear, olive and sweet chestnut.

The fact is that when manufacturing logs from these wood species certain quantity of roundwood that does not meet the requirements of standards for the sawmill logs in dimensions or quality can be made (and is made); and is most often classified as a form of stacked wood, and as such is used for making chipped wood boards, for pulp or as firewood.

The question of rational use of this wood raw material is extremely complex since it would be necessary to explore all the possibilities of its refinement or processing taking into account all important factors that influence that specific treatment. Evidently, the key factor by which to define the most appropriate use, treatment or processing considering the rationality should be determined. This paper belongs in the field of sawmill wood processing therefore it analysed factors of wood yield as one of the most important that affect the performance of sawmill processing. This certainly does not diminish the importance of other factors, particularly the economic or technological that combined with this research would provide more accurate and comprehensive results suitable for comparison.

Considering that for contemporary semi-final and final wood processing and production of various types of furniture and furniture parts, dimension stock in a complete form of extremely large size are no longer needed, however elements of smaller cross-section and length are suitable, it is likely to create such elements from a part of smaller size roundwood.

Today, we have technology which makes it possible to process almost all kinds of wood no matter what the quality and dimensions are, with a very small portion of human labour, in a very short time and with the appropriate capacity. In doing so, we should always bear in mind that in the time we live in, when we have already largely exhausted natural resources and ruined the ecological balance, we use wood in the most appropriate and optimal way. In such a route relationship it seems to be justified to scientifically explore some of the most important factors of success of small diameter roundwood sawmill processing, which can have a positive direct impact on the rational use of Croatian and overall global wood resources.

In the first part of this research, the aim was to investigate the successfulness of small diameter roundwood sawmill processing of sweet chestnut while processing it in rough dimension stock and raw parquet staves by means of volume yield, qualitative yield and value yield of roundwood.

3. OBJECTS AND METHODS OF RESEARCH

Wood of trade name European sweet chestnut belongs to the botanical species *Castanea sativa* Mill, C. Vesca Gaertn. of the Fagaceae family. European sweet chestnut tree is quite widespread in southern Europe, western Asia and northwest Africa. In Croatia, it is spread in moderate and warmer coastal and continental areas and in isolated areas in the Kvarner region of Istria, in Zagreb mountain, on Zrinska and Petrova Gora and near Karlovac. In our close region it appears in the Konjic, and the Bay of Kotor, Macedonia and Slovenia.

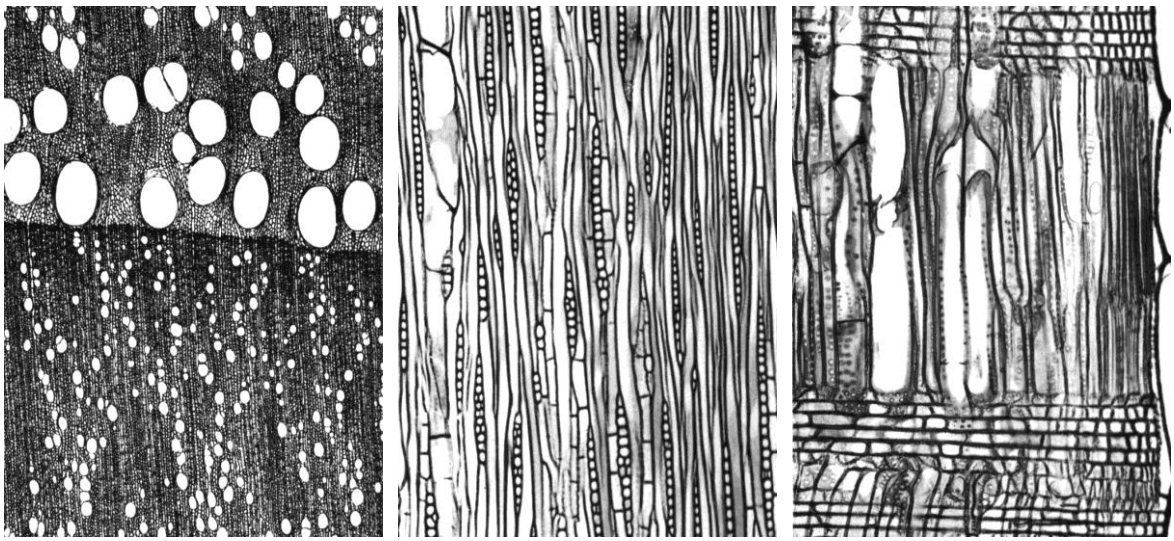
a) *b)* *c)*

Figure 1. *Sweet chestnut (Castanea sativa Mill.): a) leaf and fruit, b)stem, c) bark*

Solitary trees have short stem and low set voluminous crown composed of numerous large branches (as in the common oak). Trees grown in stand are much thinner. The tree is 15 to 30 m high with straight stem 10 to 20 m high. Mean stemwood diameter is 0.6 to 1 m. The bark of the chestnut shoot is smooth, shiny and dark grey.

The bark of young trees is dark olive-brown, streaked with white spots which are derived from lichens. Rhytidome begins to develop on the stems of trees at the age of 15 to 20. It is grey-brown and mostly only longitudinally furrowed. In favourable conditions chestnut tree can live more than 1000 years and achieve large diameters (Figure 1).

Sweet chestnut is heartwood, large ring-porous wood where early wood pores are perfectly visible to the naked eye. Latewood pores are small and fewer in number, arranged in lighter radial strings that are barely visible to the naked eye. The marrow pores are filled with tylosis. Wood rays are only isible under a magnifying glass. Sapwood is grey-white, about 13 mm wide (2 to 5 tree rings). Heartwood is grey yellow, later light to dark brown, exposure to air makes it darker (Figure 2).



a) *b)* *c)*

Figure 2. *Anatomical structure of sweet chestnut (Castanea sativa* Mill.*):*
a) cross section 25x, b) tangential section 60x, c) radial section 120x (Grosser,1977)

Sweet chestnut-wood is of medium density, hardness and strength, faintly flexible and easily splitting. It contains a very high proportion of tannin therefore is used in chemical industry.

Sweet chestnut-wood is easily processed with tools and easily glued. Wet wood in contact with the iron and steel is coloured in black-blue. Drying is good but slow. It is prone to collapsing and casehardening.

Sapwood is poorly durable and susceptible to fungi attack the cause of rot. The core is fairly resistant to fungi but is subject to the action of insects. At the beginning of the 20th century on the chestnut trees in Italy bark cancer was detected, caused by fungus *Endothia parasitica* Anders. The infection was detected in our area a little later, and to this day it has spread almost all over the area where chestnut grows, endangering the survival of this very valuable type of trees. The stems of older trees are often ring shaken. It is very durable in dry and under water. In alternating moisture and dryness it is not very durable. In dirt it lasts for 8 to 12 years. Sweet chestnut-wood is similar to oak-wood by colour, texture and the grain, and at first it can inadvertently be replaced with oak, however, there is no wide strips on sweet chestnut-wood, and there is no silky gloss radial texture as in oak-wood. Because of its similarity to ordinary oak-wood, sweet chestnut-wood of suitable size and quality is used as a substitute for oak-wood where moderate strength is required, e.g. in furniture, especially for the chairs and tables legs, and for the crates. Sweet chestnut-wood is used as construction wood, joinery-wood, shipbuilding wood, railway sleepers, staves, barrels, turned wood and carving wood, pulpwood and tannin wood. A secondary product of chestnut wood are the fruits that serve as food, and flowers that serve as bee pasture (Herman 1971; Petrić, Trajković 1995).

3.1. Small-sized roundwood selection and measurement

For the purposes of the research sweet chestnut roundwood was prepared from the site of the forest teaching-test facility Dotršćina, Faculty of Forestry, University of Zagreb.

While selecting roundwood it was taken into account that it meets the criteria listed in Table 1 in terms of qualitative features. All roundwood was cut to a length of 1 m and classified in class of 15 to 24 cm diameter. A total of 60 pieces of roundwood were sawn (Figure 3).

Table 1. *Classification criteria according to defects on roundwood*

RB	Defects on roundwood	**Feature**
1	Sound or (partially) intergrown or uncovered knots (d < 20 mm) and chinese maustacke	Permitted but placed on mutual minimum distance of 30 cm
2	Sound or (partially) intergrown or uncovered knots (d = 20 to 100 mm) and rose	One permitted
3	Water sprouts and epicormic shoot	Not permitted
4	Unsound and rotten knots	Not permitted
5	Drying check and sun cracks on roundwood ends	Permitted if they are small and contained in the oversized in length
6	Full and traversing cracks, star shake and fissure	Not permitted
7	Sabre or simple sweep	Permitted up to 5 cm in height arch tendon on roundwood length
8	Spiral grain and deflection of wood fibre flow	Not permitted
9	Taper	Permitted up to 10% of the diameter t the thicker end
10	Insect attack	Not permitted
11	Flutig and bark pocket	Permitted up to 2 cm
12	Avality	Permitted
13	Exscentric pith (tension wood)	Not permitted if very distinct
14	Animal damage, bird peck, rind gall, undercut, butt trimming, shear and carbonized wood	Permitted but only in shallow sapwood or in oversize on roundwood length
15	Double pith and fork	Permitted in oversize on roundwood length
16	Ring shake, weather shake, spiders, frost and lightning shake	Not permitted

17	Colour variation or rott in heartwood and sapwood, fustiness and doatyness	Not permitted
18	Double (included) sapwood	Not permitted
19	Cancer, burl, buckle and burr	Not permitted
Wood from which roundwood is made should be freshly cut and healthy. Roundwood can be made from parts of stem or parts of branches that meet the dimensional and qualitative requirements.		

Figure 3. *Sweet chestnut roundwood sample before sawing*

Length and mid diameter were measured to all roundwood in the sample. Descriptive statistics was performed for all analysed variables. These parameters, together with measured quality factors of logs, enabled the implementation of the analysis of the raw material structure for experimental sawing (Table 2).

Table 2. *Descriptive statistics for the dimensions of 15 to 24 cm diameter group sweet chestnut roundwood*

Roundwood size	*15 to 24 cm diameter group*					
	N	Min.	Median	Max.	*Average*	Std. dev.
Length, m	60	1	1	1	1	0,00
Mid diameter, cm	60	15.00	19.50	24.00	18.90	2.35
Volume, m^3	60	0.01766	0.02987	0.04522	0.02847	0.00699

The volume of individual roundwood and overall volume was calculated according to the equation 1

$$V_{log} = \frac{D_{mid}^{\ 2} * \pi}{4} * L_{log} \quad (1)$$

where: V_{log} = volume of roundwood; D_{mid} = mid diameter; L_{log} = length.

3.2. Yield of small-sized roundwood in rough dimension stock production

Roundwood were sawn on log band saw with wheel diameter of 1100 mm. For sawing used 1,2 mm thick saw blade with extending teeth swaging 0,6 mm on each side and 45 mm tooth pitch. Sawing was done using technique of live sawing. Sawn boards of 25 mm nominal thickness were made from the roundwood. Sawn boards thickness was calculated at 22 % moisture content according to conventional formulas (Brežnjak, 1997), and with all other necessary oversize it was 27 mm. All the sawn boards obtained by sawing roundwood were subsequently processed by rip-cross sawing in

rough dimension stock and parquet staves (Figure 4). In doing so, circular saws were used. The amount of sawmill residues was not measured nor is was considered.

Thickness and width of dimension stock and raw parquet staves were calculated according to nominal thickness and width they should have in dry state at 22 % moisture content, corresponding explanation for calculating the thickness of sawn boards. Dimension stock and raw parquet staves of 25 mm nominal thickness that is of 25, 32, 50 and 80 mm nominal width were produced. Thickness, including all necessary oversize, was 27 mm, while the width with all necessary oversize amounted to 27, 35, 55 and 86 mm. The nominal length of elements for all thicknesses and widths ranged between 200, 250, 300, 350, 400, 500, 600, 700, 800, 900 and 1000 mm. Oversize on length was 20 mm. Thickness, width and length were measured on dimension stock and raw parquet staves, and considering the nominal dimensions, volume was calculated.

Classification of dimension stock by quality is carried out according to the criteria commonly used in Croatian sawmills (Prka 1987; Babunović 1992):

- completely pure elements that should be fine and make wood fiber flow, uniform texture and structure (preferably radial board or half radial board), without bumps and cracks, uniform natural colour, without sapwood possibly in oversize. In practice, these elements are classified in class quality I / II,
- elements which have three clean sides with the same characteristics as the previous one, except that it allows the textured flat-sawn board in certain smaller share of the total amount produced for e.g. a customer. With these elements, on the one side usually one defect is allowed such as, healthy knot but not on all pieces. In practice, these elements are classified in class quality I / III,
- elements in which healthy sapwood is allowed, but then these elements are grouped in a special class.

a) *b)*

Figure 4. *a) sawn boards, b) dimension stock and raw parquet staves*

Volume yield of roundwood has been calculated as the ratio of volume of sawn boards produced, that is of dimension stock and raw parquet staves and roundwood volume according to equations 2 and 3. Volume yield of sawn boards has been calculated as the ratio of the volume of dimension stock and raw parquet staves produced and sawn boards volume according to the equation 4.

$$Y_{\text{Volume log}\rightarrow\text{board}} = \frac{V_{\text{board}_1}\cdot N_{\text{board}_1} + V_{\text{board}_2}\cdot N_{\text{board}_2} + \ldots + V_{\text{board}_n}\cdot N_{\text{board}_n}}{V_{\text{log}}} \quad (2)$$

$$Y_{\text{Volume log}\rightarrow\text{dim.stock}} = \frac{V_{\text{d.s.}_1}\cdot N_{\text{d.s.}_1} + V_{\text{d.s.}_2}\cdot N_{\text{d.s.}_2} + \ldots + V_{\text{d.s.}_n}\cdot N_{\text{d.s.}_n}}{V_{\text{log}}} \quad (3)$$

$$Y_{\text{Volume board}\rightarrow\text{dim.stock}} = \frac{V_{\text{d.s.}_1}\cdot N_{\text{d.s.}_1} + V_{\text{d.s.}_2}\cdot N_{\text{d.s.}_2} + \ldots + V_{\text{d.s.}_n}\cdot N_{\text{d.s.}_n}}{V_{\text{board}}} \quad (4)$$

where: $Y_{\text{Volume log}\rightarrow\text{dim.stock}}$ = small-sized roundwood volume yield in form of dimension stocks and raw parquet staves; $Y_{\text{Volume log}\rightarrow\text{board}}$ = small-sized roundwood volume yield in form of sawn board; $Y_{\text{Volume board}\rightarrow\text{dim.stock}}$ = sawn board volume yield in form of dimension stocks and raw parquet staves; $V_{\text{board 1…n}}$ = single sawn board volume; $V_{\text{d.s. 1…n}}$ = single dimension stocks and raw parquet staves volume; $N_{\text{board 1…n}}$ = number of sawn boards of the same volume; $N_{\text{d.s. 1…n}}$ = number of dimension stocks and raw parquet staves of the same volume; V_{board} = total sawn boards volume; V_{log} = total roundwood volume.

The goal is to produce as many dimension stock and raw parquet staves of better class quality and higher prices considering specification of elements dimension limit with considerable volume yield. Qualitative yield is expressed as mean quality coefficient of all dimension stock and raw parquet staves produced from logs according to the equation 5. As shown in Table 4, as index of the quality 1 the most valuable product, sawn dimension stock of the highest class or price was selected. Quality indices of other elements are defined in such way that their current market price is divided by the price of the most valuable element. If the average quality coefficient is multiplied by amount of money for which as the quality index is taken value 1, average quality of all dimension stock and raw parquet staves is obtained, expressed in money per unit of elements volume according to the equation 6.

$$Y_{\text{Quality}_{\text{d.s.}}} = \frac{V_{\text{d.s.}_1} \cdot k_{\text{d.s.}_1} + V_{\text{d.s.}_2} \cdot k_{\text{d.s.}_2} + \ldots + V_{\text{d.s.}_n} \cdot k_{\text{d.s.}_n}}{V_{\text{d.s.}_1} + V_{\text{d.s.}_2} + \ldots + V_{\text{d.s.}_n}} \tag{5}$$

$$Y_{\text{Quality}_{€/\text{d.s.}}} = Y_{\text{Quality}_{\text{d.s.}}} \cdot c_{\text{p}} \tag{6}$$

where: $Y_{\text{Quality d.s.}}$ = quality yield; $k_{\text{d..s. 1....n}}$ = quality index of dimension stocks and raw parquet staves; $V_{\text{d.s. 1…n}}$ = volume of dimension stocks and raw parquet staves; $Y_{\text{Quality €/d.s.}}$ = monetary value of qualitative yield; c_{p} = price of the most valuable dimension stock whose quality index is set as 1.

Value yield of roundwood in the form of dimension stock and raw parquet staves is expressed as mean coefficient of all dimension stock and raw parquet staves values in relation to the roundwood, which is the result of the multiplication of volume and quality yield coefficient according to the equation 7. If roundwood value yield coefficient is multiplied by the amount of money for which as the quality index is taken value 1, average value yield of logs is obtained, expressed in money per unit of roundwood volume according to the equation 8.

$$Y_{\text{Value}_{\text{log}}} = Y_{\text{Volume}_{\text{log}\rightarrow\text{dim.stock}}} \cdot Y_{\text{Quality}_{\text{d.s.}}} \tag{7}$$

$$Y_{\text{Value}_{€/\text{log}}} = Y_{\text{Value}_{\text{log}}} \cdot c_{\text{p}} \tag{8}$$

where: $Y_{\text{Value log}}$ = value yield of small-sized roundwood; $Y_{\text{Volume log}\rightarrow\text{dim.stock}}$ = volume yield of roundwood in the form of dimension stock and parquet staves; $Y_{\text{Value €log}}$ = amount of money of value yield; c_{p} = the price of the most valuable dimension stock whose quality index is set as 1.

For statistical data analysis on the volume, quality and value yield Microsoft Office Excel was used.

4. RESULTS

The total of 1.70509 m^3 of roundwood diameter class of 15-24 cm was sawn. Descriptive statistical analysis of data on its dimensions is shown in Table 2. A total 1.2044 m^3 of sawn boards was sawn from roundwood, and from these sawn boards was ultimately sawn 0.46277 m^3 of dimension stock and raw parquet staves.

Data on sawn boards, dimension stock and raw parquet staves, which were sawn from roundwood are shown in Tables 3 and 4. Volume, quality and value yield of roundwood in the form of sawn boards, dimension stock and raw parquet staves is presented in Table 5 and in Figures 5 to 9.

Table 3. *Descriptive statistics for the dimensions of 15 to 24 cm diameter group sweet chestnut sawn boards*

Sawn board size	15 to 24 cm diameter group					
	N	Min.	Median	Max.	*Average*	Std. dev.
Length, m	323	0.8	1.0	1.0	0.99944	0.01060
Width, cm	323	5.0	15.5	23.0	14.8	0.46767
Volume, m^3	323	0.01125	0.02012	0.03450	0.02007	0.00091

Table 4. *Dimension stock and raw parquet staves components sawed from small-sized roundwood*

Thickness	Width	Length	Diameter group, cm						Price	Quality index
			15 – 19		20 – 24		15 – 24			
			Quantity	Volume	Quantity	Volume	Quantity	Volume		
mm	mm	mm	pieces	m^3	pieces	m^3	pieces	m^3	€/m^3	
25	25	200	1	0.00013	2	0.00025	3	0.00038	170.00	0.23
25	25	250	2	0.00031	0	0.00000	2	0.00031	330.00	0.45
25	25	300	0	0.00000	0	0.00000	0	0.00000	330.00	0.45
25	25	350	1	0.00022	0	0.00000	1	0.00022	330.00	0.45
25	25	400	3	0.00075	2	0.00050	5	0.00125	330.00	0.45
25	25	500	2	0.00063	0	0.00000	2	0.00063	490.00	0.67
25	25	600	2	0.00075	0	0.00000	2	0.00075	490.00	0.67
25	25	700	0	0.00000	0	0.00000	0	0.00000	490.00	0.67
25	25	800	2	0.00100	0	0.00000	2	0.00100	490.00	0.67
25	25	900	0	0.00000	0	0.00000	0	0.00000	490.00	0.67
25	25	1000	0	0.00000	0	0.00000	0	0.00000	490.00	0.67
$\sum_{25x25}$			13	0.00378	4	0.00075	17	0.00453		
25	32	200	19	0.00304	25	0.00400	44	0.00704	170.00	0.23
25	32	250	19	0.00380	21	0.00420	40	0.00800	330.00	0.45
25	32	300	8	0.00192	15	0.00360	23	0.00552	330.00	0.45
25	32	350	12	0.00336	13	0.00364	25	0.00700	330.00	0.45
25	32	400	19	0.00608	22	0.00704	41	0.01312	330.00	0.45
25	32	500	9	0.00360	9	0.00360	18	0.00720	490.00	0.67
25	32	600	7	0.00336	3	0.00144	10	0.00480	490.00	0.67
25	32	700	4	0.00224	2	0.00112	6	0.00336	490.00	0.67
25	32	800	3	0.00192	0	0.00000	3	0.00192	490.00	0.67
25	32	900	2	0.00144	2	0.00144	4	0.00288	490.00	0.67
25	32	1000	0	0.00000	0	0.00000	0	0.00000	490.00	0.67
$\sum_{25x32}$			102	0.03076	112	0.03008	214	0.06084		
25	50	200	33	0.00825	48	0.01200	81	0.02025	170.00	0.23
25	50	250	39	0.01219	55	0.01719	94	0.02938	330.00	0.45
25	50	300	32	0.01200	38	0.01425	70	0.02625	330.00	0.45
25	50	350	16	0.00700	36	0.01575	52	0.02275	330.00	0.45
25	50	400	27	0.01350	50	0.02500	77	0.03850	330.00	0.45
25	50	500	25	0.01563	21	0.01313	46	0.02876	490.00	0.67
25	50	600	8	0.00600	12	0.00900	20	0.01500	490.00	0.67
25	50	700	8	0.00700	7	0.00613	15	0.01313	610.00	0.83
25	50	800	5	0.00500	8	0.00800	13	0.01300	610.00	0.83
25	50	900	9	0.01013	1	0.00113	10	0.01126	610.00	0.83
25	50	1000	0	0.00000	1	0.00125	1	0.00125	730.00	1.00
$\sum_{25x50}$			202	0.09669	277	0.12281	479	0.21950		
25	80	200	0	0.00000	8	0.00320	8	0.00320	170.00	0.23

25	80	250	3	0.00150	8	0.00400	11	0.00550	330.00	0.45
25	80	300	6	0.00360	9	0.00540	15	0.00900	530.00	0.72
25	80	350	10	0.00700	16	0.01120	26	0.01820	585.00	0.80
25	80	400	17	0.01360	29	0.02320	46	0.03680	585.00	0.80
25	80	500	11	0.01100	26	0.02600	37	0.03700	730.00	1.00
25	80	600	4	0.00480	19	0.02280	23	0.02760	730.00	1.00
25	80	700	1	0.00140	11	0.01540	12	0.01680	730.00	1.00
25	80	800	1	0.00160	6	0.00960	7	0.01120	730.00	1.00
25	80	900	3	0.00540	4	0.00720	7	0.01260	730.00	1.00
25	80	1000	0	0.00000	0	0.00000	0	0.00000	730.00	1.00
$\sum_{25x80}$			56	0.04990	136	0.12800	192	0.17790		
$\sum_{25x25+25x32+25x50+25x80}$			373	0.18113	529	0.28164	902	0.46277		

Table 5. *Volume, quality and value yield of 15 to 24 cm diameter group*

Yield	15 to 24 cm diameter group					
	N	Min.	Median	Max.	*Average*	Std. dev.
$Y_{\text{Volume log}\rightarrow\text{dim.stock}}$	60	0.16673	0.27016	0.41412	0.27166	0.06230
$Y_{\text{Volume log}\rightarrow\text{board}}$	60	0.59713	0.71245	0.79264	0.70610	0.04128
$Y_{\text{Volume board}\rightarrow\text{dim.stock}}$	60	0.23400	0.38196	0.55811	0.38384	0.08053
$Y_{\text{Value dim.stock}}$	60	0.34977	0.65200	0.87923	0.62126	0.14745
$Y_{\text{Value €/dim.stock}}$	60	255.33	475.96	641.84	453.52	107.64
$Y_{\text{Value log}}$	60	0.06950	0.17384	0.33582	0.17253	0.06674
$Y_{\text{Value €/log}}$	60	50.74	126.90	245.15	125.95	48.72

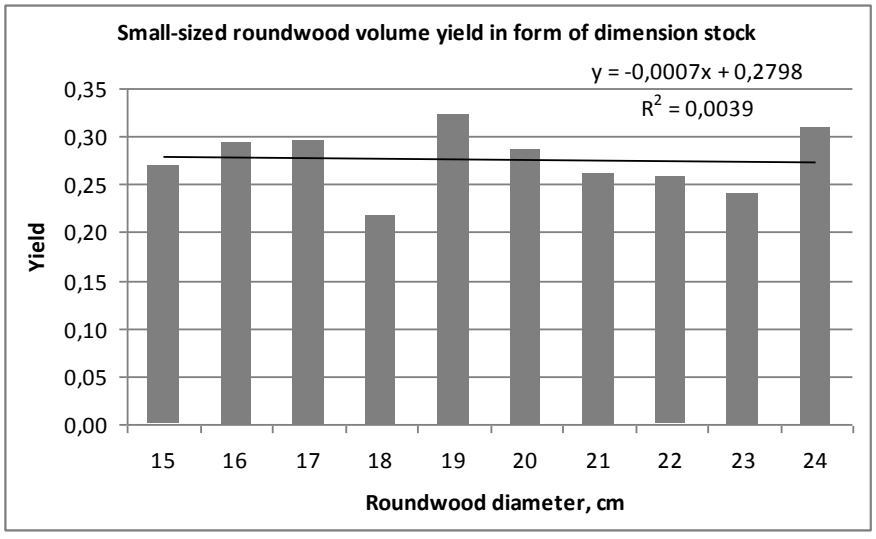


Figure 5. *Comparison of average small-sized roundwood volume yields in form of dimension stock and raw parquet staves*

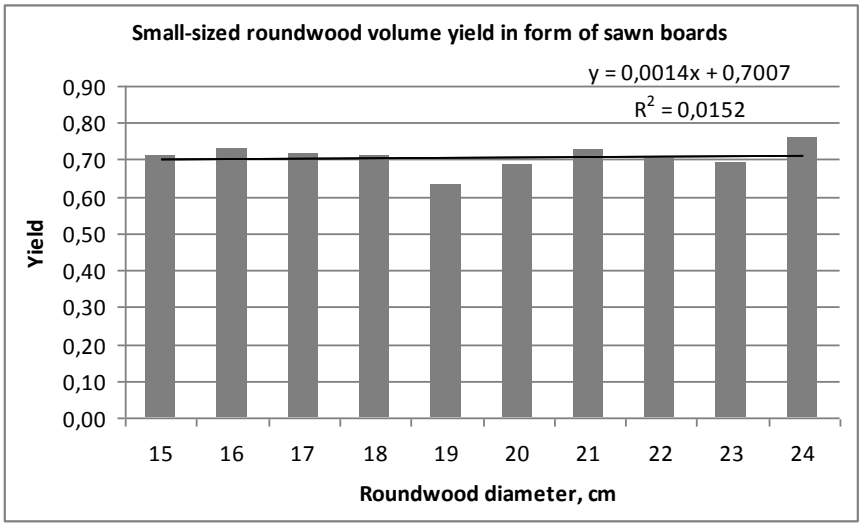


Figure 6. *Comparison of average small-sized roundwood volume yields in form of sawn boards*

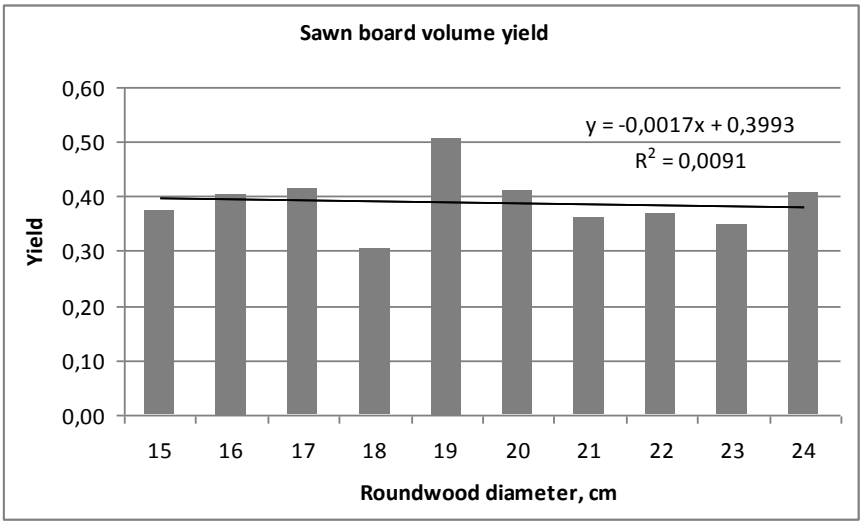


Figure 7. *Comparison of average sawn boards volume yields in form of dimension stock and raw parquet staves*

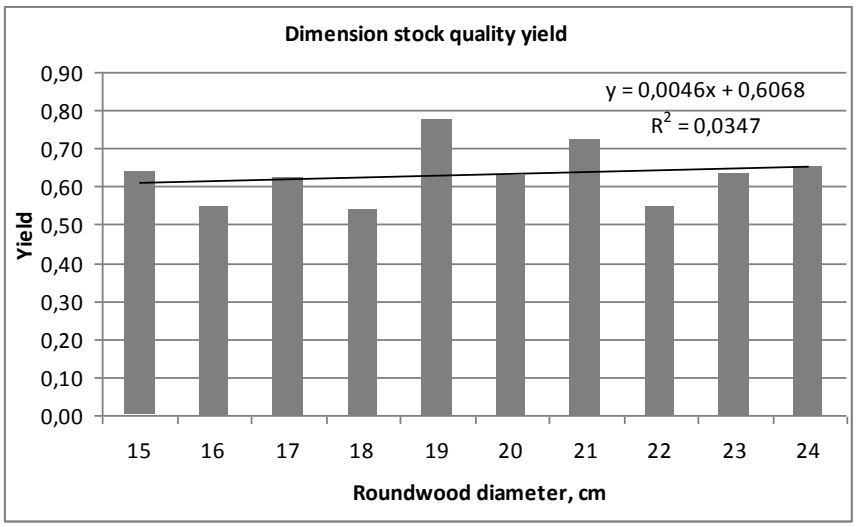


Figure 8. *Comparison of average dimension stock and raw parquet staves quality yields*

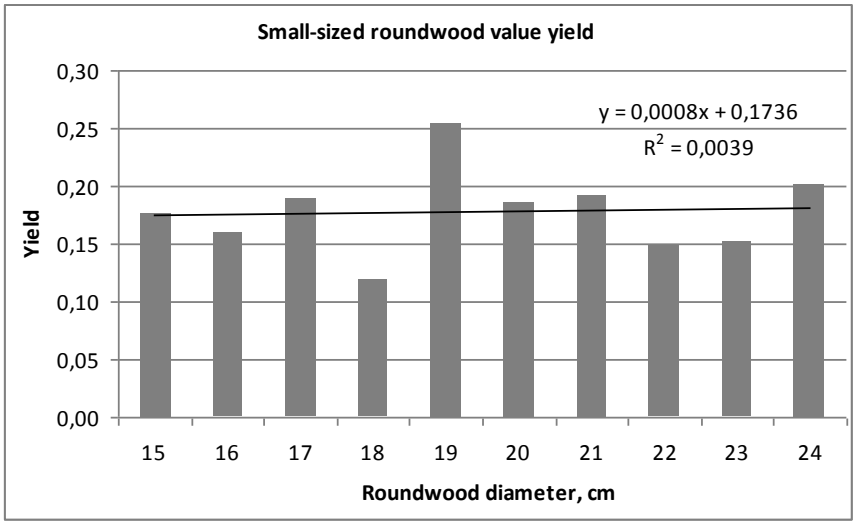


Figure 9. *Comparison of average small-sized roundwood value yields*

5. DISCUSSION AND CONCLUSION

In sweet chestnut as heartwood wood species the sapwood share in sawmill products affects its quality negatively. This was taken into account when producing the elements, so that sweet chestnut dimension stock and raw parquet staves were manufactured without sapwood share. In the end that had negative impact on the volume yield of sawn boards and roundwood yield.

It is known that sweet chestnut tree is the specie highly prone to wood defects such as ring shake and weather shake, and because of bark cancer scars from healed wounds are often found on the logs. Logs larger in diameter and those made from a part of the tree closer to stump are particularly prone to ring shake and weather shake. Although during the preparation and cutting of sweet chestnut roundwood the defects were tried to be avoided, on a certain number of roundwood they remained in trace. Partly these defects were removed by reducing or shortening sawn boards, however they were completely removed in production of dimension stock, which negatively affected volume yield. It should be noted that on the researched sweet chestnut roundwood, especially those with a diameter of 20 to 24 cm, higher prevalence of these defects was observed. I was visible according to the trend of the volume yield, which decreased as diameter increased (Figures 5 and 7).

As for the quality and value yield it has shown minor growing trend since the increase in roundwood diameter enabled production of dimension stock of larger dimensions and greater quality.

Comparing roundwood volume yield in the form of dimension stock and raw parquet staves with data from previous research conducted by Gregić (1969), Prka (1975) and Herak (1984), related to processing small sized oak roundwood as the most similar species, it can be determined that the results are approximately equal. In contrast, comparison of the results of obtained volumetric yield with the results arising while processing sawlogs (Prka, 1978), as expected, showed lower values.

In these comparisons, the diversity of research methods, types of wood and sawmill products range in each of the research, should be considered.

In considering the results of this study sawmilling technology needs to be mentioned. In this study, partially mechanized line on the basis of long band saws was used for primary cutting. The cart was electromechanical with poles at intervals of less than 1000 mm which allowed good compressing of roundwood, which is very important. Secondary cutting was performed on a simple unprofessional circular saws for longitudinal and transverse cutting with manual shift. Accordingly, simple technology with a lot of manual manipulation was used, since it was relatively small mass of workpieces. Thereby the effect was not taken into account as it was very small. However in production conditions with simple but professional equipment with partially mechanized workpiece shifting the effect would certainly be much higher. This is said because we believe that it is possible to efficiently process such raw materials with simple technology, not only with specific high-sophisticated technology; although such technology would be desirable.

In addition, a few words should be said about the quality of manufactured sawmill products. Specifically for this study dimension stock and raw parquet staves were considered and classified according to size and quality in the raw state, since the sawing was carried out by the so-called one-step procedure. In such elements the largest number of defects and irregularities of anatomical wood structure is visible, discoloration of wood, rot, worm holes and board defects due to the sawing process. Nevertheless, defects that occur subsequently while drying these elements to the desired moisture content are not visible (although the experienced workers predict them when cutting and sorting). This results in shrinkage and dimensions change and unwanted deformation (warp) of sawn boards. Cracks may also appear. Deformations were particularly distinct in the larger elements that contain juvenile or tension wood. In this way its quality and value is decreased, because it would be reshaped into smaller elements or waste, which would again affect the volume yield. In some cases, in cutting the raw sawn boards it is possible to visually recognize tension wood and accordingly create or not create the elements from such wood. For more detailed discussion of this issue, in the following investigation dry classification should be carried out in order to determine the amount of waste and elements for repair after drying.

Yield outcomes resulting from this research can be summarized as follows:

- Roundwood volume yield during its processing into sawn boards ranged from 59.7 % to 79.3 %.
- Roundwood volume yield during its processing into dimension stock and raw parquet staves ranged from 16.7 % to 41.4 %.
- Sawn board volume yield during its processing into dimension stock and raw parquet staves ranged from 23.4 % to 55.8 %.
- Roundwood qualitative yield during its processing into dimension stock and raw parquet staves ranged from 0.34977 to 0.87923, that is 255.33 EUR/m^3 to 641.84 EUR/m^3 of dimension stock and raw parquet staves.
- Roundwood value yield during its processing into dimension stock and raw parquet staves ranged from 0.06950 to 0.33582, that is 50.74 EUR/m^3 to 245.15 EUR/m^3 of roundwood.

From the results of this study the following conclusions and recommendations were derived, which confirm previous research results, or they partially agree:

- When preparing sawmill raw material from small dimension deciduous roundwood special importance should be given to avoiding defects (primarily tension wood and knots) that significantly adverse effect the dimensional stability and problems in further processing crafted sawmill products,
- Sawmill raw materials of small dimensions roundwood and the sawn boards and dimension stock and raw parquet staves made from it are relatively small in size and weight, which facilitates the necessary manual handling,
- For the sawmill processing of small dimensions roundwood, specific sawmilling technology is not necessary, but it is preferred,
- We believe that in Croatian conditions for the sawmill processing of sweet chestnut small dimension roundwood simple technology based on long band and circular saws would be suitable, in the so-called family sawmills or even as a supplementary activity of agricultural households in the cooperative relationship with the larger sawmills or sawmill product merchants,
- By applying certain method of sawing in primary and secondary processing it is possible to obtain volume yield of sawmill raw roundwood of small dimensions, which is approximately equal value or less than usual smaller diameter sawlogs,
- By applying certain method of sawing in primary and secondary processing is possible to obtain the required quality while reducing commonly known defects on the products as the cause of the large proportion of juvenile and tension wood and other defects, however sawmill products dimensions are limited given the small size of roundwood,
- In terms of determining the optimal dimensions of sawmill products that are recommended to produce, the realistic production is up to 80 mm width and length not exceeding 600 mm,

although it is possible to create elements of widths larger than 80 mm and of length up to a maximum of 1000 mm,

- Although in this study only the yield of roundwood and sawn boards in the form of dimension stock and raw parquet staves was considered, based on the size and quality of these products in the green sorting by monitoring their behaviour during air drying it was found that on the part of elements of larger lengths (800, 900 and 1000 mm) deformation occurred warranting reshaping these elements into smaller dimensions and thus decrease of quality and price, but also the volume yield,
- Given the inevitable occurrence of deformation during the drying process, which is not always possible to predict when shaping, the possibility of using two-phase modes of sawmill processing should be considered,
- Assuming volume, quality and value yield of wood as a key factor to successful sawmill wood processing, we consider the possible rational sawmill processing of sweet chestnut small sized roundwood,
- Although integral yield was not considered in this paper, due to high share of sawmill waste, for efficient processing of this sawmill raw material it is necessary to consider it and thus increase the value of the obtained products or by-products.

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The Authors' Addresses:

Josip Ištvanić, Ph.D
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: jistvanic@sumfak.hr

Alan Antonović, Ph.D.
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: aantonovic @sumfak.hr

Krešimir Greger, M.Sc.
Drvenjača d.d. – Fužine,
Donje Selo 62, Fužine, CROATIA
e-mail: kgreger @sumfak.hr

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ORGANIZATIONAL MODEL OF INSTITUTIONS FOR RESTORATION OF THE WOODEN ARTEFACTS IN THE REPUBLIC OF CROATIA

Margarita Bego[1], Ivona Milić Beran[1], Denis Jelačić[2]

[1]University of Dubrovnik, Dubrovnik, Croatia
[2]University of Zagreb, Faculty of Forestry, Zagreb, Croatia

ABSTRACT

This paper shows the organizational model of institutions for restoration of the wooden artefacts. In the Republic of Croatia several institutions and museums are working on preservations and restorations of wooden artefacts. Institutions which were analysed are HRZ (Croatian Conservation Institute) and 29 Museums. They are mostly funded by state budget and projects. Because of the fact that there is significant number of valuable wooden artefacts in the Republic of Croatia, it is necessary to establish the organizational model which will enable most effective process of restauration and preservation.

Key words: organization, organization model for system of institutions, managing processes

1. INTRODUCTION

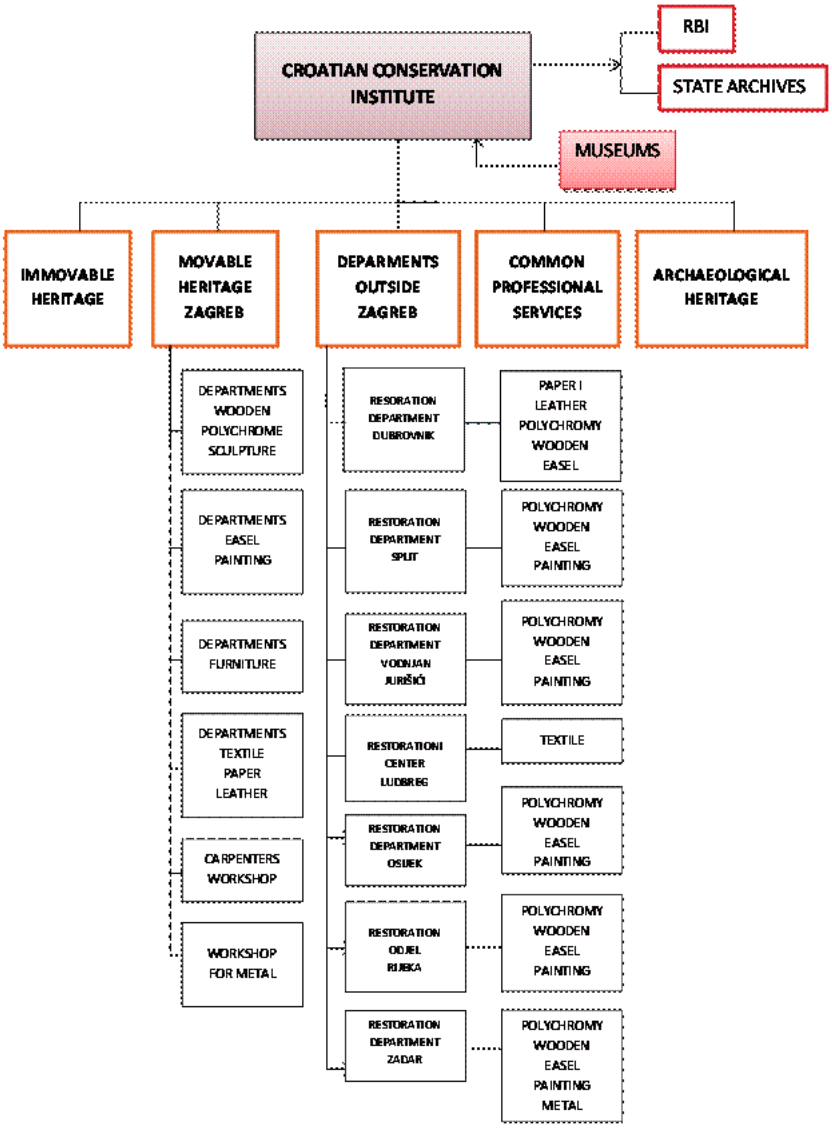
In the Republic of Croatia the umbrella institution for the conservation and restoration of cultural property is the Croatian Conservation Institute (HRZ), which functions as a public, state-owned institution under the jurisdiction of the Ministry of Culture. The conservation and restoration activities affect the preservation of tangible cultural heritage, which is the foundation of the nation's cultural identity, and represent a notable share in economic activities and in tourism. The main activities of the Croatian Conservation Institute are conservation and restoration of the immovable cultural property (architectural heritage, murals and mosaics, carved stone, stucco, and archaeological artefacts/sites), movable cultural property (easel painting, wooden polychrome structure, archaeological findings, works of art on paper, furniture, textile and leather objects, objects made of metal, glass, ceramics and similar materials), and other culturally, historically, and technically important objects.

The organizational units of the Croatian Conservation Institute are the Division for Movable Heritage in Zagreb and Division for Branch Departments with workshops in Dubrovnik, Ludbreg, Osijek, Rijeka, Vodnjan-Jurišići, Zadar and Split. Departments for polychrome wooden sculpture and easel painting are situated in Zagreb, Split, Dubrovnik, Osijek, Zadar, and Ludbreg; workshop for metal is situated in Zagreb and Dubrovnik, and Carpenter's workshop only in Zagreb. Apart from the Croatian Conservation Institute, which is the holder of all major conservation and restoration projects, the museums in the Republic of Croatia also offer restoration services. The Museum Act (Official Gazette no. 142/98, 65/09) stipulated the founding of the Croatian Museum Council of the Ministry of culture as an advisory body for the expert and related tasks for the museum activities stipulated by the aforementioned Act. According to the Museum documentation centre, the restoration and preparation activities were recorded in 49 museums.

This paper will outline the organizational model of the Croatian Conservation Institute with partner institutions. The knowledge of organizational structure is highly important for the purpose of intervention when setting up or improving the existing models. The organizational structure is not an independent variable, but influenced by a number of factors. This means that in the structuring process it is not enough to consider only certain principles of analysis and synthesis of the institution tasks, but

the following impact factors are quite important: environment, strategy, technology and the size of an institution. (Mintzberg, 1979). Taking into account the characteristics of certain types of organizational structure, Brusi (1986) concludes that the functional organizational structure is efficient in stable environment even for institutions with limited complexity and size of facilities.

Structuring of organizational units is an essential and fundamental prerequisite required to set up the organizational structure. It is implemented in a manner that individual tasks of an institution, whose design led to the primary alignment of activity factors, are connected (mutually and according to specific task) in larger tasks and thus form narrow or wide organizational units. (Bahtjarević Šiber, 1991). Management is a key factor for organizational success and development, and it represents the specific most important function within the institution. (Fayol, 1949). Like a qualification - it is the profession with a specific structure of knowledge and methods, applicable in practical work, which is important in case of the surveyed institutions. Organization is the process of designing the optimal organizational structure of an institution and its divisions. This structure is in line with the needs of effective implementation of the set objectives. (Kuvačić, 2001). This creates three central groups of tasks: design of organizational structure, design of economic relations, and eventually the design of an effective institution (Buble,1993).



ORGANIZATIONAL MODEL

To this day there was hardly any significant research tackling the issue of business operations within institutions engaged in restoration of wooden artefacts in the Republic of Croatia. So as to propose a new model, if needed, or improve the existing one, it is necessary to identify the situation in the surveyed institutions at the very beginning.

2. MATERIAL AND METHODS

The survey was conducted using a questionnaire in 49 museums and in the Croatian Conservation Institute, the most important institution for the conservation and restoration. The survey questionnaire comprised three parts: general information on the employee (number of employees, structure of employees ‘qualifications, institution rulebook), wooden artefacts conservation and restoration management system (the model of obtaining projects, determining the project manager, defining specific activities, cooperation with other institutions on specific activities), and the system of business operations in institutions for the restoration of wooden artefacts in the Republic of Croatia (project funding, institution activities, budget for a specific project).

Out of 49 museums that have a registered s preparatory or restoration activity, the received data were processed for 29 museums, i.e. 59% of the total number of surveyed museums performing the above-mentioned activities. Data were collected in the period between 2009 and 2014. They can be further analyzed so as to determine the current model in the institution, and to determine the possibility for improving or establishing a different organizational model within these institutions.

3. RESULT, DISCUSSION AND CONCLUSION

The obtained results focus on the restoration of wooden artefacts in institutions with registered activity in the Republic of Croatia. The Croatian Conservation Institute and museums are state-owned institutions mainly financed from the state budget. The results show that in case of 12% of institutions 70% of funds are allocated from the state budget; in 40% of institutions the proportion of allocated funds varies between 70 and 90%; while 48% of institutions receive over 90% of funds from the budget. Over 70% of resources are self-financed only in two institutions. On average, only 4% of funding was generated by means of donations and sponsorships (Figure 1).

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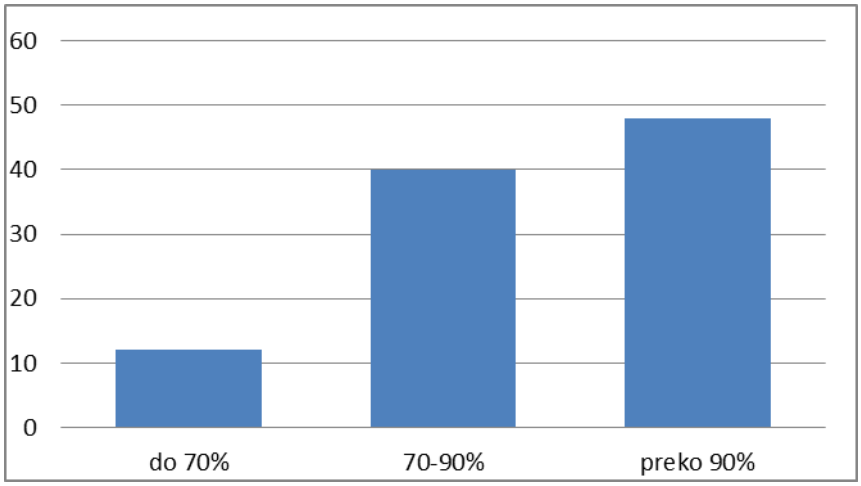

Figure 1

Comparative graph in Figure 2 shows the total number of interventions and the number of wooden artefacts in institutions (museums) from 2009 to 2013.

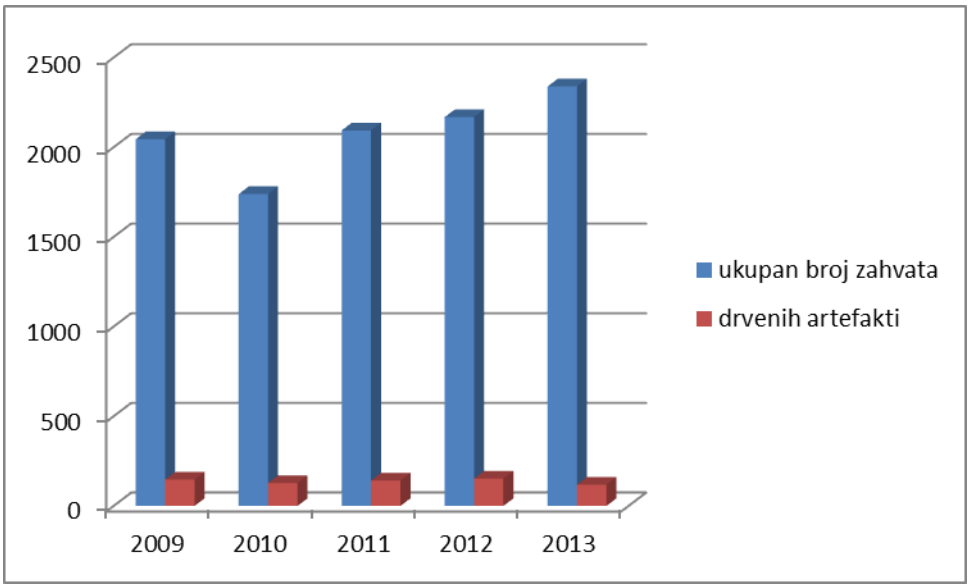

Figure 2

The share of wooden artefacts in the total number of interventions in the surveyed period ranges between 5 and 7.4%. In the five years covered by the conducted survey, the average share of wooden artefacts is 6,62494%.

Comparison of the total number of interventions and wooden artefacts in the Croatian Conservation Institute for each year is presented in Figure 3. The minimum number of interventions was carried out in 2013 and it amounted to 309. Whereas, the greatest number of interventions (496) was carried out in 2010. The average share of wooden artefacts in the observed period amounted to 21.4% (Figure 3).

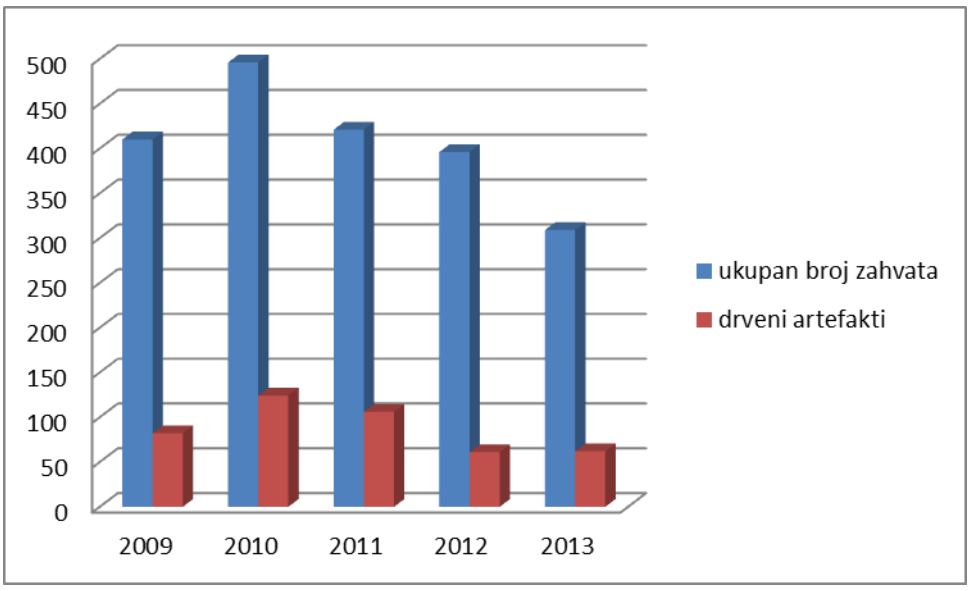

Figure 3

The survey conducted in the Croatian Conservation Institute and 29 museums with the registered conservation and restoration activities in the Republic of Croatia provided results for the period between 2009 and 2013, obtained through a questionnaire, which show the situation.

It also shows the business model of the conservation and restoration umbrella institution, the Croatian Conservation Institute. The obtained results, according to the aforementioned existing organizational model in the Croatian Conservation Institute, it can be concluded that the current model of the process and business operations management should be modified in order to establish faster

communication between individual institutions and to enable more organized flow of artefacts according to the specific materials. It could be implemented with further research of the current model of the process and business operations management.

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The Authors' Addresses:

Margarita Bego, Ph.D.
University of Dubrovnik,
CROATIA
e-mail: margarita.bego@unidu..hr

Ivona Milić Beran, Ph.D.
University of Dubrovnik,
CROATIA

Prof. Denis Jelačić, Ph.D.
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: djelacic@sumfak.hr

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COMPARATIVE ANALYSIS OF BONDING STRENGTH OF BEECH PLYWOOD (*Fagus Silvatica L.*) ACCORDING SRPS AND EN STANDARD

Vladislav Zdravković, Aleksandar Lovrić, Bojana Milanović

University of Belgrade, Faculty of Forestry, Republic of Serbia
e-mail: vladislav.zdravkovic@sfb.bg.ac.rs; aleksandar.lovric@sfb.bg.ac.rs

ABSTRACT

Both SRPS and end EN standards are actual in Republic of Serbia nowadays. In this paper the comparative analysis of accuracy and convenience of testing samples from the same eleven layers, 20 mm thickness plywood board according SRPS and EN norms has been performed. Both types of samples were treated under the same circumstances: water boiling proof test (WBP test). After treatment the glue line shear test has been performed on computer controlled testing machine. Results showed that the EN method was significantly more precise (F-test). This test treats pairs of glue lines simultaneously, includes assessment of wood failure and it is more accurate, more reliable, but in the same time more time consuming, compared to older SRPS testing procedure.

Key words: beech plywood, glue line testing, SRPS norms, EN norms, WBP test

1. INTRODUCTION

Standard is a document, established by consensus and approved by a recognized body, which determines, for common and repeated use, rules, guidelines or characteristics for activities or their results, in order to achieve an optimal level of regulation in a given context. Thus says ISO / IEC Guide 2: 2007. Our current national standards are labeled as **SRPS**, while the standard of the European Union are labeled as **EN**.

In Serbia there are still applicable SRPS standards for testing plywood, as well as the new EN standards, so that the tests are performed, after one or other standards. Although the benefits of EN standards are well known (Blomquist and Olson 1964, Cai Zhiyong 2009):, there are rare data from the practice, on which basis the numeric comparison of these two ways of testing for plywood should be performed (Zdravković 1992, Zdravković et al. 2015).

The aim of this paper is to compare the shear strength testing methodology in the layer of adhesive per SRPS and EN standards. By their comparison and seeing the difference between these two methods of testing, the conclusions shall be adopted about the advantages and disadvantages of both methods and about which method is more accurate and more comprehensive.

2. MATHERIALS AND METHODS

Testing was performed on 11- layer beech plywood panel thickness 20 mm. There were different thickness of longitudinal and transverse layers on board, i.e. transverse layers were thicker than longitudinal. The samples for testing shear strength of the adhesive layer were cutted by D.A8.067 and EN 314-1 standards from the same plywood panel, while the classification panel was according to SRPS D.C5.040 and EN 314-2 standards. To minimize the possible influence of the position of the sample in a plywood panel, the randomization of samples was performed, in such a way that all the samples are first cut and then selected at random order and clustered into groups according to the experimental design.

The main difference between the SRPS and EN standards is that, in the test according to SRPS standard all bond lines were tested simultaneously, while in the test according to EN standards, each pair bond line were tested separately.

Due to the simultaneous testing of all lines of adhesives per SRPS standard, arrangement of holes and notches should be such way that tensile force can only cover a specified glue lines (Figure 1). Arrangement and dimensions of the hole depend on the number of layers and the thickness of the veneer sheets in the structure of the plywood panel. No matter how accurately prepared probes, no matter how accurately drill the holes and notches were made, experience has shown that the fractures in such probes are generally uncontrollable. In contrast, glue bond shear strength test according EN is much more controlled. The shear strength of the adhesive layer was calculated according to the formula:

$$\sigma_s = \frac{2 \cdot F}{b \cdot l \cdot (n-1)} \quad (MPa)$$

Where:

σ_s – glue bond strength (MPa),
F – shear force (N)
b – shear width (mm)
l – shear length (mm)
n – number of plywood layers (no)

Figure 1. *The look of the testing probe according D.A8.067*

When testing according to EN 314-1 standard, each pair bond line was treated separately, which means that the number of groups for testing depends on the number of veneer sheets in the construction of the plywood (Figure 2). The shear strength of the adhesive layer was calculated for each bond line separately according to the formula:

$$\sigma_s = \frac{F}{b \cdot l} \quad (MPa)$$

Where:

σ_s – glue bond strength in treated layer (MPa),
F – shear force (N)
b – shear width (mm)
l – shear length (mm)

In this experiment the 6 groups of 10 specimens were prepared. The first group was made according to standard SRPS D.A8.067, while the other 5 were made according to EN 314 standard - each for a specified pair of bond lines.

In accordance with the adhesive used in the production of plywood, appropriate pre-treatment was chosen, for the plywoods which will be used in external conditions (WBP test). Pretreatment consisted of 6 h cooking probes at 100° C, and then from immersion in cold water for 2 h at 20° C. Pre-treatment was carried out for all established groups of testing at the same time.

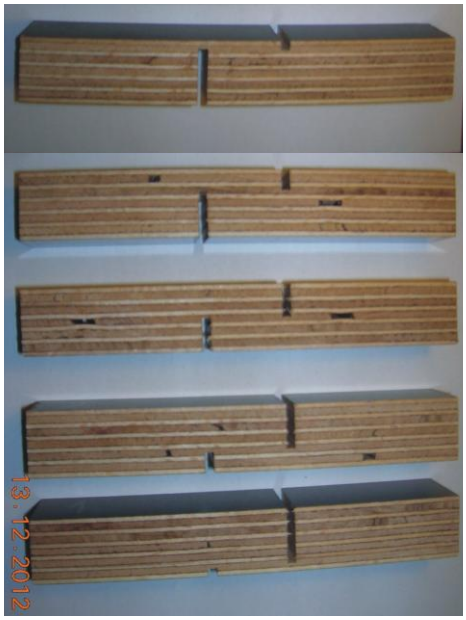

***Figure 2**. The look of the probes for testing according EN 314*

Upon completion of the pre-treatment, the probes were removed, drained and then tested on the computer controlled automatic laboratory testing machine Amsler WT 4 in accordance with the requirements of the standards.

3. RESULTS AND DISCUSSION

Table 1 shows the results obtained from testing with a basic statistical analysis. During the processing of results, some test probes were rejected, because the fractures were not occurred in the study area (one at the glue bond line one and three at the glue bond line 5).

***Table 1.** Testing results*

	Tessting according **SRPS D.A8.067**	Tessting according **EN 314-1**				
		Glueline 1	Glueline 2	Glueline 3	Glueline 4	Glueline 5
No. Samples	10	9	10	10	10	7
Mean value (MPa)	1.514	2.682	3.215	2.787	3.086	2.544
Standard deviation	0.260	0.622	0.598	0.785	0.766	0.991
Koef. Of variation (%)	17.188	23.192	18.591	28.179	24.818	38.973
Standard Error	0.087	0.207	0.199	0.262	0.255	0.330

Table 2. *Statistical analysis of the beech plywood panel test results according SRPS and EN*

STATISTICS	**METHOD SRPS**			**METHOD EN**		
Number of samples	N	10	samples	N	46	samples
Mean value	X	1.514	MPa	X	2.888	MPa
Standard deviation	σ	0.260	MPa	σ	0.757	MPa
Koeficient of variation	v	17.188	%	v	26.228	%
Standard error	St err	0.087	MPa	St err	0.252	MPa
Minimum	MIN	1.014	MPa	MIN	1.383	MPa
Maximum	MAX	1.981	MPa	MAX	4.384	MPa
Range	RANGE	0.967	MPa	RANGE	3.001	MPa
TESTING OF BOTH DISTRIBUTIONS NORMALITY	Testing performed in SPSS: **PASSED**					
VARINACE RATIO	**F**calculated**= 8.473** **F**tabulated= **2.816**					

Depending on the type of wood from which the plywood was produced, the requirements of SRPS D.C5.040 have to reach the minimum value of shear strength greater than 1 MPa for hardwoods, 0.8 MPa for softwoods, and for coniferous woods greater than 0.6 MPa. According to EN 314-2, if each test bond line achieved value greater than 1 MPa, it is considered that the plywood passed the test regardless of which type of wood is made.

Table 1, shows that the examined plywood met the criteria of both standards, but there were large differences in the calculated shear strength. Values obtained by D.C5.040 standard were far less than the values calculated for each glue lines according EN standard. The lowest shear strength according to EN was in glue line No. 5.

According to EN who requires that each test line meets prescribed criteria in relation to the percentage of fracture in the wood, so if the glue line 5 had a value of shear strength less than was required, it might be considered that plywood panel did not pass the examination, regardless of what other bond lines had values far greater than was required.

It can be said that the testing according to EN is more detail or to better indicate possible technological problems in the plywood production. From the results according to EN, it is clear that the glue line no. 5 was critical, so as due to significantly lower values of shear strength, but also because of the large spreading of results (coef. var.: 38.98%), as well as a large number of probes that had to be rejected from the sample due to the cracking out of the testing zone.

This can be a very important task for plywood producers, because if these results are replicated in other plywoods, it would mean that was a systematic error in the production process. In contrast, by testing according SRPS who give only an average value of shear strength for the test layers with a small possibility of insight where a potential problem was.

If calculated average shear strength value is lower than 1.0 MPa, than percent of breakage in the wood should be considered:

0.2-0.4 MPa - breakage in the wood must be greater or equal than 80%

0.4-0.6 MPa - breakage in the wood must be greater or equal than 60%

0.6-1.0 MPa - breakage in the wood must be greater or equal than 40%

Graphic display of this rule is shown in Figure 3. The disadvantage of this method is that the assessment of breakage in the wood is done visually with the aid of a magnifying glass, a reviewer compares the resulting fracture with pictures fracture presented in the standard. Such a decision may depend on the individual skills of examiners, and it is difficult that two different examiners make the same assessment. Also, its need a certain amount of experience and this kind of evaluation is quite slow.

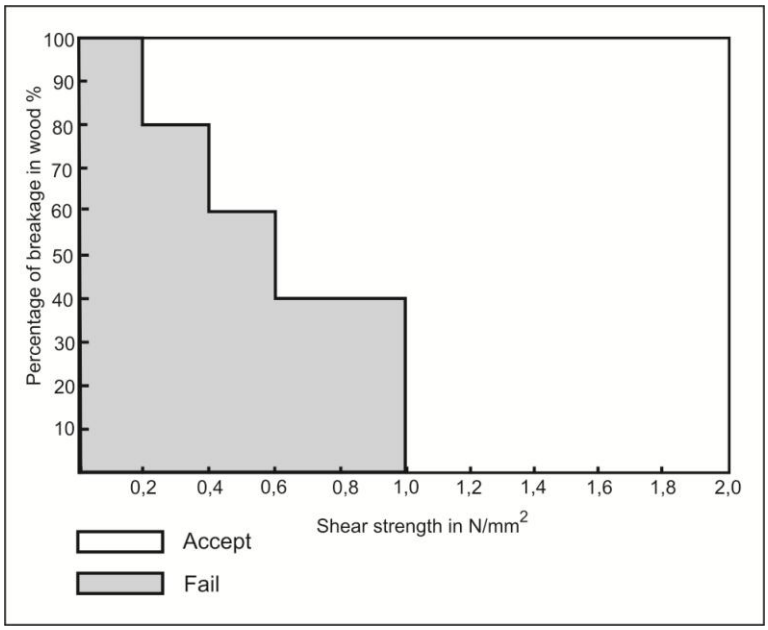

Figure 3. *Graphic illustration of the test requirements depending of percentage of breakage in wood*

Table 2 shows simultaneous statistical analysis of method SRPS and method EN. The basic idea is to statistically compare these two methods. Thus, the method SRPS has been treated as one group, and the average value for all 5 glue lines according EN as the second group. At the first time normality of distribution of both groups was tested in the software package SPSS. Since both groups passed test of normality of distribution, after that, one-tailed F test was proceeded, which showed that the EN method was more accurate (at the confidence level of p = 0.05). Also, regarding assessment of breakage in the wood, the EN method provide more information about glue bond quality, thus it is more accurate, more reliable, but in the same time more time consuming, compared to older SRPS testing procedure.

Although it can be considered that EN 314-2 standard is insufficiently precise - due to assessment of the percentage of breakage in wood, this data can provide us with valuable information. Table 3 shows the calculated values of the percentage of breakage in wood for the tested plywood.

Table 3. *Percent of breakage in wood (%) for different glue lines*

	Tessting according **EN 314-1**				
	Glueline 1	**Glueline 2**	**Glueline 3**	**Glueline 4**	**Glueline 5**
Percent of breakage in wood (%)	13.90	20.91	17.27	19.09	21.43

Results in Table 3 showed that the fracture was occurred mainly in the glue line (usually over 80%). This means that pre-treatment significantly reduced the strength glue joint, but the plywood still remained strong enough to achieve the shear strength greater than 1 MPa.

As a percentage of breakage in wood in the glue line no. 5 was the lowest than the other observed lines (together with the lowest shear sterngt value), the most likely reason for the occurrence of this was deviation in that layer quality compared to other tested layers. Or, for manual charging press, that veneer layer was long stood on the hot platen without pressure, so that a premature polymerization of the adhesive was occurred.

4. CONCLUSIONS

Upon completing an experiment and data processing, it was concluded that the test beech plywood fulfill the requirements both SRPS and EN standards, since they all calculated glue line shear strength mean were greater than 1 MPa.

Taking into account the whole experiment and theoretical study of standards, leads to the following conclusions:

1. SRPS order making probes that are more complicated, although their number is smaller. SRPS standard requires the preparation of specimens with holes, appropriate precision, which is very difficult to achieve. During the preparation of test specimens there was a problem just in this operation. During the preparation of probes according EN methodology, these problems were not existed, because their production was done without making a holes.
2. The results obtained by the EN method were refined and elaborated each layer separately. It has been concluded that the glue bond shear strength depended of the number of layers (and its position) in plywood panel, and that this value was variable in layers.
3. EN methodology introduces a new criterion: a percentage of breakage in wood, which provides detailed insight on the glue bond quality. The main disadvantage of this criterion it is i matter of individual assessment of examiners.
4. The different mean values of glue bond shear strength were obtained by examing the same plywood according the SRPS and EN methodology. The probes according SRPS gave lower values of shear strength 1.514 MPa, while the average value according EN was 2.888 MPa. The statistical tasting shoved that EN method was significantly more precise than older SRPS method.

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The Authors’Addresses:

Vladislav Zdravković, Ph.D.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: vladislav.zdravkovic @sfb.bg.ac.rs

Aleksandar Lovrić, **Ph.D**.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: aleksandar.lovric@sfb.bg.ac.rs

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WOOD DENSITY OF AUTOCHTHONOUS AND ALLOCHTHONOUS WOOD SPECIES IN THE REPUBLIC OF MACEDONIA

Mitko Nacevski[1], Borche Iliev[1], Ljupcho Nestorovski[2], Konstantin Bahchevandjiev[1], Violeta Jakimovska Popovska[1], Basri Aziri[3]

[1]Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje
e-mail: nacevski@fdtme.ukim.edu.mk; iliev@fdtme.ukim.edu.mk;
bahchevandjiev@fdtme.ukim.edu.mk; jakimovska@fdtme.ukim.edu.mk
[2]Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Forestry-Skopje
e-mail: nestorovski@sf.ukim.edu.mk
[3]Ministry of Agriculture, Forestry and Water Economy, Skopje
Republic of Macedonia
e-mail: basri-aziri@hotmail.com

ABSTRACT

In this paper are presented the results from the wood density investigation of the following wood species: *Fagus moesiaca, Quercus sessilis, Quercus conferta, Robinia pseudoacacia, Pinus nigra, Pinus silvestris, Abies alba, Picea excelsa, Pseudotsuga menziesii, Cupressus arizonica, Sequoiadendron giganteum, Pinus strobus* and *Larix decidua*.

The material used for investigation was collected from twenty-eight methodologically selected localities in the Republic of Macedonia.

The applied methodology of the experimental work is in accordance with the standard for wood investigation.

Generally, the mean values of the wood density of the tested autochthonous and allochthonous species are in the limits of the values for the species that have been synthesized by other authors.

In the same deciduous specie, the density of the wood from the vegetative origin is higher that the density of the wood from generative origin.

Within the coniferous species form artificial afforestation, in the frame of the same specie, the density of the wood is increased with the aging of the stand.

Key words: wood density, generative origin, vegetative origin, natural stands, afforested plantations

1. INTRODUCTION

In the frame of the scientific-research project „Investigation of the wood quality from autochthonous and allochthonous species in Republic of Macedonia“, the wood density is a main issue (Nacevski et al. 2002).

On the basis of the mean values of strength characteristics and density in standard partly dry condition (at 12 % moisture content), the quality parameters are formed on which basis the utilizable value of wood in structural application is evaluated. The project represents a compilation of investigations of the wood quality from beech, Cornish oak, Hungarian oak, black locust, black pine, white pine, fir, spruce, Douglas fir, cupressus aphid, giant redwood, mountain pine and European larch.

The limitation and mean values of the density of the most important European species, which Ugrenović (1950) had synthesized on the basis of the data listed in papers done by Janka, Kollmann,

Trendelenburg and Horvat, explains the variations in the density in wide range not just between different species, but in the frame of one wood specie (Šoškić 1994). Approximately the same limits are given by Tsoumis (1991). The results of new researches on wood density (Naceski and Iliev 2002, 2006; Popović and Todorović 2007; Gryc 2008; Jelonek 2009; Šoškić 2005, 2007, 2009, 2010 and 2011; Sinković 2011; Skarvelis and Mantanis 2013; Ramsay and Macdonald 2013) are consistence with the above statement.

In most of the cases in our research, trough the selection of sample trees with approximately same age, the age is a constant stimulant in cambial activity, while the site growing factors with all of its complexity, globally observed for each locality are variable stimulant on the cambial activity, so they are carrying the variations of the wood density. In certain wood species the age and the origin of stands (generative or vegetative) are variation factors.

In order to make the obtained results comparable, the wood density in standard dry condition is tested (at 0% moisture content), as well as the wood density in standard partly dry condition (at 12 % moisture content) was tested.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

The material used for investigation was collected from twenty-eight methodologically selected localities in the regions of: Mavrovi Anovi, Demir Kapija, Radovish, Kriva Palanka, Berovo, Vinica, Shtip, Pehchevo, Kavadarci, Belchishta and Skopje. The data for the localities and set test areas, as well as the description of the site growing factors are given in certain forest management plans and projects in which the investigated localities are included (Nacevski and Iliev 2002).

The method of the experimental work is consistent with the need for sufficient number of test specimens for investigation of the wood quality at real diameters and heights of the sample trees, thereto using the domestic and foreign experiences in order to make the obtained results comparable with the results from similar investigations.

In accordance with the standard for selection of the material for research, from 3 to 5 trees are cut down from each test area. The sample trees selected for investigation are representative of the stand.

From each sample tree, depending on its dimensions, from one to five trunks with 1 m length are taken. Generally, the trunks are taken from height of: 0,3 m, 1,3 m, 3,3 m, 5,3 m and 7,3 m above the ground surface.

From each trunk, radial planks are sawn, wherewith square profiles are obtained with approximate dimensions of 20×23×1000 mm, from which the test specimens are made for wood density testing.

The test specimens with dimensions of 20×20×30 mm are used for determination of the density and changes in the dimensions of the wood, wherewith the procedure is expedited and rational utilization of the material is achieved. The testing method and calculation of the wood density is prescribed by the national standard for testing of the wood properties.

After the measuring, the obtained results for the wood density are matched in classes and statistically analyzed with the common methods of the variation statistic.

3. RESULTS FROM THE RESEARCH

3.1. Wood density in standard dry condition

The wood density in standard dry condition has less relevance in practice and it is more used in scientific research work. Because of the hygroscopic nature of wood, its density in standard dry condition in atmospheric air conditions is unsustainable. This condition is achieved in artificial way trough drying at temperature of 103±2°C to constant weight.

The mean values are shown in histograms on Figure 1.

The wood density in standard dry condition of beech from generative origin (0,652 g/cm^3) is lower for 10,56 % compared to the density in standard dry condition of beech from vegetative origin (0,729 g/cm^3).

The wood density of Hungarian oak in standard dry condition (0,770 g/cm^3) is lower for 6,33 % compared to the density of Cornish oak in standard dry condition (0,822 g/cm^3).

The wood density of black locust in standard dry condition, raised on alluvial soil (0,777 g/cm^3) is higher for 3,60 % compared to the density of black locust in standard dry condition, raised on cinnamon soil (0,750 g/cm^3).

The wood density in standard dry condition of black pine artificial stands is lowest in the locality of Pochivalo in the region of Shtip (0,411 g/cm^3), while highest in the locality of Ramnoborje in the region of Pehchevo (0,509 g/cm^3). The determined densities in other ten localities are between these limits.

The wood density in standard dry condition of white pine artificial stands (0,448 g/cm^3) is lower for 11,98 % compared to the wood density in standard dry condition of black pine artificial stand in the same locality in the region of Pehchevo (0,509 g/cm^3).

The wood density in standard dry condition of fir and spruce from natural stands is 0,392 g/cm^3 and 0,420 g/cm^3, respectively.

The artificial stands of Douglas fir have the highest wood density in standard dry condition in the locality of Vitachevo (0,503 g/cm^3), lower in the locality of Gorici (0,437 g/cm^3) and lowest in the locality of Ramnoborje (0,386 g/cm^3).

The wood density in standard dry condition of cupressus aphid, giant redwood, mountain pine and European larch, all raised as artificial stands is 0,516 g/cm³, 0,322 g/cm³, 0,319 g/cm³ and 0,455 g/cm³, respectively.

3.2. Wood density in standard partly dry condition

The methodological approach, as well as the number of test specimens for determination of this property that has the biggest practical meaning, was identical as in determination of wood density in standard dry condition.

The mean values are shown in histograms on Figure 2.

The wood density in standard partly dry condition of beech from generative origin (0,690 g/cm³) is lower for 10,04 % compared to the wood density in standard partly dry condition of beech from vegetative origin (0,767 g/cm³).

The wood density in standard partly dry condition of Hungarian oak (0,803 g/cm³) is lower for 6,52 % compared to the wood density in standard partly dry condition of Cornish oak (0,859 g/cm³).

The wood density in standard partly dry condition of black locust raised on alluvial soil (0,804 g/cm³) is higher for 2,29 % compared to the wood density in standard partly dry condition of black locust raised on cinnamon soil (0,786 g/cm³).

The wood density in standard partly dry condition of black pine artificial stands is lowest in the locality of Pochivalo in the region of Shtip (0,439 g/cm³), while highest in the locality of Ramnoborje in the region of Pehchevo (0,537 g/cm^3). The determined densities in other ten localities are between these limits.

The wood density in standard partly dry condition of white pine artificial stand (0,476 g/cm^3) is lower for 11,36 % compared to the wood density in standard partly dry condition of black pine artificial stand in the same locality in the region of Pehchevo (0,537 g/cm^3).

The wood density in standard partly dry condition of fir and spruce from natural stands is 0,423 g/cm^3 and 0,450 g/cm^3, respectively.

The wood density in standard partly dry condition of cupressus aphid, giant redwood, mountain pine and European larch is 0,544 g/cm³, 0,347 g/cm³, 0,345 g/cm³ and 0,484 g/cm³, respectively.

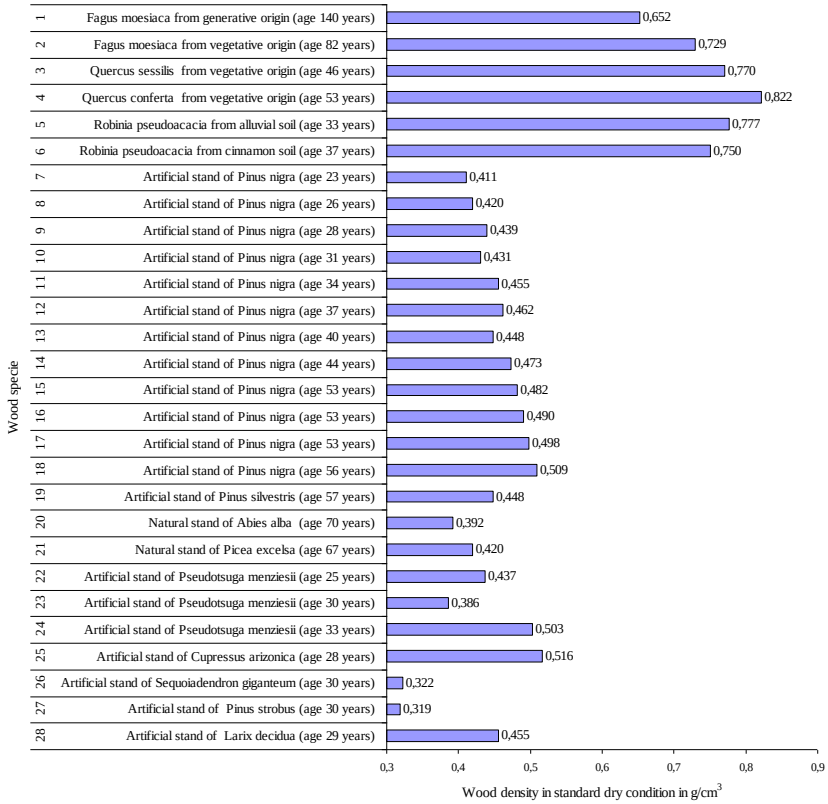

Figure 1. *Histogram for the density of the wood in standard dry condition*

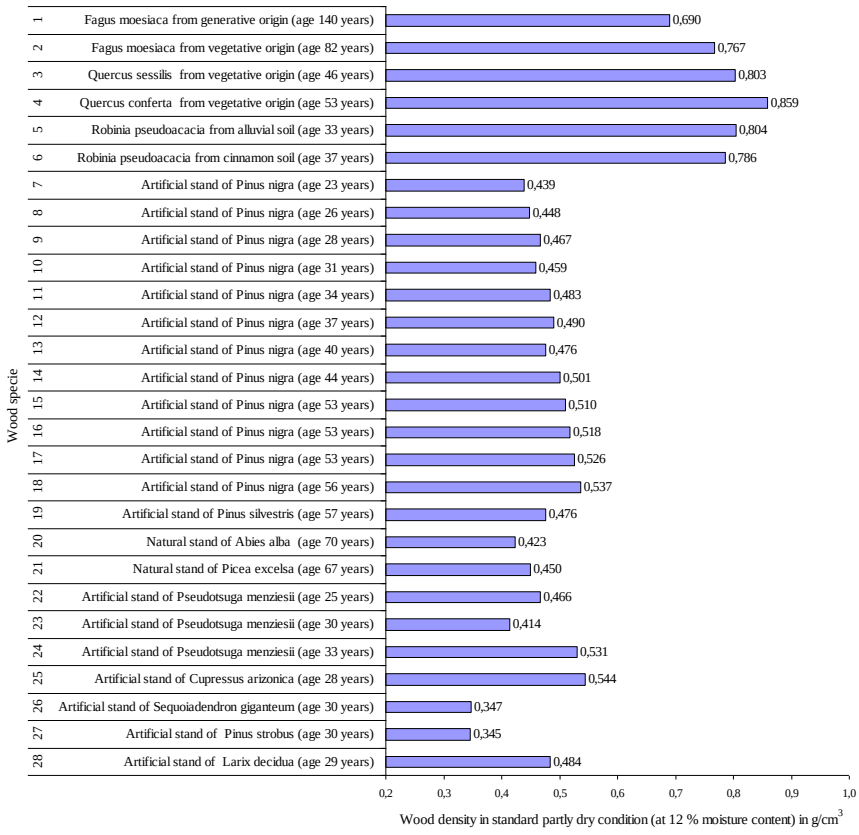

Figure 2. *Histogram for the density of the wood in standard partly dry condition*

4. CONCLUSIONS

On the basis of the research results, following conclusions can be drawn:

- In deciduous species, the highest density of wood has Cornish oak from vegetative origin at age of 46 years, followed by: black locust at age of 30 years raised on alluvial soil, Hungarian oak from vegetative origin at age of 44 years, black locust at age of 35 years raised on cinnamon soil, beech from vegetative origin at age of 74 years and beech from generative origin at age of 140 years. Only the black locust stands are artificially raised with afforestation, while all other tested species are from natural stands.
- In coniferous species, the highest density of wood has cupressus aphid at age of 30 years, followed by: Douglas fir at age of 30 years, black pine at age of 23 to 53 years, white pine at age o 55 years, European larch at age of 30 years, spruce at age of 60 years, fir at age of 64 years, giant redwood and mountain pine at age of 30 years. Only the white pine and spruce stands are natural stands, while all other species are from artificial stands.
- In *Fagus moesiaca*, the density of the wood from vegetative origin is significantly higher compared to the density of the wood from generative origin. That is a result from the influence of the differences in the structural characteristics of the wood initiated from the origin, which is a stimulant of cambial activity.
- In *Robinia pseudoacacia*, the density of the wood from stands raised on alluvial soil is significantly higher compared to the density of the wood from stands that were raised on cinnamon soil. The wider annual rings in black locust from alluvial soil, which determine the bigger participation of the zone of late wood, are the main factor that determines this difference.
- In *Pinus nigra*, the mean values of the wood density significantly differ between tested twelve localities. The differences are increasing with the increment of the differences in the age of the stands raised with afforestation.
- In *Pseudotsuga menziessii*, the mean values of the wood density significantly differ between three investigated localities. At approximately same age of artificial stands raised with afforestation, the site growing factors are the most important variable stimulant of cambium, which create wood with different density on these three localities.
- Generally, the mean values of the density of wood from tested autochthonous and allochthonous species in Republic of Macedonia are in the frame of the limitation values for the species systematized by Ugrenović and determined by other authors, but with significant differences between the determined mean values. The stated quotation are confirmed by the results from the research presented in the paper (Fig. 1 and 2)

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The Authors' Addresses:

Dr Mitko Nacevski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: nacevski@fdtme.ukim.edu.mk

Dr Borche Iliev, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: iliev@fdtme.ukim.edu.mk

Dr Ljupcho Nestorovski, Full professor
Ss Cyril and Methodius University,
Faculty of Forestry – Skopje, Republic of MACEDONIA
e-mail: nestorovski@sf.ukim.edu.mk

Dr Violeta Jakimovska Popovska, Docent
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: jakimovska@fdtme.ukim.edu.mk

Basri Aziri, **M.Sc**
Ministry of Agriculture,
Forestry and Water Economy,
Skopje, Republic of MACEDONIA
e-mail: basri-aziri@hotmail.com

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INFLUENCE OF STAPLES PARAMETERS ON DEFORMATION BEHAVIOR OF STAPLE JOINTS IN THE CONSTRUCTION OF UPHOLSTERED FURNITURE

Desislava Hristodorova, Yancho Genchev

University of Forestry - Sofia 1756, bul. Kliment Ohridski 10,
Faculty of Forest Industry, Sofia, Bulgaria,
e-mail:dhristodorova@yahoo.com; genchevy@abv.bg

ABSTRACT

Staple joints are the most commonly used joints in upholstered furniture. Better understanding of their behavior could affect to improve product quality in the industry. The current study reports results related to the deformation behavior of the joints, giving specific conclusions and recommendations directly helping manufacturers of upholstered furniture in the design of the product.

Key words: upholstered furniture, deformation behavior, corner joints, staple joints, stiffness coefficient.

1. INTRODUCTION

In the manufacturing of upholstered furniture are involved different types of materials and joints. One of the most often used joints in the design of upholstered furniture frame is joints with staples.

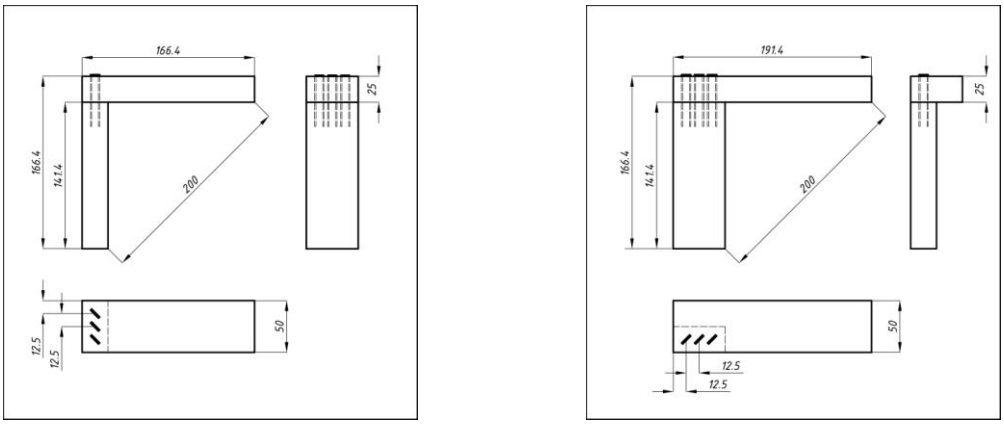
The aim of this work is to provide guidance to manufacturers of upholstered furniture for risks in the use of staples with parameters that are not suitable for the production of wood frame for upholstered furniture, giving precise data characterizing the deformation behavior of the frame construction. The present article is a continuation of a previous work that aimed to determine the maximum bending moments under compression bending tests of end corner joints from pine solid wood.The literature provides data about stiffness coefficients of the different types of end corner joints from solid wood [1,2,3,4]. There is no data about joints with staples from pine solid wood (Pinus sylvestris L.).

2. MATERIAL AND METHOD

For the purpose of the present study were used the following types of end coner joints:

1. Case butt joint with staples type M1.
2. Case butt joint with staples type 92.
3. End-to-face butt joint with staples type M1.
4. End-to-face butt joint with staples type 92.

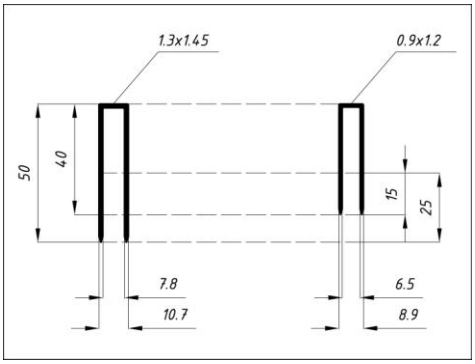
The tested samples have been made of pine solid wood (Pinus sylvestris L.), with rectangular cross section 25x50 mm , with 10% moisture content and density 432 kg/m³. The type, shape and sizes of samples are shown in Figure 1.



Case butt joint *End-to-face butt joint*

Figure 1. *Type and dimensions of the tested samples*

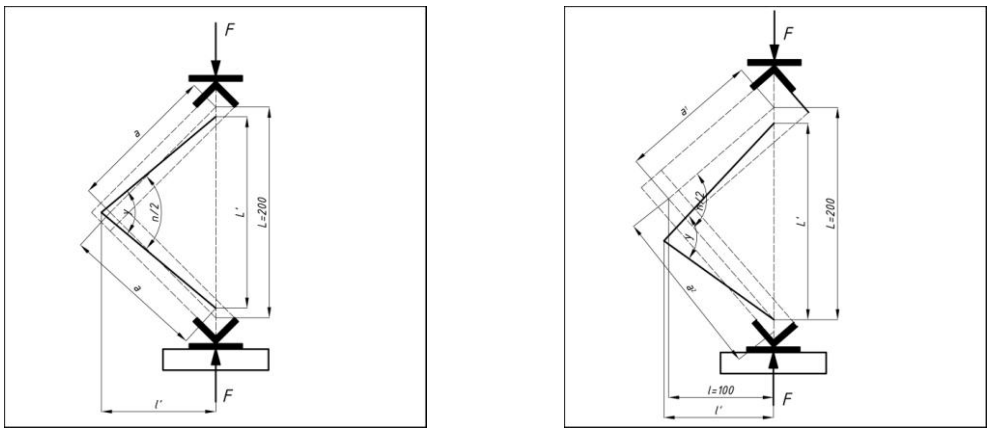
The joining of components was made by three joining staples elements of each sample, with two types of connectors: type M1 and type 92. Dimensions and penetration staples are shown in Figure 2.



type M1 *type 92*

Figure 2. *Dimensions and penetration staples*

Samples were tested under compression bending loading in the Laboratory for Technology of furniture at the Universety of Forestry – Sofia, Department Manufacture of furniture. Using the universal testing machine DINATEST.At a speed of static loading,guaranteeing the occurrence of rupture of each sample in the range of 60 ± 30 s. Scheme of loading and deformation behavior of the test samples under compression bending loading for determining the stiffness coefficients are shown in Figure 3.



Case butt *End-to-face butt joint*

Figure 3*. Type, dimensions and scheme of loading and deformation of tested samples*

3. RESULT AND ANALYSIS

Stiffness coefficients of the tested corner joints are shown in Table 1.

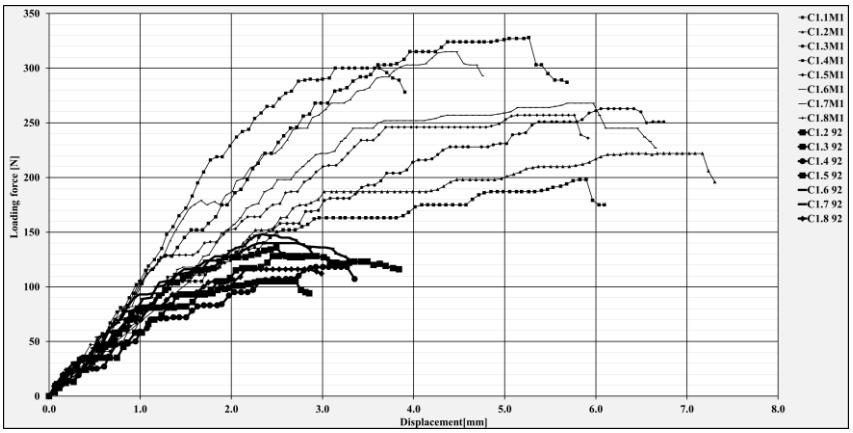
Table 1. *Stiffness coefficients of corner joints with staples from pine solid wood with cross section 25x50 mm under compression bending tests*

№	Type of joints	Stiffness coefficients [Nm/rad]						
		Variation statistics parameters						
		$\bar{\chi}$ [Nm/rad]	Cmax. [Nm/rad]	Cmin. [Nm/rad]	med. [Nm/rad]	s [Nm/rad]	v [%]	n [pc.]
1	Case butt joint with staples type M1.	925.91	1179.32	708.95	923.55	170.58	18.42	8
2	Case butt joit with staples type 92.	716.52	995.21	537.33	661.39	150.59	21.02	8
3	End-to-face butt joint with staples type M1.	2655.31	3177.11	1907.96	2706.36	395.92	14.91	8
4	End-to-face butt joint with staples type 92.	2280.56	2866.86	1762.92	2362.7	390.47	17.12	8

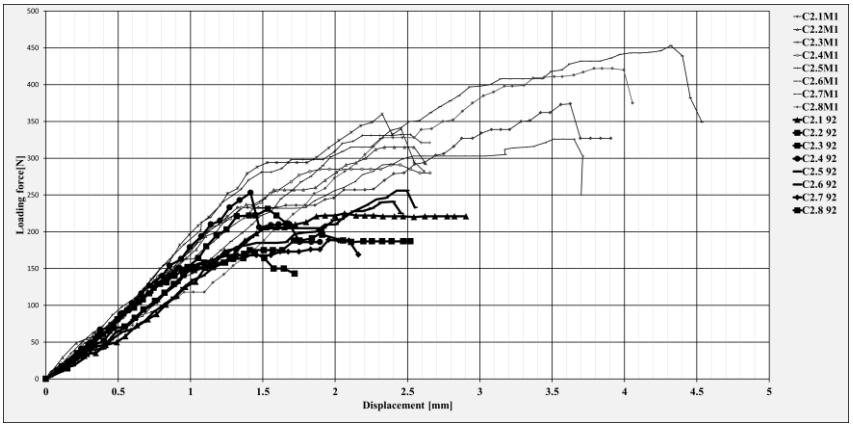
The data from Table 1 indicates that with highest values for the stiffness coefficients are end-to-face butt joint with staples type M1 – 2655.31 Nm/rad. Joints of this kind have 14.11% greater value compared with the joints of the same type with staples 92.

The lowest stiffness coefficients have case butt joints with staple type 92 – 716.52 Nm/rad. While in compounds of the same type with staples M1 stiffness coefficients are increased by 22.61%.

Figure 4 shows the relationship between the loading force and the deformation under compression loading for determining the stiffness coefficients of corner joints of staples type M1 and 92.



Case butt joints with staples type M1 and 92



End-to-face butt joints with staples type M1 and 92

Figure 4. *Dependency between the loading force and the deformation of the tested samples*

The case butt joints with staples show greater deformation at smaller forces of the maximum bending moment and respectively lower values of stiffness coefficients compared with those of end-to-face butt joints with staples.

The elastic line of deformations is clearly expressed as the destruction of the joints occurs gradually, due to a smooth extortion of the staple.

4. CONCLUSION

The results of the experimental investigation to determine the stiffness coefficients of corner joints with staples frome pine solid wood (Pinus sylvestris L.) with cross-section 25x50 mm, give reason to the following general conclusions and recommendations to be made:

- Dimensions and penetration staples directly influence values of stiffness coefficients. In the case of the joints with staples type M1 were established higher stiffness coefficients than those of joints with staples type 92.
- The stiffness coefficients have larger values for end-to-face butt joint with staples than case butt joints with staples.
- The obtained values for the stiffness coefficients are not satisfactory, therefore it is recommended to use them in upholstered furniture frames in combination with stiffening details or stiffening details with gluing.

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The Authors' Addresses:

Desislava Hristodorova
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: dhristodorova @ abv.bg

Yancho Genchev, Assoc. Professor,
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
Tel: +359 2 91 907 / 209; Mob: +359 887 218 863
e-mail: genchevy @ abv.bg

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INFLUENCE OF THE DOVEL WITHOUT ADHESIVE ON STRENGTH AND DURABILITY OF STORAGE FURNITURE

Igor Džinčić, Biserka Nestorović

University of Belgrade, Faculty of Forestry, Belgrade, Serbia
e-mail: igor.dzincic@sfb.bg.ac.rs; biserka.nestorovic@sfb.bg.ac.rs

ABSTRACT

The aim of this study is to present the influence of the dowel without presence of adhesive on strength and durability of cabinet furniture. The dowel without adhesive, which is also known as a “dry dowel“, is a significant part of construction of ready-to-assemble furniture.

The idea for this study came on the bassis of a review of testing results of cabinet furniture in Laboratory for Furniture Control, Faculty of Forestry. Analysis of construction of cabinet furniture, which didn’t fulfill demands according to EN 16122:2012, showed that there are big variations concerning construction solutions within same type of eccentric joint. For analyzing these influence four models of constructive solutions was made. The modeling was made on the basis of changing the position of the “dry dowel“, and its type of fit. In all four models same type of eccentric joint was used.

The results of this research proved the need of presence of a “dry dowel“ in ready-to-assemble furniture. Among this, recomendations for position of a “dry dowel“ are given, as also recomendations for its type of fit.

Key words: cabinet furniture, eccentric joint, strength, durability

1. INTRODUCTION

Strength and withdrawal resistance of different types of fasteners (insert fittings) in different types of wood based panels has been studied for many times (Efe and Kasal, 2000; Smardzewski and Prekrat, 2002; Kasal et all, 2006). The main reasons for using fasteners in ready-to-assemble furniture are: reduced packaging costs, reduced transportation costs of the finished product, easier manipulation, and simple use (even by unskilled person). Fasteners that are commonly used in furniture production are: screws, cam fittings, trapezoid fittings, and eccentric fittings.

Based on previous researches it is obvious that joints are weakest point in furniture construction, and durability of ready-to-assemble furniture is in direct correlation with type of insert fittings and machining accuracy. Result given by here mentioned researchers, indicates that strength of corner joints with insert fittings has slightly difference within different manufactures. Although in papers related with this topic, limited information is available to the end user. Reason for this, is that all studies, in this field, are done on insert fittings without usage of “dry dowel“. The dowel without adhesive, which is also known as a “dry dowel“, is an essential part of ony construction of ready-to-assemble furniture.

The idea for this study came on the bassis of a review of testing results of storage furniture in Laboratory for Furniture Control, Faculty of Forestry. Analysis of construction of storage furniture, which didn’t fulfill demands according to EN 16122:2012, showed that there are big variations concerning construction solutions within same type of eccentric joint. Results given by other authors showed that eccentric insert fittings resulted with very low strength values (Vassiliou and Barboutis 2006, 2009; Smardzewski and Prekrat, 2002; 2004), stated that this type of joints transferred very mall bending moments.

During its lifetime, the joints in the storage furniture are exposed to the forces of varying intensity and direction of action, Figure 1.

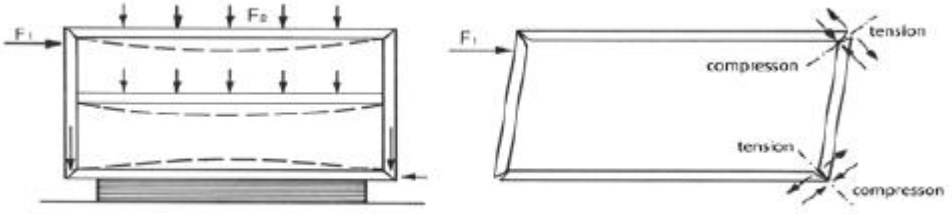

Figure 1. *Stresses in the storage furniture*

In order to fulfill exploitation demands, concerning static and dynamic loads, product must be properly designed. The aim of this study is to present the influence of the dowel without presence of adhesive on strength and durability of storage furniture connected with eccentric insert fittings. Laboratory investigations were conducted on the corner joints as well as on samples of storage furniture.

2. MATERIALS AND METHOD

For the purposes of this study four groups of samples were formed. Groups are labeled with letters from A to D, table 1. Within each group 40 samples were made for testing the bending strength of corner joints, while for the purposes of testing the strength and durability of storage furniture 10 cabinets were made. For the entire study 160 corner joints and 40 cabinets were tested.

Within all four groups of samples type of insert fitting was the same, while presence of “dry dowel“, and its type of fit were varied.

Table 1*. Groups of samples*

group	Type of joint	“dry dowel“	Type of fit of “dry dowel“*	Position of “dry dowel“
A	Häfele Minifix (conector housing with bolt)	no	/	/
B		yes	K/m	32mm from the axis of conector
C		yes	K/p	
D		yes	K/r	

*Type of fit was calculated according to DIN 68101 2012

All samples were manufactured on CNC machine. Fittings were tightened by torsion moment of 5Nm. Before joining the parts of the samples, machining accuracy was tested by the digital caliper, accuracy was in the range of ±0.01mm. All samples (corner joints and cabinets) were made from a three-layer particle board, thickness of 18 mm manufactured by Falco. The density of this panel was 710m^3, with the modulus of elasticity of 1950 N/mm^2. Häfele Minifix (conector housing with connecting bolt) was used. This type of insert fitting represent most common fitting for ready-to-assemble furniture designed for board thickness of 18mm. Dry dowel was made in beech wood. Dimensions was 8•32mm. Type of fit of dry dowel was set according to table 1. Samples for both types of tests had two joints in length. Distance between joints was 288mm. Variation of joints was made according to table 1.

Dimensions of samples for testing the bending strength of corner joints was 400•150•132mm, Figures 2 and 3.

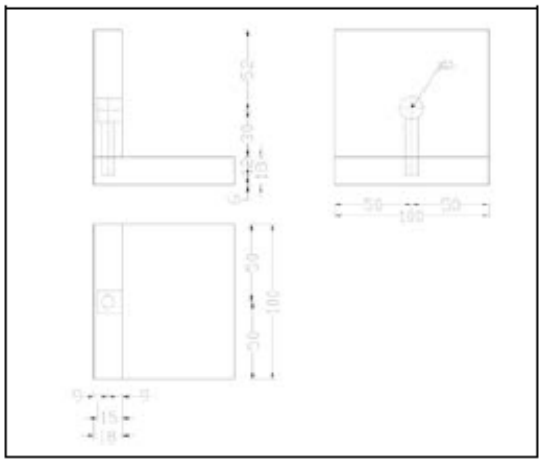

Figure 2. *Construction of sample-group A / section of sample with joint*

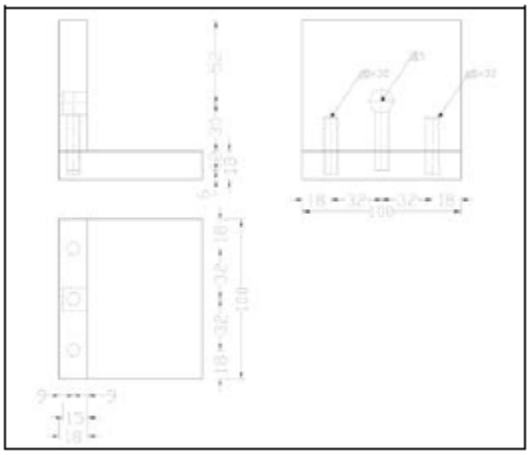

Figure 3. *Construction of sample-group B, C, D/ section of sample with joint*

Dimensions of cabinets for testing strength and durability was 1600•600•400mm (height;width;depth).

All samples was stored in indoor ambient according to EN16122 chapter 4.1.

Testing methods for determination bending strength of angle joints has not been standardized yet. Therefore, method of testing used within this research is made on the basis of testing equipment used by other researchers (Zhang and Eckelman, 1992; Smardzewski and Prekrat, 2002; Tankut and Tankut, 2009; Koreny et all, 2013), Figure 4. Test was conducted in AMSLER universal testing machine, with a rate of 10mm/min. Tests was continued until a major failure occurred. Bending moment was calculated according to expression M=F•r, where M is compression moment (Nm), F is applied load (N), r is arm of loading force (m), which was r =0.099m.

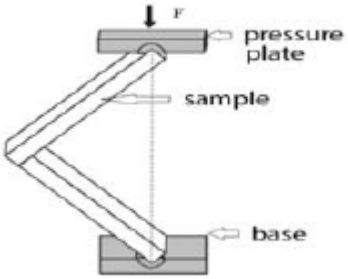

Figure 4. *Schematic view of testing equipment*

Testing of strength and durability of cabinets was done according to EN16122:2012, chapter 6.4. Figure 5 shows force application points.

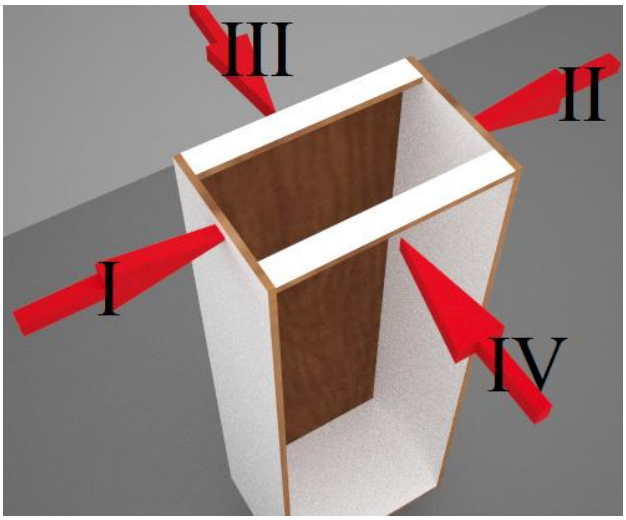

Figure 5. *Force application points*

3. RESULTS AND DISCUSSION

Figure 6 presents test results of bending strength of corner joints of all groups of samples. Moment was calculated by from force multiplied by arm distance. Number of samples within each group was higher than in papers with similar topics. The author felt that larger number of samples will provide meaningful statistic analysis, and deviation brought by nature of materials (particleboard and fittings) will be avoid.

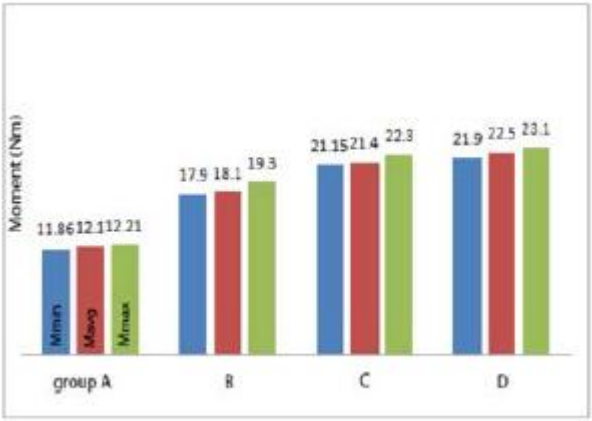

Figure 6. *Results of bending strength of corner joints*

The results of the experiment showed that presence of dry dowel caused high influence on strength of the tested joints. Best results for eccentric joint with the dry dowel are reached by the joints where dry dowel was inserted with overlap (groups C and D). Samples from group B, where dry dowel was inserted with loose fitting, showed higher values of strength comparing with group A, about 33%. Joints, where dry dowel is inserted with overlap (groups C and D), showed higher values of bending moment, than joints where there was a gap between dowel and the hole (group B). Average difference between those groups was about 15%. If we compare strength of joints in-between groups where dry dowel was set with the presence of overlap (groups C and D) we will find the there is no significant difference (about 5%). However, assembling furniture with higher value of overlap within dry dowel in home edition, where end consumer has limited tools selection, could cause problems during furniture joining.

Apparently, the joint strength comes from the presence of dry dowel, and not only from insert fittings. Insert fitting only draws horizontal and vertical element of storage furniture, but dry dowel is the one who bears the loads.

Korny and Simek (2013) analyzed effects of different type of cam fitting and different dowel spacing. Best results were achieved with cam fitting with dowel spacing of 160mm. They didn't gave any information about dry dowels type of fit. This is result was expected because stress was divided upon three carriers, and reaction force was not concentrated in one zone. Result given by these authors is very close to one presented in this paper. Only difference is they set their experiment on single joint per sample, so reaction forces, and bending moments are twice lower. From the practical point of view this position of dry dowel is possible only in big wardrobe closets with depth between 550 and 650mm.

Abdulkadir et all (2013) investigate effects on number and distance between dowels on ready to assemble furniture on bending moment resistance of corner joints. Deference between their results achieved on particle board and results given in this paper, for groups of samples with dry dowel are between 19% for group B and 1% for samples of group D. Also as in the previous paper information about dry dowels type of fit has been omitted.

Stiffness of furniture represents its ability to resist change of shape and damages that may arise due to the forces provided the appropriate standard. Thus, the observed values of stiffness are given as an average value for all four groups of samples. Figure 7 presents values of displacement of cabinets during test of strength and durability according to EN16122:2012, chapter 6.4. Results shoved in Figure 7, presents only displacements during lateral movement (directions of 1 and 2).

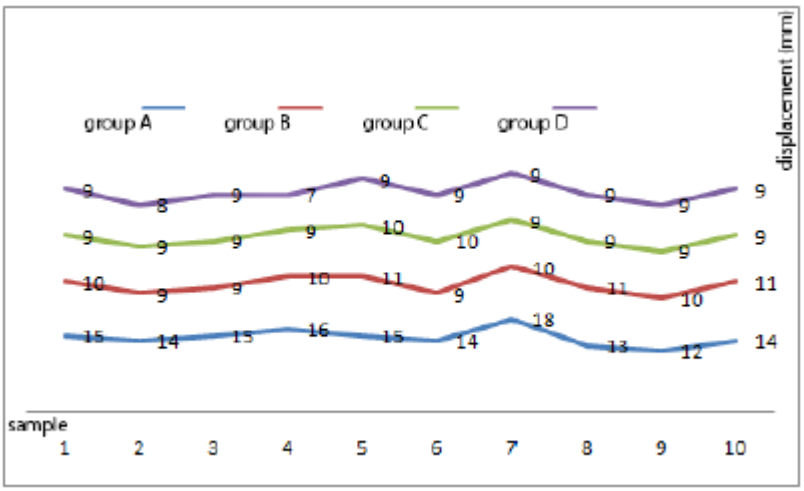

Figure 7. *Values of displacement of cabinets*

Best results of analysis are reached by the groups C and D, where dry dowel was inserted with the presence of overlap. Dry dowels which are too loose don't give enough support to the insert fittings. If we analyze results between groups of samples with the presence of dry dowel we will not find any significant difference. Worst result is within the group A, and it is caused by the absence of dry dowel. Unfortunately results given by other authors are pointed only on angle joints, so any kind of comparing results for displacement of cabinets won't be possible.

4. CONCLUSIONS

The aim of this study is to present the influence of the dowel without presence of adhesive on strength and durability of cabinet furniture. The dowel without adhesive, which is also known as a "dry dowel", is a significant part of construction of ready-to-assemble furniture. For analyzing these influence four models of constructive solutions was made. The modeling was made on the basis of changing the position of the "dry dowel", and its type of fit.

Analysis of joint strength and construction of cabinet furniture proved the need of presence of a “dry dowel“ in ready-to-assemble furniture. Among this, recomendations for type of fit of a “dry dowel“ was given.

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The Authors' Addresses:

Igor Džinčić, **Ph.D**.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: igor.dzincic@sfb.bg.ac.rs

Biserka Nestorović, **Ph.D**.
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: biserka.nestorovic@sfb.bg.ac.rs

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STUDY ON THE NOISE LEVELS GENERATED DURING MILLING OF WOOD FROM COMMON BEACH (*Fagus Sylvatica* L.)

Pavlin Vitchev

University of Forestry, 10 Kliment Ohridski blvd., 1797 Sofia, Bulgaria
e-mail: p_vitchev@abv.bg

ABSTRACT

Wood machining through milling is one of the wide-used, however the noisiest cutting processes in woodworking and furniture industry. The high noise immission levels generated during milling often exceed the accepted sanitary standards.

The objective of this study was to investigate the changes of the noise level, measured at the workplace during flat milling of details from common beech (*Fagus Sylvativa* L.) depending on the feed rate *U*, the speed of the working shaft *n* (cutting speed, respectively) and the thickness of the out cut layer *h*. The sound pressure level was assessed in accordance with the BDS EN ISO 3744:2010 requirements.

Key words: noise, sound imission, milling noise, milling process

1. INTRODUCTION

Woodworking milling machines are widely used in the woodworking and furniture industry, despite being one of the noisiest (*HSE 2007*). It is well-known that the noise immission levels exceeding the acceptable sanitary limits can be hazardous to human health and resulted in a variety of health risks and negative physiological effects including hearing impairment, annoyance, sleeping disturbances, and psychological problems. Therefore the noise levels at work are the main factor which impact on occupational safety and health has to be considered (Brezin, 1992). According to the European Directive 2003/10/EO the upper limit for a workplace noise exposure based on the eight-hour working day is $L_{EX, 8h}$ = 85 dB(A).

For evaluation of the noise levels at workplace, the noise generated by the machine itself and the noise which is a result of the technological process of cutting have to be taken into account. The factors influencing the technological noise levels could be divided into three main groups: factors related to the processing material – wood type, density, moisture content, size of the processing details etc. (HSE, 2009); factors that characterize the cutting tool –operating parameters, construction (HSE, 2009; Vitchev, 2013); factors related to the cutting process – cutting speed, feed rate, cutting height, thickness of the out-cut layer etc.

The objectives of the following study was to investigate the influence of the rotational speed of the cutting tool, the feed rate and the thickness of the output layer on the sound pressure level, measured at workplace and generated during the milling process of wood from common beach (*Fagus Sylvatica* L.).

2. MATERIALS AND METHODS

The experiments have been carried out using woodworking spindel moulder machine, type T1002S (ZMM “Stomana” GmbH, Bulgaria). The machine was equipped with a two-speed three-phase electric motor with power 3,2/4,0 kW, which through a belt drive provides the following rotating frequency of the working shaft: 3000, 4000, 5000, 6000, 8000 and 10000 min^{-1}.

A cutting tool with an assembled construction for longitudinal plane milling, kindly provided by Metal World – Italy, was used. The technical characteristics of the tool are given in Table 1, where *D* is the diameter of the milling machine, *d* – diameter of the threaded hole, *B* – width of the milling, β – sharpening angle, γ – hook angle, *z* – number of teeth.

Table 1. *Technical characteristics of the used cutting tool*

General look of the milling cutter	***D*** **[mm]**	***d*** **[mm]**	***B*** **[mm]**	**β [°]**	**γ [°]**	***z*** **[No]**	**Material of the teeth**
	125	30	50	47	16	4	Carbide (HM)

The work pieces with the following characteristics: density ρ = 490 kg.m^{-3}, moisture content W = 12,7 % and dimensions 1000 x 30 x 50 mm were used. The work pieces have been submitted to the cutting tool by a feeder, part of the woodworking milling machine and driven by a separate motor. The experiments were conducted in a free sound field using a standardized methodology (Vitchev, 2013a).

The *A*-weighted sound pressure level $L`_{p(A)}$ in dB(A) is measured at a point corresponding to the to the location of the operator and standing at a distance of 1 m from the edges of the machine, and at a height of 1,5 m from the reverberating floor.

The actual *A*-weighted sound pressure level measured at workplace $L_{p(A)}$, is calculated using the following equation:

$$L_{p(A)} = L`_{p(A)} - K_1 - K_2 \text{, dB(A),} \quad (1)$$

where K_1 is a background noise correction coefficient, dB(A);
K_2 is an environmental correction coefficient, dB (A).

The measurements were performed using precise impulse sound level meter (RFT, Germany) that measures both linear sound pressure levels and sound levels, corrected according to the standard frequency characteristics: *A, B, C* and *D* weighted curves with a frequency range from 20 Hz to 20 kHz. The measurements were done at a time constant “fast” (*F*). Before the initiation of the experiments the entire measurement track has been calibrated, using a standard sound source Pistonfon PF 101 (RFT, Germany).

Before the initiation of the experiments the entire measurement track has been calibrated, using a standard sound source Pistonfon PF 101 with a constant sound pressure level equal to 117,1 dB on $p_0 = 2.10^{-5}$ Pa at a frequency f = 180 Hz.

The requirements given in BDS EN ISO 3744:2010 and BDS ISO 7960:2005 were strictly followed throughout the experiments.

In order to trace the combined influence of the all three parameters: the rotational speed (*n*) of the cutting toll, the rate feed (*U*) and the thickness of the output layer (*h*) on the changes in the sound pressure level, three factorial regression analysis was used (Vuchkov et al. 1986)

The levels of the input variables in coded and explicit form are given in Table 2. The values are consistent with those that are the most frequently used in practice.

Table 2. *Values of the variables n, U and h*

Variable	Minimum value		Avarage value		Maximum value	
	explicit	coded	explicit	coded	explicit	coded
Rotating frequence $n = x_1$ [min^{-1}]	4000	- 1	6000	0	8000	1
Feed rate $U = x_2$ [m.min^{-1}]	3,5	-1	7	0	10,5	1
Thickness of the cut-out layer $h = x_3$ [mm]	1	-1	2	0	3	1

The measurements were performed in accordance with a preliminary designed matrix B_3 for three factorial experiment plan of G.Box of second order which is shown in Table 3. For the statystical analysis of the data QstatLab softwear was used.

3. RESULTS AND DISCUSSION

After applying the method of regression analysis and statistical analysis of the data we received the following polynomial of second degree:

$$\hat{y} = 80{,}743 + 2{,}617x_1 + 2{,}766x_2 + 1{,}533x_3 - 0{,}686x_1x_2 + 0{,}604x_2x_3 - 0{,}811x_1x_3 + 0{,}157x_1^2 + 1{,}572x_2^2 + 1{,}407x_3^2, \quad (2)$$

The average sound pressure level values $(\overline{L_{p\,(A)}})$, calculated on the basis of the results obtained from the three factorial experiments are presented in Table 3. The values of the regression coefficients are given in Table 4. The coefficient of determination (*R*-squared value) is $R^2 = 0{,}855$.

Table 3. *Planning matrix for three factorial experiment and average sound pressure level values* $(\overline{L_{p\,(A)}})$

№ опит	$x_1 = n$ [min^{-1}]		$x_2 = U$ [m.min^{-1}]		$x_3 = h$ [mm]		$\overline{L_{p(A)}}$ [dB(A)]	№ опит	$x_1 = n$ [min^{-1}]		$x_2 = U$ [m.min^{-1}]		$x_3 = h$ [mm]		$\overline{L_{p(A)}}$ [dB(A)]
1	-1	4000	-1	3,5	-1	1	76,57	8	1	8000	1	10,5	1	3	89,40
2	-1	4000	-1	3,5	1	3	79,40	9	-1	4000	0	7	0	2	77,40
3	-1	4000	1	10,5	-1	1	81,23	10	1	8000	0	7	0	2	84,40
4	-1	4000	1	10,5	1	3	88,73	11	0	6000	-1	3,5	0	2	79,73
5	1	6000	-1	3,5	-1	1	83,23	12	0	6000	1	10,5	0	2	84,90
6	1	6000	-1	3,5	1	3	85,07	13	0	6000	0	7	-1	1	81,57
7	1	6000	1	10,5	-1	1	87,40	14	0	6000	0	7	1	3	82,73

Table 4. *Regression coefficients*

Coefficient	Coded values	Coefficient	Coded values
b_1	2,617	b_{33}	1,407
b_2	2,766	b_{12}	-0,686
b_3	1,533	b_{23}	0,604
b_{11}	0,157	b_{13}	-0,811
b_{22}	1,572		

Regarding the regression coefficient values (Table 4) the highest influence on the sound level, generated during milling of work pieces from beech wood was exerted by the feed rate $U = x_2$ with a regression coefficient $b_2 = 2{,}766$. It is also notable that the rotational frequency of the working shaft $n = x_1$ with a regression coefficient $b_1 = 2{,}617$ had nearly equal influence on the sound pressure level. The lowest influence had the thickness of the output layer $h = x_3$ with the regression coefficient

b_3 = 1,533. The positive values of the all three regression coefficients showed that by increasing the values of the tested parameters, the sound pressure level at workplace will also increase.

The changes in the *A*-weighted sound pressure level $L_{p(A)}$ dependent on the rate feed *U* at different thickness of the output layer are shown in Figure 1.

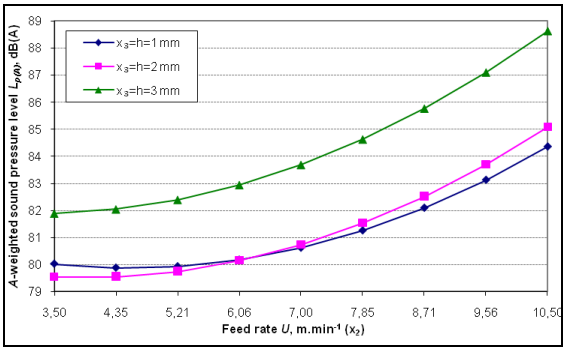

Figure 1. *Influence of the feed rate U on the sound pressure level $L_{p(A)}$ measured at workplace and generated during milling of beech wood work pieces at different thickness of the output layer h and at the rotational speed of the working shaft $n \equiv x_1 = const = 6000$ min^{-1}*

It is visible from the graph that the sound pressure level $L_{p(A)}$ increases with the increase of the rate feed *U*. This relationship is the most pronounced at the output layer thickness *h* = 3 mm where the sound level started to increase with the increase of the feed rate. At feed rates *U* from 3,5 m.min^{-1} to 7 m.min^{-1} and thickness of the output layer *h* = 3 mm the sound level increased with less intensity compared to feed rate higher than 7 m.min^{-1}.

In the whole tested range of feed rate (from 3,5 to 10,5 m.min^{-1}) the highest noise levels were measured at the output layer thickness *h* = 3 mm as at the feed rate up to 8 m.min^{-1} it was within the sanitary acceptable range of 85 dB(A). With increasing the feed rate from 8 m.min^{-1} to 10,5 m.min^{-1} the values of the sound pressure level increased from 85 dB(A) to 88,6 dB(A), respectively. Thus the noise level was increased by 3,6 dB(A) which accounts for nearly two fold higher noise measured at workplace.

At the output layer thicknesses *h* = 1 mm and *h* = 2 mm the sound pressure level was nearly equal and has not been influenced by the change of the feed rate within the range from 3,5 m.min^{-1} to 6,0 m.min^{-1}.

In Figure 2 the changes of the sound pressure level depending on the rotational frequency *n* at different rate feeds *U* is presented.

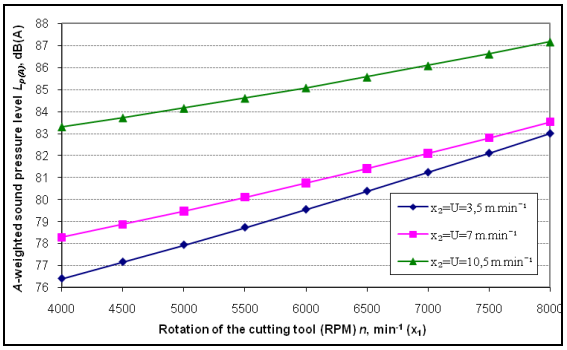

Figure 2. *Influence of the rotational frequency of the working shaft n on the sound pressure level $L_{p(A)}$ measured at workplace and generated during milling of beech wood work pieces at different feed rate U and thickness of the $h \equiv x_3 = const = 2$ mm*

It is visible that for the all tested rotational speeds of the working shaft during the cutting mode of the machine, the highest generated noise levels were at rate feed *U* = 10,5 m.min^{-1}, which is in good correlation with the results shown in Figure 1. At feed rate 10,5 m.min^{-1} and rotational frequency *n* up to 5500 min^{-1} the sound pressure level was within the sanitary standards. The sound pressure level

increased with the increase of the rotational frequency of the working shaft as at n = 8000 min^{-1} it reached 87,1 dB(A).

When the feed rate was U = 3,5 m.min^{-1} and U = 7 m.min^{-1} the sound pressure level was under the sanitary norm of 85 dB(A). At rotational frequencies of the working shaft n from 4000 min^{-1} to 6500 min^{-1} difference in the noise levels between the lower rate feed was observed. With an increase of the rotational frequency, however, this difference decreased and at n = 8000 min^{-1} and U = 3,5 m.min^{-1} and U = 7 m.min^{-1} the sound pressure level values were nearly equal (Figure 2).

Comparing the all three rate feed the heist increased in noise intensity was observed at the lowest rate feed U = 3,5 m.min^{-1}, as its level changed from 76,4 dB(A) at n = 4000 min^{-1} to 83 dB(A) at n = 8000 min^{-1}, i.e. increased by 6,6 dB(A). With the increase of the rate feed the intensity of the noise level decreased. At feed rate U = 10,5 m.min^{-1} the sound pressure level changed from 83 dB(A) at n = 4000 min^{-1} to 87 dB(A) at n = 8000 min^{-1}, i.e. by 4 dB(A).

The changes in the sound pressure level depending on the rotational frequency of the working shaft n at different thicknesses of the output layer h are shown in Figure 3.

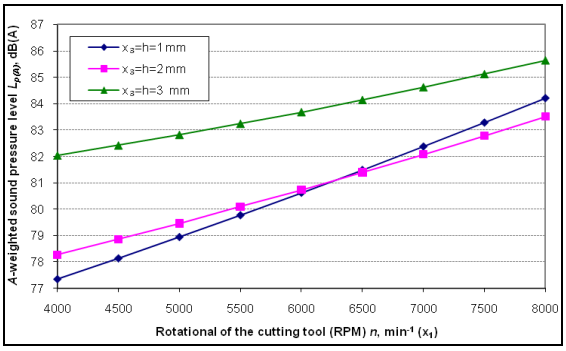

Figure 3. *Influence of the rotational frequency of the working shaft n on the sound pressure level $L_{p(A)}$ measured at workplace and generated during milling of beech wood work pieces at different thicknesses of the output layer h and feed rate $U \equiv x_2$=const=7 m.min^{-1}*

It is visible from the graph that depending on the rotational frequency, for the three tested output layer thicknesses (h = 1 mm, h = 2 mm and h = 3 mm) the changes in the sound pressure level followed the same tendency. The highest sound pressure level was measured at h = 3 mm, as at rotational frequency of the working shaft n=8000min^{-1} it was 85,7 dB(A). At h = 1 mm and h = 2 mm, the changes in the sound pressure level, measured at all rotational frequencies of the working shaft of the mill were under the accepted sanitary standards. From the figure is also observed that the noise intensity was greater at values of the output layer thickness h = 1 mm, h = 2 mm and when the rotational frequency of the working shaft was increased. At the thickness of the output layer h = 3 mm the sound pressure level changed from 82 dB(A) at rotational frequency n = 4000 min^{-1} to 85,7 dB(A) at n = 8000 min^{-1}, i.e. the noise increased by 3,7 dB(A). At h = 1 mm the change in the noise levels at n = 4000 min^{-1} and n = 8000 min^{-1} was 7,2 dB(A), and at h = 2 mm was 5,5 dB(A).

4. CONCLUSIONS

On the basis of the experiments carried out to investigate the changes in the sound pressure level, measured at workplace and generated during milling of wood from common beech, the following conclusions can be drawn:

Among the investigated factors (rotational speed of the cutting tool n, rate feed U and thickness of the output layer) the highest influence on the sound pressure level exerted the rate feed U. At feed rate up to 7,9 m.min^{-1} and for the all tested thickness of output layer (h = 1, h = 2 and h = 3 mm), the sound pressure level measured at workplace was under the accepted sanitary standards.

Our results determined one more time that the rotational speed of the working shaft or the cutting tool, respectively is the major factor influencing the sound pressure level, generated by the woodworking milling machines.

When a cutting tool with a diameter D = 125 mm and rotational frequency up to 6000 min^{-1} have been used the level of the generated noise was within the sanitary standard limits. At a constant rotational frequency of the cutting tool, the noise levels increased with an increase of the speed rate.

Amongst the investigated factors, the less influence on the sound pressure level was exerted by the thickness of the output layer h. For the whole examined range of rotational frequencies n from 4000 min^{-1} to 8000 min^{-1} and rate feed U = 7 $m.min^{-1}$ the highest noise levels were measured at h = 1 mm and h = 2 mm. Compared to those two lower values of the thickness of the output layer, the sound level was significantly higher at h = 3 mm (see Figure 3).

Regarding the results of our study we observed significant influence of the evaluated factors on the sound pressure levels, measured at workplace. The influence of these factors on the cutting process has to be taken into account for better planning of the technological process and for reducing the noise immission levels alike. The later will ensure healthier and safer work conditions at the workplace.

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The Authors' Addresses:

Pavlin Vitchev
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1797, BULGARIA
e-mail: p_vitchev@abv.bg

UDC (UDK): 613.644:674(496.5)

THE EFFECT OF MECHANICAL PROCESSING OF ALBANIAN BEECH ON ACOUSTIC POLLUTION

Holta Çota, Arben Bejtja, Entela Lato, Doklea Quku

Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz, Albania,
e-mail: h.cota@hotmail.com

ABSTRACT

The wood processing industry consists in primary and secondary processing of the wood, by both performing a wider work processes from the production of saw timber, wood drying, production of wood based panels, furniture manufacturing etc.

The wood processing employees are exposed to work hazards starting from various accidents at work, to the risks of contaminations by wood dusts, noise pollution, chemical agents etc.
The noise pollution is an environmental contaminant, which is known as a real threat to people’s health and quality of life. The noise may at least decrease the work effectiveness; affects health and increases the rate of incidents. Hearing loss is caused by prolonged exposure in noise which exceeds the level of 85 dB (A) in an eight hours period.

This study consists in analyzing some elements of noise pollution during the processing of beech timber in planner and router machines, which are available in woodworking facility of the Faculty of Forest Sciences of Tirana. Albanian beech is one of the most used woods in wood processing companies in Albania. During the tests, the above mentioned machines are run in two different feeding rates. The measurement method of noise levels are those approved by WHO (World Health Organization) and used by the PHI – Public Health Institute of Albania. All measurements are done using the Sound Level Metter EXTECH 40 7764 RS-232/Data logger equipment.

From all the measurements, it resulted that during the beech processing in planner machine, the noise levels don’t exceed the permissive noise level of 85 dB(A), while during the beech processing in router machine the levels of noise are higher, exceeding considerably the permissive noise level of 85 dB(A) in both feeding rates.

Key words: noise pollution, beech, noise level, planner machine, router machine

1. INTRODUCTION

The wood processing industry is a very important industry with a considerable number of employees.

The wood processing industry consists in primary and secondary processing of the wood, by conducting a wider work processes from the production of saw timber, wood drying, production of wood based panels, furniture manufacturing etc.

Every day, millions of employees in Europe and worldwide are exposed to noise pollution and to hazards that this noise causes in the work environment* (European Agency for Safety and Health at Work, 2005, Reducing the risks from occupational noise.) Noise may be defined as unwanted sound.

The noise pollution is an environmental contaminant, which is known as a real threat to people's health and quality of life. Noise pollution can be considered as the contaminant of the air in the same way as by various gases.

There are indicators that a noise may at least weaken the effectiveness at work; affects health and increases the rate of incidents. At much higher levels, noise can damage hearing immediately, but even lower levels can have gradual hearing damage.

There is a reasonable correlation between noise exposure and hearing loss: the greater the noise and the longer the exposure time, much greater is the damage to the delicate hearing nerve.

Hearing loss is caused by prolonged exposure in the noise which exceeds the level of 85 dB(A) in a 8 working hours period. The cause of hearing damage from exposure to these noise levels is the damage of the inner ear. The irreparable hearing damage starts at the peak noise level at about 130-140 dB(C). There are not very complete data about the number of employees suffering from the hearing loss. The hearing loss from the work noises is very spread and irreparable.

Many studies were carrying out all over the world to determine the effects of noise on the human health and actually the industry is governed by noise regulations adopted by OSHA (Occupational Safety and Health Administration).

In accordance with amendments to Division 2.10 of the Occupational Health, Safety and Welfare Regulations 1995, which came into effect on 7 October 2004, the noise exposure standard is:

• An eight-hour equivalent continuous A-weighted sound pressure level, LAeq, 8h of 85 dB(A) referenced to 20 micropascals (μPa).The LAeq,8h is that steady state noise level, which would in the course of an eight-hour period, cause the same A-weighted sound energy as that due to the actual noise over an actual working day. That is, when the work period is either shorter or longer than eight hours the LA eq value must be extrapolated to an eight-hour LA eq and should be designated LAeq,8h.

• A C-weighted peak sound pressure level, LC, peak of 140dB(C) reference to 20 μPa. This means that exposure to varying, intermittent or impulse noise should not exceed 140 dB(C) at any instant in time (as measured on the peak setting on the sound level meter).

Also in Albania are set sanitary norms on permissible levels of noise in the work area, according the Article 2 of Decree Nr.4396, dt.7.6.1968 on State Sanitary Inspectorate. There are some exposure limits according this Article:

Table 1. *Table of noise exposure limits*

Work hour	**Average Noise level dB(A)**
8 orë	85 dB(A)
4 “	90 “
2 “	95 “
1 “	100 “
1/2 “	105 “
1/4 “	110 “

This study consists in analyzing the noise level during the use of beech in some wood processing machines.

Tests were performed for two operations, which were carried out in the main wood processing machines, which are located in every workshop, such as the wood planner machine and router machine, which are available in the workshop of the Faculty of Forest Sciences of Tirana.

During the tests two feeding rates were used V1 = 3m/min and V2 = 7m/min, which differ considerably among them.

The method for such measurements is that approved by the WHO (World Health Organization) and used by the PHI (Public Health Institute of Albania).

For noise measurements, the Sound Level Metter EXTECH 407764 RS-232/Datalogger equipment was used.

Figure 1. *Sound Level Meter EXTECH 407764*

The devices for measuring the dust and noise were inquired at PHI (Public Health Institute of Albania) since they are certified and calibrated. These devices are portable.

The data derived through these measurements were subject to statistical processing.

2. MATERIAL AND METHODS

The tests were performed using the beech timber from the hardwood as one of the most wide spreaded species in Albanian forest and among the most useful types of wood in Albanian wood industry.

Tests were carried out in wood planner machine and router machine, which are available in the workshop of the Faculty of Forest Sciences of Tirana.

For all samples were taken moisture measurements, which resulted an average moisture of 14.28 % to 14.78 %.

During the tests two feeding rates were used V1 = 3m/min and V2 = 7m/min, which differ considerably among them. The samples were 36 x 36 x 800 mm.

The method for such measurements is that approved by the WHO (World Health Organization) and used by the PHI (Public Health Institute of Albania).

For noise measurements, the Sound Level Metter EXTECH 407764 RS-232/Datalogger equipment was used. This instrument enables to perform measurements every 3 seconds, i.e. about 20 readings per minute.

The measurement from the noise source at a distance about 1.5 m, were according the European Union (EU) Directive 86/188/EEC. The device was placed near the employee’s ear performing the work.

After determining the next steps of the process, initially it was preceded by passing the samples into the planner machine for two minutes without interruption. Every measurement lasts 2 minutes and Sound Level Metter read every 3 seconds the equivalent noise level Laeq. The measurements for each group were carried out for two feeding rates. The thickness of the processing is 1 mm for each case. After the measurements of in the planner machine, it is preceded with the measurements in the router machine for each feeding rate.

Figure 2. *View during the experimental work*

All the data obtained the measurements were subject to statistical processing.

3. RESULTS

The Average Noise Levels Laeq for the different work regimes are given in the Table 2.

Table 2. *The Average Noise Levels Laeq*

Average value				
Feeding rate	**Material**	**Machine**	**b width (mm)**	**Laeq**
V1	Beech	Planner	36	83.1
V1	Beech	Planner	36	82.43
V1	Beech	Planner	36	83.19
V1	Beech	Planner	36	82.4
V1	Beech	Router	36	90.91
V1	Beech	Router	36	90.24
V1	Beech	Router	36	90.78
V1	Beech	Router	36	90.39
V2	Beech	Planner	36	84.6
V2	Beech	Planner	36	83.8
V2	Beech	Planner	36	83.98
V2	Beech	Planner	36	84.39
V2	Beech	Router	36	90.4
V2	Beech	Router	36	91.29
V2	Beech	Router	36	90.23
V2	Beech	Router	36	91.49
V2	Beech	Router	36	90.07
V2	Beech	Router	36	90.45
V2	Beech	Router	36	90.51
V2	Beech	Router	36	90.01

The beech samples were processed with two feeding rates in planner machine.

Table 3. *Summary of studied cases*

	Cases					
	Studied		Excluded		Mean	
	Nr	Percentage	Nr	Percentage	Nr	Percentage
Laeq (dB) Feeding rates Thickness (mm)	8	100.0%	0	.0%	8	100.0%

In the following table are given the Eqivalent Noise levels Laeq (dB) resulting from the beech worked in planner machine for the two feeding rates

Table 4. *Eqivalent Noise levels Laeq (dB) resulting from the beech worked in planner machine for the two feeding rates*

Feeding Rate	h Thickness (mm)	Mean	Test Nr	Standard Dev
V1	36	82.7800	4	.42324
	Mean	82.7800	4	.42324
V2	36	84.1925	4	.36709
	Mean	84.1925	4	.36709
Mean	36	83.4863	8	.83939
	Mean	83.4863	8	.83939

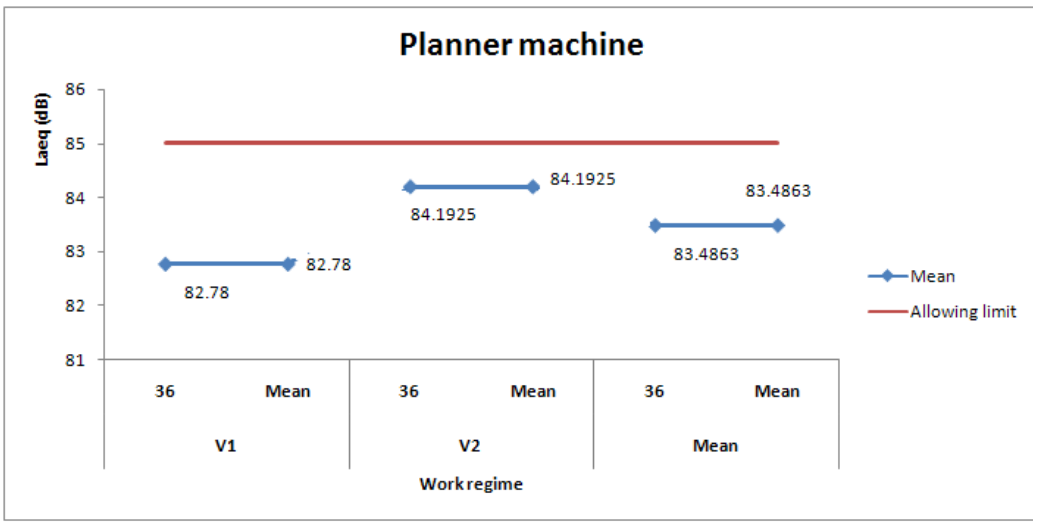

Figure 3. *Equivalent Noise Level (dB) during the processing of beech in planner machine*

From the processing of beech in planner machine it is noticed:

- During the beech proceesing in planner machine for the two feeding speed, the Equivalent noise level doesn’t exceed the allowing limit of 85 dB.
- The noise level that results from the V2 feeding rate is bigger than the noise level resulting from the V1 feeding rates because the cutting forces are larger during the processing with the V2 since the V2>V1.

The beech samples were processed with two feeding rates in router machine.

Table 5. *Summary of studied cases*

	Cases					
	Studied		Studied		Studied	
	Nr	Nr	Nr	Nr	Nr	Nr
Laeq (dB) Feeding rates Thickness (mm)	8	100.0%	0	.0%	8	100.0%

In the following table are given the Eqivalent Noise levels Laeq (dB) resulting from the beech worked in router machine for the two feeding rates.

Table 6. *Eqivalent Noise levels Laeq (dB) resulting from the beech worked in router machine for the two feeding rates*

Feeding Rate	h Thickness (mm)	Mean	Test Nr	Standard Dev
V1	36	90.5800	4	.31654
	Mean	90.5800	4	.31654
V2	36	90.8525	4	.62983
	Mean	90.8525	4	.62983
Mean	36	90.7163	8	.48391
	Mean	90.7163	8	.48391

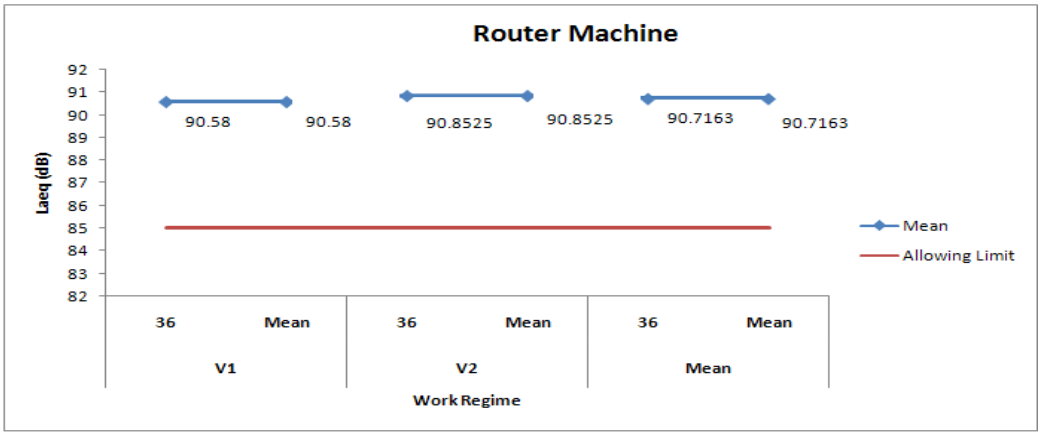

Figure 4. *Equivalent Noise Level (dB) during the processing of beech in router machine*

From the table and chart data it is noticed:

- During the beech proceesing in router machine for the two feeding speed, the Equivalent noise level exceeds the allowing limit of 85 dB, reaching the max value of 90.85 dB.
- The Equivalent noise level exceeds the allowing limit of 85 dB for the two feeding rates

4. CONCLUSION

Based on the results this research, it is noticed:

- Highest level of noise results from the processing of beech samples processing in the router machine, at 90.85 dB level, by exceeding considerably the permissive noise level of 85 dB. This happens for the two feeding rates.
- The level of noise resulting from the processing of beech in planner machine doesn’t exceed the permissive noise level of 85 dB.

- In general, by increasing the feeding rate from V1 to V2 increases the noise level, for all the work regimes carried out, because the cutting forces are larger than working with V2 feeding rates.

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The Authors’ Addresses:

Holta Çota, PhD
Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz
ALBANIA
e-mail: h.cota@hotmail.com

Arben Bejtja
Associate Professor
Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz
ALBANIA
e-mail: arbenbejtja@yahoo.com

Entela Lato
Professor
Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz
ALBANIA
e-mail: entela.lato@yahoo.com

Doklea Quku
Associate Professor
Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz
ALBANIA
e-mail: dokleaquku@yahoo.com

UDC (UDK): 674.053:621.934

RESEARCH ON KERF NUMBER INFLUENCE ON CUTTING POWER DURING WOODPROCESING ON CIRCULAR SAW

Kiril Paralidov[1], Vladimir Koljozov[2], Zoran Trposki[2], Vladimir Karanakov[2]

[1]Ki-par doo Strumica, Macedonia, e-mail:paralidov@hotmail.com
[2]Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje,
e-mail: koljozov@fdtme.ukim.edu.mk; trposki@fdtme.ukim.edu.mk;
karanakov@fdtme.ukim.edu.mk

ABSTRACT

The research have been carried using a circular saws with equal diameter of 250 mm, saw thickness of 3,2 mm, and different kerf number (40/60/80). The cutting elements of the tool are carbide tipped. The processing is made on MDF boards with thickness of 16 mm. By combining one, two or three boards we obtained cutting heights of 16, 32 and 48 mm respectively. Measuring of cutting resistance is done by measuring the electrical current, using a voltage clamp type KYORITSU 2056R. For each cutting section separately, and length of 1m, 30 measurements are made.

Key words: circular saw, cutting power, cutting height, surface quality

1. INTRODUCTION

The aim of this research is to determine the influence of circular saw kerf number on processing quality and cutting resistance.

When processing on circular saws with equal diameter and equal peripheral cutting speed, the number of teeth that actively participate in the process of cutting per time is different. This has a significant impact on the thickness of wood chips, as well as the pressure on the kerf, especially at the rear surface of the blade.

The data collected from experimental measurements are analytically and statistically processed. The final results are used to obtain appropriate conclusions about the impact of input parameters on the cutting resistance.

2. MATERIALS AND METHODS

The main raw material used in the research is MDF board with thickness of 16 mm. Selected material from wood particles having a relatively high homogeneous properties in all directions. The different cutting height is achieved by multiplying the thickness of 16 mm. Volume mass of MDF boards is 710 kg/m^3.

We used three different circular saws with diameter 250 mm, thickness 3,2 mm, with different number of teeth (Z = 40, 60 and 80). The teeth are TCT blades with identical geometrical parameters.

To achieve the cutting height of 16, 32 and 48 mm, we used MDF boards with modular thickness of 16 mm. For different cutting heights (16, 32 and 48 mm) we used one board of 16 mm for the first cutting height, two plates (2×16) for cutting height of 32 mm and three boards (3×16) the height of the cutting 48 mm.

For a selected number of teeth of the circular saw (Z = 40/60/80) and for different cutting heights (h = 16 / 32 / 48mm) we made five series of 30 measurements.

Measuring the intensity of current is accomplished by voltage clamp pliers type KYORITSU kew snap 2056R, 30 measurements on length of 1m, for each cut separately.

Statistical processing of measurements includes average values of central tendency, standard error, standard deviation, coefficient of variation and t-test to determine the significance of differences between the studied groups.

3. RESULTS

The dependence between the cutting resistance and cutting height for kerf number Z=40 is shown in Figure 1, Figure 2 and Figure 3.

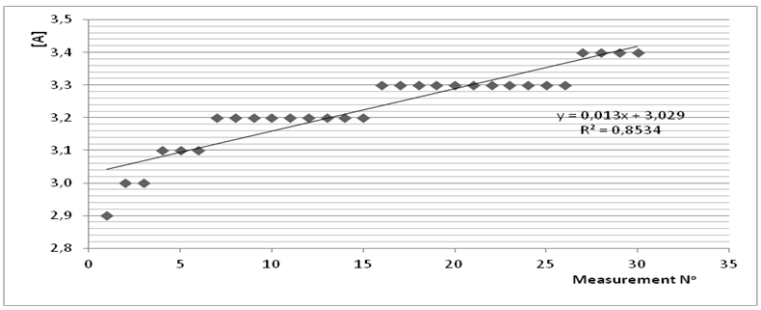

Figure 1. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=40, cutting height h=16 mm)*

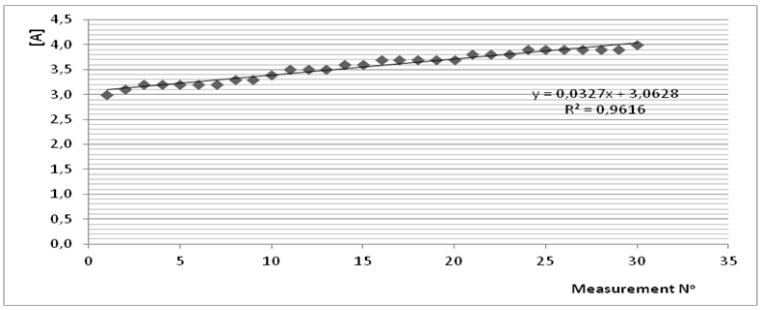

Figure 2. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=40, cutting height h=32 mm)*

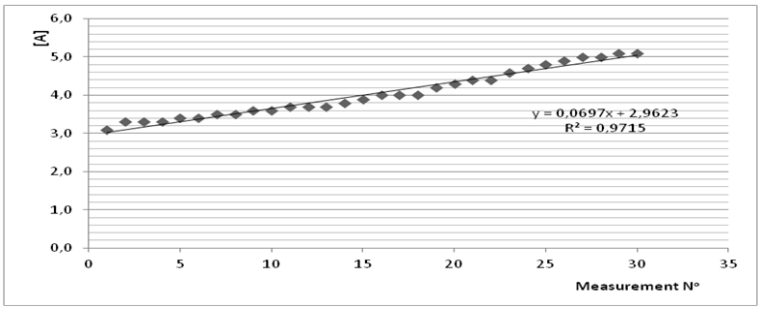

Figure 3. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=40, cutting height h=48 mm)*

The dependence between the cutting resistance and cutting height for kerf number Z=60 is shown in Figure 4, Figure 5 and Figure 6.

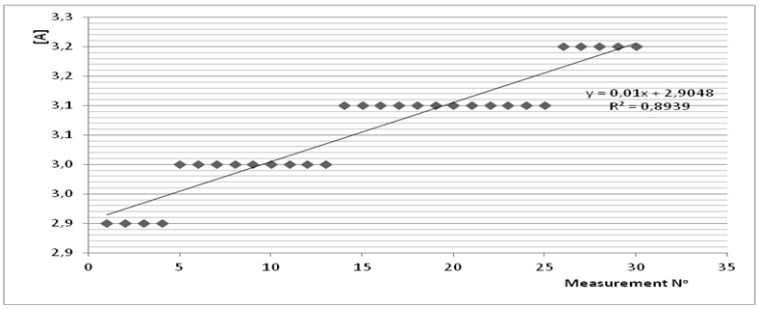

Figure 4. Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=60, cutting height h=16 mm)

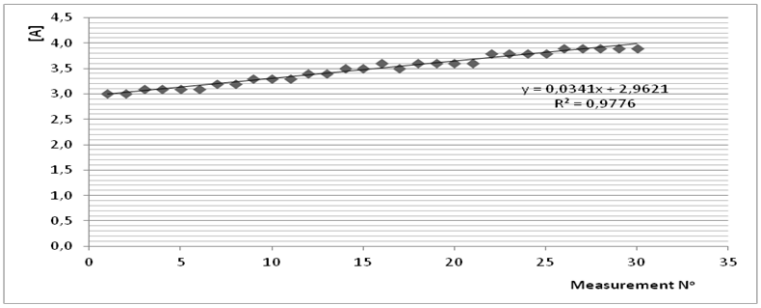

Figure 5. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=60, cutting height h=32 mm)*

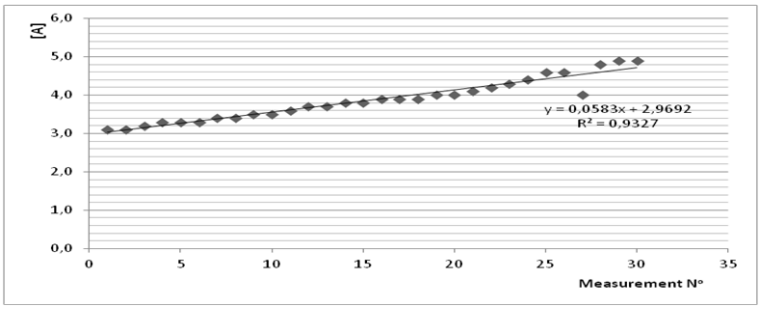

Figure 6. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=60, cutting height h=48 mm)*

The dependence between the cutting resistance and cutting height for kerf number Z=80 is shown in Figure 7, Figure 8 and Figure 9.

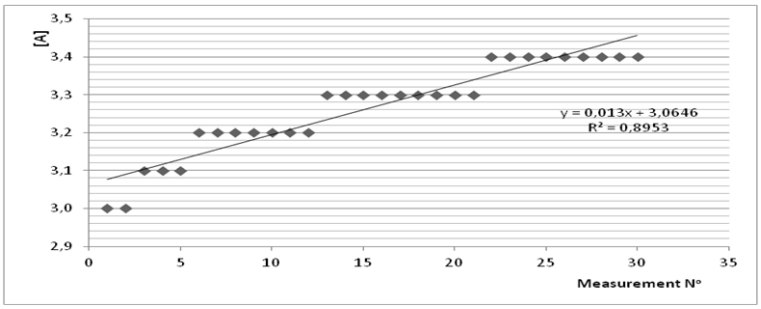

Figure 7. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=80, cutting height h=16 mm)*

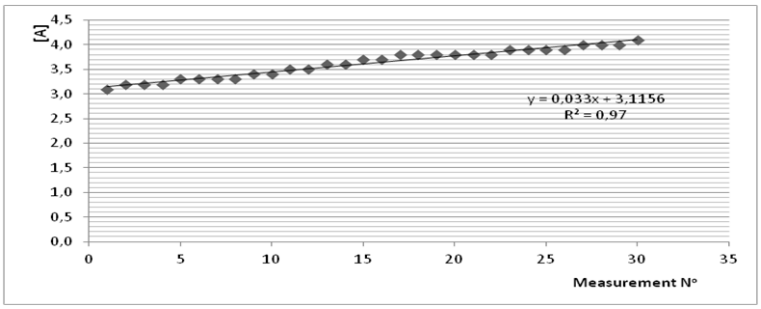

Figure 8. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=80, cutting height h=32 mm)*

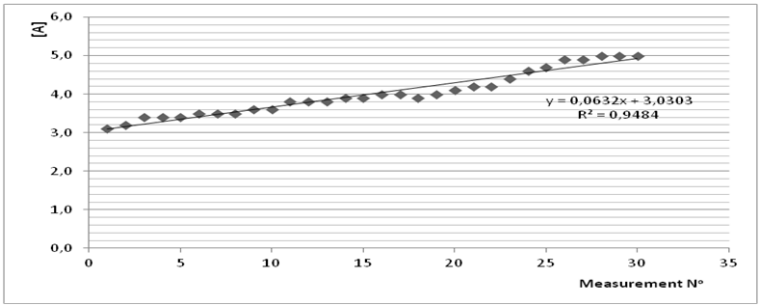

Figure 9. *Cutting resistance measured data, average value, correlation coefficient for circular saw processing (saw diameter D=250 mm, kerf number Z=80, cutting height h=48 mm)*

4. CONCLUSIONS

- The cutting resistance values, for kerf number Z=40 and cutting height h=16/32/48 mm, show proportional dependence. It is determined by linear equation y=0,34x+2,69 and high correlation coefficient R^2=0,9897.
- The cutting resistance values, for kerf number Z=60 and cutting height h=16/32/48 mm, show proportional dependence. It is determined by linear equation y=0,4x+2,6667 and high correlation coefficient R^2=0,9992.
- The cutting resistance values, for kerf number Z=80 and cutting height h=16/32/48 mm, show proportional dependence. It is determined by linear equation y=0,39x+2,8467 and high correlation coefficient R^2=0,99980.

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The Authors' Addresses:

M.Sc. Kiril Paralidov
Ki-par doo Strumica, Republic of MACEDONIA
e-mail: paralidov@hotmail.com

Dr Vladimir Koljozov, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: koljozov@fdtme.ukim.edu.mk

Dr Zoran Trposki, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: trposki@fdtme.ukim.edu.mk

Dr Vladimir Karanakov, Associate professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: karanakov@fdtme.ukim.edu.mk

UDC (UDK): 674.031.628-412

QUANTITATIVE YIELD OF WALNUT (*JUGLANS REGIA* L.) SAWLOGS, II – ND CLASS OF QUALITY DURING ONE PHASE SAWMILL CONVERSION

Branko Rabadjiski[1] , Goran Zlateski[1], Neno Trichkov[2], Zoran Milchovski[3]

[1]Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior - Skopje,
e-mail: zlateski@fdtme.ukim.edu.mk; rabadziski@fdtme.ukim.edu.mk
[2]University of Forestry, Faculty of Forest Industry, Sofia, Bulgaria,e-mail: nenotr@abv.bg
[3]Mebel Mi Design, Berovo, Republic of Macedonia
e-mail: mebelmidizajn@yahoo.com

ABSTRACT

This paper presents the results of investigation of quantitative yield of sawmill walnut logs (*Juglans regia* L.). The logs were 1,5 m to 3,0 m in length, mean diameter ranging between 33,0 cm to 55,0 cm and II - nd class of quality. A total number of 40 logs were investigated and distributed in IV (four) groups of length. Maximum quantitative yeald from experimental test ranges between 61,24% and 68,10%. The values of sawdust ranges between 9,88 to 10,60%.Course waste varies from 20,30% and 28,88%. Technologically, the logs were first sawn on logs bandsaw, and the secondary includes machines for cross and longitudinal sawing. Sawn wood is used in the production of solid wood panels.

Key words: logs, walnut, max quantitative yield, one – phase conversion

1. INTRODUCTION

The literature data indicate that the origin of wood of walnut (*Juglans Regia* L.) comes from Far East and for the first time has been cultivated in China and later in India and Japan. The area of expandability of wood of *Juglans Regia* L is extended from Far East to the Mediterranean countries through campaigns of Roman Empire. However, with the development of machine industry the era of higher utilization of forest has been launched where the wood of walnut (*Juglans regia* L.) takes significant place. According to quality grade, the wood of walnut is used for production of quality veneer, parquet, luxurious stocks of guns, furniture industry, solid wood panels etc. During saw mill processing of walnut logs, (Prka et al., 2001) showed quantitative yield of 72,23 % and 69,32 % for I and II class respectively. Rabadjiski and Trposki, 2009, saw miil processing of walnut I/II class of quality, middle diameter of 28,0 to 52, 0cm resulted in average quantitative yield of 73,56 % for planks 25,0 and 55,0 mm in thickness.

2. METHOD OF WORK

In order to obtain scientific and relevant results, the adequate methodology was taken applying mathematical expressions and formulas from variation statistics. In this paper we cover a few stages related to the row material, sawing disposition, applied method for data processing. The row material which was subject of investigations originated from Osogovo Mountains, Republic of Macedonia. They were logs from 1,5 to 3,0 m long. Depending on their length, the logs were distributed into the IV (four) group:1,50 m; 2,0 m; 2,5 m and 3,0 m. A total number of 40 logs were analyzed, i.e.10 logs for each group of length.

3. RESEARCH RESULTS

Having applied the technological procedure and sawing dispositions, we will here provide the results of the row material and max. quantitative yield in sawing walnut logs. Firstly, we will present the data related to the raw material. It is given in Table 1.

Table 1. *Data regarding walnut logs (Juglans regia* L.*)*

Ord. No.	**Group of length**	**Number of samples (N)**	**Class of quality**	**Mean diameter**	**Volume**
	L [m]	**N**	**K**	**dsr [cm]**	**V [m^3]**
1	1,5	10	II	44,0	0,228
				45,0	0,238
				43,0	0,218
				39,0	0,180
				36,0	0,152
				45,0	0,238
				41,0	0,198
				41,0	0,198
				47,0	0,260
				46,0	0,249
					2,160
2	2,0	10	II	36,0	0,203
				53,0	0,441
				51,0	0,408
				43,0	0,209
				53,0	0,441
				51,0	0,408
				49,0	0,377
				47,0	0,347
				52,0	0,424
				43,0	0,290
					2,500
3	2,5	10	II	55,0	0,594
				44,0	0,380
				42,0	0,346
				41,0	0,300
				46,0	0,415
				49,0	0,471
				47,0	0,434
				45,0	0,397
				45,0	0,397
				42,0	0,346
					4,080
4	3,0	10	II	51,0	0,510
				43,0	0,363
				51,0	0,510
				43,0	0,363
				45,0	0,397
				42,0	0,346
				41,0	0,330
				45,0	0,397
				42,0	0,346
				41,0	0,330
					3,890
1-4	1,5 ÷ 3,0	40	II	36,0 ÷ 55,0 cm	**12,63 m^3**

The table contains length, number of samples, class of quality, mean diameter and volume of logs. The total quantity of logs was distributed into 4 (four) group of length: 1,5 m; 2,0 m, 2,5 m and 3,0 m. From each group 10 samples were analyzed, which totals to 40 logs (Column 3).

Data regarding mean diameter of the logs are given on column 5. The mean diameter depending on length of the logs and varies from 36,0 to 47,0 cm for logs of 1,5 m length, from 36,0 to 53,0 cm for logs of 2,0 m length, from 41,0 to 55,0 cm, for logs of 2,5 m length and from 41,0 to 51,0 cm for logs of 3,0 length.

Based from the data shown in column 6, it can be concluded that the volume of logs varies from 2,160 m^3 and 4,080 m^3, which totals to 12,63 m^3.

In order to obtain material for production of solid wood panel, the logs were sawn applying of adequate technological procedure and sawing dispositions according to thickness of the planks and one phase conversation

Figure 1 shows the sawing disposition of walnut log with diameter of 34,0 cm, length of 2,0 m and belong to II class of quality.

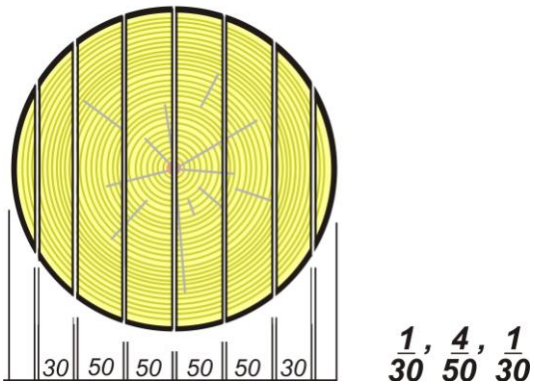

Figure 1. *Disposition of sawing of walnut log, diameter 34,0 cm*

After sawmill processing there were three forms of planks: edged, one side edged and edged (Figure 2).

Figure 2. *Unedged, one side edged and edged planks (Juglans regia* L.*)*

At the end of the sawmill processing we have planks, course residues and sawdust. In order to estimate the quantity of planks i.e. quantitative yield during one phase sawmill processing were taken applying mathematical formula and methods from variation statistic.

On the basis of the obtained data we will here provide the statistical calculated value regarding max. quantitative yield of walnut logs, II class of quality. It is given in Table 2.

***Table 2**. Statistical value of quantitative yield of walnut logs (Juglans regia* L.*), II class of quality*

Group of length	**x ±f x**	**σ±fσ**	**V±fv**
L (m)	(%)	(%)	(%)
1,5	61,24 ± 0,148	0,665 ± 0,105	1,085 ± 0,171
2,0	65,44 ± 0,122	0,548 ± 0,087	1,016 ± 0,161
2,5	68,10 ± 0,199	0,891 ± 0,128	1,308 ± 0,207
3,0	64,22 ± 0,200	0,898 ± 0,142	1,400 ± 0,221

In Figure 3 are presented the values of max. quantitative yield of logs in relation to different group of length.

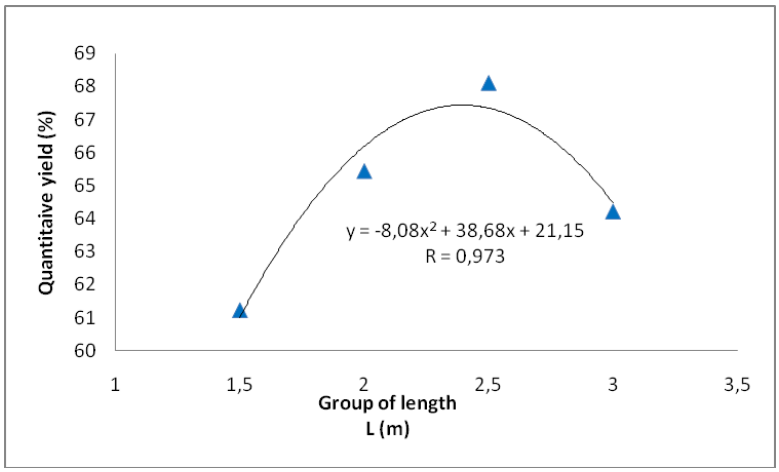

***Figure 3**. Relation between quantitative yield and group of length, walnut logs (Juglans regia* L.*), II class of quality*

The relation between quantitative yield and group of length of logs is determined using the function $Y = - 8,08\ x^2 + 38,68\ x + 21,15$. The coefficient of correlation (R) was very high above 0,97.

Accuracy of the results is obtained using the method (Ugrenović,1960). According to this method, each statistically calculated value of quantitative yield, standard deviation and coefficient of correlation is divided with their average values (Table 3).

***Table 3**. Data accuracy*

Group of length	**(x ±f x) > 3**	**(σ±fσ) > 3**	**(σ±fσ) > 3**
L (m)	(%)	(%)	(%)
1,5	419 > 3	6,33 > 3	6,34 > 3
2,0	536 > 3	6,29 > 3	6,31 > 3
2,5	340 > 3	6,92 > 3	6,32 > 3
3,0	321 > 3	6,32 > 3	6,33 > 3

From the data shown in Table 3, it can be concluded that all values are bigger than 3 which means that the practical measurements were accurate.

In the Table 4 are presented the statistically values of the sawdust in percentage. For the better presentation the same results are graphically shown (Figure 2). It can be concluded that relation between sawdust and length of the logs is determined according to function $Y = -1,62x^2 + 7,79x + 1,635$ and coefficient of correlation of 0,73.

***Table 4**. Statistical value of sawdust percentage,
walnut logs (Juglans regia L.), II class of quality*

Group of length	**x ±f x**	**σ±fσ**	**V±fv**
L (m)	(%)	(%)	(%)
1,5	9,88 ± 0,172	0,767 ± 0,122	7,783 ± 1,231
2,0	10,12 ± 0,093	0,415 ± 0,065	4,100 ± 0,648
2,5	11,60 ± 0,144	0,645 ± 0,102	5,560 ± 0,879
3,0	10,22 ± 0,098	0,439 ± 0,069	4,295 ± 0,679

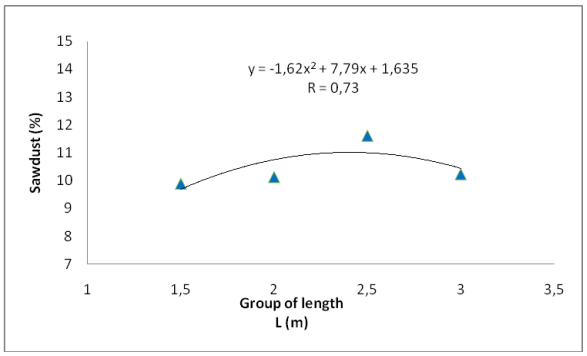

***Figure 4**. Relation between sawdust and group of length,
walnut logs(Juglans regia* L.*), II class of quality.*

The statistical values of course waste obtained from sawmill processing of walnut logs, II class of quality are presented in Table 5.

***Table 5**. Statistical values for percentage of course waste,
walnut logs (Juglans regia L.), II class of quality*

σ±fσ	**x ±f x**	**σ±fσ**	**V±fv**
L (m)	(%)	(%)	(%)
1,5	28,88 ± 0,226	1,010 ± 0,105	3,497 ± 0,553
2,0	24,44 ± 0,096	0,423 ± 0,068	1,767 ± 0,279
2,5	20,30 ± 0,100	0,448 ± 0,071	2,207 ± 0,348
3,0	25,16 ± 0,131	0,584 ± 0,093	2,321 ± 0,367

From the table it can be concluded that the course waste vary from 20,30 ± 0,100 to 28,88 ± 0,266 % with standard deviation from 0,423 ± 0,068 to 1,010 ± 0,105 % and coefficient of variation from 1,767 ± 0,279 and 3,497 ± 0,553 %. In order to get better access of previous results, they are shown in Figure 5. It can be noticed the function $Y = 9,3\ x^2 + 44,91\ x + 75,755$ as a relation between course waste and group of length of the walnut logs. The coefficient of correlation is 0,947.

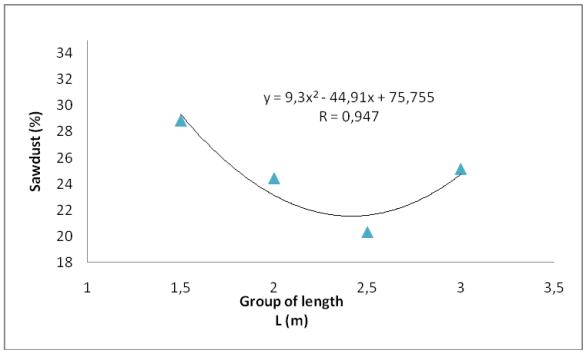

***Figure 5**. Relation between course waste and group of length,*

walnut logs(Juglans regia L.*), II class of quality*

4. CONCLUSIONS

The results presented in this study are concerned with sawmill processing of walnut logs *(Juglans regia* L.*),* II class of quality.

According to the presented data and results, the following more important conclusion may be drawn:

1. Raw material to be tested, walnut logs. *(Juglans regia* L). Quality class II. Diameter of 33,0 to 55,0 cm. Length of 1,5 m to 3,5 m. The investigation covered 40 logs with total volume of 12,63 m^3.
2. Quantitative yield of walnut logs: minimum 61,24 %, maximum 68,10 %.
3. Relation between quantitative yield and group of length in walnut logs is determined using the function $Y = - 8,08 x^2 + 38,68 x + 21,15$ with coefficient of correlation of 0,973.
4. Sawdust: minimum 9,88 %, maximum 11,60 %.
5. Relation between sawdust and group of length in walnut logs is obtained using the function $Y = -1,62x^2 + 7,79x + 1,635$ with coefficient of correlation 0,73.
6. Course waste: minimum 20,30 %, maximum 28,88 %.
7. Relation between course waste and group of length in walnut logs is determined using the function $Y = 9,3 x^2 + 44,91 x + 75,755$ with coefficient of correlation of 0,947.

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The Authors' Addresses:

Dr Branko Rabadjiski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: rabadziski@fdtme.ukim.edu.mk

Dr Goran Zlateski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: zlateski@fdtme.ukim.edu.mk

Dr Neno Trichkov, Full professor
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: nenotr@abv.bg

M.Sc. Zoran Milchovski
Mebel Mi Design, Berovo, Republic of MACEDONIA
e-mail: mebeldizajn@yahoo.com

UDC (UDK): 674.031.632.2-412

INVESTIGATION OF LOG TAPER OF BEECH WOOD

Branko Rabadjiski, Goran Zlateski, Zoran Trposki, Vladimir Koljozov

Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior - Skopje,
e-mail: rabadziski@fdtme.ukim.edu.mk; zlateski@fdtme.ukim.edu.mk;
trposki@fdtme.ukim.edu.mk; koljozov@fdtme.ukim.edu.mk

ABSTRACT

The paper presents the results of the investigation of log taper of beech wood. The logs were 4,0 m in length, min. diameter of 25,0 cm to 55,0 cm and max. of 62,0 cm. A total log’s volume of 70,0 m^3 was investigated. For timber of 4,0 m in length log taper was ranged from 1,06 ± 0,100 cm/m to 1,82 ± 0,126 cm/m. The log taper expressed in relative units was in the limit of 2,5 ± 0,204 % to 0,254 % . A total number of 40 logs were investigated and distributed in IV (four) groups of length.

Key words: logs, beech, max quantitative yield, one – phase conversion

1. INTRODUCTION

Primary wood processing always attracts attention by forest and wood specialists. Due to the great interest in wood and possibility of greater use is the need for its rational and complete utilization. With the advancement and development of technology and the growing development of the means of work, the appearance and introduction of new processing technologies, are striving to achieve is greater quantitative, qualitative and value advantage.

The raw material that is used in sawmill capacity is deciduous and coniferous origin. Mechanical wood processing involves primary and secondary processing of logs. From sawmill are obtained elements with prismatic form, intended for manufacture of the final products.

According to forest resources we can noticed that in the Republic of Macedonia the total geographical area of the forest land belongs to 50% or 1.299.000 ha. While possible year annual cutting of timber is estimated of 1.041.000 m^3. From the total forest area in Macedonia, deciduous (hardwood) wood species have area of 90% and conifer wood species (softwood) 10%.

Considering what was said previously, in this paper will be directed towards a very important factor that directly affects the utilization of wood volume of logs and that is log taper of beech wood or fall in diameter. For these reasons, the analysis will be made of beech logs from the region of Baba Mountain in the area of the municipality of city of Resen.

2. MATERIALS AND METHODS

Method of works consist the choice of logs and measuring their parameters and for data processing applied mathematical methods of variation statistics.

The selection of timber i.e. selection of the raw material for processing is made according to the wood species, size and class quality. Beech logs have a length of 4,0 m, and distributed in the II-class quality. Diameters of logs are measured on thin and thick ends of logs.

The middle diameter represents an average arithmetic mean of the values measured of the thin and of the thick end of logs. Is calculated according to the formula:

$$d_{sr} = \frac{d_1 + d_2}{2} \qquad [cm]$$

d_{sr} - middle diameter f log [cm]
d_1 - diameter of thin end of log [cm]
d_2 - diameter of thick end of log [cm]

Volume of log is calculated according to the equation:

$$V = \frac{d^2_{sr} + \pi}{4} \times l$$

V - volume of log [m^3]
d - middle diameter of log [m^3]
l - length of log [m]
π - Ludolf number (3.14)

For the calculation of the log taper are used formulas:

$$S = \frac{d_2 - d_1}{l} \quad [cm/m]$$

$$S_1 = \frac{d_2 - d_1}{l \times d_2} \times 100 \quad [\%]$$

3. RESULTS AND DISCUSSION

In this section will show the obtained data with all necessary analysis of the raw material regarding to diameter, length, taper and class of quality. For log taper examination were analyzed 100 logs from beech wood, 4,0 in length and II quality class.

Table 1 shows the data for average diameter of sawmill logs.

Table 1. *Statistical values of average diameter of beech sawmill logs*

Ord. No.	Diameter (cm)	$\overline{x} \pm f_x$	$\sigma \pm f_\sigma$	$V \pm f_v(\%)$
1	26.1-36.0	32.30 ± 0.50	2.49 ± 0.35	7.71 ± 1.09
2	36.1-46.0	40.40 ± 0.54	2.72 ± 0.38	6.73 ± 0.95
3	46.1-56.0	50.08 ± 0.52	2.62 ± 0.37	4.97 ± 0.70
4	56.1-66.0	59.80 ± 0.48	2.39 ± 0.34	3.99 ± 0.47

From the Table 1, it can be concluded that the average diameters of sawmill logs from the first, second, third and fourth class of thickness class is 32,3 ± 0,50 cm; 40,4 ± 0,54 cm; 50,08 ± 0,52 and 59,8 ± 0,48 respectively.

The results of the taper of the diameter of sawmill beech logs , II class quality are presented in Table 2.

Table 2. *Statistical values of taper of diameter of beech logs*

Ord. No.	Diameter (cm)	$\overline{x} \pm f_x$	$\sigma \pm f_\sigma$	$V \pm f_v(\%)$
1	26,1-36,0	1,20±0,102	0,51±0,072	42,50±7,01
2	36,1-46,0	1,06± 0,100	0,50±0,070	47,17±8,01
3	46,1-56,0	1,82±0,126	0,63±0,090	34,60±5,44
4	56,1-66,0	1,74±0,106	0,53±0,750	30,46±4,68

According to data in Table 3, one can say that taper of log diameter ranges from 1,06 ranges from 1,06 ± 1,01 to 1,82 ± 0,126 cm / m. The standard deviation is within from 0.50 ± 0.070 to 0.63 ± 0.090, and the coefficient of variation ranged from 30,46 ± 4.68 to 47,17 ± 8,01. For better presentation these data are graphically shown in Figure 1.

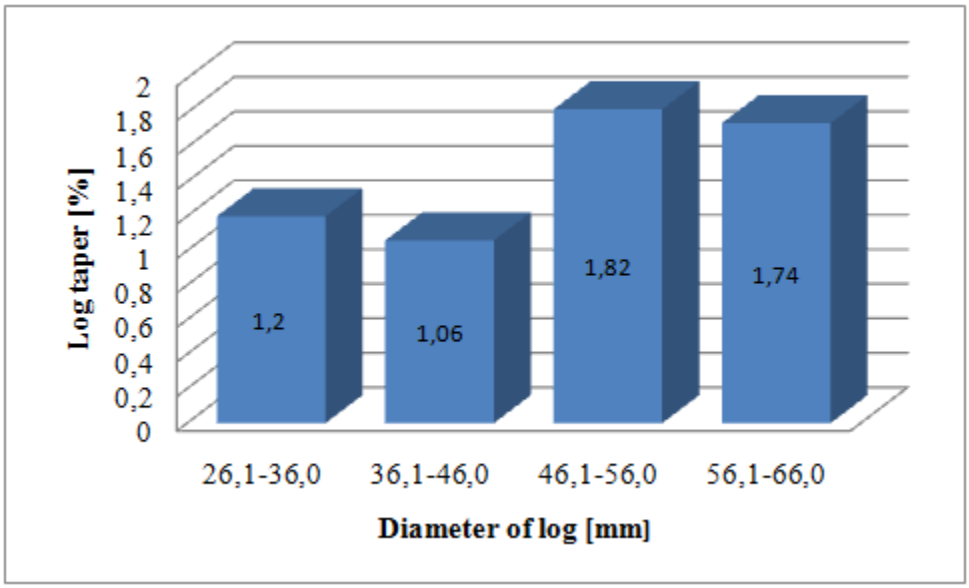

Figure 1. *Dependence of the log taper in cm/m and log class of thickness*

The log taper can also be expressed in a percentage. The calculated values are shown in Table 4. and Figure 2 as well.

Table 3. *Statistical values of log taper of beech wood in percenatge*

Ord. No.	Diameter (cm)	$\overline{x} \pm f_x$	$\sigma \pm f_\sigma$	$V \pm f_v(\%)$
1	26,1-36,0	3,4±0,254	1,27±0,180	37,35±5,97
2	36,1-46,0	2,5±0,204	1,02±0,144	40,80±6,60
3	46,1-56,0	3,3±0,200	1,00±0,141	30,30±4,65
4	56,1-66,0	2,8±0,164	0,82±0,116	29,28±4,14

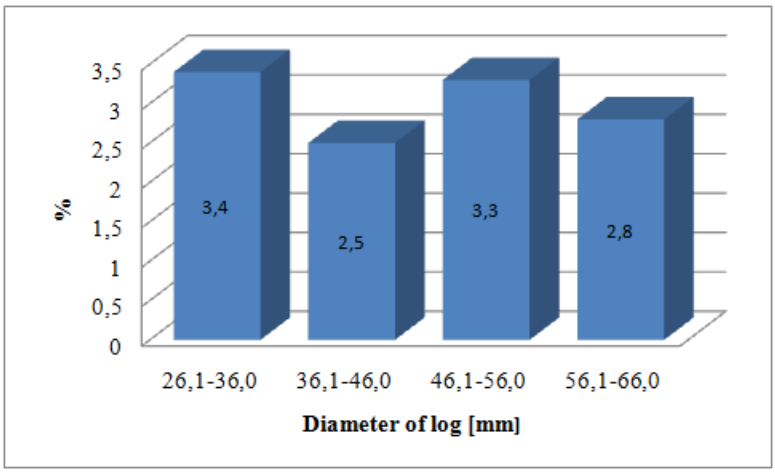

Figure 2. *Dependence of the log taper in % and log class of thickness*

Based on data from Table 4 and Figure 2, it can be seen that the log taper expressed in percentage ranges from 2,5 ± 0,204 to 3,4 ± 0,254. The standard deviation of 0,82 ± 0,116 to 1,27 ± 0,180 and the coefficient of variation in the limit of 29,28 ± 4,14 to 40,8 ± 6,60%.

4. CONCLUSIONS

This paper describes the results of research carried out on beech sawmill logs distributed in 4 classes of thickness according to their log taper.

Based on the data obtained we can conclude following:

1. Total analysis include 100 saw mill beech logs, II class quality.
2. Sawmill logs are divided by 25 logs into 4 classes of thicknes: 26,1-36,0 cm; 36,1-46,0 cm. 46,1-56,0 cm; and 56,1-66,0 cm.
3. The minimum diameter is 25,0 cm, and maximum 62,0 cm.
4. The length of beech logs is constant of 4,0 m.
5. The total volume of logs is 70,0 m^3.
6. Log taper expressed in cm / m ranges from 1,06 ± 0,1 to 1,82 ± 0,126 cm / m.
7. Log taper expressed in % ranges from 2,5 ± 0,204 to 3,4 ± 0,254%.

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The Authors' Addresses:

Dr Branko Rabadjiski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: rabadziski@fdtme.ukim.edu.mk

Dr Goran Zlateski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: zlateski@fdtme.ukim.edu.mk

Dr Zoran Trposki, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: trposki@fdtme.ukim.edu.mk

Dr Vladimir Koljozov, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: koljozov@fdtme.ukim.edu.mk

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QUALITY WOOD DRYING ESTIMATION THROUGH MOISTURE CONTENT GRADIENT DURING VACUUM DRYING OF WALNUT PLANKS

Goran Zlateski, Branko Rabadjiski, Violeta Jakimovska Popovska, Mira Stankevik Shumanska

Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior - Skopje,
e-mail: zlateski@fdtme.ukim.edu.mk; rabadziski@fdtme.ukim.edu.mk;
jakimovska@fdtme.ukim.edu.mk

ABSTRACT

The aim of this research is the defining of moisture content gradient in walnut elements after vacuum drying. The elements were 50,0 mm thick, 20,0 cm in width and 4,0 m in length. According to the drying schedule, the temperature of the wood and of the heating units in the kiln chamber during drying varied from 17 to 60 ^{0} C and from 25 to 65 C respectively. The elements were kiln dried from initial average moisture content (MCi) of 33,0 % to a final average moisture content (MCf) of 10,0% for 168 h. Moisture content gradient in the cross section of walnut elements is – 1,89 %. The elements are used for manufacturing solid wood products.

Key words: walnut, vacuum drying, moisture gradient, draying quality

1. INTRODUCTION

In the conditions of wood drying, it is necessary to determinate the wood moisture content distribution in the cross – section of a piece of wood. The procedure for defining of the moisture content gradient is connected with the determining of both surface and core moisture content (MC). During the drying, a moisture gradient from the outer to the inner layers of the wood will be developed. How big will the MC gradient be depends on the severity of the drying process. If we have an adequate regime according to wood species and thickness, there is no condition for the development of a big difference of MC of the wood core and the wood surface. If the moisture gradient is too high at the end of the drying, this can lead to an increase in the stresses and instability in the wood, especially during subsequent machining, so that reducing the final moisture gradient is essential for the wood drying process.

The woodworking industry in vacuum drying is mainly interested in a short drying and a satisfying quality for species that are difficult to dry (Behnke, C., Militzer, K. E., 1996). Vacuum drying is characterized by evaporation of water from wood taking place with a decreased pressure in comparison with the atmospheric one (Trebula, P., Dzurenda, L., Klement I., 1993). At lowered pressure water boiling process takes place in lower temperatures, while amount of heat indispensable for water vaporization in such conditions increases (Swigon, 1993)

2. MATERIAL AND METHODS

A total quantity of 3 m ^{3} walnut elements were dried for this investigation. Their origin was from the Negotinska kraina, Republic of Serbia. The investigation was performed on material with the following dimensions: 50,0 mm thickness, 20,0 cm width and 2,0 length.

The evaluation of drying quality was made in accoradance with the European Drying Group Recommendations (1994).

The information on the temperature and moisture content of the wood was obtained with:

- probes for determining moisture content gradient in the cross section of elements using oven dry method (Figures 1 and 2).
- three temperature probes consisting of a PT 100 sensor
- three probes MC, that is, five pairs of electrodes planted in three elements which were previously chosen with highest initial moisture content

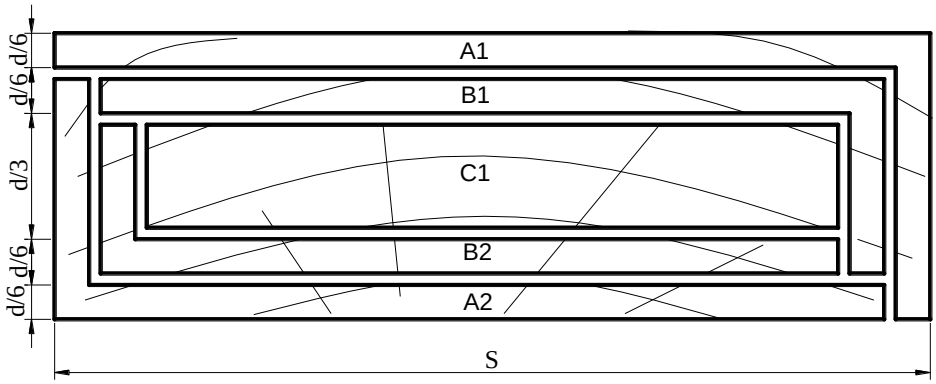

Figure 1. *Slicing test (specimen production) for wood moisture gradient*

Figure 2. *Oven dry method - determination of moisture content distribution*

2.1. Electrode positioning

The temperature probe was planted in the position shown in Figure 3. For a correct reading of the temperature, it is necessary that the electrodes are planted in 1/2 of the board thicknesses.

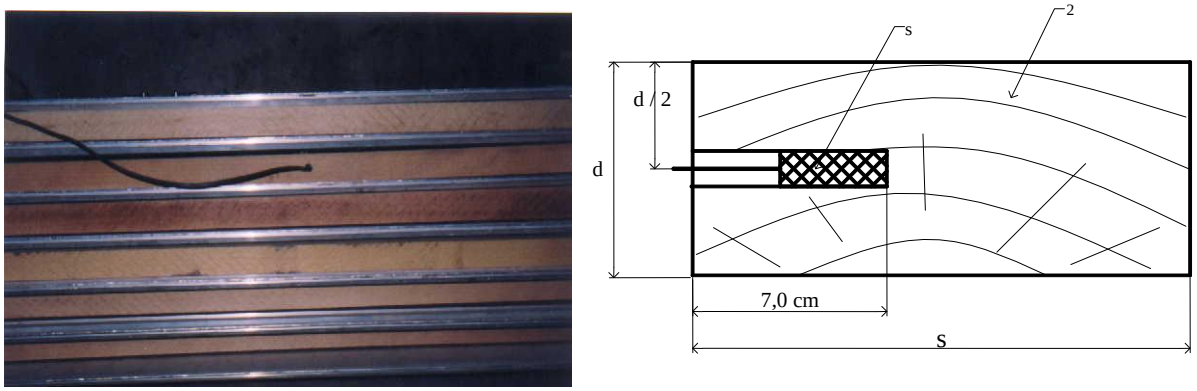

Figure 3*. Wood temperature measuring*
d – wood thickness, S – wood width

The electrodes for measuring moisture content of the elements and their position within the wood are shown in Figure 4.

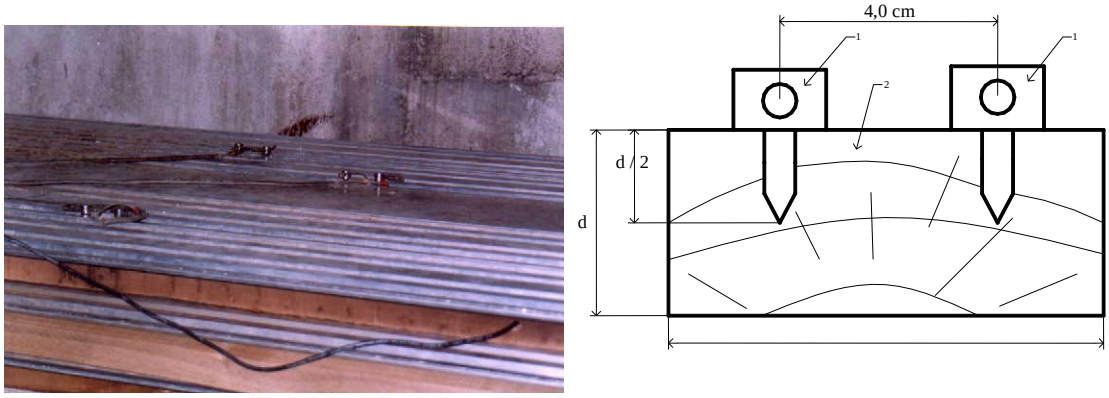

Figure 4. *Electrode for measuring of wood moisture content, d – wood thickness, S – wood width*

2.2. Drying regime

The drying regime is defined on the basis of: heating temperature, temperature of the wood and wood moisture content (MC) during all stages of the drying cycle.

The drying of the walnut elements was performed in the vacuum kiln dryer type ES 3 (Figure 5) equipped with control and heating unit (Figure 6) as well as an automatic system for drying control, manufactured by “ISVE” Italy. The main benefits of this drying technique pertain to the lowering of the boiling point of water and the subsequent generation of an over-pressure within the medium (Sebastian et at all, 1996). Duration of vacuum drying by contact heating of wood, with initial moisture content of 40,0 % and final of 10 % is 52,0 hours (Todorovski, 1983).

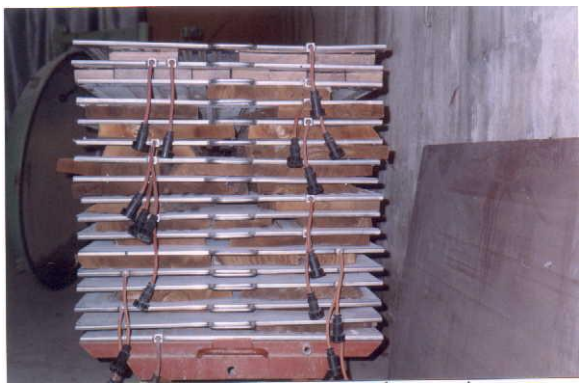

Figure 5. *Vacuum dry kiln*

Figure 6. *Control and heating unit of drying*

3. RESULTS AND DISCUSSION

The drying regime of 50,0 mm thick walnut elements is shown in Table 1. This figure evidently shows that the temperature of the wood during the first 12 h rapidly increases from 17 ^{0} C to 49 ^{0} C and reaches its maximum of 60 until the end of drying for 24 h. In the same way, temperature of heating (heating units) increases from 25 to 55 ^{0} C for 12 h and to 65 ^{0} C for 24 h, which is the maximum value of heating. Initial average moisture content of the wood is 33,0 %, and during drying it decreases to a final MC of 10,0 %. The duration of the complete drying process is 168 h.

Table 1. *Drying regime of 50,0 mm thick walnut elements*

Temperature of heating [^{0} C]	Wood temperature [^{0} C]	Wood moisture content – sonde [%]			Average wood moisture content [%]	Time of drying [h]
25	17	32	33	33	33	0
55	49	31	32	32	32	12
65	59	28	29	28	28	24
65	60	26	27	26	26	36
65	60	25	26	25	25	48
65	60	23	24	23	23	60
65	60	21	22	21	21	72
65	60	19	20	19	19	84
65	60	18	18	17	18	96
65	60	17	16	16	16	108
65	60	15	15	16	15	120
65	60	13	13	14	13	132
65	60	13	12	12	12	144
65	60	12	11	11	11	156
65	60	11	10	10	10	168

Data from the investigation concerning the average moisture content of the core and the surface of the elements is presented in Table 2.

Table 2. *Data of the surface and core moisture content of walnut elements*

Wood thickness [mm]	**Layer –wood surface**	**Layer –wood core**	**Surface moisture content [%]**	**Core moisture content [%]**
50	A		**9,51**	
	B		10,1	
	A+B		9,76	
		C		11,65

Based on the data shown in Table 2, it can be concluded that the moisture of the surface of the elements is 9,51% (layer A) and 10,1 % (layer B), respectively. Average moisture surface content (layers A+B) is 9,76 %. The moisture of the core (layer C) is 11,65%.

For best access to obtained results, they are shown in Figure 7.

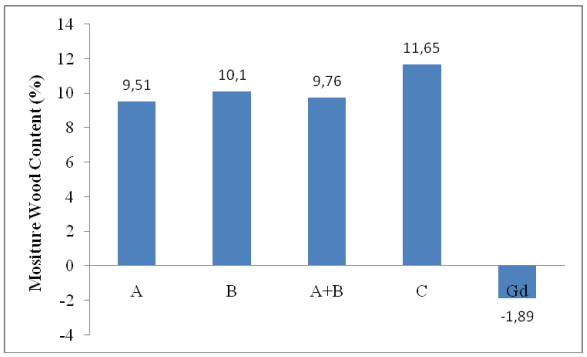

Figure 7. *Wood moisture gradient within walnut elements*

From the histogram it can be concluded that in the process of vacuum drying of walnut elements, a moisture content gradient of - 1,89 % has been reached by the drying process. It means that obtained results for moisture content distribution in the cross – section of a piece of wood are in accordance with the production of solid wood construction details.

4. CONCLUSIONS

Investigations of moisture content gradient of 50,0 thick walnut planks which appear in the vacuum drying process, give appropriate results for MC distribution in the cross – section of a piece of wood. The MC gradient as predicated occurrence is defined as the difference between the board's core moisture content (MC core) and the board's surface moisture content (MC surface). This provides moisture movement in the drying process. According to the drying regime, the MC gradient in the walnut elements has been present after drying.

The investigation of the most important technological parameters, characteristics of the process of vacuum drying, has shown the following:

1. The elements were dried from their initial average moisture content of 33,0% to a final average moisture content of 10,0 % for 168 h.
2. Wood temperature in the drying process increases from 17 ^{0} C to 60 ^{0}
3. The plank's surface moisture content (layers A + B) is 9,76 %
4. The plank's core moisture content (layer C) is 11,65%.
5. The moisture content gradient is – 1,89 % which means that the MC of the surface is smaller than the MC of the core of the elements.

Due to many factors influencing the drying process, such as: origin and quality of the wood, type of kiln; the methods of drying behavior of the walnut elements might be different from the ones discussed in this paper.

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The Authors’ Addresses:

Dr Goran Zlateski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: zlateski@fdtme.ukim.edu.mk

Dr Branko Rabadjiski, Full professor
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: rabadziski@fdtme.ukim.edu.mk

Dr Violeta Jakimovska Popovska, Docent
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: jakimovska@fdtme.ukim.edu.mk

Dr Mira Stankevik Shumanska, Associate professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: stankevik@fdtme.ukim.edu.mk

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COMPARATIVE INVESTIGATION OF CONVECTIVE AND VACUUM DRYING OF BEECH WOOD

Goran Zlateski[1], Branko Rabadjiski[1], Goran Jovanović[2], Zoran Trposki[1], Vladimir Koljozov[1]

[1]Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje,
e-mail: zlateski@fdtme.ukim.edu.mk; rabadziski@fdtme.ukim.edu.mk;
trposki@fdtme.ukim.edu.mk; koljozov@fdtme.ukim.edu.mk
[2]CasaItalia, Backa Palanka, Serbia,
goran.jovanovic@casaitalia.rs

ABSTRACT

Beech woods components with initial moisture of approximately 33.0% on dry basis were dried using two different drying methods, convective and vacuum. The beech components thick 25.0 mm each were dried until their moisture content fell down to about 10 %. The following drying levels were used in each of the drying processes: for convective drying 31,0; 32.0, 41.0, 59.0 and 60.0 ^{0}C temperature of air; 15.0, 13.0, 12.0, 6.0 and 3.7 % equilibrium moisture content; 33.0, 30.0, 23.0, 20.0, and 10.0 % wood moisture content, for vacuum drying 26.0, 58.0, 56.0 and 65.0 ^{0} C temperature of heating;19.0, 53.0, 55.0 and 58.0 ^{0} C temperature of wood; 33.0, 25.0, 17.0 and 10.0 % wood moisture content. Drying periods ranged from 3- 15 days for vacuum and convective drying, respectively.

Key words: beech, drying period, convective drying, vacuum drying

1. INTRODUCTION

Wood drying is very important and complex process which includes treatment of wood water removal and achieved high quality properties. There are two general method of wood drying: air drying and kiln drying. The first one is mainly conducted in the open area under the influence of atmospheric conditions (relative humidity, temperature and velocity of the circulation of air). Kiln drying is carried our in specially manufactured constructions called drying chamber equipped with apparatus and instruments for conducting and control of the process of water evaporation from the wood to the surrounding area. Generally speaking there is no wood working enterprise, which produce raw material without wood drying.

The various methods used to dry kiln can be divided into two categories: the commonly used procedures of convective drying and specialized techniques using high frequency and vacuum for accelerated kiln drying.

In vacuum drying, lumber is placed in a tight drying chamber. A vacuum is pilled on the lumber so that the water in the wood is boiling and is drawn out (Simpson, 1994). Vacuum drying is actually based on the principle that the boiling point of water is lowered when the atmospheric pressure is lowered (Zhangjing and Lamb, 2001). Previous study showed that vacuum drying of 54,0 mm thick beech using dielectric hating of wood with initial moisture content of 50,0 % and final 7,0 % provide very short time of 40,8 hours (Resch and Gautsch, 2000).

Conventional kiln drying is conducted in a closed chamber or building in which heated, humidity controlled air is rapidly circulated over the surface of the wood being dried (Denig, Wengert, Simpson, 2000).

Taking into account previously spoken we came to some consideration that of interest to science and technique of wood drying the wood to make a comparative analysis between the convective and accelerated vacuum drying.

2. MATERIAL AND METHODS

2.1. Drying methods

Convection-drying is the conventional way of seasoning lumber. For this method, the lumber is stacked in a kiln equipped with a heating system and fans. The heated air rises. The fans move the warm air through the stacks. The humidity of the air can be controlled by regulating the temperature, by admitting water vapor through steam sprays, or by changing the air by removal of the saturated air at given intervals through flaps. The operation was programmed according to tables (schedules) that summarize the optimal drying parameters (temperature and humidity of air) in correlation with average wood moisture content.

Vacuum contact drying process works on the basis that vacuum reduces the boiling temperature of the water contained in the wood and thus allows its easier and faster evaporation. The vacuum dryer consists basically of a pressure cylinder and a vacuum pump.

The dryer was loaded from the bottom, with alternating heating plates and lumber layers. The heating plates were placed flat in the dryer between the wood board layers. The plates was heated electrically and then produced heat that was transferred to the wood boards by conduction. The dryer unit was equipped with a programmable automat to allow controlling and regulating the operating conditions (temperature and vacuum pressure).The operation was programmed according to tables (schedules) that summarize the optimal drying parameters (temperature and vacuum).

2.2. Wood moisture measurement (convective and vacuum drying)

Drying experiments were conducted on beech limber (*Fagus Sylvatica*), 25 mm thickness. Oven dry mass of the lumber was used for wood moisture distribution on three samples (dimensions 25 x 25 x 200 mm) sawn from three test boards (Figure 1).

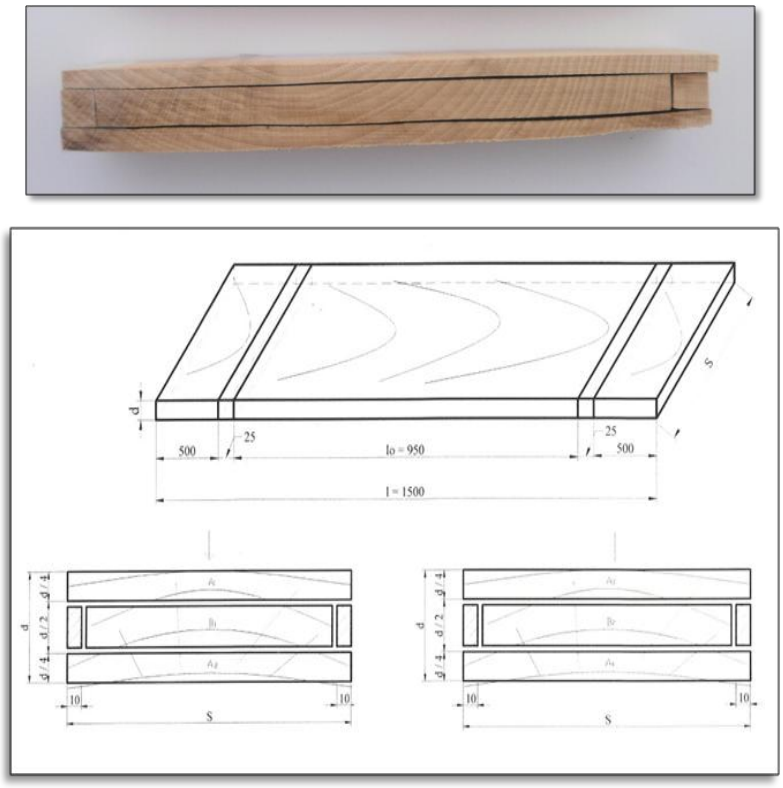

Figure 1*. Sample sawing protocol*

Average wood moisture content was determined from the three test boards (dimensions 1500 mm length, 200 mm width, and 25 mm thickness during the drying process (Figure 2).

Figure 2*. Probe placement for moisture content measurement (convective drying and vacuum drying)*

The probe for moisture content measurements was connected to the automatic control system (Figure 3).

Figure 3. *Automatic control system (convective drying and vacuum drying)*

2.3. Air temperature and humidity measurements (convective drying)

The air temperature and humidity measurements were measured using a probe shown on Figure. 4.

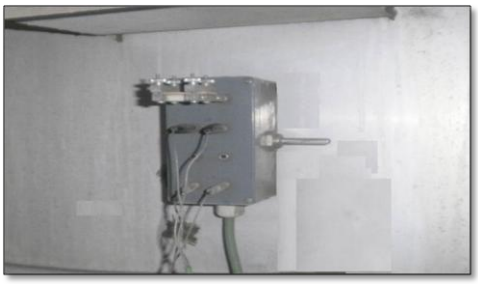

Figure 4. *Air temperature and humidity measurements*

2.4. Wood temperature measurement (vacuum drying)

The internal wood temperature profiles of beech wood samples was measured using a probe inserted to about 70 mm into the wood. The probe was connected to the microcomputer for data recording.

3. RESULTS AND DISSCUSION

The boards were visually checked after they were taken out of the dryers. The visible defects were found to be at minimum level.

3.1. Drying schedule

The experimental schedules of convective and vacuum drying of beech wood 25,0 thickness used in this study are shown in Tables 1 and 2 respectively.

Table 1. *Drying schedule of convective drying of beech wood 25,0 mm thickness*

Time	Temperature of the air in dry kiln	Equilibrium moisture content	Moisture content Probe Number 1	Moisture content Probe number 2	Moisture content Probe number 3	Average wood moisture content
[h]	T [^{0}C]	[%]	[%]	[%]	[%]	[%]
0	31,70	15,00	33	35	32	33
24	31,0	15,20	31	31	28	30
48	32,0	13,50	30	29	27	29
60	31,8	13,70	28	27	25	27
84	32,0	13,60	26	25	23	25
108	33,70	12,70	24	23	22	23
132	32,0	13,50	22	21	21	21
156	41,10	12,00	18	20	19	19
180	59,60	6,10	16	17	18	17
204	54,0	9,70	13	15	16	15
228	60,0	4,20	11	12	13	12
252	60,0	3,70	10	11	11	11
276	60,0	3,40	9	10	10	10

Table 2. *Drying schedule of vacuum drying of beech wood 25,0 mm thickness*

Time	Temperature of heating plates	Temperature of wood	Moisture content Probe Number 1	Moisture content Probe number 2	Moisture content Probe number 3	Average wood moisture content
h	T [^{0}C]	T [^{0}C]	[%]	[%]	[%]	[%]
0	26	19	32	33	33	33
12	56	53	31	32	32	32
24	58	54	24	25	26	25
36	58	54	22	22	23	22
48	65	55	17	17	18	17
60	65	58	14	14	15	14
72	65	58	12	13	14	13
84	65	58	10	10	11	10

It is confirmed from Table 1 and Table 2 that vacuum drying could drive moisture much easily remove this moisture than convective drying.

3.2. Drying curve

Figure 5. shows the comparison among the drying curves of convective and vacuum drying of beech wood.

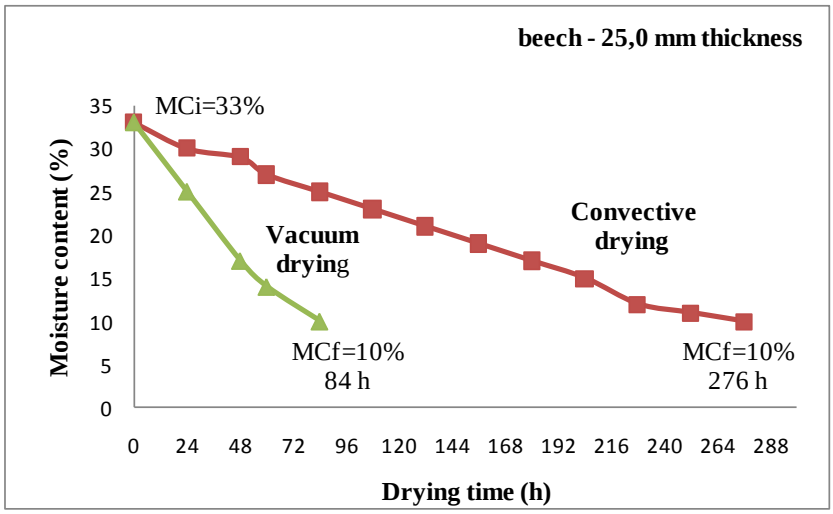

Figure 5. *Comparison of drying curves between convective and vacuum drying*

3.3. Moisture content distribution

After the drying test samples (Figure 1) were taken at the position where moisture content has been measured. Figure 6 shows the final moisture content distribution across the wood (transversal). There is no significant difference between the moisture content of wood surface (shell) and middle of the lumber (core) for each of drying. Moisture content gradient at the end of drying process for convective and vacuum drying is 1,52 % and -1,66% respectively. Therefore both methods of drying give almost uniformly distribution of final moisture content.

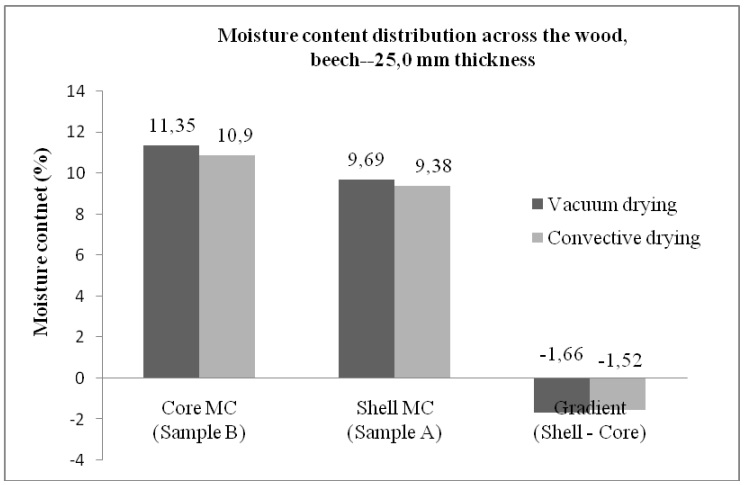

Figure 6. *Transversal Moisture Content Distribution*

3. CONCLUSIONS

The presented experimental data indicate that method of wood drying has significant influence on the drying time. Characteristics drying schedules for convective and vacuum drying have been determined from measurement of sample boards. On the basis of these measurements comparison have been established by the drying time. The results of the experiment show that using vacuum for

drying 25 mm thick lumber, the drying time is 3- 4 times lower than convective drying. Concerning the internal moisture content distribution across the boards after drying it can conclude that there is no big difference between shell moisture content and core moisture content which leads to high quality of drying.

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The Authors’ Addresses:

Dr Goran Zlateski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: zlateski@fdtme.ukim.edu.mk

Dr Branko Rabadjiski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: rabadziski@fdtme.ukim.edu.mk

M.Sc. Goran Jovanović
CasaItalia, Backa Palanka, SERBIA,
e-mail: goranjovanovic@casaitalia.rs

Dr Zoran Trposki, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: trposki@fdtme.ukim.edu.mk

Dr Vladimir Koljozov, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: koljozov@fdtme.ukim.edu.mk

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LIGNOCELLULOSIC MATERIALS AS ENERGY RESOURCE

Julia Mihajlova[1], Borche Iliev[2], Violeta Jakimovska Popovska[2]

[1]University of Forestry-Sofia, Republic of Bulgaria
e-mail: jmihajlova@yahoo.com
[2]Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje
e-mail: iliev@fdtme.ukim.edu.mk; jakimovska@fdtme.ukim.edu.mk

ABSTRACT

Nowadays the energy is one of the most important factors for the development of the economy of one country. Globally, because of the population growth and improvement of standard of living, the need for energy continually is increasing. On the other hand, the classic energy resources (coal, oil and natural gas) are slowly exhausting and they are geographically irregularly distributed.

The exploitation of the lignocellulosic biomass from the forestry and agriculture (wood, straw and agricultural residues) is of interest for energy production. Thereto, only waste biomass which is not subjected to technological exploitation or used as animal food should be considered.

The results from the research of the properties of the briquettes made from different types of lignocellulosic biomass are presented in the paper.

Key words: lignocellulosic biomass from forestry, lignocellulosic biomass from agriculture, briquettes, properties

1. INTRODUCTION

Briquetting is a rational method for utilization of wood raw material in order to improve its energy efficiency. In this production, beside wood and wood waste material, lignocellulosic agricultural residues can be also used as raw material. This fact is important in the countries with developed agriculture, such as Republic of Macedonia and the Republic of Bulgaria, whereupon beside wood industry economy, also the profitability of cultivation of agricultural plants is increased.

Iliev et al. (2008) stated that the total biomass from agriculture on world level is estimated on 9 billion tons per year. For now, mainly, this biomass is used as animal food and for natural fertilization of the acre. Besides this, the biomass from the agriculture remains as big energy resource for further utilization as bio fuel (Iliev et al. 2008, Yossifov 2005).

Every year in Republic of Macedonia and Republic of Bulgaria certain quantities of lignocellulosic agricultural residues are obtained. These quantities are not rationally used, so they are ballast for agriculture and in some cases are also pollutants of the environment. In these countries, grape pruning residues, corn, tobacco and sunflower stems and wheat straw draw attention as potential raw material for production of energy briquettes. Together with other lignocellulosic agricultural residues, these lignocellulosic materials do not have economic importance until now.

The technical and technological development of briquettes production in the past years made a real supposition for their utilization as substitute of wood raw material for this kind of production. It should be mentioned that some economic and technological issues remains incompletely solved, such as those associated with: collecting, transport and storing of the raw material; the choice of an appropriate technological process in regard to the raw material quality and the competitive power of the finished product; the use of optimal technological processes that warrant high quality of the briquettes at relatively low production costs.

Because of the above mentioned, our investigations from one hand were directed to defining the technological possibilities for production of briquettes from grape pruning residues, sunflower, tobacco and corn stems as a substitute for wood raw material and on the other hand, to observe the influence of the participation of chipped lignocellulosic raw material on the properties of the briquettes.

2. METHOD OF THE EXPERIMENTAL WORK

For the realization of the research, lignocellulosic agricultural raw material is collected from the regions in the Republic of Macedonia where this biomass is mostly present. The inspection, measuring and preparation of the raw material is made in laboratory conditions. All dirt and impurities were separated from the raw material. The leaves and roots form tobacco stems, corn stems and sunflower stems were also removed. After that, the raw material was cut in 10 cm length for easy transport and manipulation during the processing.

The raw material processing was made in two stages: first stage – chipping on standard cylindrical chipping machine and second stage: milling on hammer mill. The chipping is made together with the heartwood part (Figure 1). In such a way the technology is rationalized, as well a rational and complete utilization of the raw material is achieved.

Figure 1. *Chipped raw material from sunflower stems*

For briquettes production chipped beach wood raw material was also used. This raw material was obtained from the wood industry factories in the Republic of Macedonia. Chipping and milling of beech wood is made in the same way as lignocellulosic agricultural raw material.

The fraction analysis of the chipped raw material is made on sieve shaker with five sieves with the following mesh dimensions: 4,0×4,0; 2,5×2,5; 1,6×1,6; 1,0×1,0 and 0,5 ×0,5 mm. The fraction analysis is made on a mean test specimen with mass of 100 g in time of 5 minutes, by amplitude of oscillation of the 0,5 mm sieve and 250 rotations/minutes. The fractions from the individual sieves were measured by electronic balance with precision of 0,01 g (Table 1).

Table 1. *Fractions of the chipped wood and lignocellulosic agricultural raw material*

Type of chipped raw material	Fractions of the chipped raw material, %					
	above 4,0/4,0 mm	4,0/2,5 mm	2,5/1,6 mm	1,6/1,0 mm	1,0/0,5 mm	0,5/0 mm
Wood particles	2,40	6,35	14,72	22,66	38,09	15,78
Grape vine rods’ particles	1,38	5,14	29,66	28,59	14,38	20,85
Tobacco stems’ particles	1,36	15,92	57,63	4,86	10,45	9,78
Sunflower stems’ particles	1,04	4,59	62,02	6,14	13,52	12,69
Corn stems’ particles	1,12	2,94	42,61	12,51	19,45	21,37

The raw material from all fractions was mixed for briquette production.

Before briquette production, certain quantities of chipped raw material from grape vine rods, sunflower, tobacco and corn stems are weighed on electronic balance with precision of 0,01 g in laboratory conditions.

The modeling was made by mixing the wood raw material (WRM) and lignocellulosic agricultural raw material (LCARM) in different ratios, whereupon five models were made, i.e., one model made only from wood raw material and four models from each type of lignocellulosic agricultural raw material (Table 2).

Table 2. *Structure of different briquette models*

Model	LCARM, %	WRM, %
0	0	100
I	25	75
II	50	50
III	75	25
IV	100	0

Hydraulic briquette press was used for production of briquette with cylindrical shape. The specific pressure of 20 MPa (≈ 20 MN/m^2) was used for briquette pressing.

Briquettes made from lignocellulosic agricultural raw material (briquettes made from 100 % sunflower particles) are shown on Figure 2.

Figure 2. *Briquettes made of particles from sunflower stems*

The testing of the properties of the briquettes is made in accordance to the standard MKS D.B9.021/87. According to this standard, the following properties were tested:

- form and dimensions;
- density,
- moisture content;
- ash content;
- content of sulfur;
- low calorific value .

For determination of the ash content, sulfur, volatile compounds and gross calorific value, special briquettes in a form of pill with mass of 1 g were used, made in a special device for that assignment (Figure 3).

Figure 3. *Briquettes in a form of pill with mass of 1 g*

The ash content and content of free sulfur after combustion, as well as the moisture content of the raw material were determined during the testing of calorific value of the briquettes. The ash content

was tested according to the standard MKS B.H8.3120 in accordance with ISO 1171, while the total sulfur content was tested according MKS B.H8.316 in accordance with ISO/DR 241.

The caloricity of the briquettes was tested according to the standard MKS B.H8.318 in accordance with ISO/R 1928. This standard defines the method for determination of the caloricity of the hard fuels during constant density according to the bomb calorimetry method. During determination of the caloricity of the briquettes, the high (gross) calorific value was tested in laboratory condition, while the low (net) calorific value was calculated.

The volatile compounds that are separated during combustion of the briquettes are tested according to the standard MKS B.H8.317/65 in accordance with ISO/DR 550. The content of volatile matters is defined as mass loss, decreased by the moisture content that is created during combustion of the hard fuel without presence of air in certain conditions. The determination of the volatile matters is empirical, so it is important to strictly control the regime of heating, the end temperature and time for analysis in order to obtain reliable results. The moisture content of the hard fuel (briquettes) should be determine in the same time with the investigation of the material in order to decrease the volatile matters with certain moisture content.

3. RESULTS FROM THE RESEARCH

The measuring of the shape and dimensions of the briquettes showed that briquettes with cylindrical form are made, with mean diameter in the limits of 82,82 to 84,54 mm and mean length in the limits of 67,51 to 143,20 mm (Table 3).

In laboratory conditions the properties of different briquettes structures (models) are determined, whereupon the mean values of the results are shown in tables: in table 3 - for dimensions, density and moisture content of the briquettes and in Table 4 - for the moisture content, ash content, sulfur content, high and low calorific value, during the determination of the caloricity of the briquettes.

Table 3. *Mean values for the dimensions, density and moisture content of the briquettes*

Models	LCARM / WRM [%]	Mean diameter [mm]	Mean length [mm]	Properties	
				Density [kg/m^3]	Moisture content [%]
Briquettes made from wood raw material					
0	0 / 100	84,12	111,56	782,73	7,18
Briquettes made from grape pruning residues					
L-I	25 / 75	83,30	109,08	615,00	8,10
L-II	50 / 50	83,42	124,80	644,89	9,23
L-III	75 / 25	83,90	127,80	726,57	8,85
L-IV	100 / 0	83,98	143,20	825,97	8,69
Briquettes made from tobacco stems					
T-I	25 / 75	83,64	72,21	758,65	8,01
T-II	50 / 50	83,72	67,51	652,48	8,66
T-III	75 / 25	83,60	78,72	574,13	8,52
T-IV	100 / 0	84,54	80,76	526,61	9,47
Briquettes made from sunflower stems					
S-I	25 / 75	83,56	85,20	706,42	9,62
S-II	50 / 50	84,06	90,08	749,71	8,24
S-III	75 / 25	83,68	84,02	756,85	9,61
S-IV	100 / 0	83,80	90,46	789,15	9,93
Briquettes made from corn stems					
P-I	25 / 75	83,26	72,70	516,56	9,17
P-II	50 / 50	83,26	83,36	520,95	9,52
P-III	75 / 25	83,00	81,62	558,99	8,92
P-IV	100 / 0	82,82	86,32	582,38	8,82

Table 4. *Mean values for the moisture content, ash content, sulfur content, high and low calorific value during the determination of the caloricity of the briquettes*

Models	LCARM / WRM [%]	Moisture content [%]	Ash [%]	Sulfur [%]	High calorific value [kJ/kg]	Low calorific values [kJ/kg]
Briquettes made from wood raw material						
0	0 / 100	6,70	0,32	0,003	17773,40	16505,42
Briquettes made from grape pruning residues						
L-I	25 / 75	7,11	0,81	0,009	15790,23	15569,42
L-II	50 / 50	7,28	0,97	0,009	15818,40	15597,67
L-III	75 / 25	6,92	1,46	0,010	16531,43	16300,53
L-IV	100 / 0	6,98	2,53	0,011	16726,27	16495,53
Briquettes made from tobacco stems						
T-I	25 / 75	6,76	1,04	0,008	16120,10	14812,12
T-II	50 / 50	7,21	1,28	0,008	15740,11	14432,50
T-III	75 / 25	7,30	1,69	0,007	15730,35	14423,80
T-IV	100 / 0	8,11	2,17	0,007	15507,00	14199,60
Briquettes made from sunflower stems						
S-I	25 / 75	7,30	1,23	0,120	16211,10	14936,18
S-II	50 / 50	6,89	2,11	0,120	15821,10	14548,12
S-III	75 / 25	7,28	2,89	0,128	15340,21	14068,30
S-IV	100 / 0	7,37	3,66	0,130	15048,00	13776,00
Briquettes made from corn stems						
P-I	25 / 75	7,08	1,34	0,008	16920,34	15641,30
P-II	50 / 50	6,73	1,61	0,008	16876,75	15599,76
P-III	75 / 25	6,76	3,22	0,009	16790,11	15514,14
P-IV	100 / 0	6,71	6,02	0,009	16529,56	15252,41

4. ANALYSIS OF THE RESULTS FROM THE RESEARH

The analysis of fraction composition of chipped raw material (Table 1) shows that the minimum content of chipped raw material from all particle types is found in the fraction above 4,0 mm. The highest percentage of wood raw material (38,09 %) is reported in fraction 1,0/0,5 mm, while of lignocellulosic raw material in fraction 2,5/1,6 mm as follows: 29,66 % for particles from grape pruning residues, 57,63 % for tobacco stems particles, 62,02 % for sunflower stems particles and 42,61 % for corn stems particles. In other fractions form different particle types it cannot be noticed an explicit tendency of the obtained values.

Yossifov (2005) states that technologically the best fraction for production of wooden briquettes is that one in the limits of 0,5 to 7,0 mm. According to the same author, for briquettes production can be used particles with very fine agglomeration (dust) to particles from the fraction of the basic sieve of 10 mm. This shows that the fraction composition of the used raw material is in accordance with the recommendation given in the literature. It can be only remarked on the percentage of the participation of the fine fraction bellow 0,5 mm, which does not have significant impact on the properties of the briquettes.

The values for the briquettes density are shown in Table 3. The density of different briquette models made from lignocellulosic agricultural raw material has the values in the following limits: for briquettes made of particles from grape pruning residues – from 615,00 kg/m^3 in model L-I to 825,97 kg/m^3 in model L-IV; for briquettes made from tobacco stems particles – from 526,61 kg/m^3 in model T-IV to 758,65 kg/m^3 in model T-I; for briquettes made from sunflower stems particles – from 706,42 kg/m^3 in model S-1 to 789,15 kg/m^3 in model S-IV and for briquettes made from corn stems particles – from 516,56 kg/m^3 in model P-I to 582,38 kg/m^3 in model P-IV. For briquettes made from beech wood particles, the mean density is 782,73 kg/m^3. The obtained values of the density of the briquettes

show that only in models L-IV and S-IV (briquettes made with 100 % grape pruning particles and sunflower stems particles) the mean density is higher compared to the density of the briquettes made of wood particles, while in all other models the mean density is lower compared to the density of the wooden briquettes. In models made from grape pruning residues, sunflower stems and corn stems it was noticed an increment of the density with the increment of the participation of the lignocellulosic agricultural raw material in the briquettes composition. In briquettes made from tobacco stems particles it was noticed a reversed dependence – the density of the briquettes decreases with the increment of the participation of the tobacco stems particles in briquette composition.

On the basis of the conducted researches and the analysis of the density of the produced briquettes from agricultural lignocellulosic raw material, it can be stated that with the exception of model L-IV (mean density of 825,97 kg/m^3) in other types of briquettes the obtained density is bellow 800 kg/m^3 (the minimal density according to standard MKS D.B9.021/87). Lower mean density is also obtained in briquettes made only from wood particles. The low density values should be attributed to the technological processing for briquette manufacturing. The specific pressure of 20 MPa in the hydraulic press is low and cannot meet the requirements for production of briquettes with density in accordance with the above mentioned standard. Pressure increase of above 20 MPa will provide production of briquettes with density above 800 kg/m^3 for all types of briquettes.

The analysis of the results showed that the mean value of the moisture content of the briquettes is in the limits of 7,18 % in model 0 (briquettes made from wood particles only) to 9,93 % in model S-IV (Tab. 3). In accordance with the standard MKS D.B9.021/87 the moisture content of the briquettes should not exceed 18 %, i.e., the briquettes made from wood and lignocellulosic agricultural raw material meet the requirements of the standard regarding their moisture content.

The determination of the caloricity of the briquettes is a complex investigation which contains tests and analysis of several parameters. Beside determination of the caloricity of the briquettes, these tests contain test for determination of the moisture content of the chipped raw material, ash content and content of the total sulfur.

The values for the moisture content of the chipped raw material are in the limits of 6,70 % in model 0 to 8,11 % in model T-IV (Tab. 4). These values are lower compared to the values of the moisture content of the briquettes, which can be attributed to the fact that the briquettes are hygroscopic material with a tendency to absorb moisture from the environment.

The ash content of the briquettes models is in the limits of 0,32 % in model 0 to 6,02 % in model P-IV (Table 4). The obtained values show that with the increment of the participation of the lignocellulosic agricultural raw material in briquette composition the ash content increases.

The analysis of the results for the content of sulfur in the briquettes shows that these quantities are very small (Tab. 4). In model 0 the content of sulfur is 0,003 %, while in other models the values are in the limits of 0,007 to 0,011 %. Higher values are obtained in briquettes made from sunflower stems particles – from 0,12 % to 0,13 %.

The impact of the participation of the lignocellulosic agricultural raw material in the briquette composition on their caloricity can be seen from the data given in table 4. The results for the caloricity of the briquettes show that the mean value of the high calorific value is in the limits of 15048,00 kJ/kg in model S-IV to 17773,40 kJ/kg in model 0 (briquettes made from wood particles only). The mean value of the low calorific value is in the limits of 13776,00 kJ/kg in model S-IV to 16505,42 kJ/kg in model 0.

On the basis of the analysis of the caloricity of the briquettes it can be stated that the briquettes made from lignocellulosic agricultural raw material are characterized by relatively high values of the high and low calorific value, low values of ash content and insignificantly low sulfur content. Above mentioned confirmed that quality briquettes with good caloricity are made. The low ash and sulfur content put the briquettes in the group of environmentally friendly fuels which can have practical use.

5. CONCLUSIONS

The analysis of the results from the research of the briquettes made from wood raw material and lignocellulosic agricultural raw material is a base for drawing the following major conclusions:

1. The utilization of lignocellulosic agricultural raw material as biomass for briquette production does not cause technological difficulties, except the necessity of providing areas for storage

and preservation due to the seasonal collecting. The loss of mass during storage in chipped condition in form of chips should not be big higher than 10 %.

2. The briquettes made from lignocellulosic agricultural raw material are characterized by high values of the gross and net calorific values, have small amounts of ash content and insignificantly small amount of sulfur. This confirms that quality briquettes with good caloricity were made.
3. In relation with the low calorific value, with some exceptions, all of the briquettes meet the requirements of the standard MKS D.B9.021/87 and can be classified as extra and first class. This important property shows that the raw material is adequately prepared and can be recommended as raw material for production of briquettes in industrial conditions.
4. Because of the low ash content and insignificantly small amount of sulfur during combustion, the analyzed briquettes are eco-friendly products. Low ash and sulfur content put the briquettes in the group of environmentally friendly fuels which can have practical use.
5. For briquette production lignocellulosic agricultural residues can be used as raw material, but for rational utilization and bigger economic effect it is recommended a mixture of lignocellulosic agricultural raw material and wood raw material, which guarantee production of ecological briquettes with high energy value.
6. The good properties of the briquettes made on base of lignocellulosic agricultural raw material, as well as the relatively low price of the raw material, predetermines the competitiveness of these briquettes for different areas of application.

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The Authors' Addresses:

Dr Julia Mihajlova, Professor
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: jmihajlova@yahoo.com

Dr Borche Iliev, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: iliev@fdtme.ukim.edu.mk

Dr Violeta Jakimovska Popovska, Docent
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: jakimovska@fdtme.ukim.edu.mk

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IMPACT OF THE PARTICIPATION OF THE PHENOL FORMALDEHYDE RESIN ON PHYSICAL AND MECHANICAL PROPERTIES OF PANELS MADE FROM LIGNOCELLULOSIC AGRICULTURAL RESIDUES

Julia Mihajlova[1], Borche Iliev[2], Violeta Jakimovska Popovska[2]

[1]University of Forestry-Sofia, Republic of Bulgaria
e-mail: jmihajlova@yahoo.com
[2]Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje
e-mail: iliev@fdtme.ukim.edu.mk; jakimovska@fdtme.ukim.edu.mk

ABSTRACT

The lignocellulosic agricultural residues with its anatomical and chemical composition are similar to wood and they represent an effective alternative resource for production of particleboard production when appropriate technological conditions are created.

An important factor from technological and economical point of view is the participation of the resin in panel structure and its impact on the panels' physical and mechanical properties.

Three-layer particleboards from two types of lignocellulosic agricultural residues (grape wine rods and raspberry stems) are made in laboratory conditions. The participation of the phenol formaldehyde resin in the panel structure varies from 8 to 16 %.

In order to determine the impact of the participation of the phenol formaldehyde resin on the physical and mechanical properties of the panels the following properties are tested: swelling, water absorption, bending strength and internal bond according to standard methodology.

Key words: phenol formaldehyde resin, lignocellulosic agricultural residues, grape wine rods, raspberry stems, particleboard, physical and mechanical properties

1. INTRODUCTION

Republic of Bulgaria and Republic of Macedonia have developed agriculture, that every year produced big quantities of lignocellulosic residues. These quantities are not rationally used, so they are ballast for agriculture and in some cases are also pollutants of the environment. In these countries, grape pruning residues, fruit trees pruning's, sunflower stems, corn stems, tobacco stems, cotton stems, wheat straw, hemp and flax residues draw attention as potential lignocellulosic materials.

Beside above mentioned, it should be noticed that both countries have moderate forest resources, so wood is a deficit material and its rational utilization is important economical issue. One of the solutions for the economy of solid wood is a development of particleboard industry where as raw material forest residues and wood processing residues will be effectively utilized.

In many countries in the world, the attention is directed to research of the lignocellulosic agricultural residues as a possible raw material for production of particleboards, as one of the possible solution for its rational utilization. Many authors have published their researches that concern this issue (Bektas et al. 2005, Güler et al. 2006 and 2009, Gürüler et al. 2015, Iliev et al. 2005, Khristova et al. 1998, Mihailova et al. 2006, 2007, 2008 and 2009, Todorov et al. 2007, Yang et al. 2003, Yasar et al. 2010, Yossifov et al. 2001).

Lignocellulosic agricultural residues have similar anatomical and chemical structure to wood, so when adequate technological conditions are created, these residues can represent a efficient alternative resource for particleboard production.

The participation of the resin in particleboard production and its impact on particleboards' physical and mechanical properties is an important factor from technological and economical point of view.

2. METHOD OF THE EXPERIMENTAL RESEARCH

The aim of the research presented in the paper is to produce panels from two types of agricultural residues – raspberry stems and grape vine pruning residues, as well as to trace the impact of the participation of the resin on the physical and mechanical properties of these panels.

For the realization of the research, lignocellulosic agricultural raw material (raspberry stems and grape pruning residues) is collected from the regions in the Republic of Bulgaria where this biomass is mostly present.

The preparation of the lignocellulosic agricultural raw material is made in laboratory conditions at the Faculty of Forestry in Sofia. After that, the raw material is milled in particles on laboratory hammer mill.

The moisture content of the chipped raw material was tested. The fraction analysis of the chipped raw material is made on sieve shaker with four sieves with the following mesh dimensions: 10,0×10,0; 4,0×4,0; 2,5×2,5 and 1,5×1,5 mm. The obtained values of these parameters are given in Table 1.

Table 1. *Moisture content and fraction composition of the particles made from raspberry stems and grape pruning residues*

Type of particles	Moisture content, %	Fractions of the raw material, %				
		above 10/10 mm	10/4 mm	4/2,5 mm	2,5/1,5 mm	1,5/0 mm
Raspberry stems	9	0,25	6,27	34,38	22,56	36,38
Grape pruning residues	7	0,03	21,24	25,50	27,70	29,90

Three-layer particleboards from two types of agricultural residues are made in laboratory conditions – panels made only from raspberry stems particles (panels TP-M) and panels made only from particles made of grape pruning residues (panels TP-L). Surface layers of the panels are made from the fraction 2,5/1,5, while the core layer from the fraction 4/2,5. The ratio of the surface layer and core layer was 40:60. The panels are made using the following parameters: moisture content of the lignocellulosic particles of 8 %, type of the adhesive – phenol formaldehyde resin with initial concentration of 55 % and work concentration of 45 %, dimensions of the panels of 500×500×16 mm and moisture content of the panels of 8 %. The density of the panels ranges in the limits of 500 to 900 kg/m^3, the participation of the glue from 8 to 16 % and pressing temperature from 150 to 190 °C.

Seventeen panels from each type of lignocellulosic agricultural residues are made in accordance to the experimental matrix shown in Table 2.

After production, the panels were left for acclimatization for a time of 24 hours, after which adequate test specimens were cut in accordance with the valid European norms for testing of the physical and mechanical properties of the panels. Eight test specimens from each panel were cut.

The test specimens for testing the physical and mechanical properties of the panels were made in accordance with the standard BDS EN 326-1, while the testing of the panels' properties was done in accordance with the general rules for testing the physical and mechanical properties of the panels defined in the European norms for particleboards.

Before testing, the test specimens were conditioned to the constant mass at a temperature of 20±2°C and relative humidity of the air of 65±5 %.

Following properties of the panels were tested:

- water absorption;
- thickness swelling;
- bending strength;
- internal bond.

For each tested property of each panel, variation-statistical coefficients are calculated: mean arithmetical value (X_{mean}), standard deviation (S_x), coefficient of variation (V_x), error of the mean arithmetical value (m_x) and the index of correctness (P_x).

Table 2. *Experimental matrix*

Panel number	ρ, kg/m^3	Resin participation (Rp), %	Pressing parameters		
			τ, min/mm	P, MPa	T, °C
1	500	12	0,75	$P_{initial}$ - 2,4 P_{mean} - 1,2 P_{end} - 0,6	170
2	600				
3	700				
4	800				
5	900				
6	700	8	0,75	$P_{initial}$ - 2,4 P_{mean} - 1,2 P_{end} - 0,6	170
7		10			
8		14			
9		16			
10	700	12	0,55	$P_{initial}$ - 2,4 P_{mean} - 1,2 P_{end} - 0,6	170
11			0,65		
12			0,85		
13			0,95		
14	700	12	0,75	$P_{initial}$ - 2,4 P_{mean} - 1,2 P_{end} - 0,6	150
15					160
16					180
17					190

3. RESULTS FROM THE RESEARCH

The results for the water absorption at different participation of the phenol formaldehyde resin in the structure of the three-layer panels type TP-M and TP-L, made all form raspberry stems and grape pruning residues are shown in Table 3.

Table 3. *Water absorption of three-layer panels made of raspberry stems (TP-M) and grape pruning residues (TP-L) at different participation of the phenol formaldehyde resin in its structure*

Rp, %	Panels type TP-M					Panels type TP-L				
	X_{mean}, %	S_x, %	m_x, %	V_x, %	P_x, %	X_{mean}, %	S_x, %	m_x, %	V_x, %	P_x, %
8	91	14,1	4,4	22,6	2,1	85	4,7	1,6	12,6	4,4
10	73	14,3	4,5	16,3	4,5	79	4,0	1,4	12,3	4,3
12	67	12,3	3,9	24,5	3,6	67	1,3	0,7	10,3	3,6
14	50	19,6	6,2	30,6	3,7	55	1,9	0,7	13,2	4,7
16	30	22,5	7,1	48,4	4,6	40	2,4	0,9	14,1	4,4

The results for the thickness swelling at different participation of the phenol formaldehyde resin in the structure of the three-layer panels type TP-M and TP-L, made all form raspberry stems and grape pruning residues are shown in Table 4.

The impact of the phenol formaldehyde resin participation on bending strength and internal bond of the three-layer panels made of raspberry stems (TP-M) and grape pruning residues (TP-L) can be seen from the data given in Tables 5 and 6.

Table 4. *Thickness swelling of three-layer panels made of raspberry stems (TP-M) and grape pruning residues (TP-L) at different participation of the phenol formaldehyde resin in its structure*

Rp, %	Panels type TP-M					Panels type TP-L				
	X_{mean}, %	S_x, %	m_x, %	V_x, %	P_x, %	X_{mean}, %	S_x, %	m_x, %	V_x, %	P_x, %
8	42,8	5,6	1,8	26,7	2,4	36,9	11,9	4,2	13,4	4,9
10	38,9	3,8	1,2	18,5	3,8	32,6	9,1	3,2	11,6	4,0
12	19,0	4,8	1,5	27,2	3,9	19,1	11,6	4,1	14,5	4,8
14	17,4	3,7	1,1	21,3	4,8	14,4	13,3	4,2	14,1	4,5
16	11,6	2,5	0,8	18,5	3,1	10,0	17,1	6,3	13,1	1,5

Table 5. *Bending strength of three-layer panels made of raspberry stems (TP-M) and grape pruning residues (TP-L) at different participation of the phenol formaldehyde resin in its structure*

Rp, %	Panels type TP-M					Panels type TP-L				
	X_{mean}, N/mm^2	S_x, N/mm^2	m_x, N/mm^2	V_x, %	P_x, %	X_{mean}, N/mm^2	S_x, N/mm^2	m_x, N/mm^2	V_x, %	P_x, %
8	10	2,1	0,7	18,6	4,5	13	4,10	1,3	14,8	4,9
10	13	1,6	0,5	13,3	4,1	13	2,58	0,8	14,6	4,7
12	18	4,5	1,4	25,2	2,9	18	2,80	0,9	14,1	4,7
14	20	2,4	0,8	23,3	4,7	19	3,20	1,0	14,9	4,9
16	22	2,7	0,9	18,8	2,5	21	5,50	1,7	11,2	3,2

Table 6. *Internal bond of three-layer panels made of raspberry stems (TP-M) and grape pruning residues (TP-L) at different participation of the phenol formaldehyde resin in its structure*

Rp, %	Panels type TP-M					Panels type TP-L				
	X_{mean}, N/mm^2	S_x, N/mm^2	m_x, N/mm^2	V_x, %	P_x, %	X_{mean}, N/mm^2	S_x, N/mm^2	m_x, N/mm^2	V_x, %	P_x, %
8	0,61	0,10	0,03	11,6	3,7	0,27	0,11	0,04	14,3	4,6
10	0,72	0,08	0,03	7,3	2,3	0,40	0,12	0,04	15,8	4,5
12	0,80	0,06	0,02	8,0	2,5	0,48	0,13	0,04	14,5	4,5
14	1,00	0,04	0,01	3,5	1,1	0,65	0,22	0,07	13,8	4,4
16	1,10	0,06	0,02	8,4	2,6	0,80	0,15	0,05	14,8	4,2

The impact of the phenol formaldehyde resin participation on water absorption of the panels can be seen from the data given in table 3 and on Figure. 1. With increasing of the participation of the resin in panels' composition, the water absorption considerably decreases. In panels made from raspberry stems this decreasing is more intensive – the water absorption is 91 % at 8 % resin content and 30 % at 16 % resin content, which means decreasing of 61 %. In models made from grape pruning residues the decreasing of this property is 45 % – the water absorption is 85 % at 8 % resin content and 40 % at 16 % resin content.

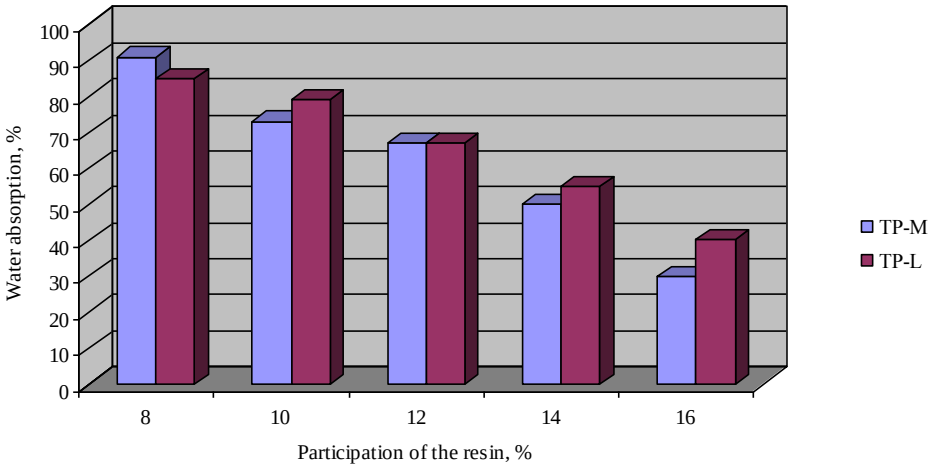

Figure 1. *Water absorption of the panels type TP-M and TP-L at different participation of the phenol formaldehyde resin in its structure*

The thickness swelling of the tested panels is also decreased with the increment of the resin participation in panels' composition. This can be seen in Table 4 and on Fig. 2. According to the results, the both types of panels made with 16 % resin content meet the requirements of the standard BDS EN 312 for particleboard type P3 for non-load-bearing construction in humid conditions. As load-bearing panels for dry conditions, panels type TP-L with 14 and 16 % resin content can be used, as well as the panel type TP-M with 16 % resin content (particleboard type P4 according to BDS EN 312). Only the panel type TP-L with 16 % resin content meets the requirements for load-bearing panels for use in humid conditions (type P5) defined by the standard BDS EN 312.

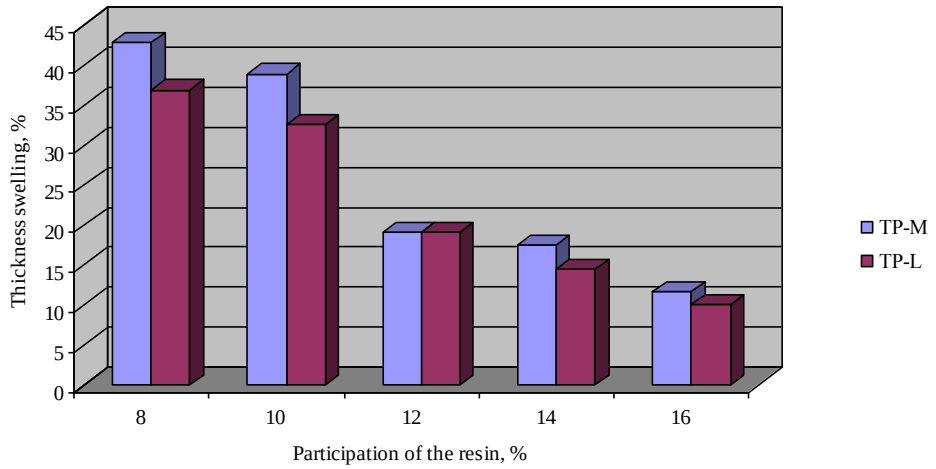

Figure 2. *Thickness swelling of the panels type TP-M and TP-L at different participation of the phenol formaldehyde resin in its structure*

The impact of resin participation on bending strength of the panels can be seen from the data given in table 5 and on figure 3. As it can be seen from the data, there is a clear tendency of increasing of bending strength by increasing of the resin participation. In panel type TP-M the increment is 12 N/mm^2 – from 10 N/mm^2 for the panels made with 8 % phenol formaldehyde resin content to 22 N/mm^2 for the panels made with 16 % resin content. The increment of the bending strength in panel type TP-L is 8 N/mm^2 – from 13 N/mm^2 for the panels made with 8 % phenol formaldehyde resin content to 21 N/mm^2 for the panels made with 16 % resin content.

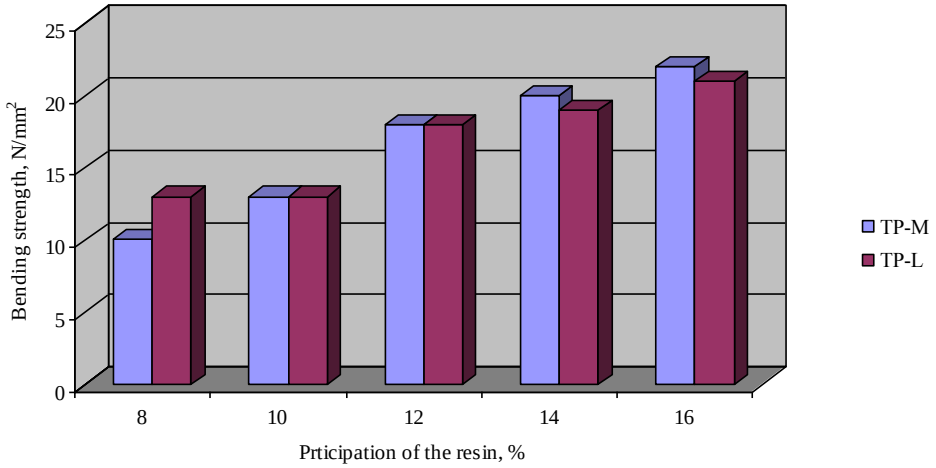

Figure 3. *Bending strength of the panels type TP-M and TP-L at different participation of the phenol formaldehyde resin in its structure*

Regarding the bending strength, with the exception of the panels made from raspberry stems (Type TP-M) with 8 % phenol formaldehyde resin content, all other panels meet the requirements for panels for general purposes used in dry conditions and interior design (including furniture making) – panel types P1 and P2 according to the standard BDS EN 312. Panel types TP-M and TP-L with 12 % resin content and more, can be used as non load-bearing panels in humid conditions (type P3 according to BDS EN 312) and also as load-bearing panels in dry and humid conditions (type P4 and P5 according to BDS EN 312). The obtained results give the right to classify the panels type TP-M with 14 % and 16 % resin content and panels type TP-L with 16 % resin content as P6 particleboards according to the standard BDS EN 312 (as heavy-duty load bearing panels for use in dry conditions). Only the panels TP-M have bending strength of 22 N/ mm^2 which is a rewuirement for panel type P7 in accordance with the standrad BDS EN 312 (for heavy-duty load bearing panels for use in humid conditions).

The impact of the participation of phenol formaldehyde resin on the internal bond of the panels can be seen from the data given in Table 6 and on Fig. 4. The increment of the participation of the resin causes increment of the internal bond of the panels. Higher values of internal bond are obtained in panels made form raspberry particles (TP-M), but generally speaking, both types of panels have good values. Only the panels made from grape pruning particles with 8 % resin content do not meet the requirement for panel types P1, P2 and P4 according to the standard BDS EN 312. All panels TP-M (with different participation of the resin) and panels TP-L with 14 and 16 % resin content meet the requirements of the standard BDS EN 312 for panel type P6 (heavy-duty load bearing panels for use in dry conditions).

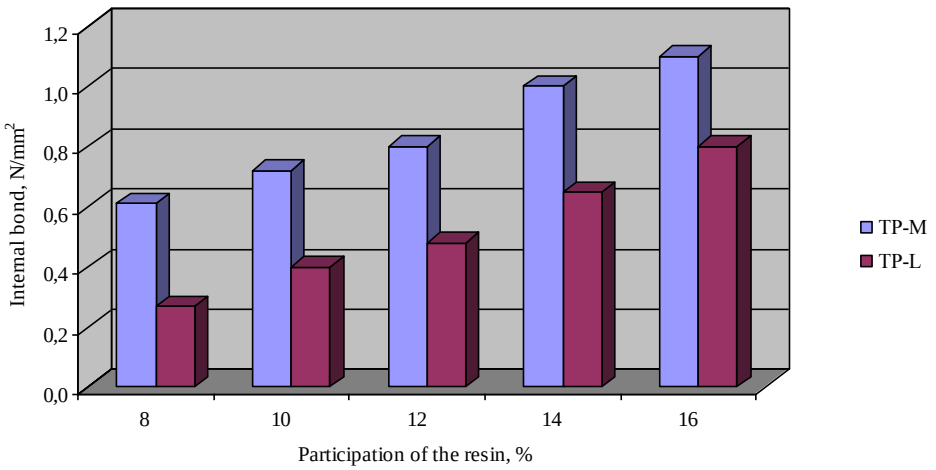

Figure 4. *Internal bond of the panels type TP-M and TP-L at different participation of the phenol formaldehyde resin in its structure*

4. CONCLUSIONS

As a result of the research and on the basis of the analysis of the obtained results, following more important conclusions can be drawn:

1. The utilization of raspberry stems and grape pruning residues as lignocellulosic agricultural raw material for wood based panels' production doesn't cause technological difficulties, except the necessity of providing areas for storage and preservation due to the seasonal collecting.

2. The manufactured panels from particles made from raspberry stems and grape pruning residues are characterized with good results of basic physical and mechanical properties, which confirm the quality of produced panels and possibility for their practical application.

3. Increment of the participation of the resin content in panel structure has impact on physical and mechanical properties of the panel – water absorption and thickness swelling decrease, while the bending strength and internal bond increase.

4. When selecting the percentage of the resin participation it should have in consideration the application of the panel, i.e., the required values of the properties of the panels on one hand and the economical efficiency on other hand. The higher participation of the resin increases the panels' production costs.

5. The good properties of the panels made from raspberry stems and grape pruning residues, as well as the relatively low price of the raw material, predetermines the competitiveness of these panels for different areas of application.

6. The raspberry stems and grape pruning residues represent quality lignocellulosic agricultural residues for panels' production and this raw material can be recommended for production of wood panels.

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The Authors' Addresses:

Dr Julia Mihajlova, Professor
University of Forestry,
10 Kliment Ohridsky Blvd., Sofia 1756, BULGARIA
e-mail: jmihajlova@yahoo.com

Dr Borche Iliev, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: iliev@fdtme.ukim.edu.mk

Dr Violeta Jakimovska Popovska, Docent
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: jakimovska@fdtme.ukim.edu.mk

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PRODUCTION OF POLYMER BINDER FOR WASTE WOOD AND CARBON DUST COMPOSITE MATERIALS

Jelena D. Rusmirović[1], Milica P. Rančić[2], Vuk D. Tomić[3], Ivana Popović[3], Aleksandar D. Marinković[3]

[1]*Innovation center, Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia, e-mail: jrusmirovic@tmf.bg.ac.rs*
[2] *Faculty of Forestry, University of Belgrade, Serbia, e-mail: milica.rancic@sfb.bg.ac.rs*
[3]*Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia e-mail: marinko@tmf.bg.ac.rs*

ABSTRACT

Polymer binders for waste wood and carbon dust composite materials were obtained by polyethylene terephthalate (PET) depolymerization with following alcohols: benzyl alcohol, diethylene glycol, glycerol and polyethylene glycol 200. The synthesized binders were characterized by FT-IR and NMR analysis. Moisture content, residual ash, total sumpor content, strength of the pressure and net calorific value of the obtained wood/carbon dust briquets with these binders were investigated. All samples showed significant improvement of thermal and physical-mechanical properties in wood and carbon dust composite materials.

Key words: polymer binder, wood/carbon dust briquets

1. INRODUCTION

Poly(ethylene terephthalate) (PET), by virtue of its good physical-mechanical and gass and solvetnts barrier properties, is one of the most used engeenering thermoplastic materials (Atta *et. al.*, 2007). PET is widely used for soft drink packaging, magnetic or pressure-sensitive adhesive tapes, and as a consequence of its widespread use there is a problem of managing waste PET (Al-Salem, Lettieri, Baeyens, 2009). Four major recycling categories of PET are re-extrusion (primary), mechanical (secondary), chemical (tertiary) and energy recovery (quaternary) (Awaja, Pavel, 2005), and the chemical recycling processes provide waste PET transformation into raw materials that can be reused for new products (Lorenzetti, *et. al.*, 2006). Waste PET transesterification using different glycols converted PET into glycolysates which can be used for the synthesis of a variety of materials such as polyester, alkyd and epoxy resins or binder for composites materials (Marinković *et. al.*, 2013).
Various polymeric materials can be used as a binder in the process of waste wood/carbon dust briquettes production. The most commonly used polymeric binder material is low density polyethylene (LDPE) (Massaro, Son, Groven, 2014). LDPE has desirable energy waterproofing and binder characteristics, and in appropriate concentration provides efficient particles size. Addition of 10 wt.% LDPE increases the coal dust heating value from 21.9 MJ/kg to 24.3 MJ/kg, but the addition of LDPE in a concentration lower than 5 wt.% reduce the occurrence of exothermic decomposition temperature. Addition of LDPE has a positive impact at the coal burning. In addition to LDPE, as a binder for wood and carbon dust briquetting also can be used other solid waste polymeric materials (Massaro, Son, Groven, 2012). Polymeric materials, such as resins based on polyethylene, polystyrene and poly(vinyl acetate), can be used for briquetting, combined with petroleum products (Takashi *et. al.*, 1979).

Waste PET, with other communal wastes, can be used for briquetting solid fuels such as wood and carbon dust (Drozd *et. al.*, 2009).
In this paper, the process of polymer binder synthesis from waste poly(ethylene terephthalate) and the production of wood and carbon dust briquets are demonstrated. The waste PET glycolzates were prepared in order to study the influence of the glycolysates type on moisture content, residual ash, total sumpor content, strength of the pressure and net calorific value of the obtained wood/carbon dust briquets.

2. THE MATERIALS AND METHODS

MATERIALS

PET waste, collected from soft drink bottles, was flaked into small pieces (app. 0.5 × 0.5 cm) and washed with a detergent, ethanol and dichloromethane to remove any trace of impurities and residual adhesives. Benzyl alcohol, dichloromethane (DCM) and diethylene glycol were purchased from Fluka, glycerol was purchased from Centrohem and polyethylene glycol 200 was purchased from Riedel-de Haën Seelze-Hannover. Zinc-acetate was purchased from Sigma Aldrich.

Synthesis of polymer binder based on PET glycolizate

PET waste depolymerization was performed in a four-necked round bottom flask by glycolysis with alcohols: benzyl alcohol, diethylene glycol, glycerol and polyethylene glycol 200, in the following way: a certain amount of dried PET, glycol and zinc-acetate (0.5 wt.%) were placed into a four-necked flask equipped with a mechanical stirrer, water condenser and a thermometer. The flask was placed in a previously heated oil bath and the reaction mixture was maintained at 210-220 ^{o}C providing efficient mixing for 6 h. The prescriptions of the synthesized glycolizates are given in Table 1.

Table 1. *Prescriptions of the synthesized glycolizates*

Sample	***PET (mol)***	***Glycol (mol)***	***Experimental melting temperature (^{o}C)***
PET/BA	0.93	0.69	92-93
PET/DEG	0.41	1.66	Viscous mass at 25 ^{o}C
PET/GLY	0.41	0.21	45
PET/PEG$_{200}$	0.41	0.91	Viscous mass at 25 ^{o}C

Purification of PET/DEG glycolyzed product

The purification of the glycolyzed product was performed after glycolysis. The reaction product was dissolved in 200 ml of DCM (1:1 v/v). Afterwards, water (1:5 v/v DCM/water) was added under mechanical mixing, maintaining 20 ^{o}C during mixing for 30 min, and after that, the solution was cooled under ambient condition. The upper water layer was separated and the procedure was repeated in two more cycles. After filtration, the purified product was dried in an oven at 90 ^{o}C for 24 h, and subsequently in a vacuum oven (5 mbar) at 80 ^{o}C for 3 h.

Production of wood/carbon dust composite materials

The producing briquettes process based on PET glycolizates and materials selected from municipal waste is carried out by mixing of a certain amount of glycolizates with municipal waste selected materials (polyethylene (PE) bags, oligomeric low and high density PE and paraffin waxes). Blending of synthesized glycolizates and waste municipal materials was carried out after the completion of the PET depolimerization, in the following way: the obtained PET glycolizates was heated to the melting point of PE (120-140 ^{o}C) and mixed with the liquid oligomeric LDPE and HDPE for 30 minutes. The compositions of the binder mixtures for briquetting are presented in Table 2. The

hot mass was transferred to the pre-heated mold presses and defined pressure of 5 MPa was applied for 5 minutes. After the operation of pressing mass for briquetting, the mold is allowed to cool resulting in a briquette coal dust of the desired shape. The composite materials were removed from the mold and physical-chemical and mechanical properties were tested, as well as the heat content of the briquettes.

Table 2. The compositions of the binder and wood/carbon dust mixture for briquetting

Sample	***Wood/Carbon dust (50/50), %***	***Glycolizates, %***		***PE, %***	***LDPE, %***	***Paraffin wax, %***
1	85	PET/BA	6	1.5	3.5	4
2	85	PET/DEG	6	1.5	3.5	4
3	85	PET/GLY	6	1.5	3.5	4
4	85	PET/PEG_{200}	6	1.5	3.5	4

Figure 1 shows laboratory apparatus used for wood/carbon dust composite materials production.

Figure 1. *Laboratory apparatus used for wood/carbon dust composite materials production*

Characterization method

The structural analysis of the obtained glycolyzed product and synthesized polyesters was performed by FTIR (Bomem MB-102) spectroscopy, within a range of 400-4000 cm^{-1}, at a resolution of 4 cm^{-1}.

^{1}H and ^{13}C NMR spectra were recorded in deuterated chloroform ($CDCl_3$), using a Varian-Gemini 200 spectrometer at 200 MHz for the ^{1}H NMR and 50 MHz for the ^{13}C NMR spectra.
Elemental analyses were performed using a VARIO EL III Elemental analyzer.
Characterization methods for for wood/carbon dust composite materials are given in Table 3.

Table 3. *Characterization methods for wood/carbon dust composite*

Parameter	***Unit***	***Characterization methods***
Moisture content	%	ISO 5068-1:2007
Residual ash	%	ISO 1171:2010
Total sumpor content	%	ISO 334:2013
Net calorific value	MJ/kg	ISO 1928:2009

% - Based on the weight of the sample

3. RESULTS

Characterization of the obtained glycolizates

Figure 2 shows the structural formulas of the obtained glycolizates.

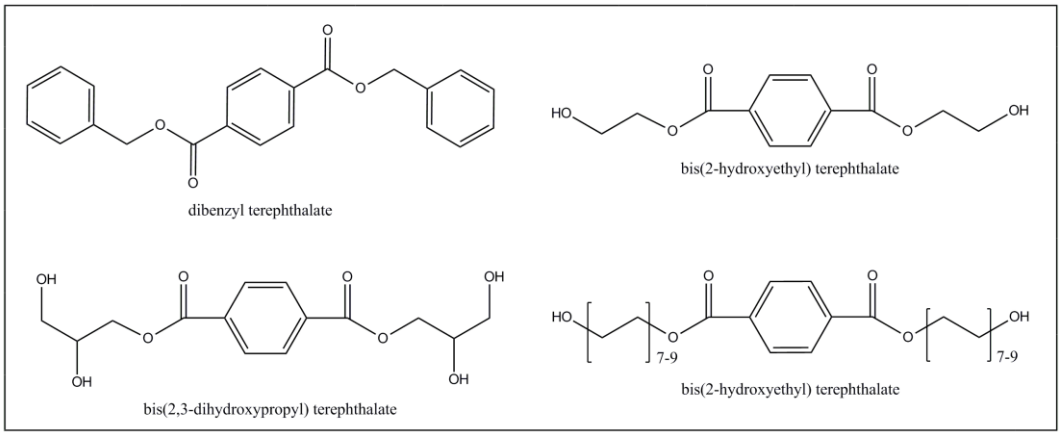

Figure 2. *The structural formulas of the obtained glycolizates*

FTIR analysis:
- Valence stretching vibration (stretching) of a methylene group (CH_2) - asymmetrical at around 2929 cm^{-1} and symmetric at around 2859 cm^{-1},
- Stretching vibration at 1723 cm^{-1} of the carbonyl group on phthalic ring,
- Skeletal stretching vibration of C=C double bond of the phenyl nucleus of the 1600-1580 cm^{-1},
- Deformation vibrations of methylene groups in the plane: shredding (scissoring) overlaps with the asymmetric deformation vibration of methyl groups at 1463 cm^{-1},
- Valence asymmetric stretching vibration of C=O of the ester groups present at 1269 and 1250 cm^{-1},
- Symmetric deformation vibration of the methyl group at 1380 cm^{-1},
- Valence symmetric stretching vibration of C-O group of the ester links present in phthalic ring at around 1117 and 1102 cm^{-1},
- The tape in the range of 800-600 cm^{-1} corresponding to CH out of plane deformation vibrations of the phenyl nucleus.

NMR analysis of PET/BA:
^{1}H NMR ($CDCl_3$): 5.26 (2H, C_6H_5-C$\underline{H}_2$-), 7.38 (*t*, 3H, HAr), 7.47 (*d*, 2H, HAr), 7.83 (*m*, 4H, HAr); ^{13}C NMR ($CDCl_3$): 65.7 (C_6H_5-$\underline{C}H_2$-), 127.1 (CAr), 127.6 (CAr), 128.9 (CAr), 129.8 (CAr), 134.4 (CAr), 136.1 (CAr), 165.9 (C=O).
NMR analysis of PET/DEG:
^{1}H NMR ($CDCl_3$): 3.65 (*t*,1H, $\underline{H}$O-CH_2-CH_2-), 3.73 (*t*, 2H, HO-C$\underline{H}_2$-CH_2-), 4.39 (*t*, 2H, HO-CH_2-C$\underline{H}_2$-), 7.83 (*m*, 4H, HAr); ^{13}C NMR ($CDCl_3$): 60.2 (HO-$\underline{C}H_2$-CH_2-), 66.5 (HO-CH_2-$\underline{C}H_2$-), 128.9 (CAr), 134.4 (CAr), 165.9 (C=O).
Similar result was obtained from NMR spectra of PET/GLY and PET/PEG_{200}. Table 4 shows results of elemental analysis of obtained glycolizates.

Table 4. *Results of elemental analysis of obtained glycolizates*

Sample	***%C***		***%H***		***%O***	
	Calculated	***Exp. Deter.***	***Calculated***	***Exp. Deter.***	***Calculated***	***Exp. Deter.***
PET/BA	76.29	76.24	5.24	5.22	18.48	18.55
PET/DEG	56.69	56.67	5.55	5.56	37.76	37.70
PET/GLY	55.61	57.90	5.40	5.77	38.99	36.33
PET/PEG_{200}	56.60	56.69	5.60	5.55	37.80	37.76

4. DISCUSSION

Physical-chemical and mechanical characteristic of wood and carbon dust composite materials

The material was removed from the mold after the pressing of briquetting mass and physical-chemical and mechanical properties were tested, as well as the heat content of the briquettes. Table 5 shows results of the physical-chemical and mechanical properties of wood and carbon dust composite materials.

Table 5. *Physical-chemical and mechanical properties of wood/carbon dust composite materials*

Samle	*Moisture content, %*	*Residual ash, %*	*Total sumpor content, %*	*Impact strength, MPa*	*Net calorific value, MJ/kg*
1	4.10	0.63	15.4	17.5	24.9
2	4.70	0.61	15.4	18.2	21.7
3	4.90	0.64	15.4	17.9	21.1
4	4.60	0.62	15.6	16.8	24.5

As it can be seen from the physical-chemical and mechanical properties of the wood/carbon dust, the highest net calorific value of composite materials is obtained for composition 1, where the PET/BA was used as a polymeric binder. The net calorific values of Samples 2-3, where the aliphatic alcohols were used for PET glycolysis, are lower. The highest net calorific value is observed for Sample 4, which consists of polymeric binder with long aliphatic PEG_{200} chain. It is also observed that the Sample 1 moisture content is the lowest, and increases with the increasing number of hydroxyl group in glycolizates structure (Figure 2). The residual ash and total sumpor content are similar for all wood/carbon dust composites.

5. CONCLUSION

Based on presented physical-chemical and mechanical test results, it can be concluded that all samples can be used as polymeric binder for wood/carbon dust briquething and showed significant improvement of thermal and physical-mechanical properties in wood and carbon dust composite materials, esspecialy samples with aromatic core (PET/BA) and long aliphatic chain (PET/PEG_{200}). The net calorific value decreases with the increasing number of hydroxyl group in binder’s structure. The opposite is observed for moisture content.

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The Authors' Addresses:

Jelena D. Rusmirović,
PhD student
Innovation center, Faculty of Technology and Metallurgy,
University of Belgrade,
Karnegijeva 4, 11000 Belgrade, SERBIA,
e-mail: jrusmirovic@tmf.bg.ac.rs

Dr Milica Rančić,
assistant professor
Faculty of Forestry,
University of Belgrade,
Kneza Višeslava 1, 11030 Belgrade, SERBIA,
e-mail: milica.rancic@sfb.bg.ac.rs

Vuk D. Tomić,
PhD student
Faculty of Technology and Metallurgy,
University of Belgrade,
Karnegijeva 4, 11000 Belgrade, SERBIA,
e-mail: vtomic@tmf.bg.ac.rs

Ivana Popović,
PhD student
Faculty of Technology and Metallurgy,
University of Belgrade,
Karnegijeva 4, 11000 Belgrade, SERBIA,
e-mail: ivana.popovic@gmail.com

Dr Aleksandar D. Marinković,
assistant professor
Faculty of Technology and Metallurgy,
University of Belgrade,
Karnegijeva 4, 11000 Belgrade, SERBIA,
e-mail: marinko@tmf.bg.ac.rs

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COMPARATIVE RESEARCH ON THE DESTRUCTIVE BENDING MOMENTS OF SOME CORNER JOINTS OF FRAME STRUCTURAL ELEMENTS MADE OF SOLID SPRUCE WOOD WITH A CROSS SECTION OF 50 x 30 mm PART IV: T-SHAPE CORNER JOINTS

Georgi Kyuchukov[1], Borislav Kyuchukov[1], Vassil Jivkov[1], Assia Marinova[1], Gjorgi Gruevski[2], Georgi Gligov[1]

[1] University of Forestry, Sofia, Republic of Bulgaria, Faculty of Forest Industry,
e-mail: borislav65@abv.bg; vassil.jivkov@prodes.bg; assiamar@abv.bg;
[2] Ss. Cyril and Methodius University, Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior
e-mail: gruevski@fdtme.ukim.edu.mk

ABSTRACT

The results from the research on the destructive bending moments of the T-shape corner joints of structural elements made of solid spruce wood with a cross section of 50 x 30 mm are given.

1. It was established that the type of the joints has significant influence on the destructive bending moment.
2. According to the value of the destructive bending moment the tested types of T-shape corner joints are set in the following hierarchical order:
   - mortise and tenon joints;
   - dowel joints;
   - dovetail mortise and tenon joints;
   - splined joints;
   - butt joints.
3. It is recommended that the research results of the strength characteristic of the corner joints are taken into consideration in strength design of furniture.

Key words: T-shape corner joints, frame structural elements, destructive bending moments, solid spruce wood

1. INTRODUCTION

The strength of the T-shape corner joints is of great importance to the strength and stiffness characteristics of the construction of skeleton furniture. In the previously published papers (Kyuchukov et al, 2014a; Kyuchukov et al, 2014b; Kyuchukov et al, 2014c) for the strength characteristic of the joints of frame structural elements made of solid spruce wood (Picea abies Karst.) data are given for the destructive bending moments of the end corner joints.

In the present part IV of the series of articles data are given for the destructive bending moments of some of the most often used in practice T-shape corner joints of frame structural elements made of solid spruce wood (Picea abies Karst.).

The data refer to 9 types of T-shape corner joints of frame structural elements made of solid wood with a cross section 50 x 30 mm, approved in the Bulgarian State Standard (BSS) 5527-73.

2. MATERIAL AND METHODS

The test samples of the joints were made of solid spruce wood, supplied from the Educational Experimental Forestry Enterprise of the University of Forestry at “Yundola”. They were manufactured from the same sample tree as the tested in the part I, II and III samples of the series of papers on these lines (Kyuchukov et al, 2014a; Kyuchukov et al, 2014b; Kyuchukov et al, 2014c), i.e. from the solid wood with the same physical and mechanical properties: density – 387 kg/m^3; bending strength – 56 N/mm^2; compressive strength parallel to grain – 34 N/mm^2; longitudinal elasticity modulus – 9 500 N/mm^2.

The following types of T-shape corner joints were tested:

1. **T-shape corner butt joints** (Figure 1):
   - butt joint at right angle;
   - butt joint at other than right angle.
2. **T-shape corner mortise and tenon joints** (Figure 2):
   - blind mortise and tenon joint;
   - through mortise and tenon joint.
3. **T-shape corner dovetail mortise and tenon joints** (Figure 3):
   - bilateral dovetail mortise and tenon joint at right angle;
   - one-sided dovetail mortise and tenon joint at right angle;
   - one-sided dovetail mortise and tenon joint at other than right angle.
4. **T-shape corner splined joints** (Figure 4):
   - dowel joint;
   - splined joint.

The parameters of the joints correspond to the Bulgarian State Standard 5527-73 and are given at Figures 1 to 4.

The joints of the structural elements were made with polyvinylacetate adhesive with the following characteristics: outer appearance – cream homogeneous viscose mass; viscosity – 3500 cP (middle viscosity suitable for brush coating); open time at 20 ^{0}C – not bigger than 10 min.

The type and dimensions of the samples are shown on figure 5. The size L_1 = 141 mm, and L_2 = 332 mm. The other sizes are as shown on Figures 1 to 4.

It is the custom to test the samples under the arm compression bending load.

By reason of asymmetry of the connecting elements and difference in mutual position of the joined frame structural elements of some of the joints, it is the custom to test them at arm compression bending load in two directions – in the direction of the ends of the arms A ↔ B and in the direction B ↔ C (Figure 5 and 6). With a view to this for each type of joint were manufactured 30 numbers of test samples – at 15 numbers for compression bending load in both directions (see Figure 5).

The schemes of loading of the samples in their testing (Figure 6) correspond to the standardized methodology (BSS 9165-90), worked out at the Laboratory of Furniture Construction at the University of Forestry.

Before testing the samples were conditioned 5 days and nights at temperature (21 ± 3) ^{0}C and relative air humidity (55 ± 10) %.

The experiment was carried out at universal testing machine at an even speed of loading in the length of (60 ± 30) s from the beginning of the loading and accuracy of reading of the results 1 % of the failure force of loading.

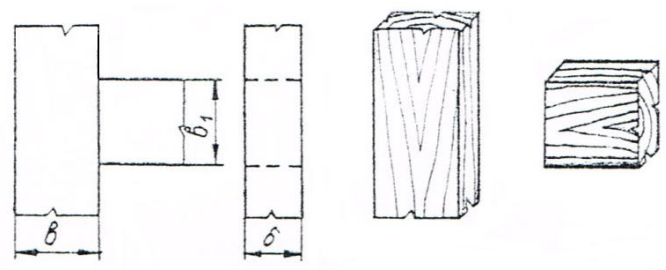
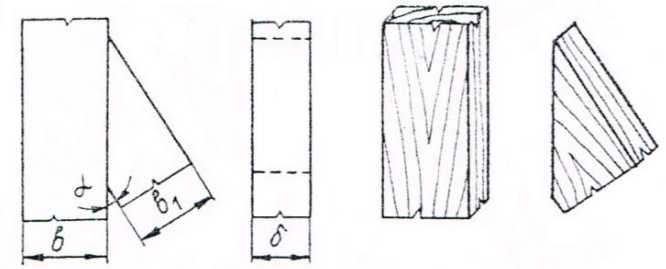
 **1**	$b = b_1 = 50$ mm $\delta = 30$ mm
 **2**	$b = b_1 = 50$ mm $\delta = 30$ mm $\alpha \leq 90^0 (= 45^0)$

Figure 1. *T-shape corner butt joints:* ***1*** *– butt joint at right angle;*
2 *– butt joint at other than right angle*

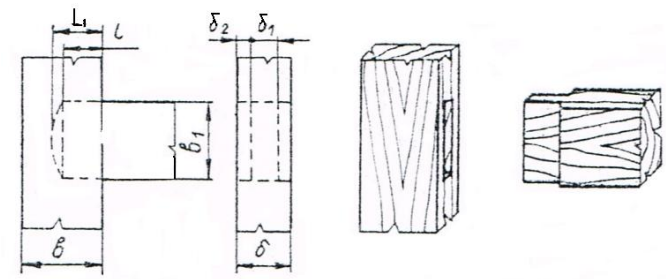
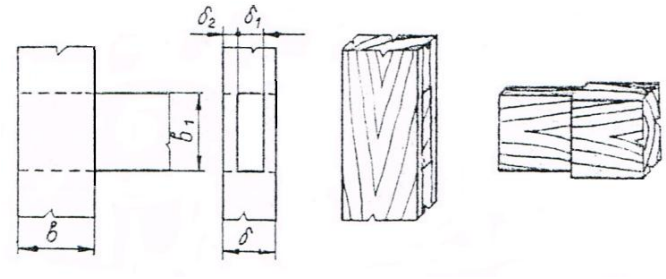
 **3**	$b = b_1 = 50$ mm $b_2 = (0,6 \div 0,8) b_1 = 30$ mm $\delta = 30$ mm $\delta_1 = 0,4\ \delta = 12$ mm $\delta_2 = 0,3\ \delta = 9$ mm $L = (0,5 \div 0,8)\ b = 35$ mm $L_1 = L + 1 \div 2$ mm $= 37$ mm
 **4**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = 0,4\ \delta = 12$ mm $\delta_2 = 0,3\ \delta = 9$ mm

Figure 2. *T-shape corner mortise and tenon joints:* ***3*** *– blind mortise and tenon joint;*
4 *– through mortise and tenon joint*

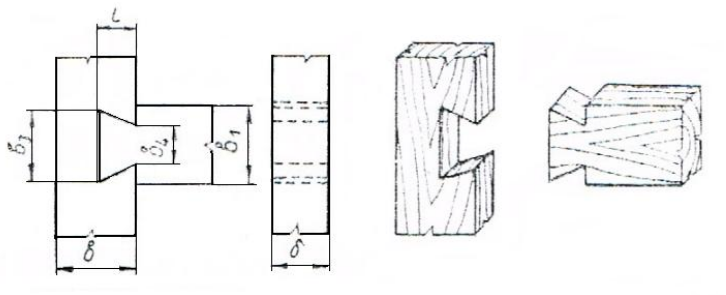
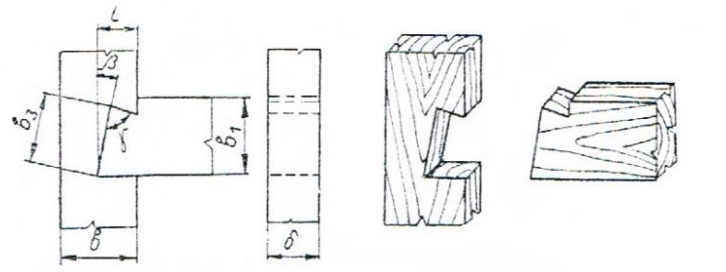
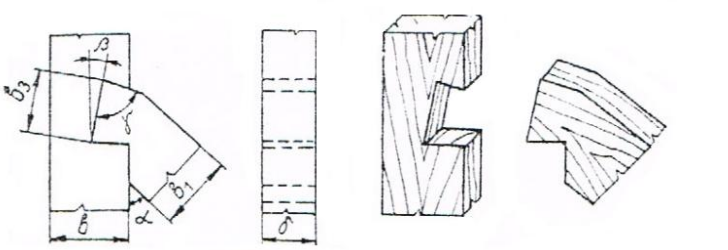
 **5**	$b = b_1 = 50$ mm $\delta = 30$ mm $b_2 = (0,6 \div 0,8) b_1 = 30$ mm $b_3 = 0,85\ b_1 = 42$ mm $b_4 = 0,5\ b_1 = 25$ mm $l = (0,3 \div 0,5)\ b_1 = 25$ mm
 **6**	$b = b_1 = 50$ mm $\delta = 30$ mm $b_3 = 0,925\ b_1 \approx 45$ mm $l = (0,5 \div 0,6)\ b_1 = 30$ mm $\beta = 10^0$ $\gamma = 80^0$
 **7**	$b = b_1 = 50$ mm $b_3 = 0,9\ b_1 = 45$ mm $\alpha < 90^0$ $\beta = 10^0$ $\gamma = 80^0$

Figure 3. *T-shape corner dovetail mortise and tenon joints:* ***5*** *– bilateral dovetail mortise and tenon joint at right angle;* ***6*** *– one-sided dovetail mortise and tenon joint at right angle;* ***7*** *– one-sided dovetail mortise and tenon joint at other than right angle*

The destructive bending moments M_1 under compression bending test in direction A ↔ B and M_2 under compression bending test in direction B ↔ C have been calculated correspondingly by formulas (1) and (2).

$$M_1 = F_1 . l_1 \quad (1)$$

$$M_2 = F_2 . l_1 \quad (2)$$

where

F_1 and F_2 are the failure forces in compression bending test (Figure 6) in N;

l_1 – the corresponding arm of bending in compression bending test under the scheme of loading a, b and c (Figure 6) in m.

The results from the experiments are processed by the variation statistics methods.

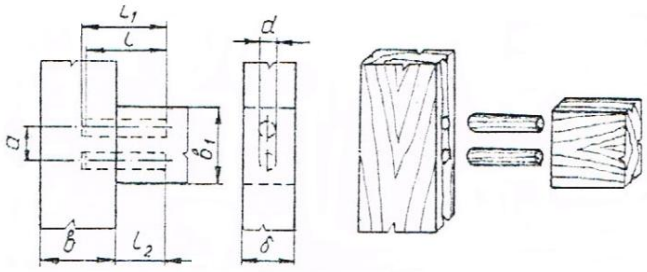
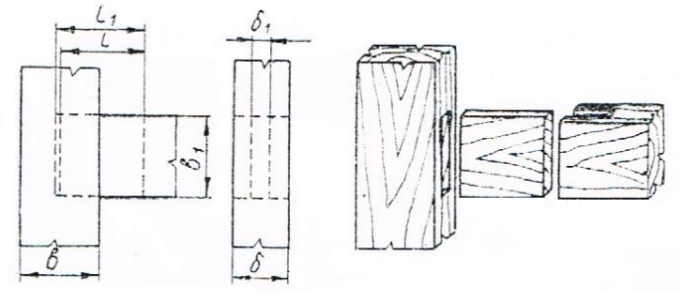
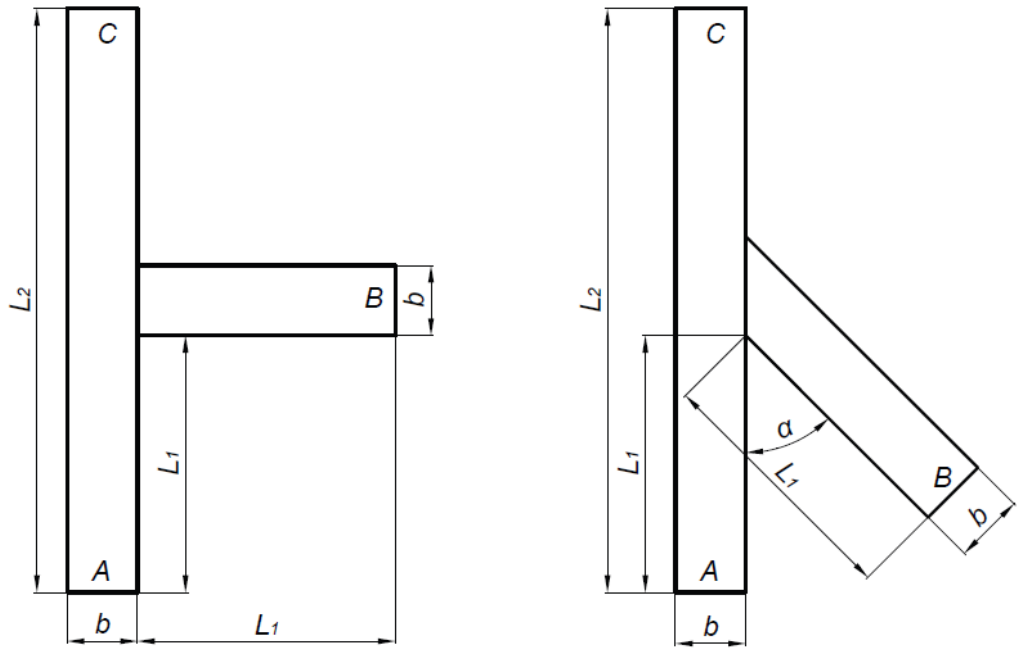
 **8**	$b = b_1 = 50$ mm $\delta = 30$ mm $d = 0{,}4\ \delta = 12$ mm $l=(2{,}5\div6)\ d = 60$ mm $l_1= l + (2\div3)$ mm $= 62$ mm $l_2= 0{,}55\ l = 33$ mm $a \geq 2\ d = 26$ mm
 **9**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1= 1/3\ \delta = 10$ mm $l = (1\div1{,}6)\ b = 65$ mm $l_1 = l + (2\div3)$ mm$= 67$ mm

Figure 4. *T-shape corner splined joints:* ***8*** *– dowel joint;* ***9*** *– splined joint*



a **b**

Figure 5. *Type and dimensions of the samples for testing the T-shape corner joints of frame structural elements made of solid wood:* ***a*** *– joints at right angle;* ***b*** *– joints at other than right angle*

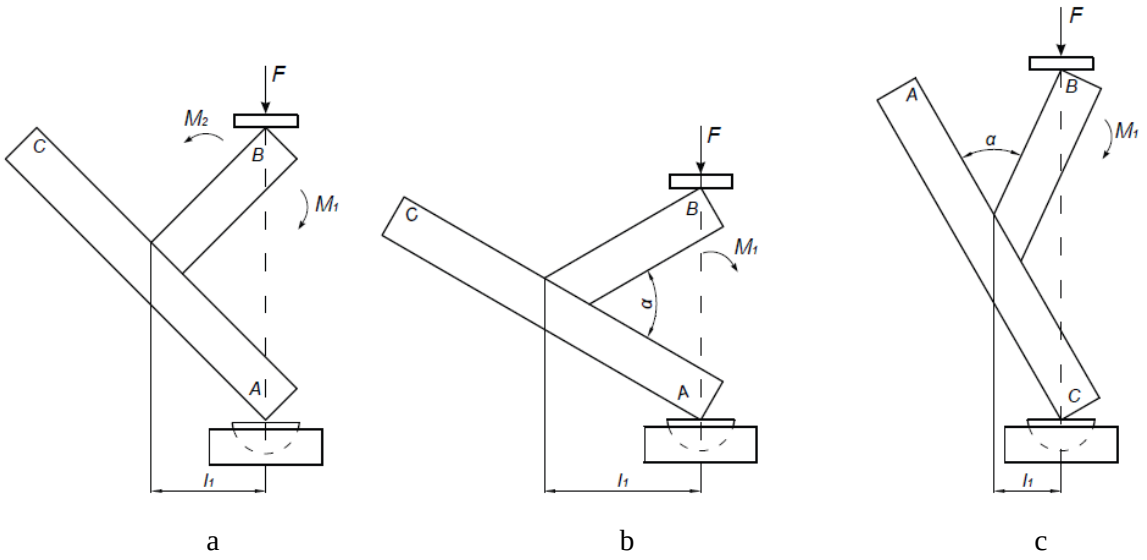


Figure 6. *Schemes for testing of samples of the T-shape corner joints at compression bending load:* ***a*** *– joints at right angle;* ***b*** *– joints at other than right angle in direction A ↔ B;* ***c*** *– joints at other than right angle in direction B ↔ C*

3. COMPARATIVE ANALYSIS OF THE EXPERIMENTAL RESULTS

The results from the research are given in Table 1, and the ratio between the destructive bending moments of the tested corner joints is presented graphically in the same order on Figure 7.

From the data in Table 1 and Figure 7 is seen that the destructive bending moments M_1 and M_2 at compression bending load are very close (in the limits of tolerable error). Since the T-shape corner joints at right angle have symmetrical connecting structural elements, their loading at both opposing directions leads to the same results. The proportion between the mean values of bending moments from the testing of these types of joints (No 1, 2, 3, 4, 5, 8 and 9 on Figure 7) in the both directions is 235 : 239, i.e. they are almost equal. Comparatively considerable difference in the values of the destructive bending moments at the loading of the samples in the both opposing directions is obtained for the joints with asymmetrical connecting structural elements (No 6 and 7 on Figure 7). The proportion between the mean values of M_1 and M_2 is 233:200, i.e. difference of 16,5 %.

Determining factor for the value of the destructive bending moment is the type of the joint.

At biggest bending moment are destroyed the through and blind mortise and tenon joints (see Figure 2). This can be explained with the fact that these corner joints have connecting elements made of the joined frame structural elements and moreover have a large area of the glue line between their contacting surfaces. The destroying of the samples of these types of joints occurs by breaking and knocking out the tenon.

In the second place according to the value of the destructive bending moments are the dowel joints. This is due to the circumstance that the dowels are made of solid beech wood, which is much harder than the solid spruce wood and the destroying of the samples happens by withdrawing the dowels away. It is due to receive bigger destructive bending moment for the splined joint as well. In view of the fact that the spline is made of the solid spruce wood the destruction occurs in the spline and glue line.

Table 1. *Destructive bending moments of T-shape corner joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm*

Type of joints	**Variation statistics parameters of destructive bending moments M_1 and M_2**					
	$\bar{x}$, Nm	s, Nm	s_r, Nm	v, %	p, %	n, pc.
A. Compression bending load in direction A ↔ B, M_1						
1. Butt joint at right angle	70	11	2,8	15	4,0	15
2. Butt joint at other than right angle	121	14	3,7	12	3,0	15
3. Blind mortise and tenon joint	413	80	20	19	4,8	15
4. Through mortise and tenon joint	435	46	11,8	10	2,7	15
5. Bilateral dovetail mortise and tenon joint at right angle	153	17	4,5	11	2,9	15
6. One-sided dovetail mortise and tenon joint at right angle	230	19	4,9	8	2,1	15
7. One-sided dovetail mortise and tenon joint at other than right angle	236	43	11,0	18	4,7	15
8. Dowel joint	255	19	5,0	13	2,0	15
9. Splined joint	200	36	9,3	9	4,6	15
B. Compression bending load in direction B ↔ C, M_2						
1. Butt joint at right angle	75	12	3,0	15	4,0	15
2. Butt joint at other than right angle	125	20	2,6	8	2,1	15
3. Blind mortise and tenon joint	416	51	13,3	12	3,2	15
4. Through mortise and tenon joint	441	51	13,1	11	3,0	15
5. Bilateral dovetail mortise and tenon joint at right angle	152	17	4,3	20	2,8	15
6. . One-sided dovetail mortise and tenon joint at right angle	209	25	6,5	12	3,1	15
7. One-sided dovetail mortise and tenon joint at other than right angle	192	24	6,2	12	3,2	15
8. Dowel joint	262	18	4,6	11	1,8	15
9. Splined joint	207	20	5,2	10	2,5	15

In the third place according to the value of the destructive bending moments are the dovetail mortise and tenon joints (see Figure 3). Due to the high fracture resistance under bending load of dovetail tenon which thickness is equal to that of the joined frame structural elements, in 90 % of the cases their destroying happens by splitting of the frame structural elements. Lowest according to the value of the destructive bending moments are the butt joints. Since they do not have connecting elements, the area of the glue line is smallest and the destroying of about 100 % of the samples occurs along the glue line.

The ratio between the mean values of destructive bending moments for the fourth groups of joints (Figures 1 to 4) is 1,0 : 4,3 : 2,0 : 2,3, i.e. the difference is from 1,15 to above 4 times.

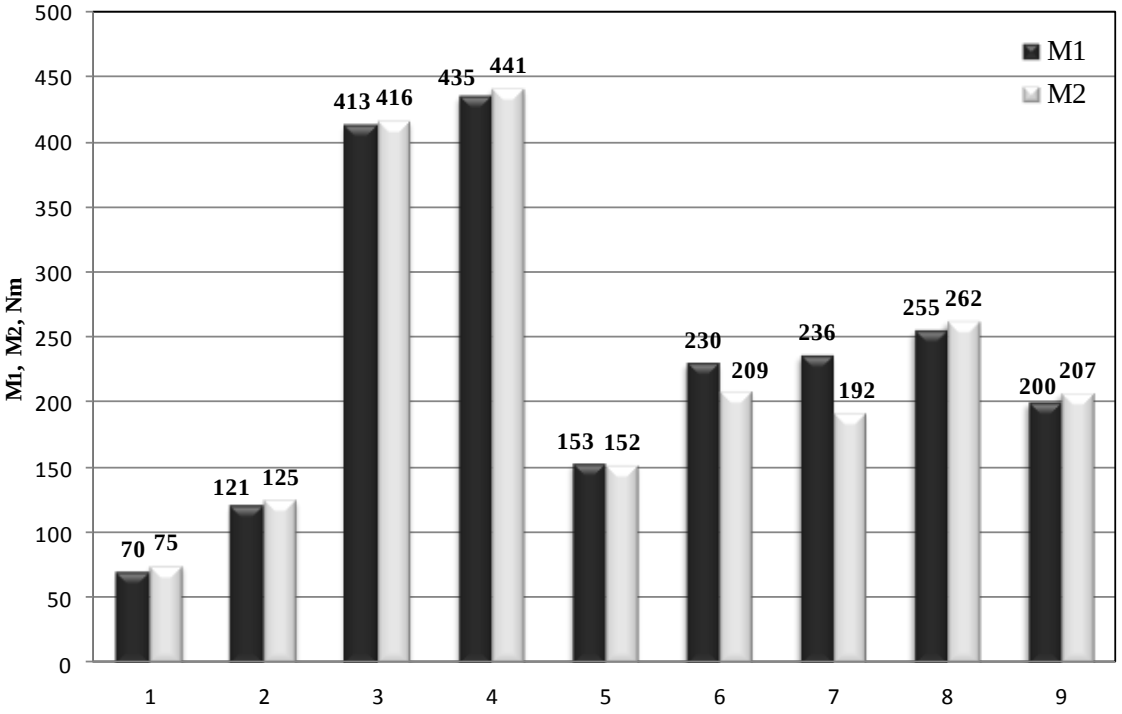


Figure 7. *Comparative data for the destructive bending moments M_1 and M_2 of the tested T-shape corner joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm (1 to 9 as in Table 1)*

4. CONCLUSION

The results from the carried out research give reason to make the following more common conclusions:

1. The type of joint is a determining factor for its strength characteristic. It is defined by the type and dimensions of the joining elements and the area of the gluing of the contacting surfaces of the joints.
2. According to the value of the destructive bending moment the tested types of T-shape corner joints are set in following hierarchical order:
   - mortise and tenon joints;
   - dowel joints;
   - dovetail mortise and tenon joints;
   - splined joints;
   - butt joints.
3. It is recommended that the strength characteristic of the tested joints should be taken into account in the strength design of the sitting furniture, tables and beds.

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The Authors' Addresses:

Prof. Georgi Kyuchukov, PhD[1]
Assoc. prof. Borislav Kyuchukov, PhD[1], borislav65@abv.bg
Assoc. prof. Vassil Jivkov, PhD[1], vassil.jivkov@prodes.bg
Prof. Assia Marinova, PhD[1], assiamar@abv.bg
Prof. Gjorgi Gruevski, PhD[2], gruevski@fdtme.ukim.edu.mk

[1] University of Forestry, Faculty of Forest Industry,
10 Kl. Ohridski Blvd, 1756 Sofia, Bulgaria
[2] Ss.Cyril and Methodius University
Faculty of Design and Technologies of Furniture and Interior,
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of Macedonia

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NORMS FOR DESTRUCTIVE BENDING MOMENTS OF END CORNER BUTT, LAP, DOWEL AND SPLINED JOINTS OF FRAME STRUCTURAL ELEMENTS MADE OF SOLID SPRUCE WOOD WITH A CROSS SECTION OF 50 x 30 mm

Georgi Kyuchukov[1], Borislav Kyuchukov[1], Vassil Jivkov[1], Assia Marinova[1], Gjorgi Gruevski[2], Zoran Janjić[3]

[1] University of Forestry, Sofia, Republic of Bulgaria, Faculty of Forest Industry, e-mail: borislav65@abv.bg; vassil.jivkov@prodes.bg; assiamar@abv.bg;
[2] Ss. Cyril and Methodius University, Skopje, Republic of Macedonia, Faculty of Design and Technologies of Furniture and Interior, e-mail: gruevski@fdtme.ukim.edu.mk
[3] College of Applied Vocational Studies, Vranje, Republic of Serbia, info@visokaskola.edu.rs

ABSTRACT

In the presented research are established the normative values for the destructive bending moments of the end corner butt, lap, dowel and splined joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm in arm opening and arm compression bending load.

The normative values of the tested end corner joints follow the same dependencies as the experimental data.

The normative values for the destructive bending moments of the joints in arm opening bending test are at an average 73,1 % from the experimentally established values, and in the arm compression bending test – 78,1 %.

The established normative values for the destructive bending moments of the end corner butt, lap, dowel and splined joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm can be used for the needs of the preventive quality control of furniture production as well as for the strength design of the sitting furniture, tables and beds. For that purpose it is recommended to draw up these normative values as a normative document which to use in the inner factory control of furniture quality.

Key words: end corner joints of frame structural elements, destructive bending moments, solid spruce wood, norms for destructive bending moments of corner joints

1. INTRODUCTION

Norms for the destructive bending moments of end corner butt, lap, dowel and splined joints of frame structural elements made of solid spruce wood are worked out on the basis of the experimental research on the same types of joints with a cross section of 50 x 30 mm (Kyuchukov et al, 2014). The solid wood was supplied from the Educational Experimental Forestry Enterprise of the University of Forestry at “Yundola” on the basis of selected sample spruce trees (Picea abies Karst.). For testing the joints one sample tree with a diameter of breast height 520 mm was selected. The tree was cut out into sections with a length of 2500 mm which were then cut into radial boards dried naturally till air dry condition, initially under a shelter, and later in room temperature conditions (temperature 21 ± 3 ^{0}C and relative air humidity 55 ± 10 %) up to 12 % water content. The basic physical mechanical properties of timber are: density – 387 kg/m^3; radial, tangential and volumetric shrinkage – respectively 4,0, 8,6 and 12,7 %; radial, tangential and volumetric swelling – respectively 4,2, 7,8 and

11,7 %; bending strength – 56 N/mm^2; compressive strength parallel to grain – 34 N/mm^2; longitudinal elasticity modulus – 9 500 N/mm^2. The established strength characteristics of this solid wood are less than the data available in literature for spruce wood from Central Europe (Kyuchukov et al, 2014).

2. MATERIAL AND METHODS

For the purpose of the research butt joints (Figure 1), lap and dowel joints (Figure 2) and splined joints (Figure 3) were tested. The parameters of the joints correspond to the Bulgarian State Standard 5527-73 (Kyuchukov, Enchev, Blaskova, 1990) and are shown on figures 1 to 3.

The corner joints of the frame structural elements were manufactured by gluing with polyvinyl acetate glue with the following characteristics: outer appearance – cream homogeneous viscose mass; viscosity – 3 500 cP (middle viscosity suitable for brush coating); open time at 20 ^{0}C – not bigger than 10 min.

For each type of joint 30 numbers of test samples were manufactured – 15 numbers for arm opening bending load (Figure 4 a) and 15 numbers for arm compression bending load (Figure 4 b) (Kyuchukov, 1988; Kyuchukov, 1995). Before testing, the samples were conditioned for 5 days and nights at temperature (21 ± 3) ^{0}C and relative air humidity (55 ± 10) %.

The type and schemes of loading of the samples in their testing (Figure 4) correspond to the standardized methodology (BSS 9165-90) (Kyuchukov, 1995; Kyuchukov, Jivkov, 2015), worked out at the Laboratory of Furniture Construction at the University of Forestry. The distance between the inner edges of the joint is L = 200 mm.

The experiment was carried out at universal testing machine at an even speed of loading in the length of (60 ± 30) s from the beginning of the loading and accuracy of reading of the results 1 % of the failure force of loading.

The destructive bending moments M_1 at arm opening bending test and M_2 at compression bending test have been calculated correspondingly by the formulas (1) and (2) .

$$M_1 = \frac{F_1 . L}{4} \tag{1}$$

$$M_2 = F_2 . l \tag{2}$$

where

F_1 and F_2 are the failure forces, at respectively arm opening and compression bending test, N;

L – the span distance at arm opening bending test, m;

l – the arm of bending in compression bending test, m.

The results from the experiments are processed by the variation statistics methods.

The norms for the destructive bending moments of the corner joints of the frame structural elements are worked out on the basis of the results of the previously published experimental research (Kyuchukov at al, 2014). Experimentally established mean values of the destructive bending moments of the joints cannot be accepted as normative values by reason of big dispersion of the results as a result of even minimum differences in the wood properties as well as differences of the contacting surfaces of the joined structural elements and the thickness of the glue line of the particular samples. With a view to that the normative values of the destructive bending moments of the investigated types of joints are worked out on the basis of the mean values taking into account the dispersion of the data from the experimental research according to the Gauss law of normal distribution.

The normative values for the destructive bending moments of the tested corner joints of the frame structural elements made of solid spruce wood are determined by the formulas (3) and (4).

$$M_{1\,\mathrm{norm}} = \overline{x_1} - \alpha . s_1 \tag{3}$$

$$M_{2\,\mathrm{norm}} = \overline{x_2} - \alpha . s_2 \tag{4}$$

where

$\overline{x_1}$ is the mean value of the destructive bending moment of the joint at arm opening bending load, Nm; $\overline{x_2}$ – the mean value of the destructive bending moment of the joint at compression bending load, Nm;
α – the coefficient of uniformity;
s_1 – the mean square deviation at arm opening bending load, Nm;
s_2 – the mean square deviation at arm compression bending load, Nm.

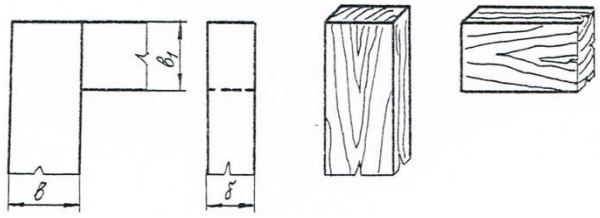
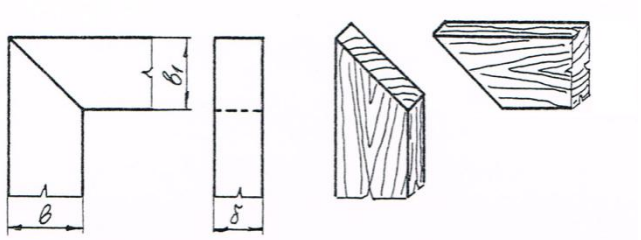
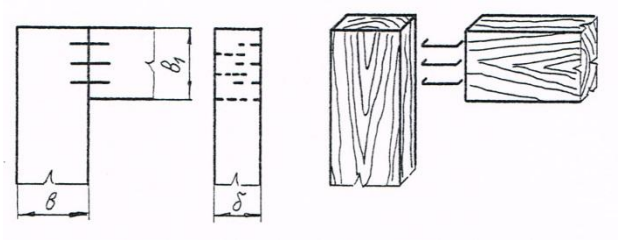
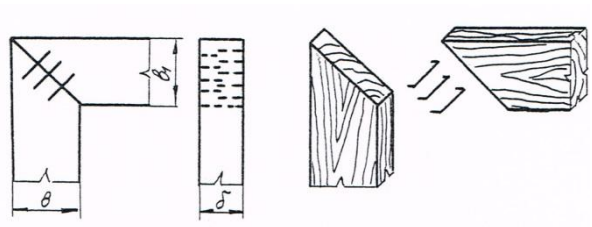
 **1**	b = b_1 = 50 mm δ = 30 mm
 **2**	b = b_1 = 50 mm δ = 30 mm
 **3**	b = b_1 = 50 mm δ = 30 mm n = 3
 **4**	b = b_1 = 50 mm δ = 30 mm n = 3

Figure 1. *End corner butt joints:* ***1*** *– butt joint at right angle;* ***2*** *– miter butt joint;* ***3*** *– butt joint at right angle with staples;* ***4*** *– miter butt joint with staples*

The coefficient of uniformity α specifies the range of the experimental data spread. In the theory of probability it is given a proof that all the variants of experimental data practically lie into the limits $\bar{x}$ ± 3s, and over 99 % of the data lie into the limits $\bar{x}$ ± 2,5s. On the grounds of that fact it can be assumed that the lower bound $\bar{x}$ – 2,5s can be accepted as a normative bound of the relevant strength characteristic of the tested types of corner joints of the frame structural elements made of solid spruce wood.

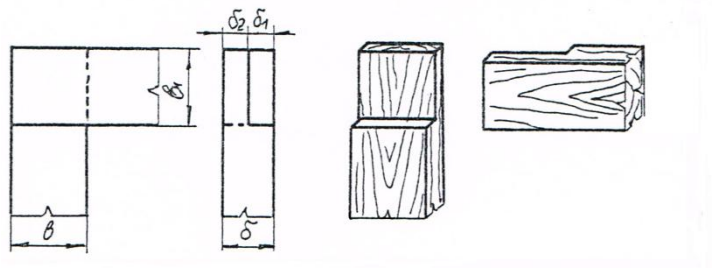
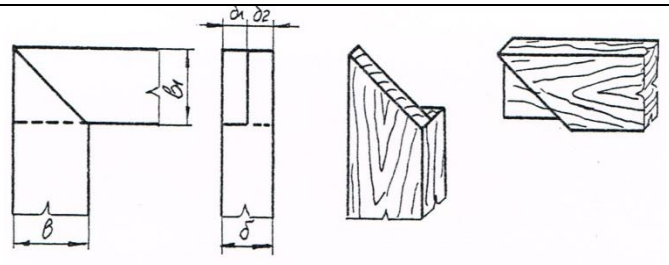
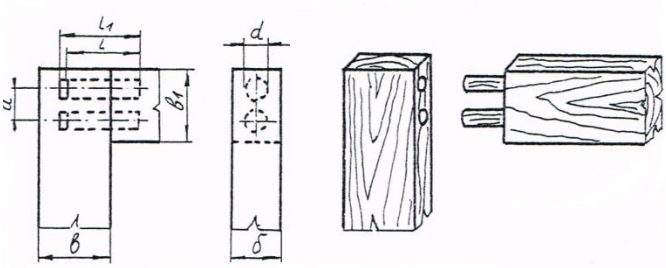
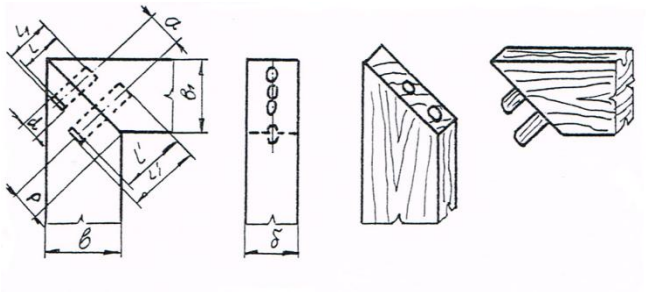
 **5**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = \delta_2 = 15$ mm
 **6**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = \delta_2 = 15$ mm
 **7**	$b = b_1 = 50$ mm $\delta = 30$ mm $L_1 = 34$ mm $L = 32$ mm $d = 12$ mm $a = 24$ mm
 **8**	$b = b_1 = 50$ mm $\delta = 30$ mm $L_1 = 32$ mm $L = 30$ mm $L^I = 34$ mm $L_1^I = 36$ mm $d = 12$ mm $a = 32$ mm $p = 6$ mm

Figure 2*. End corner lap and dowel joints:* ***5*** *– corner lap joint;* ***6*** *– corner miter lap joint;* ***7*** *– dowel joint;* ***8*** *– miter dowel joint*

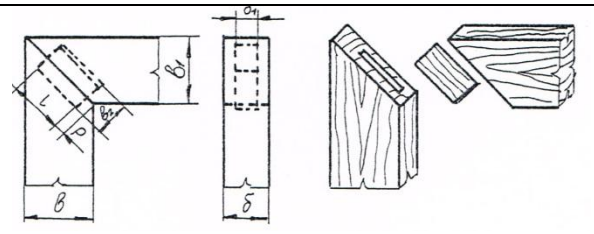
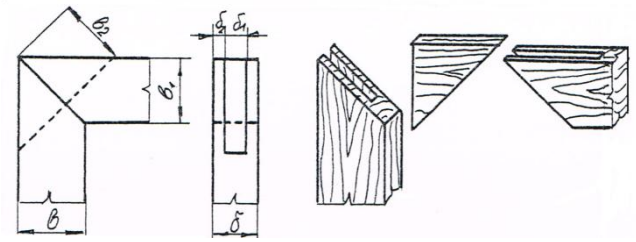
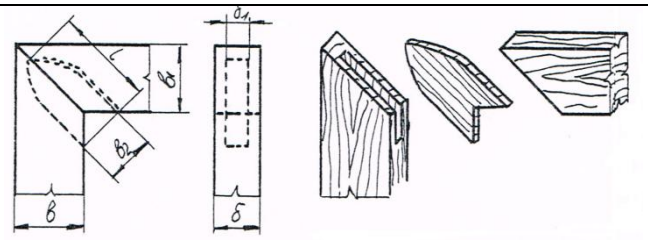
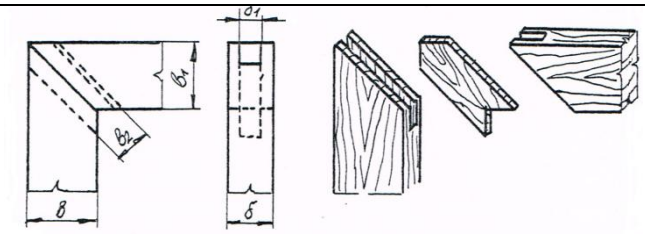
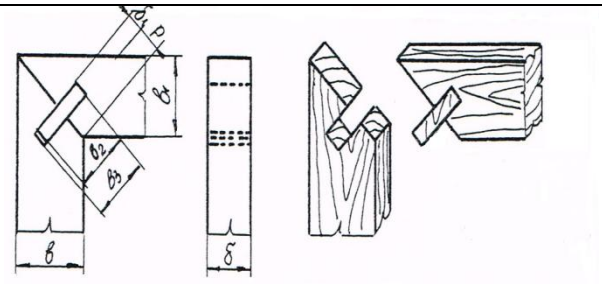
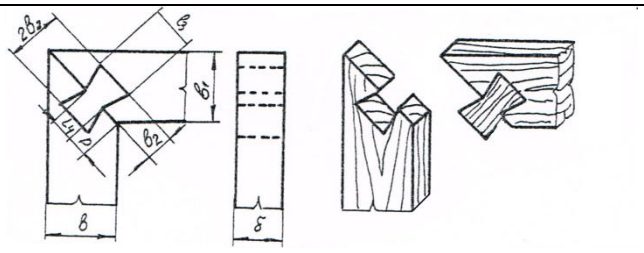
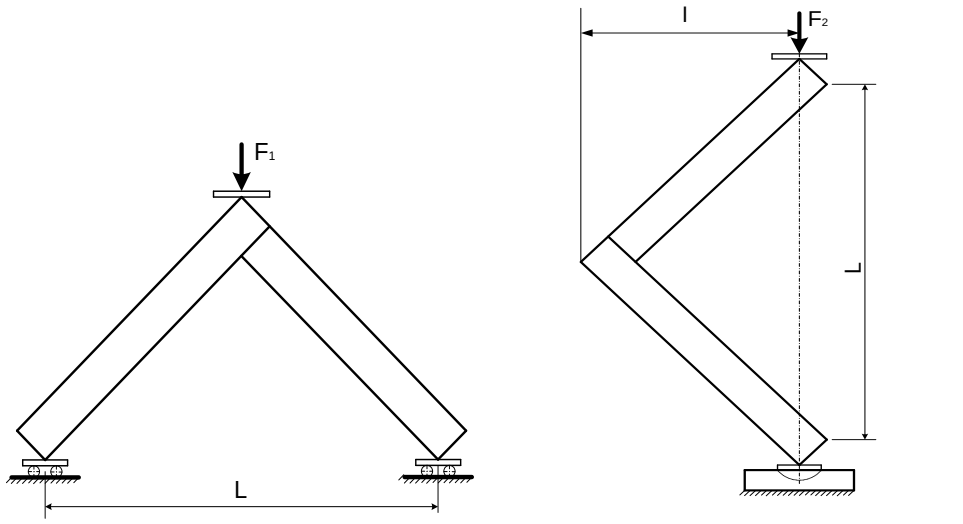
 **9**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = 12$ mm $b_2 = 25$ mm $p = 5$ mm $L = 40$ mm
 **10**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = 12$ mm $\delta_2 = 9$ mm $b_2 = 50$ mm
 **11**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = 12$ mm $L = 40$ mm $b_2 = 37{,}5$ mm
 **12**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = 12$ mm $b_2 = 25$ mm
 **13**	$b = b_1 = 50$ mm $\delta = 30$ mm $\delta_1 = 9$ mm $b_2 = 40$ mm $b_3 = 42$ mm $p = 9$ mm
 **14**	$b = b_1 = 50$ mm $\delta = 30$ mm $b_2 = 15$ mm $L_3 = 30$ mm $L_4 = 16{,}5$ mm $p = 10$ mm

Figure 3*. End corner splined joints:* ***9*** *– blind splined miter joint;* ***10*** *– feather splined miter joint;* ***11*** *– half blind splined miter joint;* ***12*** *– splined miter joint;* ***13*** *– face splined miter joint;* ***14*** *– face dovetail keyed miter joint*



a **b**

Figure 4. *Scheme for testing of test samples of end corner joints:* ***a*** *– in arm opening bending load;* ***b*** *– in arm compression bending load*

The mean square deviation *s* is a function both of the data spread about the mean and the number of the tested samples. The average variational coefficient v_{av} is determined to eliminate the influence of the accidental factors of particular samples of the given type of joint. On this basis the value of the mean square deviation for each type of joint is specified by the formulas (5) and (6).

$$s_1 = \frac{v_{av}}{100} \cdot \overline{x_1} \tag{5}$$

$$s_2 = \frac{v_{av}}{100} \cdot \overline{x_2} \tag{6}$$

The normative values for the destructive bending moments of the tested end corner butt, lap, dowel and splined joints in arm opening and arm compression bending load are determined by the formulas

$$M_{1\,norm} = \overline{x_1} - 2{,}5.s_1 \tag{7}$$

$$M_{2\,norm} = \overline{x_2} - 2{,}5.s_2 \tag{8}$$

3. COMPARATIVE ANALYSIS OF THE EXPERIMENTAL RESULTS

The results from the research are presented graphically on figures 5 and 6. From the data shown on the figures it is obvious that the destructive bending moment depends on the type of the joint as well as the scheme at which the joint was loaded. The destructive bending moments at arm opening bending test are on the average about 49 % in comparison with the ones at arm compression bending test.

The type of the joints has a considerable influence on the destructive bending moment. This is defined by the type and dimensions of the joint elements and the area of the contacting surfaces of the

joints, e.g. the area of the glue line. The corner splined joints and dowel joints are destroyed at an appreciably higher bending moment than the rest tested types of joints.

From the butt joints, the miter butt joints and those strengthened with staples have a higher destructive bending moment. From the end corner lap joints, the joints at right angle have higher bending moment, due to their greater glue area.

In both types of loading with a comparatively high bending moment are destroyed the following joints: corner lap joint at right angle, the half blind splined miter joint, the miter dowel joint, the blind splined miter joint, the feather splined miter joint, the splined miter joint and the face dovetail keyed miter joint. In most of these types of joints the destruction of the samples is in the range of 30 to 100 % on the element outside the glue line.

The normative values for the destructive bending moments of the tested corner joints follow the same dependencies as the experimental data. The normative values for the destructive bending moments of the joints in arm opening bending test are at an average 73,1 % from the experimentally established values, and in the arm compression bending test – 78,1 %.

A biggest normative value from the joints tested in arm opening bending load has the corner lap joint (139 Nm), and a lowest one – the miter butt joint (42 Nm). The proportion between them is 3,3 times.

A biggest normative value from the joints tested in arm compression bending load has the blind splined miter joint (209 Nm), and a lowest one – the butt joint at right angle (87 Nm). The proportion between them is 2,4 times.

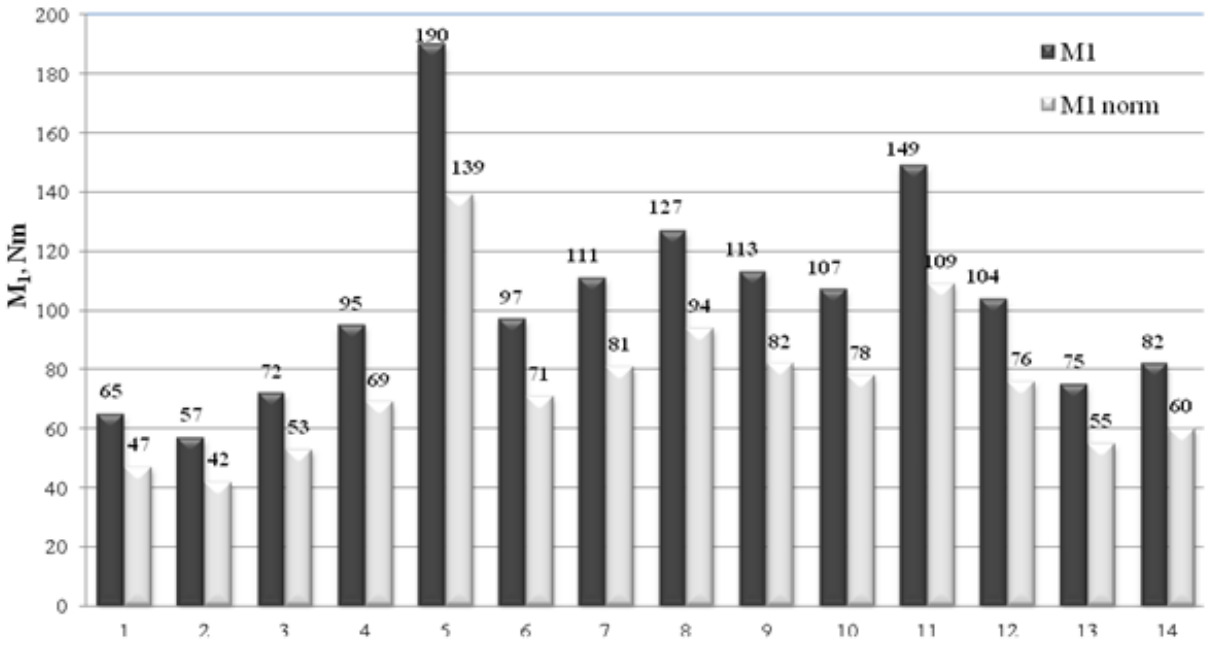


Figure 5. *Destructive bending moments and norms for end corner butt, lap, dowel and splined joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm at arm opening bending test:* ***1*** *– butt joint at right angle;* ***2*** *– miter butt joint;* ***3*** *– butt joint at right angle with staples;* ***4*** *– miter butt joint with staples;* ***5*** *– corner lap joint;* ***6*** *– corner miter lap joint;* ***7*** *– dowel joint;* ***8*** *– miter dowel joint;* ***9*** *– blind splined miter joint;* ***10*** *– feather splined miter joint;* ***11*** *– half blind splined miter joint;* ***12*** *– splined miter joint;* ***13*** *– face splined miter joint;* ***14*** *– face dovetail keyed miter joint*

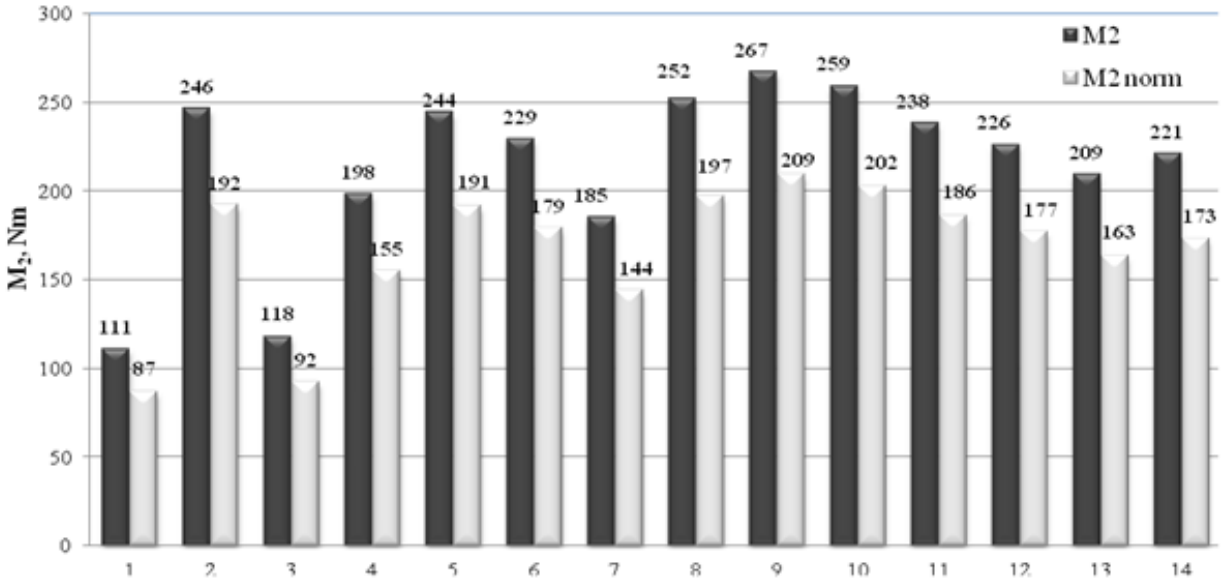


Figure 6. *Destructive bending moments and norms for end corner butt, lap, dowel and splined joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm at arm compression bending test:* ***1*** *– butt joint at right angle;* ***2*** *– miter butt joint;* ***3*** *– butt joint at right angle with staples;* ***4*** *– miter butt joint with staples;* ***5*** *– corner lap joint;* ***6*** *– corner miter lap joint;* ***7*** *– dowel joint;* ***8*** *– miter dowel joint;* ***9*** *– blind splined miter joint;* ***10*** *– feather splined miter joint;* ***11*** *– half blind splined miter joint;* ***12*** *– splined miter joint;* ***13*** *– face splined miter joint;* ***14*** *– face dovetail keyed miter joint*

4. CONCLUSIONS

The established normative values for the destructive bending moments of the end corner butt, lap, dowel and splined joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm can be used for the needs of the preventive quality control of furniture production as well as for the strength design of the sitting furniture, tables and beds. For that purpose it is recommended to draw up these normative values as a normative document which to use in the inner factory control of furniture quality.

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The Authors' Addresses:

Prof. Georgi Kyuchukov, PhD[1]
Assoc. prof. Borislav Kyuchukov, PhD[1], borislav65@abv.bg
Assoc. prof. Vassil Jivkov, PhD[1], vassil.jivkov@prodes.bg
Prof. Assia Marinova, PhD[1], assiamar@abv.bg
Prof. Gjorgi Gruevski, PhD[2], gruevski@fdtme.ukim.edu.mk
Prof. Zoran Janjić, PhD[3], info@visokaskola.edu.rs

[1] University of Forestry, Faculty of Forest Industry,
10 Kl. Ohridski Blvd, 1756 Sofia, Bulgaria
[2] Ss.Cyril and Methodius University
Faculty of Design and Technologies of Furniture and Interior,
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of Macedonia
[3] College of Applied Vocational Studies, Vranje, Serbia

UDC (UDK): 674.031.632.2:621.78

PROPERTIES OF HEAT-TREATED BEECH WITH RED HEARTWOOD

Nebojša Todorović, Zdravko Popović, Branko Kolin, Ranko Popadić, Goran Milić

University of Belgrade, Faculty of Forestry,
Department of Technology, Management and Design of Furniture and Wood Products,
Belgrade, Republic of Serbia
nebojsa.todorovic@sfb.bg.ac.rs; zdravko.popovic@sfb.bg.ac.rs; branko.kolin@sfb.bg.ac.rs;
ranko.popadic@sfb.bg.ac.rs; goran.milic@sfb.bg.ac.rs;

ABSTRACT

Considering the different market values of sapwood and red heartwood, the aim of this study was to establish whether these parts of beechwood differ after a heat treatment. Samples were exposed to temperatures of 170 ^{o}C, 190 ^{o}C and 210 ^{o}C, respectively, for 4 hours. In this paper, physical properties (moisture content, color change, mass loss, oven-dry density, density loss) and mechanical properties (MOR and MOE) were examined. FT-NIR spectra and colour coordinates (L*, a*, b*) were recorded from the radial surface of samples before and after heat treatment. It has been shown that heat treatment reduces the properties of sapwood and red heartwood in the same manner and equalizes the colors. Most of the properties did not differ between heat-treated sapwood and red heartwood. Density loss and bending strength were the only properties with significant differences between sapwood and red heartwood treated at 190 °C. The PCA analysis of recorded spectra indicates that there is no difference between heat-treated beech sapwood and red heartwood. The equalized colors and properties of heat-treated red heartwood and sapwood can significantly increase the use of products made out of red heartwood.

Key words: beech, heat treatment, red heartwood, color, FT-NIR spectroscopy

1. INTRODUCTION

Besides being an ecological treatment for the preservation of wood, heat treatment also improves its biological durability, physical properties, and dimensional stability of wood. It reduces its hygroscopicity and consequently makes wood irreplaceable in variable conditions of exploitation (Militz 2002, Bekhta and Niemz 2003, Birchke et al. 2005, Shi et al. 2007). Along with the improvement of hygroscopicity and durability, one of the important reasons for heat-treating is also the change in wood color (Mitsui et al. 2001; Bekhta and Neimz 2003; Johansson and Morén 2006; Esteves et al. 2008; González-Peña and Hale 2009).

Beech is one of the most important wood species in Europe and in spite of its good mechanical properties it is prone to deformities under variable conditions and climatic conditions of the environment. From the aspect of wood processing and use of beech wood, presence of red heartwood is particularly interesting as it is a less valuable part of the wood. With the optimal regime which can lead to no essential difference in the properties of heat treated beech wood with red heartwood and sapwood, the less valuable wood can, in that case, be used for getting highly valuable products.

Therefore, the aim of this paper was to determine changes in physical (moisture content, color change, density loss, oven dry density and mass loss) and mechanical properties (bending properties - MOR and MOE) of heat-treated beech sapwood and red heartwood. Also, in order to define the structural changes that occurred during heat treatment, the FT-NIR spectra were recorded. This could improve the understanding of changes on heat treated beech sapwood and red heartwood.

2. MATERIAL AND METHODS

Randomly chosen 11 beech trees were obtained from the forest area of Goč mountain (southwestern Serbia). The average breast height diameter was 45 cm. All the trees had a similar amount of healthy red heartwood (around 50%) and were cut into 2 m long logs. Three logs were cut from each tree (33 logs in total): above breast height, at the middle and at the height of first green branches. Each log was cut into eight radial boards 30 mm thick (four from sapwood and four from red heartwood – Figure 1.). Four samples from the central part of each kiln dried board were cut (1 untreated + 3 for heat treatment). The samples (marked 1, 2, 3 and 4) had clearly defined anatomic directions and had no visible defects. They were cut into specimens that were used to determine the physical and mechanical properties (Figure 1). Specimens that were used for determining the moisture content (MC), the density (oven dried-Odd), the mass loss (Ml) and the density loss (Dl) had dimensions: 20x20x20 mm, and specimens for determining the bending properties – modulus of rupture (MOR) and modulus of elasticity (MOE) were 20x20x320 mm (radial, tangential and longitudinal). There were a total of 576 specimens: 288 out of sapwood (72 + 3x72) and 288 out of red heartwood (72 + 3x72).

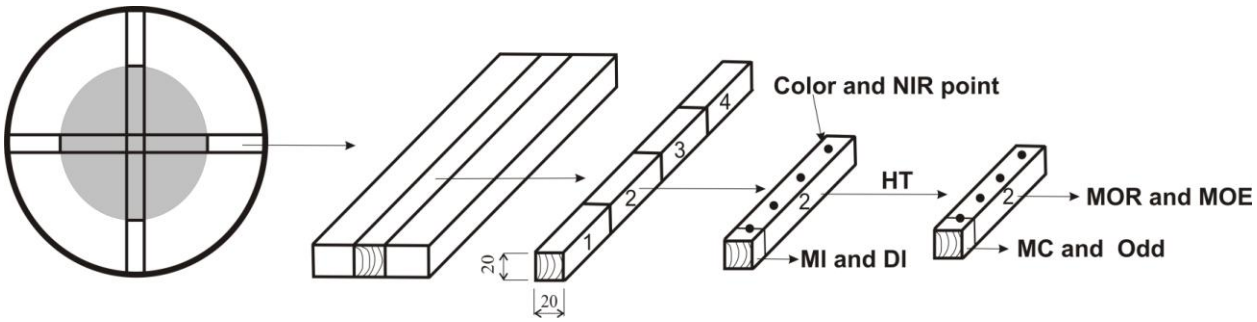

Figure 1. *Sawing pattern and test samples. (1-untreated, 2-170 ºC, 3-190 ºC, 4 -210 ºC, HT – heat treatment, MOR – modulus of rupture, MOE – modulus of elasticity, MC –moisture content, Odd – oven dry density, Ml – mass loss, Dl – density loss)*

Heat treatment was carried out in a laboratory chamber ($1m^3$, ± 1 °C sensitivity) for heat treatment filled with water vapor, where samples were exposed to temperatures of 170 ^oC, 190 ^oC or 210 ^oC. It took approximately twenty-four hours to heat the samples from room temperature to the treating temperature, after which the temperature was kept constant for 4 hours. The chosen schedules are often used in industrial heat treating of beech timber.

The untreated and heat treated samples were conditioned at 23 ^oC and relative humidity of 50% during eight weeks. The mechanical properties (bending properties) and physical properties (Odd and MC) were determined after conditioning. MOR and MOE were determined by a three-point bending test on specimens measuring 20x20x320 mm. Distance from supports was 280 mm. Odd and MC (20x20x20) were determinated gravimetrically subsequent to the bending tests. Masses and volumes of oven dried specimens (20x20x20 mm) that were to be heat-treated were measured. After heat treatment, they were oven-dried and had their masses and volumes measured again. According to these data, Ml and Dl of heat-treated wood were calculated.

Color assessments were performed on radial surfaces of untreated and heat-treated samples by BYK (BYK Gardner GmbH) colorimeter. Color was assessed at four places and average values were used for further calculations. The sensor head was 11 mm in diameter. Measurements were made using a D65 illuminant and a 10 ° standard observer. The coordinates L* (black-white), a* (green-red) and b* (blue-yellow), measured before and after the treatment, were used to determine: ΔL, Δa, Δb (exemplified for $\Delta L = L^*_{treated} - L^*_{untreated}$), ΔE – total color difference.

FT-NIR spectra were collected before and after thermal treatment with a Nicolet Nexus 670 FT-IR spectrometer equipped with a Thermo Nicolet Smart Near-IR UpDrift probe in the wavenumber range from 11000–4000 cm^{-1} using the default parameters. The NIR spectra were acquired by an integrating sphere scanning an area of about 7 mm in diameter. For each scanning point, 100 scans (4 cm^{-1}) were collected and averaged into a single spectrum. Eight spectra on the radial longitudinal face

of bending test samples were averaged to one average spectrum per face. The measurements were taken on a planed surface.

One-way ANOVA and Tukey’s multiple range test (SPSS 13.0 software) were used for comparing and determining any significant differences in color and wood properties between the groups.

3. RESULTS AND DISCUSSION

Color Changes

Mean values of color parameters for untreated and treated beechwood are shown in Table 1. Measured coordinates had positive values both before and after treatment. Colors of untreated sapwood and red heartwood differ significantly. The L* values are higher in sapwood than in red heartwood, whereas a* and b* coordinates are lower. After heat treatment, the L* coordinate was decreased significantly and its reduction was greater in sapwood than in red heartwood (Table 1, Figure 2). In sapwood, coordinates a* and b* increased at 170 ºC, but decreased at 190 ºC and 210 ºC. However, these changes were smaller than the changes of L* coordinate. Red heartwood showed a decrease of a* and b* with the increase of temperature.

Table 1. *Mean values for three color coordinates and color difference*

Part of beechwood	Treatment	L*	a*	b*	ΔE
Sapwood	Untreated (N=72)	79.1 (*) (2.4)	6.3 (*) (1.0)	18.9 (*) (1.1)	-
	170 °C (N=72)	55,9 (4.9)	8,4 (*) (0.5)	19,8 (1.1)	23,3 (*) (5.8)
	190 °C (N=72)	39,8 (3.3)	7,7 (*) (0.9)	15,2 (2.0)	39,5 (*) (4.0)
	210 °C (N=72)	30,9 (1.2)	5,1 (0.5)	8,9 (0.9)	49,2 (*) (3.4)
Red heartwood	Before (N=72)	68.3 (3.4)	9.5 (1.1)	20.5 (1.1)	-
	170 °C (N=72)	55.4 (3.9)	9.2 (0.8)	20.0 (1.4)	12.9 (4.3)
	190 °C (N=72)	40.4 (4.5)	8.3 (1.0)	15.2 (2.3)	28.4 (5.7)
	210 °C (N=72)	30.8 (1.7)	5.1 (0.6)	8.8 (1.3)	39.5 (3.4)
N – number of samples. The standard deviations are in parentheses.					
(*) statistically significant difference between sapwood and red heartwood ($p<0.05$).					

A significant difference in values of L*, a* and b* between sapwood and red heartwood (Table 1) was noticed in L* (untreated), a* (untreated, 170 ºC and 190 ºC) and b* (untreated). There is no difference between the values of a* and b* in red heartwood treated at 170 ºC in comparison with untreated wood. In all other cases, both sapwood and red heartwood showed significant differences in L*, a* and b* as compared to untreated wood.

As was expected, a higher means value of total color difference were obtained for sapwood (ΔE=37.3) than for red heartwood (ΔE=27.0). According to a table frequently used for color classification (e.g. Allegretti et al. 2008), the color difference between sapwood and red heartwood before treatment was high (ΔE= 11.4 (>6)), whereas after heat treatment it was small at 170 °C (ΔE=0.96<2) and 190°C (ΔE=0.85<2), and not visible at 210 °C (ΔE=0.14<0.2).

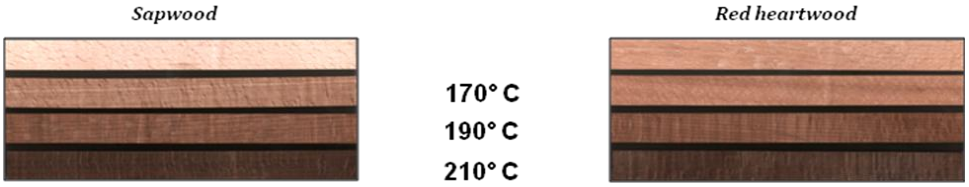

Figure 2. *Untreated and heat-treated beech sapwood and red heartwood*

Properties of Heat-Treated Beechwood

Hygroscopicity of wood decreased significantly as a consequence of heat treatment. Untreated wood (after 8 weeks of conditioning) had an average MC of 9.0% in sapwood and 9.6% in red heartwood. Mean values of MC for treated samples were 4.7% (3.0 – 6.6%) in sapwood and 4.2% (2.3 – 6.2%) in red heartwood. Values of other physical and mechanical properties are shown in Table 2. Properties of untreated and heat-treated sapwood and red heartwood mostly do not differ much and were within the values from previous researches. Odd of untreated beechwood was 0.676 g/cm^3 in sapwood and 0.677 g/cm^3 in red heartwood. Densities of untreated sapwood and red heartwood were no different and the values were similar to those in previous researches (Pöhler et al. 2006; Popadić and Todorović 2008; Popović et al. 2010). This research confirmed that mass loss increases with the rise of temperature (Bourgois and Guyonnet 1988; Zaman et al. 2000) both in sapwood and in red heartwood. Average mass loss (for all three treatments) was 10.3% in sapwood and 10.4% in red heartwood. Average density loss was lower than mass loss and it was 5.2% in sapwood and 4.9% in red heartwood. There was no difference between sapwood and red heartwood in density loss, except for treatment at 190ºC.

Compared to untreated samples, MOR decried significantly at higher temperatures (190ºC and 210ºC), which is in agreement with results in previous studies (Kocaefe et al. 2008; Windeisen et al. 2009;). There was no difference between sapwood and red heartwood in MOR both for untreated and samples treated at 170ºC and 210ºC. Higher value in sapwood than in heartwood at 190ºC was found, mainly as a consequence of similar trend in density loss. The heat treatment at 170ºC and 190ºC slightly improved MOE, while at 210ºC was not different compared to untreated wood. No difference between sapwood and red heartwood in MOE was obtained both in untreated and treated samples.

Table 2. *Physical and mechanical properties of untreated and treated samples*

Part of beechwood	Treatment	Odd (g/cm^3)	Ml (%)	Dl (%)	MOR (N/mm^2)	MOE (N/mm^2)
Sapwood	Untreated (N=72)	0.676 (0.048)			126.9 (16.0)	11739 (1629)
	170 °C (N=72)	0.667 (0.031)	4.7 (0.9)	0.8 (0.2)	132.1 (15.9)	12500* (1864)
	190 °C (N=72)	0.644* (0.030)	9.2 (1.1)	5.2 (*) (1.4)	95.7* (*) (16.8)	12540* (1910)
	210 °C (N=72)	0.619* (0.027)	16.9 (1.1)	9.7 (2.5)	69.6* (14.1)	11721 (1705)
Red heartwood	Untreated (N=72)	0.677 (0.051)			124.1 (17.9)	12095 (1513)
	170 °C (N=72)	0.674 (0.038)	5.0 (0.7)	0.7 (0.2)	127.9 (21.6)	12663* (1840)
	190 °C (N=72)	0.650* (0.033)	9.3 (0.8)	4.0 (1.3)	88.7* (24.7)	12624* (2076)
	210 °C (N=72)	0.621* (0.033)	17.0 (1.1)	10.0 (2.9)	65.7* (17.4)	11638 (1982)
N – number of samples. The standard deviations are in parentheses.						
* statistically significant difference as compared to untreated wood ($p<0.05$).						
(*)statistically significant difference between sapwood and red heartwood ($p<0.05$).						

Spectroscopic characterization

Based on the raw NIR spectra, untreated red heartwood had higher values of absorption as compared to sapwood, mostly because of its darker hue.

Unlike the spectra of untreated wood, the average raw spectra of heat-treated sapwood and red heartwood were mostly matched at same temperatures (Figure 3). The baseline shift to higher wave numbers with increasing temperature intensity can be observed. This is due to the darker colors of the samples (Windeisen et al. 2009). Knowing the fact that raw spectra provide only rough information about spectral alterations (the second overtone of CH stretching vibration around 8300 cm^{-1} and OH bands at 7100 and 5150 cm^{-1} show only change in absorption), NIR spectra were observed in the second derivative mode - 2nd derivative (not shown). 2nd derivative spectra of the sapwood show features similar to the spectra of the red heartwood (both before and after thermal treatment). The obtained spectra are in line with the results of Windeisen et al. (2009) for beech, and similar to the spectra of the spruce specimens (Bächle et al. 2010). At the CH stretching, first overtone bands at 5800 and 5865 cm^{-1} alterations indicate degradation of carbohydrates and deacetylation reactions of the polyoses. The differences before and after thermal treatment (both for sapwood and red heartwood) were found at the OH stretching vibration absorption bands of the amorphous (7000 cm^{-1}), semi-crystalline (6722 and 6790 cm^{-1}) and crystalline (6460 cm^{-1}) regions of cellulose (Schwanninger et al. 2003; Mitsui et al. 2008). These differences could be attributed to the cleavage of OH groups during thermal treatment (Mitsui et al. 2008). Although lignin is supposed to be comparatively stable at higher temperature, the skeletal CH absorption band at 5974 cm^{-1} (Schwanninger et al. 2011) shows differences, which indicates modifications in lignin after thermal treatment. Also, there is an increase of the absorption band around 6874 cm^{-1}, which can be assigned to the phenolic hydroxyl groups originating from lignin (Fackler and Schwanninger 2010) and to a decrease of the absorption band assigned to the amorphous region in cellulose at 7000 cm^{-1}.

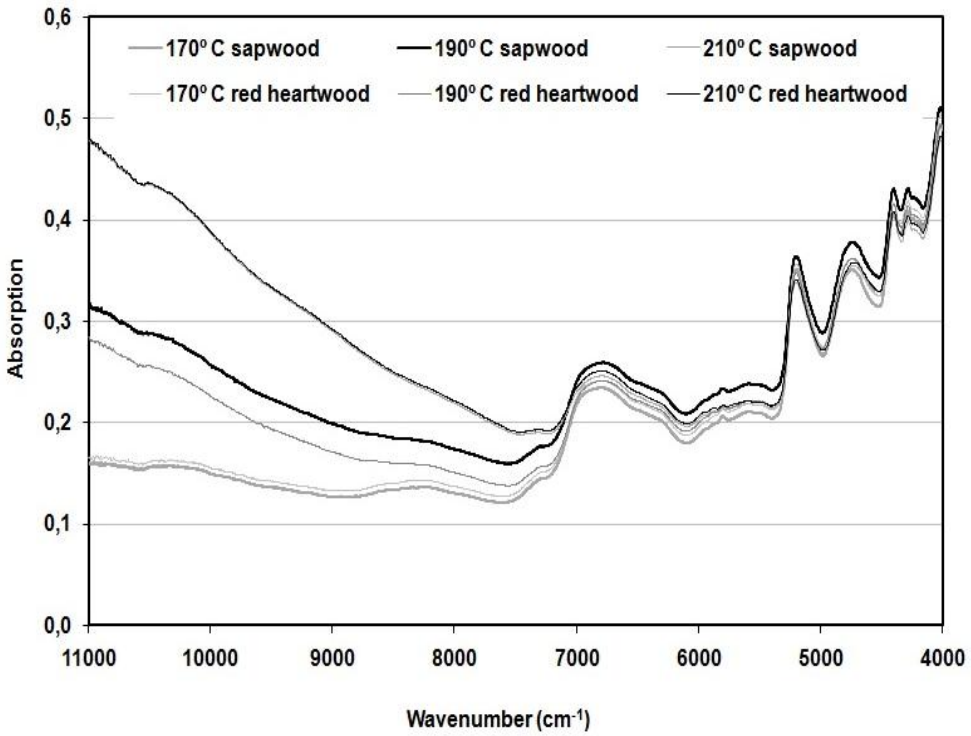

Figure 3. *Normalized NIR spectra of beech sapwood and red heartwood samples after heat treatment*

Hansmann et al. (2007), using the PCA analysis, found a difference between sapwood and red heartwood after thermal modification, which was a consequence of different levels of lignin deacetylation and degradation. In this paper PCA analysis of processed NIR spectra after thermal modification were used and three clusters were observed that indicated that there is a difference

between treatments, and that there is no difference between samples of sapwood and red heartwood at same temperatures (Fig. 4). The explained variance (R^2) was 100 %. The first PC (PC1) explained 90 % and the second PC (PC2) 10 % for the beech samples. On the other hand, there are differences in bending strength and density loss between sapwood and red heartwood only at 190 °C, but more detailed conclusions could be obtained after a chemical analysis of samples.

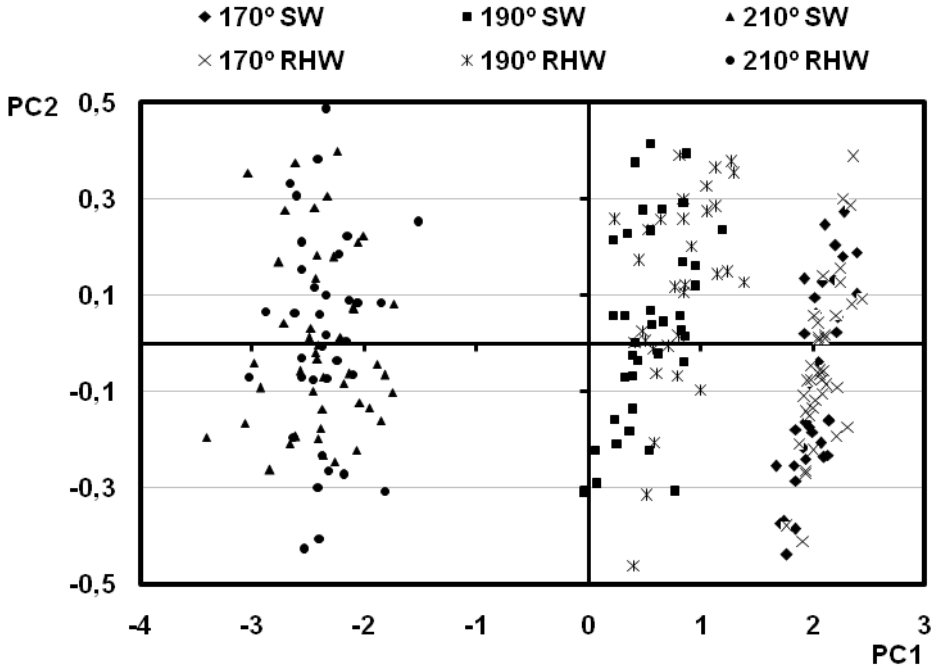

Figure 4. *PCA scoreplot of normalized NIR spectra of heat-treated sapwood (SW) and red heartwood (RHW) samples*

4. CONCLUSIONS

Untreated sapwood and red heartwood of beech are treated as different parts of wood, according to their market value. This research shows that heat treatment can equalize colors of these two parts of beech wood and, considering the equal changes of their properties, they could be equally important for market. This paper indicates that:

1. Coordinates of sapwood and red heartwood color have positive values both before and after treatment. Changes in color after heat treatment were caused by the decrease in L* whereas influence of changes in a* and b* was small. Differences in color (ΔE) between sapwood and red heartwood before treatment were high, but after treatment they were small at 170°C and 190°C, and not visible at 210°C.
2. Most of properties of sapwood and red heartwood showed no significant difference both before and after treatment. Higher temperatures caused a rise in mass loss and density loss, and a reduction of bending strength, whereas the effect on MOE was small.
3. The analyzed FT-NIR spectra recorded on the surface of sapwood and red heartwood indicate that same changes occur in both parts of wood after applying a high temperature. Using the PCA analysis, it is established that there was no difference between these two parts of heat-treated wood.
4. Heat-treated red heartwood and sapwood had similar color and properties, which can increase the usage of beech red heartwood for products made out of heat-treated wood.

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The Authors' Addresses:

Dr. Nebojša Todorović
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: nebojsa.todorovic@sfb.bg.ac.rs

Dr. Zdravko Popović
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: zdravko.popovic@sfb.bg.ac.rs

Dr. Branko Kolin
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: branko.kolin@sfb.bg.ac.rs

Dr. Ranko Popadić
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: ranko.popadic@sfb.bg.ac.rs

Dr. Goran Milić
Belgrade University,
Faculty of Forestry,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: goran.milic@sfb.bg.ac.rs

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INFLUENCE OF LIQUEFIED WOOD pH VALUES AS A HARDENER ON PARTICLEBOARDS PROPERTIES

Alan Antonović[1], Vladimir Jambreković[1], Josip Ištvanić[1], Nikola Španić[1], Sergej Medved[2]

[1]University of Zagreb - Faculty of Forestry
Wood Technology Department - Institute for Material Technologies
Zagreb, Republic of Croatia
e-mail: alan.antonovic@zg.htnet.hr; vladimir.jambrekovic@sumfak.hr;
jistvanic@sumfak.hr;
[2]University of Ljubljana - Biotechnical Faculty
Wood Science and Technology Department,
Ljubljana, Republic of Slovenia

ABSTRACT

Wood liquefaction is a new technique of chemical wood processing, and its aim is to convert wood material in environment frendly and biodegradable polymer materials, and increase percentage of its utilization. Nowdays, according to previous published researches, maximum attention attracted wood liquefaction in presence of some organic reagents and the most interesting are two methods. The first method is the preparation in presence of phenol, which resulted in liquefaction products rich with phenol units. The second liquefaction method was achieved in presence of polyhydric alcohols. Wood composite materials and fragmented wood-based panels (particleboards, fibreboards, OSB, MDF, WPC and other panels) are materials of the future. With their wide spectra of potential applications these materials occupy almost all fields of use. Quality of wood composite materials does not exclusively depend on wood species and their properties applied in production, but with application of other essential non-wooden synthetic chemical components, such as a different types of resins and adhesives, hardeners and paraffin emulsion, which were designed in accordance with the requirements of everyday use and utilisation demands. According to above, this research has focused on the possibility of using liquefied wood (LW) as a hardener in particleboards production, and the impact of different LW pH values on the polymer structure and adhesion-cohesion properties of polymerization of urea-formaldehyde (UF) and melamine-urea-formaldehyde (MUF) adhesives. Furthermore, aim of this research was also the influence of mentioned new adhesion system on the particleboards physical and mechanical properties, and formaldehyde emission.

Key words: liquefied wood, particleboards, hardeners, urea- and melamine-urea formaldehyde resins

1. INTRODUCTION

The last few decades, lignocellulosic biomass as a environmentally friendly materials are becoming more widely used as our society becomes aware of the consequences associated with the use of petrochemical derived products. Production of polymers has long relied on fossil resources to provide raw materials. However, increasing concerns have been raised with this massive consumption of fossil oil. First of all, usage of fossil oil is considered a big contributor increase the level of carbon dioxide (CO_2), the major part of greenhouse gas, which is directly associated with the global warming and climate change (Antonović et al., 2011). Disposal of polymer waste is another highly visible environmental problem because the synthetic polymers are highly resistant to natural degradation, and its incompatibility with nature is often more visible and in some cases dangerous problem. In addition to the environmental issues, the ultimate problem with petroleum based materials is the ever declining

proven fossil reserves and increasing demand in both developing and developed countries, which has caused the skyrocketing of the price of petroleum products. The global use of polymers has experienced decades of consistent growth and is showing no signs of reduction, especially as developing countries are poised to increase their per capita consumption. The growth in polymer consumption is in principle limited by finite oil reserves. The solution to both problems could be increasing the use of lignocellulosic biomass as a renewable resources for polymer production. By improving properties of polymers such as biodegradation, polymers would remain in the natural carbon cycle. All these concerns have become the major drivers in finding alternative to fossil resources, where the lignocellulosic biomass is a promising resource that can replace fossil oil for sustainable production of bio-fuel and chemicals, and therefore it is the most abundant renewable resource on Earth. By using ‘green’ materials, we moderate the intense exploitation of fossil resources, reduce the amount of carbon dioxide that enters the atmosphere and take upon the responsibility of using earth’s resources in a sustainable manner, thus improving resource management, indoor air quality, and generally the overall performance and efficiency of human kind on earth. Biomass is far less expensive than other resources, such as crude oil and natural gas, for energy and chemical production based on energy content. They are short growing cycle plants. Burning fuel or producing products from biomass do not add net CO_2 to the atmosphere. In other words, they are carbon neutral (Antonović et al., 2010a; Antonović et al., 2012).

Furthermore, to overcome the challenges facing the wood industry, it is necessary to develop the current state of innovations. As long as more attention will not be given to innovations, wood industry will continually lose economic ground in front of a more aggressive competition. In order to strengthen the competitiveness of the role of wood, along with the lignocellulosic products, scientists have recognized the need to improve the properties and performance of these obtained natural products by chemical modification of their polymeric chemical components, as well as the need to find new directions in wood chemical processing as a raw material for bio-based chemicals, new types of resins and adhesives, and fuel (Antonović et al., 2010c).

One approach, that has been researched last two decades, is to chemically derivate the wood components and thus increase their solubility in selected solvents. The dissolved macromolecules are then used in preparing useful polymeric materials. Another approach is to partially degrade the macromolecules to smaller soluble oligomers which are then used as feedstock for further use. Very often both methods overlap slightly, meaning that a limited degree of degradation takes place during the derivation and/or dissolution process. Such is indeed the case in wood liquefaction in which wood reacts with different types of reagents under elevated temperatures and in the presence of catalysts to yield a liquid product mixture known as liquefied wood (Antonović, 2009a; Antonović et al., 2013). At the present time, the most attention attracted wood (biomass) liquefaction in presence of some organic reagents and their application in preparation of resins for wood composites. The most interesting are two wood liquefaction methods. First one is preparation in presence of phenol, which resulted with liquefaction products rich with phenol units, so it could be applied in phenol resins preparation (similar to conventional phenol resins), mouldings and other. Second liquefaction method was achieved in presence of alcohols, especially polyhydric alcohols, and gained products can be used as polyols for preparation urea- and melamine-formaldehyde, polyurethane and epoxy resins (Antonović, 2009b).

Quality of wood composite materials, respectively particleboards, fiberboards, plywoods, oriented strand boards (OSB), wood-plastic composites (WPC), high pressure laminates (HPL) and other, does not exclusively depend on wood species and their properties applied in production, but with application of sophisticated technologies, composite quality is designed according to utilisation demands (Medved et al., 2011a). Resins (adhesives), paraffin emulsions and hardeners (catalysts) for wood composite materials are essential non-wooden components in wood composite production. With regard to this issue, numerous studies have focused on the wood liquefaction and application of liquefied wood as a potential adhesive or hardener, the bonding solid wood particles with liquefied wood respectively. By using these natural adhesives, we will eliminate the problems of formaldehyde emissions contained in composites produced using the synthetic formaldehyde adhesives, which would contribute to improving the ecological purity of panels based on fragmented wood, and further enlargement of integral utilization of wood components (Antonović et al., 2009b; Medved et al., 2011b).

Resins for particleboards are synthesized on formaldehyde base, such as phenol- (PF), urea-(UF), melamine-(MF), resorcinol-formaldehyde (RF) resins and their mixtures. From these, the most applied in the particleboards production are UF resins, due to its low cost, although have the worst properties in comparison with others. The advantages of UF adhesives are their (1) initial water solubility (this renders them eminently suitable for bulk and relatively inexpensive production), (2) hardness, (3) non-flammability, (4) good thermal properties, (5) absence of color in cured polymers, and (6) easy adaptability to a variety of curing conditions (Medved et al., 2010). Furthermore, the essential characteristic of resins applied for the particleboards production is accelerated polymerization under the influence of elevated temperatures and chemical catalysts, and the best properties are obtained by their mutual action. Salts of strong acids, usually ammonium chloride NH_4Cl, ammonium sulfate $(NH_4)_2SO_4$ and their mixtures are used as chemical catalysts in industrial production. These catalysts are considered to be environmentally unacceptable, because their toxicity have ecotoxic reactions if in the form of industrial water and liquids are discharged into natural waterways that serve as sources of drinking water, for fish farming, agricultural purposes, industrial needs and for people recreation (Španić et al., 2010).

Several authors who had researched the possible liquefied wood application in the preparation and modification of UF resins for experimental particleboards production, can be found in the literature. Antonović (2008) researched the new systems of urea-formaldehyde adhesives modified with liquefied wood for particleboards production. He conducted laboratory synthesis of designed liquefied wood-formaldehyde resin (LWF resin), liquefied wood is synthesized with formaldehyde respectively. Thus prepared LWF resin was used in the modification of urea-formaldehyde resin up to 15%, and obtained results showed a significant reduction of free formaldehyde emissions, with maintaining a good particleboards physical and mechanical properties according to European standards. Furthermore, Kunaver *et al.* (2010) applied liquefied wood in condesation reaction with different melamine-formaldehyde and melamine-urea-formaldehyde resins formulations, and used it as adhesives for particleboards. The mechanical properties of these particleboards, as well as determination of free formaldehyde emission, showed that adding a 50% of liquefied wood in the resins mixture causes the product that meets the European quality standards for particleboards. Also, a 40% reduction in formaldehyde emissions, as well as reduction of pressing temperature from 180 to 160°C in the particleboards, without significant influence on the mechanical properties, was achieved. Antonović *et al.* (2010) explored the influence of experimental pressing parameters on the compatibility of liquefied wood with urea-formaldehyde resins, the influence on polymer structure and adhesion-cohesion properties of modified urea-formaldehyde adhesives and on the particleboards physical-mechanical properties and formaldehyde emission. The results showed significantly reduced formaldehyde emission in particleboards in all cases of replacement urea-formaldehyde resin with liquefied wood.

According to above mentioned, in this study liquefaction of black poplar wood with polyhydric alcohol glycerol using an acid catalyst method was used (sulfuric acid, H_2SO_4) to prepare liquefied wood as environmentally friendly catalyst. Thus prepared liquefied wood was used as a hardener for UF and MUF with 18% melamine addition resin polymerization in the production of experimental three-layer particleboards. Particleboards quality was determined based on physical-mechanical and chemical properties testing. Also, in order to compare obtained results, next three-layer particleboards were produced, in which for the UF and MUF resins polymerization were used commercial catalysts, ammonium chloride and ammonium sulfate.

2. MATERIALS AND METHODS

Researches are done by production of experimental particleboards using the hardeners of UF and MUF resins which are commonly used in clasical production, such as ammonium chloride (NH_4Cl) and ammonium sulphate ($(NH_4)_2SO_4$). At the same conditions, were produced particleboards using LW as a hardener, which was alkylized with aqeous solution of 0.5 N NaOH prior to use to prepare a pH-value to 4 and 5 respectively. With the mentioned two LW pH values, it was take advantage of highly acidic nature of its components that enabled liquefaction.

The objectives of this researches were focused on the application of different LW pH values as a hardener in the process of urea- (UF) and melamine-urea-formaldehyde (MUF) resin polimerisation

with the addition of 18% melamine at a high temperature, and their impact on particleboards physical and mechanical properties and formaldehyde emission.

Materials and methods were prepared and performed based on previous studies (Antonović et al. 2010a; Antonović et al. 2010b; Antonović et al. 2014). These studies comprised several phases, which are: liquefied wood (LW) preparation, experimental particleboards production and testing, and analysis of test results. Production of experimental particleboards included the design of technological parameters, particles preparation, chemical components preparation, applying adhesives to the particles, forming and pressing of particle carpet (total of 21 panels). After the production, the panels were subjected to processes of conditioning and equalizing the moisture content, and other internal stresses. Furthermore, after conditioning, panels were cut into samples, on which were performed physical-mechanical and chemical properties testing according to standards.

The testing results are presented as a cumulative results of each type of experimental panels, i.e. their physical, mechanical and chemical properties. For all series of panels has been applied perforator method, with UV spectrophotometric analysis of formaldehyde solution, so that the samples of each panels series were mixed for formaldehyde determination. As such, they represent the basic set of series samples for free formaldehyde emission determination.

As already mentioned, 7 series of particleboards (total of 21 panels) has been made in this study in order to determine the influence of different pH value of liquefied wood on particleboards properties, and compatibility of liquefied wood as an alternative to conventional catalysts or hardeners.

Furthermore, based on previous studies (Jambreković 1996, Jambreković 2000), the quality of particleboards based on the variable values of density, water content, swelling in thickness, bending and tensile strength was researched.

For the analyzing of obtained results, with the aim of description and analysis, descriptive statistics and T-test of significance were applied, with the help of a computer softwear Statistica, based on which were the results described.

2.1. Liquefied wood (LW) preparation

Liquefied wood was prepared based on previous studies (Antonović et al. 2006; Antonović, 2008; Antonović et al. 2009b; Antonović et al. 2010a; Antonović et al. 2010b; Antonović et al., 2012; Antonović et al., 2013; Antonović et al., 2014). For wood liquefaction (without any prior chemical treatment), as a starting raw material, were used black poplar wood (Populus nigra L.). As a liquefaction reaction reagent was used glycerol as a polyhidric alcohol. Sulfuric acid was used as acid catalyst, so we can say that liquefaction was caried out according to acid catalyst method. All used chemicals were of high degree of purity and were purchased from commercial sources.

2.2. Chemicals preparation

Based on previous studies (Antonović, 2008; Antonović et al., 2012; Antonović et al., 2013; Antonović et al., 2014), in the experimental particleboards production ammonium chloride NH_4Cl and ammonium sulfate $(NH_4)_2SO_4$ as a catalysts were used. They were prepared as 20% aqueous solution. Density of ammonium chloride is determined by pyknometer and it was 1,0596 g/cm^3, and pH-value is determined by digital pH-meter and it was 5 (at 20°C). Furthermore, the density of ammonium sulphate was 1,0523 g/cm^3, and pH-value was 4,5.

The aim of this study was to use highly acidic character of liquefied wood as a hardener (pH-value was below 1), and to achieve a pH-value similar to above conventional hardeners, liquefied wood was due to the already mentioned very high acidity alkalyzed with 0,5N NaOH to achieve pH value 4 and 5. Furthermore, because of its very low viscosity, in terms of achieving better particles adhesion, liquefied wood was alkalyzed with as much as possible lesser concentration of NaOH (for this reason was used concentrations of 0,5N) to avoid the problem of poor bonding between adhesive mixture and particles.

Commercial UF and resin Lendur 920 (Nafta, Lendava, Slovenia) was used in this study. Sampling of representative UF resin was carried out according to standard HRN EN ISO 15605:2005 Adhesives – Sampling and standard HRN EN 1067:2007 Adhesives – Examination and preparation of samples for testing (EN 1067:2005). Paraffin emulsion Sasol Hydrowax, manufactured in

petrochemical industry, was used for reduction of swelling in thickness, prepared as a 55% aqeous solution.

2.3. Experimental particleboard testing

For sampling, cutting and presentation of test results, the following standard was used: HRN EN 326-1:1999: Wood-based panels – Sampling, cutting and inspection – Part 1: Sampling and cutting of test pieces and expression of test results (EN 326-1:1994).

Swelling in thickness (q-2) was tested as a physical property on experimental particleboards. This testing was provided according to standard HRN EN 317:2000: Particleboards and fiberboards – Determination of swelling in thickness after immersion in water (EN 317:1993) for samples with dimensions 50x50xpanel thickness (mm) and HRN D.C8.104: Particleboards – Water immersion and swelling for samples with dimensions 25x25xpanel thickness (mm).

Bending strength was tested according to standard HRN EN 310:1999: Wood based panels – Determination of modulus of elasticity in bending and bending strength (EN 310:1993) and tensile strength perpendicular to the plane of the board (delaminating strength) according to HRN EN 319:1999: Particleboards and fiberboards – Determination of tensile strength perpendicular to the plane of the board (EN 319:1993) were tested as mechanical properties.

Free formaldehyde content in experimental samples was determined according to standard HRN EN 120:2000: Wood based panels – Determination of formaldehyde content – Extraction method called the perforator method (EN 120:1991).

3. RESULTS AND DISCUSSION

3.1. Density and water content

Based on the standard deviation it can be concluded that the density of the particleboards are equally distributed over the entire cross section of the panel (Figure 1). Significant differences in the particleboards density have proven to be among several panels, and even although the projected density for all panels was 0.750 g/cm^3, we can say that on average, all panels had significantly lower density.

Furthermore, the panels that were made with MUF18% resin showed a slightly higher density than UF resin regardless of the type and pH of the hardener. Panels that are made with different pH values of LW as hardener show a significant difference in mixture with UF resin, as well as in a mixture with MUF18% whereby with increasing the pH from 4 to 5 showed reduction of density.

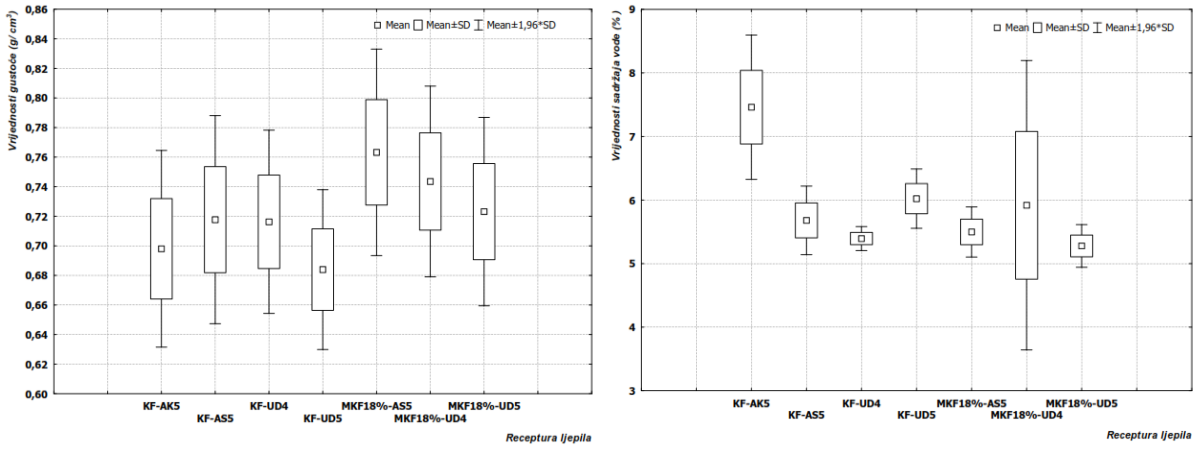

Figure 1. *Graphic distribution of the density and moisture content values for particleboards made with different types of resins and different hardeners types and hardeners pH values*

Based on statistical analysis, a significant difference in the final water content of particleboards have proven to be among all series of panels, which means between panels made with UF and MUF18% resin and various hardeners types and pH values (Fig.1). Although the designed water

content for all panels was 9%, we can say that all particleboards, regardless on each significant difference, had a water content below the designed value, and thus met the criteria.

It should be noted that all series of particleboards, made with either of the two resin and three mentioned hardeners with their different pH values, according to the water content obtained results, they all meet the technical properties of particleboards according to HRN EN standards for its thickness class (5-11%) .

3.2. Thickness swelling and bending strength

A statistically significant difference, if we look at the thickness swelling property, proved to be also between some series of particleboards (Figure 2). But in spite of these differences, based on the mean values of thickness swelling, we can say that all series of particleboards meet maximum allowed value of thickness swelling according to technical properties of HRN EN standards, which is 8%.

Panels made with MUF18% resin proved to be significantly better than those made with UF resin with use of LW hardener regardless of its pH value. The influence of pH value of LW is prominent at UF resins where with the increasing of pH value resulted with swelling reduction, while at the MUF18% resin that impact was not significant or thickness swelling was similar regardless of the change in pH value of LW.

Favorable results of thickness swelling showed panels that are made from LW as a hardener, and based on this we can assume a positive effect of the hardener to successful polymerization and compatibility with paraffin emulsion, in terms of increasing the particleboards water resistance.

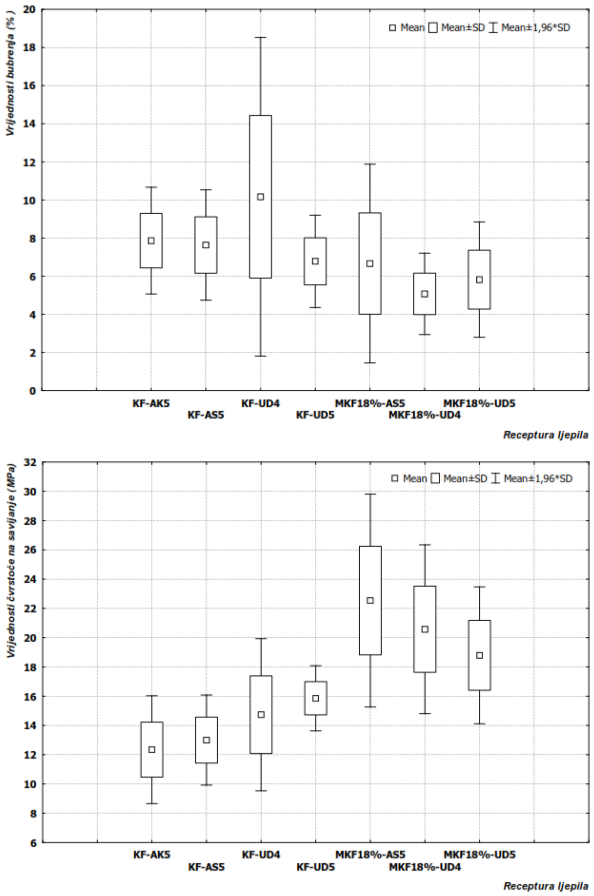

Figure 2. *Graphic distribution of the thickness swelling and bending strength values for particleboards made with different types of resins and different hardeners types and hardeners pH values*

A statistically significant difference, if we look at the bending strength property, was showned between series of particleboards made with UF resin and LW hardener with pH=5 compared to both

commercial catalysts also with the same pH (Fig.2). Reducing the pH value of LW to 4 caused a decrease of the same properties. Panels made with MUF18% resin showed much better bending properties, as confirmed by previous studies by other authors. For panels with MUF18% resin and LW hardener, we can see an increase in bending properties with a decrease in pH value from 5 to 4. The best bending strength property showed the panels made with the adhesive recipe which contains MUF resin with the addition of 18% melamine and ammonium sulfate at pH=5 as a hardener.

According to the obtained results, a significantly higher value of bending strength showed panels that are made with LW as a hardener in comparison with the other two hardeners, either in mixture with UF or MUF resin, and based on this we can assume successful polymerization and compatibility with UF and MUF resin, in terms of better mechanical properties.

Furthermore, based on the bending strength mean values, we can say that all series of particleboards meet minimum allowed bending strength values according to the technical properties of HRN EN standards, which is 11,5 N/mm^2 for the panels for general use in normal conditions, and 13 N/mm^2 for panels for furnishing (including furniture) in normal conditions.

3.3. Tensile strength and free formaldehyde emission

Based on statistical analysis, if we look tensile strength property (Figure 3), a significant difference was showed between a series of particleboards with UF resin and all hardeners types and hardeners pH values. The commercial types of hardeners shown to be superior to the LW regardless on the pH value. Particleboards made with LW as a hardener and pH=5 showed significant differences and reducing properties if we compared with pH=4 with the same UF resin, while at MUF18% was an increase of the same propertie with the change of the pH value of LW.

Furthermore, based on the tensile strength mean values, we can say that all series of particleboards meet minimum allowed tensile strength value according to the technical properties of HRN EN standards, which is 0,24 N/mm^2 for the panels for general use in normal conditions. However, based on the statistical analysis, we can conclude that the improved properties of tensile strength show panels made with MUF18% resin and commercial types of hardeners (ammonium chloride and ammonium sulfate), as well as LW hardener.

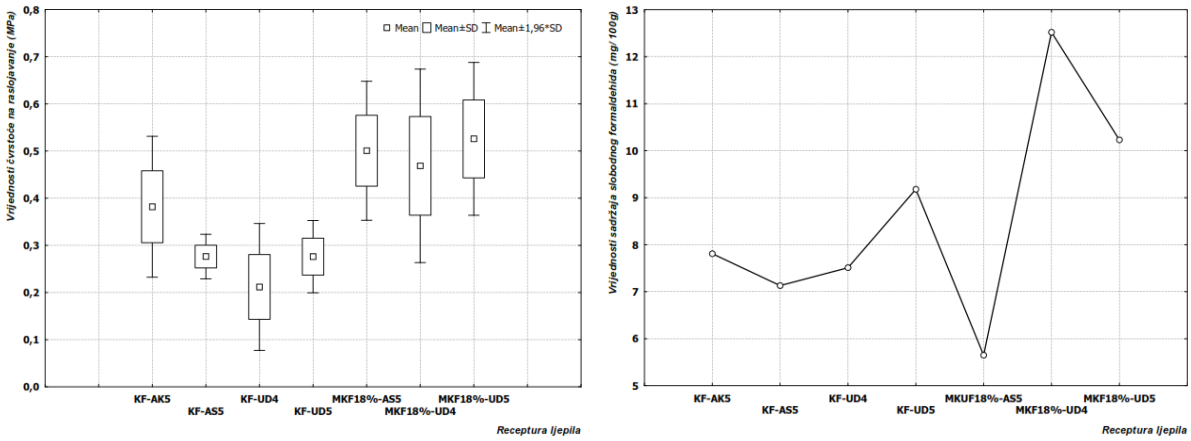

Figure 3. *Graphic distribution of the tensile strength and free formaldehyde emission for particleboards made with different types of resins and different hardeners types and hardeners pH values*

The obtained results for free formaldehyde emission in experimental particleboards made with different hardeners showed different concentrations (Figure 3). Minimum emission showed a series of particleboards made with MUF18% resin and ammonium sulfate as a hardener (pH=5), followed by the same only with UF resin and mixture of UF resin and LW hardener (pH=4). Furthermore, in the case of increasing the LW pH value from 4 to 5 in mixture with UF resin, we can see a increasing of the free formaldehyde emission concentration. That mean that the influance of the LW pH value has a

different polymerization effect between UF and MUF18% resin, wherein the melamine addition causes decrease the free formaldehyde emission.

We can conclude that the use of MUF resin with the addition of 18% melamine and using LW as a hardener cause a significant increasing in the free formaldehyde emission if we compare with the same hardener but in a mixture with UF resin. The obtained results for the commercial hardeners are identical with the previous studies, in which was proved lower free formaldehyde emission at particleboards with ammonium sulfate as a hardener.

It should be noted, that all the series of particleboards with different hardeners types and hardeners pH values meet emission class E1 (up to 8 mg HCHO/100 g of sample), except a series of particleboards with MUF18% resin and LW as a hardener and both pH values, which have a slightly incresed that content and litlle bit enter in the emission class E2.

4. CONCLUSION

Generally, all the series of particleboards which are made with different types of resins (UF and MUF18%), hardeners types (ammonium chloride, ammonium sulfate and liquefied wood) and hardeners pH values (pH=4 and 5) showed good physical, mechanical and chemical properties according to the technical properties of HRN EN standards for particleboards, either for general use in normal conditions, either for furnishing (including furniture) in normal conditions.

Liquefied wood as a hardener showed to be successful in replacing the commercial type of hardeners. The research results proved it, and depending on the particleboards properties they have minimum or maximum allowed values. Obtained researches of new urea- and melamine-urea-formaldehyde resins systems showed that liquefied wood, as a hardener, has a positive effect on the polymer structure and adhesion-cohesion properties of UF and MUF adhesives, as well as on the particleboards physical-mechanical properties and free formaldehyde emission.

This paper showed the research validity for LW application in "wood with wood" adhesive systems, and implied unforeseen opportunities for scientific and developing researches focused on specialization of adhesion-cohesion potential of resins obtained from LW. Consequently, this study opened new challenges in research area of natural and ecologically perfect materials with unlimited raw material potential.

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The Authors' Addresses:

Alan Antonović, PhD. (Corresponding author)
Assistant professor
University of Zagreb - Faculty of Forestry
Wood Technology Department - Institute for Material Technologies
Svetošimunska cesta 25, 10 002 Zagreb, CROATIA
e-mail: alan.antonovic@zg.htnet.hr

Vladimir Jambreković, Ph.D
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: vladimir.jambrekovic@sumfak.hr

Josip Ištvanić, Ph.D
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA
e-mail: jistvanic@sumfak.hr

Nikola Španić, Ph.D
University of Zagreb,
Faculty of Forestry,
Svetosimunska 25, Zagreb, CROATIA

Sergej Medved, Ph.D
University of Ljubljana - Biotehnical Faculty
Wood Science and Technology Department,
Rožna dolina, Cesta VIII/34, 1001 Ljubljana, SLOVENIA

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CHEMICAL COMPOSITION VARIABILITY OF GREY ALDER WOOD (*Alnus incana* (L.) Moensch) FROM JOŠANIČKA RIVER BASIN (KOPAONIK, SERBIA)

Gordana Petrović[1] , Milica Rančić[1], Dragoljub Jovanović[2], Milena Krstić[2], Milanka Điporović-Momčilović [1]

[1] *Faculty of Forestry, University of Belgrade, Serbia,*
e-mail: milica.rancic@sfb.bg.ac.rs
[2] *Faculty of Veterinary Medicine, University of Belgrade, Serbia,*
e-mail: milena@vet.bg.ac.rs

ABSTRACT

Alnus incana (L.) Moensch, commonly known as grey alder, is a deciduous tree widely distributed in northern Europe that could represent a potential source of valuable „green“ chemicals, including biologically active compounds. *Alnus incana* (Grey Alder or Speckled Alder) is a species of alder with a wide range across the cooler parts of the Northern Hemisphere. *Alnus incana* is a light-demanding, fast-growing tree that grows well on poorer soils.

Grey alder also posses high content of the bark extracts compared to the other deciduous species, that have been used in traditional medicine for treating bacterial and fungal infections. The most characteristic feature of the *Alnus* genus is the occurrence of large quantities of diarylheptanoids and their glycosides in different morphological parts of the tree.

Alnus incana wood samples were collected from *Jošanička river* basin in Raška, Kopaonik (Serbia) from 25 years old normal wood in order to analyse chemical composition variability. The chemical composition and its variability with the tree height were investigated: contents of cellulose, lignin, hemicellulose and ash were determined, as well as contents of lipophilic and hydrophilic extractives. The contents of acetyl and methoxyl functional groups, uronic acids, pentosans and inorganic substances were also determined.

Key words: *Alnus incana*, grey alder, wood chemical composition

1. INTRODUCTION

Due to its ability to produce large amounts of biomass in a short period of time, grey alder can be considered to be a prospective tree species for short-rotation forestry (SRF) in Eastern Europe and the Nordic countries (Bikovens *et al*., 2013; Telysheva *et al*., 2011). However, relatively scanty data is available about grey alder yield and growth dynamics.

Good knowledge of wood chemical composition and anatomic structure, together with other wood properties, represents the essential base for higher level of wood utilization as raw material in wood processing applying clasical, promoted or new technologies. Though *Alnus incana* comprise just 0.2% of the total forest area of Serbia (Banković *et al*., 2009), it has a great potential for producing forest biomass, together with clons of poplar and willow as the most used plantation species. The advantages of *Alnus incana* tree originate from the fact that its stem reach average height of 15-20 m, that is very important for industrial processing. Besides, compared to black alder, grey alder is more adaptable since it stands better limestone substrate and drier terrain, so it can be also find at higher altitudes that makes it suitable for cultivation. From that reason, there is growing interest in forestry and wood industry for grey alder tree. In the other hand, there are not many data in our scientific and professional literature about investigations of chemical composition of grey alder.

However, grey alder could alsso be a potential source of valuable green chemicals (Bikovens *et al*., 2013; Telysheva *et al*., 2011), including biologically active chemical compounds. It is possible to exploit high-value low molecular weight compounds, such as phytosterols (Fernandes and Cabral, 2007) and lignans (Pietarinen *et al.*, 2006) from by-products of the industrial processing (bark, knotwood, etc.). Various parts of some alders,s uch as bark, flowers, cone, and leaves, have been used in folk medicine as remedies for fever, hemorrage, and alcoholism (Tung *et al.*, 2010). The most characterisic feature of the genus Alnus is the occurence of large quantities of diarylheptanoids and their glycosides in different morphological parts of tree.

The aim of this work is to investigate the chemical composition variability with the height of the tree *Alnus incana* (L.) Moensch. Wood samples were collected from Jošanička river basin in Raška, Kopaonik (Serbia) from three normal trees 23, 25 and 33 year old in order to analyse chemical composition variability of both xylem and bark with the tree height.

2. MATERIAL AND METHODS

The chemical composition of both xylem and bark and its variability with the tree height were investigated including moisture and ash content, content of cellulose, lignin, and hemicellulose were determined, as well as contents of accompanying substances, lipophilic and hydrophilic extractives. The contents of acetyl and methoxy functional groups, uronic acids, pentosans and inorganic substances were also determined.

Three healthy *Alnus incana* (L.) Moench trees were felled in *Jošanicka river* basin near *Jošanicka Banja* (Kopaonik, Serbia, 43^0 23’ N latitude, 20^0 45’ E longitude), within the Forest Estates Raška (tree 1-lenght 9 m, 33 year old, tree 2- lenght 8,5 m, 30 year old, and tree 3- lenght 9.8 m, 23 year old).

According to variability of chemical composition of wood, as main factor was choosen the position at tree trunk: 1.3 m, ½ h and ¾ h.

All samples were air-dried at ambient temperature for three months, then ground before analysis using mill to pass a 0.5 mm sieve. In order to obtain representative sample mixture for analysis, approximately 40 g of air-dried 0.5 mm fraction of xylem or bark were measured, from the same height of every tree and combined by intensively shaking during 10 min.

Analysis was performed using standard experimental methods described in the literature (Stevanović-Janežić and Bujanović, 1998; Browning, 1967 a, 1967 b) and prescribed bz European (EN) standards.

Determination of moisture content was performed by drying of wood on temperature of 103±2^{o}C (TAPPI T12 method). Ash content was determined after burning of wood on temperature of 575±25^{o}C during 3 h (TAPPI 15wd-80 method).

Cellulose content was determined by *Kurschnerd-Hofferd* method by treating of wood with nitric acid/ethanol mixture 20:80 (% v/v) during 4 h. Lignin content was determined using modified *Klason* method - previously extracted wood with toluene/ethanol mixture was treated with 72% sulfuric acid and diluted 3% sulfuric acid afterwards. Precipitate was filtered off, washed with distilled water and dried. Precipitate obtained is classified as *Klason’s* lignin.

Uronic acid content was determined by modified *Barker* method, acetyl groups content by *Froudenberg-Harder’s* method, methoxy groups content by method of *Vieböck* and *Schwappach*.

Procedure of determing total pentosanes is based on the formation of furfural when the pentose sugars are destilled with hzdrochloric acid.

All powdered samples (1 gram) were extracted with corresponding extraction solvent using *Soxhlet* extraction method (TAPPI T 6 osd 50 and TAPPI T1 osd 50). The *Soxhlet* extraction was performed at ambient pressure for 8 h. The obtained extracts were evaporated and weighed.

All results were reported as weight percent and calculated related to absolutely dry wood.

Inorganic substances content (except phosphorus) was determined from the ash, which is determined in bark and xylem samples of invesigated species by SRPS ISO 5984-2002 method.

Macro (except phosphorus) and microelements content in the ash was obtained using atomic-absorption spectroscopy, by flame technique, method SRPS ISO 6869-2007 on Perkin Elmer Analyst 700 apparatus. Macroelements calcium, sodium, magnesium, as well as microelements iron, copper, mangan and zink were determined this way.

Phosphorus is determined spectrophotometrically by spectrophotometer UNICAM apparatus.

3. RESULTS AND DISCUSSION

The absolute moisture content of grey alder bark the varies from 3.3 to 4.6% for different position at trunk height and decreases with the trunk height, as expected. The same trend is present for relative moisture and the results vary from 3.2 to 4.4% decreasing with tree height. Also, the results show that the absolute moisture content of grey alder xylem varies from 7.6 to 8.1% for different position at trunk height, with the highest moisture present in the samples at 1.3 m, and the lowest moisture is obtained for the samples taken from ½ trunk height, while the moisture in grey alder xylem sampled at ¾ h is slightly higher, but still lower than in the xylem taken from a height of 1.3 m. Results of relative moisture content of xylem vary from 7,0 - 7,5% and depend on the position at tree trunk, displaying the same trend as the absolute moisture.

Coefficients of dryness of grey alder xylem are lower (0.9287 to 0.9492) compared to the same obtained for the bark from the same trunk position (0.9560 to 0.9679), as expected, implying that bark, compared to the xylem, always contains lower percentage of moisture (Stevanovic-Janežić, Bujanović, 1998).

Table 1. *Results of chemical composition variability of Alnus incana (L.) Moensch xylem*

Height	Cellulose (%)	Lignin (%)	Extractives (%)		
			Toluen/EtOH	Hot H_2O	1%NaOH
1.30	46.85	18.15	4.55	3.92	19.69
1/2	46.05	17.71	4.99	4.39	20.03
3/4	44.83	17.49	5.76	5.49	21.43

Cellulose and lignin content

As it can be seen from Table 1, the values of cellulose contents are in the range from 44.83 to 46.85%. From Figure 1, it can be clearly seen that the highest average content of cellulose obtained in the lower part of the trunk for the samples at a height of 1.3 m, while with increasing tree height, cellulose content decreases. The decreasing of cellulose content with trunk height is in acordance with the increasing of the juvenile wood with the trunk height, which normally has less pulp (Stevanovic-Janežić, 1993).

In addition, it is important to point out that the content of cellulose in grey alder xylem at all three tested positions, does not deviate from the global average content of cellulose in deciduous species (45 ± 2)% (Stevanovic-Janežić, 1993). These comparison is important for the assessment of wood quality. It is desirable that wood contains more cellulose, because it contributes to improving the mechanical properties, especially if the direction of the force is parallel to the direction of extension of axial anatomical elements of the wood structure. Additionally, cellulose essentially determines the behavior of wood under the influence of moisture, such as swelling and shrinkage which is crucial to the process of mating tree and its usage, in conditions of varying moisture. Overall, based on the cellulose content results, it can be concluded that the grey alder wood from Kopaonik possess similar characteristics as any other deciduous tree.

Lignin content results for grey alder xylem, depending on the position of tree trunk, are also presented in Table 1, and their values are graphically illustrated in Figure 1. As it can be seen from Table 1, lignin content values are in the range of 17.49 to 18.15%. It is expected that the lignin content increases with the trunk height, with increasing participation of juvenile wood, which has a higher lignin content than a mature tree. However, the results show the opposite, as it can clearly be seen in Figure 1. Grey alder contains the highest average lignin content of 18.15% at the trunk height of 1.3 m, and the lowest (17.49%) at ¾ of trunk height. This trend can be explained by the fact that the analysis was not performed on isolated tissues of juvenile and mature wood, but the samples that consist of both tissues, but in different proportions for different heights.

Compared to the other domestic deciduous species, it has been noticed that the lignin content in grey alder wood is lower, *i.e.* at the lower limit of the range of 20 ± 4% (Stevanovic-Janežić, 1993). This value for the lignin content is the closest to the species *Betula papyrifera*, which has the lignin

content of 18% and *Alnus glutinosa* (lignin content 22%). That fact is not surprising, taking into account that these species belong to the same family of birch (*Betulaceae*).

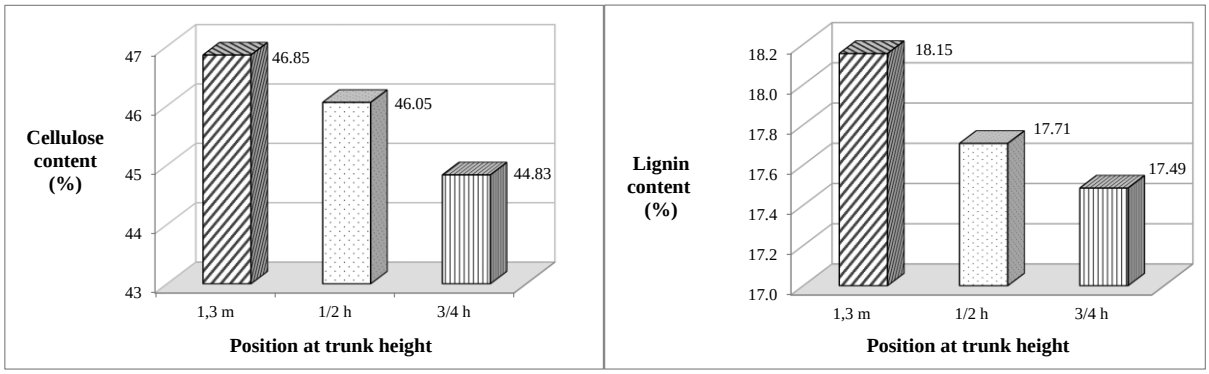

Figure 1. *Cellulose and lignin content of the grey alder xylem from different positions at tree trunk*

Determination of pH

Results of pH determination for xylem and bark of grey alder tree are shown in Table 2. Results of the medium pH values for grey alder wood (xylem), are in the range of 5.14 to 5.22, and the lowest value was measured at a half of the trunk height. pH value of grey alder bark are slightly lower and varies from 4.54 to 4.71 where, again, the lowest value was observed in the middle of the trunk height. Lower pH values of bark indicate that it is more acidic compared to the xylem, which is to be expected, since bark contains a large amount of extractive substances that are mainly acidic in nature.

Table 2. *Results of pH values of the grey alder xyleme and bark from different positions at trunk height*

Sample	pH value					
	xylem			bark		
	position at trunk height			position at trunk height		
	1,3m	1/2 h_{st}	¾ h_{st}	1,3m	1/2 h_{st}	¾ h_{st}
pH_{sr}	**5,22**	**5,14**	**5,20**	**4,71**	**4,54**	**4,62**

Extractives content

In Table 1. the results of the extractives contents are presented (extractives soluble in hot water, organic solvents and 1% NaOH). Results of the contents of extractive substances soluble in hot water in grey alder tree depending on the position of tree height are shown in Table 1. A graphical representation is shown in Figure 2. Starting from the principle that the concentration of primary extractives grows with the height of the tree, due to the larger volume of metabolic processes that occur in the upper part of the tree, the results are in accordance with this rule. The content of extractives soluble in hot water vary in the range between 3.92 to 5.49% and are in line with the average extractives content for deciduous species (5±3%) as it is stated in literature (Stevanovic-Janežić, 1993).

From Figure 2, it can be observed that the lowest average content was found at lowest trunk height (1.3 m), and the highest value was obtained at ¾ of the trunk height and its concentration increases from the bottom to the top of the trunk. This relationship may be probably due to the presence of simple carbohydrates, not only in the sapwood, but also even more in alburnum, especially at lowest trunk height (1.3 m).

However, compared with the data in the literature (Janežić-Stevanović et al., 1995) of the content of extractives soluble in hot water for beech (1.66%), poplar (0.59%) and oak (5.09%) as our native species, it can be concluded that examined grey alder wood contains a large amount of extractives soluble in hot water compared with the native species. This fact of higher extractives content

designates grey alder wood as a species that is suitable for use where greater resistance to decay is needed.

Secondary plant substances (extraktives) that are generally soluble in organic solvents, lead the general rule that their concentration increases from the bottom to the top of the tree. In this study it was found that grey alder tree exxtractivs soluble in organic solvents range from 4.55 to 5.76%, increasing with the trunk height.

Results of contents of extractives soluble in 1% sodium hydroxide solution obtained in this work for the grey alder at various positions of trunk height, are in the range from 19.7 to 22.1% (Table 1). In Figure 2, it can be observed that their concentration increases from the bottom to the top of the trunk. Also, it can be seen that the content of extractives soluble in sodium hydroxide is extremely high compared with other types of ekstraktives, hence, it can be concluded that grey alder wood mostly contains extraktives of acidic character.

Besides, it can be derived that content of the extractives soluble in 1% sodium hydroxide, obtained in this study, is somewhat higher compared to domestic beech (15.6%), while very similar to the content of 21.7% obtained for the oak that was also from the local habitat (Stevanovic-Janežić et al., 1995).

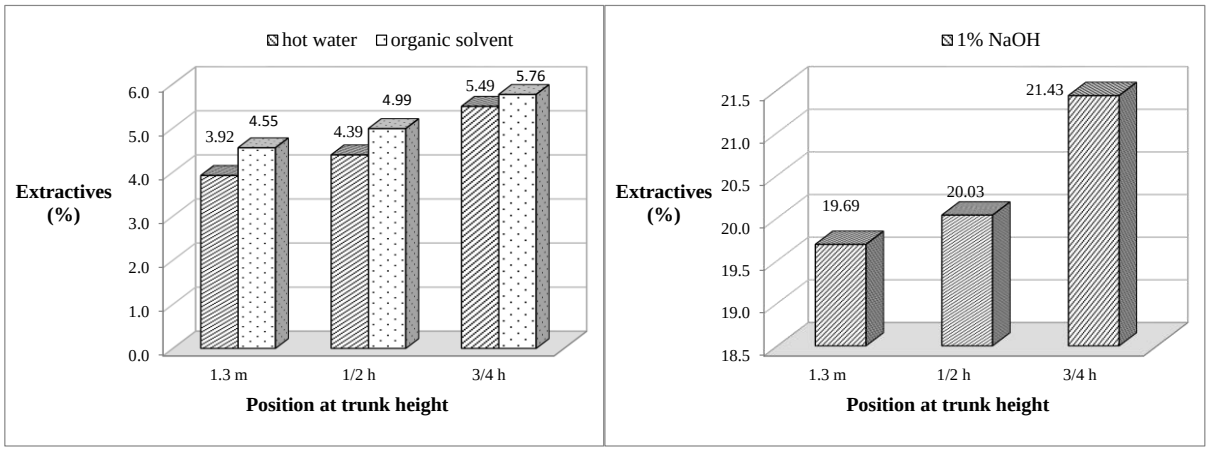

Figure 2. *Content of extractives soluble in hot water, organic solvents and 1% NaOH of the grey alder xyleme with the position at trunk height*

Content of acetyl, metoxy groups, pentosanes and uronic acids

According to the theory, it is known that the pentosane content can be estimation for the hemicellulose content in wood. In addition, it is known that there is no significant difference in the amount of hemicellulose in the juvenile and mature wood, which is consistent with the results obtained pentosane content in this study. For these reasons, it can be seen in Table 3. that there are neglecting differences among pentosane content values in grey alder wood taken at different trunk heights. The results for pentosanes contents vary in the range from 23.44 to 23.92% with the position at trunk height.

The values of acetyl groups content in grey alder wood are in the range of 4.1 to 5.5% (Table 3). It can be observed that their concentration increases from the bottom to the middle of the tree, and then slightly decreases. The highest content of acetyl groups is in the middle of the height of the tree. Similar values were found in the literature (Stefanovic-Janežić *et al*., 1995) - value of 4.30% established for the oak tree (*Quercus patraea*) domestic deciduous species. The same authors reported a significantly higher content of acetyl groups (10.05%) in beech (*Fagus moesiaca*), as the most popular domestic species.

Table 3. *Results of contents of acetyl, metoxy groups, pentosanes and uronic acids of Alnus incana (L.) Moensch xylem*

Height	Pentosanes (%)	Acetyl groups (%)	Metoxy groups (%)	Uronic acids (%)
1.30	23.48	4.27	5.48	3.89
1/2	23.44	4.97	5.50	2.82
3/4	23.92	4.69	5.65	4.57

The individual values of methoxy groups content in grey alder wood, vary in a narrow range of 5.47 to 5.66% depending on specific positions of trunk height (Table 3). For this reason, we can notice that their concentration is uniform with the trunk height, and since there are no statistically significant differences, it can be concluded that the content of methoxy groups in grey alder wood does not depend on the position of trunk height. The obtained results for methoxy groups content in grey alder tree are close to the average of 6.42%, for beech (*Fagus moesiaca*), and oak (*Quercus patraea*) - 6%, which is found by Stefanović-Janežić *et al*.

The data in Table 3. indicate that results obtained for uronic acids contents are in the range of 4-5%, which is characteristic for deciduous species. In this study, the variation of uronic acid content in the grey alder wood is a little higher than normal specified range, ranging from 2 to 4.8%. Results of uronic acid content at the trunk height of 1.3 m (3.89%) and at ¾ of trunk height (4.57%) of grey alder wood are close to the value of 4.35% established by Stefanovic-Janežić *et al.* in their studies of domestic oak species (*Quercus patraea*). The highest average value content of uronic acid was obtained at the top of the trunk (3/4 hst), which can be explained as a consequence of the higher content of pectin, which probably possess O-galacturonic acid, that are concentrated in the upper part of the tree due to the activities of the primary metabolites.

Micro and macroelements content

Results and analysis of the ash content of macro- and microelements in and grey alder bark and xylem are shown in Figure 3 and in Table 4.

As it is known, wood xylem contains a significantly smaller amount of mineral substances, *i.e.* a smaller amount of the ash relative to the bark of a tree, that can be clearly observed in Figure 3. However, oppositely, statistical analysis showed no significant differences between the values of ash contents at different positions of trunk heights, both in wood and bark of grey alder. Comparisons of obtained results for ash content in this study with an average ash content in typical wood species of temperate continental climate zone, which includes sampled tree, confirm that the proportion of ash in wood and grey alder is in the same range of 0.2 to 1%.

The data in Table 4. show that the proportion of calcium (Ca) is the highest in ash of wood and bark of white alder as the main cation. Furthermore, according to the representation, magnesium (Mg) is at the second place, followed by phosphorus (P), and the last presented is sodium (Na) of the investigated macroelements.

The content of macroelements generally increases from the bottom to the top of the trunk, except in the case of Na and P, where the opposite trend was observed. Increasing concentrations of macroelements with height is consistent with the fact that their concentration is higher in physiologically active parts of the plants at the top of the tree.

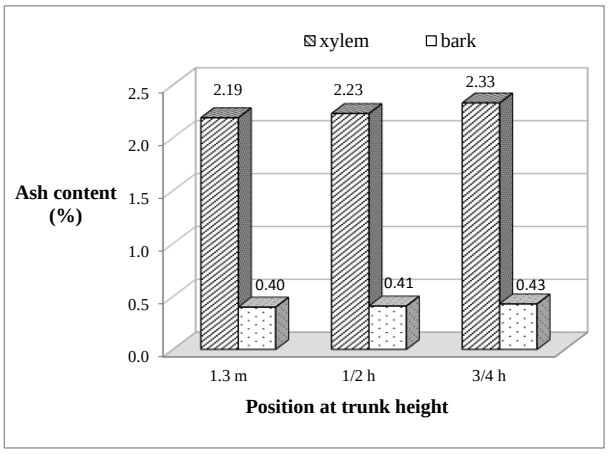

Figure 3. *Ash content of the grey alder xyleme at different positions of trunk height*

Table 4. *Results of determination of macro and microelements content in xylem and bark of Alnus incana (L.) Moensch*

Element (mg/kg)	bark			xylem		
	position at trunk height			position at trunk height		
	1,3m	1/2 h_{st}	¾ h_{st}	1,3m	1/2 h_{st}	¾ h_{st}
Ca	5400	5600	6000	520	590	650
Mg	840	840	900	380	390	400
P	310	365	290	250	210	250
Na	55	53	35	48	47	41
Fe	36	49	60	5.0	5.2	5.5
Cu	4.7	4.6	4.8	1.4	1.4	3.5
Mn	23	24	27	3.1	3.6	4.1
Zn	32	34	34	4.3	5.3	6.2

In relation to the position of the trunk height, it can be seen that the portion of corresponding microelements (Fe, Cu, Mn and Zn) in ash of grey alder wood and bark, also increases towards the top of the trunk for the same reasons as for the macroelements. Results clearly show that the iron (Fe) and zinc (Zn) are the most common in the grey alder ash of wood and bark. A minimum concentrations of copper (Cu) were found in both cases.

Hemicellulose content

The amount of hemicellulose in grey alder wood is mathematically calculated by subtracting from 100% of the sum of the mean values of the analyzed chemical components. The calculated values of hemicellulose depending on the tree height are shown graphically in Figure 4. According to the literature, it is known that there is no difference in the amount of hemicellulose in the juvenile and mature wood, which is important in terms of the position of the sampling. The calculated values of hemicellulose in this study for grey alder wood are: 26.12% for the tree height of 1.3 m; 26.45% for ½ of the tree height and 26.00% for ¾ height of the tree. The calculated amount of hemicellulose are in the range of average values for domestic deciduous species (30 ± 5%) (Stefanovic-Janežić, 1993). Slightly lower hemicellulose content, *i.e.* closer to the lower limit, is probably a consequence of hydrolyzed hemicellulose extracts obtained by extraction by organic solvent. In addition to this, the reason for the lower content of hemicellulose in grey alder wood is a loss of hemicellulose and cellulose content in determining by the Kirschner-Hofer method due to possible hydrolysis of pentosanes even in the amount of 75% (Stefanovic-Janežić, 1993).

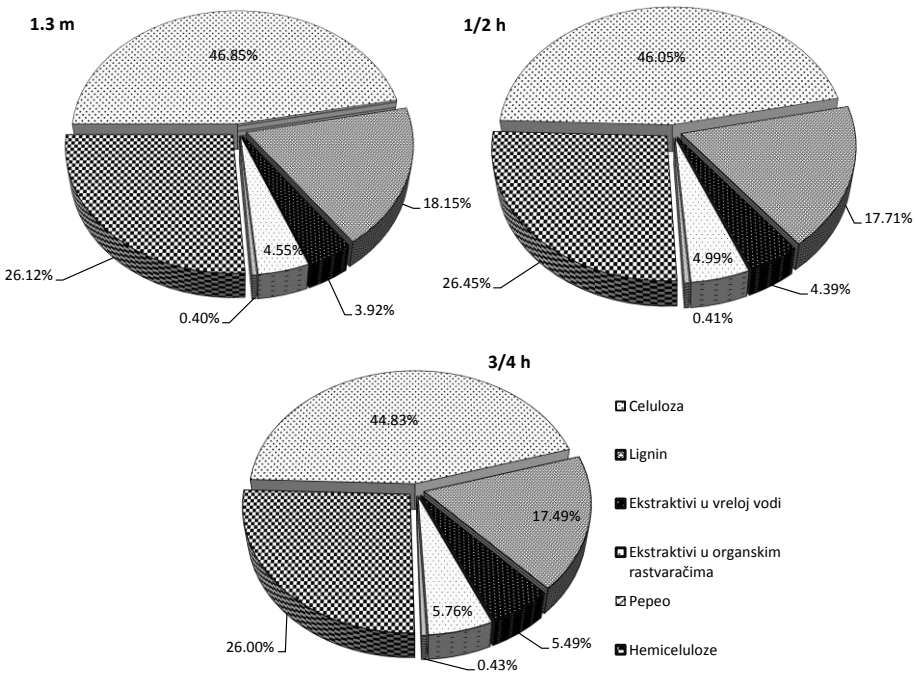

Figure 4. *Total chemical composition of Alnus incana (L.) Moensch xylem*

4. CONCLUSIONS

In most cases, the choice of a particular wood species for the selected product is done on the basis of its physical and chemical characteristics. In order to establish and maintain the quality of wood products, it is necessary to know the variability of its properties. The introduction of new species of wood in application, requires knowledge of its behavior during processing, which is primarily a consequence of its chemical structure. In addition, for the assessment of the suitability of the type of treatment and processing for a particular wood species, knowledge of its chemical composition is also very significant.

In order to determine the most rational application areas of grey alder wood, in this paper were carried out research on the variability of the chemical composition of this kind. The results obtained indicate that:

• The content of cellulose in wood and grey alder shows the typical trend of decreasing from the bottom to the top of the tree and varies in the range of 44.83% to 47.83%. From the results, it can be seen that the highest average content of cellulose obtained in the lower part of the tree in the samples taken from the position at a trunk height of 1.3 m, while it decreases with the trunk height.

• White alder xylem contains a relatively low content of lignin highest average content of lignin, which is in the range of 17.49% at the trunk height of 1.3 m to 18.15% at ¾ height of the trunk. This trend can be explained by the fact that the analysis was not performed on isolated tissues of juvenile and mature wood, but the samples that contained both tissues, but in different proportions for different heights.

• Contents of extractives soluble in hot water obtained in this study for grey alder wood are in the range of 3.9 to 4.5%. It is important to note that examined white alder wood contains a large amount of extractives soluble in hot water compared with other domestic species. Based on the results of chemical constituents content, it can be reasonably assumed that white alder wood has good mechanical properties and resistance to rot and slight swelling and shrinkage.

• For secondary plant substances (extractives) that are soluble in organic solvents, the general rule that their concentration increases from the bottom to the top of the trunk height, which is in line with the given results. In this study, it was found that white alder wood containes extractives soluble in organic solvents in the range from 4.5 to 5.8%, while the lowest average content was observed in samples taken at the trunk height of 1.3 m (4.55%), the highest content was found in samples taken at

¾ of trunk height (5.76%), and that results are slightly higher compared with the content extractives in hot water.

• Contents of extractives soluble in 1% sodium hydroxide are in the range of from 19.6 to 21.5%. Also, it can be seen that these results are extremely high compared with other types of extractives.

• Grey alder xylem contains a smaller amount of substances of mineral origin, as weel as a smaller amount of ash in relation to bark.

• The calculated amount of hemicellulose were in the range of average values for deciduous species (30±5%) and do not vary significantly with position at trunk height.

Although related to the total timber mass volume of the forest fund in Serbia, grey alder accounts for only 0.2%, it has great potential for the production of forest biomass. Its advantages as a plantation timber species, stems from the fact that grey alder trees reach an average height of 15 to 20 meters, which is very important for industrial processing. Grey alder also has great potential as a raw material for natural substances valuable for the chemical "green" industries, or for the production of chemical substances which are obtained by methods that do not harm the environment.

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The Authors' Addresses:

Mr Gordana Petrović
research assistant
Faculty of Forestry, University of Belgrade,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: gordana.petrovic@sfb.bg.ac.rs

Dr Milica Rančić
assistant professor
Faculty of Forestry, University of Belgrade,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: milica.rancic@sfb.bg.ac.rs

Mr Dragoljub Jovanović
research assistant
Faculty of Veterinary Medicine, University of Belgrade,
Bulevar Oslobodjenja 18, 11000 Belgrade, SERBIA
e-mail: djovanovic@vet.bg.ac.rs

Dr Milena Krstić
assistant professor
Faculty of Veterinary Medicine, University of Belgrade,
Serbia, Bulevar Oslobodjenja 18, 11000 Belgrade, SERBIA
e-mail: milena@vet.bg.ac.rs

Dr Milanka Điporović-Momčilović
full professor
Faculty of Forestry, University of Belgrade,
Kneza Višeslava 1, 11030 Belgrade, SERBIA
e-mail: milanka.djiporovic@sfb.bg.ac.rs

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DETERMINING FACTORS ON THE PRODUCTIVITY OF WOOD PROCESSING MACHINERIES

Elva Çaushi, Pandeli Marku, Entela Lato

Agricultural University of Tirana, Tirana, Albania
Faculty of Forestry Sciences
e-mail: alcaushi@abcom.al

ABSTRACT

The aim of this research presented in the paper is the effectiveness of the wood processing machineries used in Albania. For studying this, the machinery utilization coefficient was taken into account. About 300 furniture manufacturing companies and more than 200 sawn timbers producing SME-s operates in the field of wood industry in Albania. For the production of furniture and other wood objects, a wide range of wood processing machineries are being used. Although the effectiveness of these machineries is affected by many factors, such as the technical features, the velocity, the number of details that can be processed simultaneously, etc., the machinery utilization coefficient is of the highest importance. It shows in which part of the working period (during the shift), the machinery works at full capacity without any visible or hidden interruption.

The machinery utilization coefficient (k) consists of both k1 and k2, from which the 1-st indicates the machinery working time utilization and the 2-nd indicates the machinery utilization that can be called machinery effective-cut time. This study took place in Ardeno, a furniture manufacturing company since 2000. Coefficients’ measurement is done in four types of machineries. It turns out that the utilization coefficient of the disk chainsaw machinery was low, 0.58. Even in the drilling machinery utilization coefficient resulted low, 0.61. In the four-faceted machinery the utilization coefficient was 0.79, higher than in the first two cases. But still there is room to increase this radio, and hence the machinery’s the productivity.

It is important that furniture manufacturing firms in Albania should carry out more investments for the introduction of new technologies, in terms of new machineries and equipments. This way they will be able to boost production, improve the quality and better face competition in this area. More companies need to install mechanized lines of production and use modern numerical command machineries, vacuum presses for gluing PVC, cutting equipment for panels with laser ray, finishing lines with electrostatic field, modern lines of pneumatic transport for wood dust etc.

Key words: wood, timber, manufacturing, technology, sawing, milling

1. INTRODUCTION

In Albania, the wood manufacture companies usually used to produce office and school, equipments, as well as kitchen, bedroom and soft furniture, based on large amounts of plywood, particleboard, veneer, etc., for which worked a whole industry. Meanwhile, to prepare such products was spent a lot of time because of the large number of operations (automatic or by hand) was required a large labor force (Ajdinaj and Marku, 2008).

The introduction in recent years of melamine panels and the MDF average density fiber panels, brought significant changes in the Albanian furniture manufacturing industry (Lato and Quku, 2008).
For the production of furniture and other wooden objects a wide range of wood processing machineries began to be used. The efficiency of these machineries is being affected by many factors that have to do with technical features, the advance speed, the details number processed

simultaneously etc. (Fico, Marku, Shqau, 1998). The wood processing machineries' utilization coefficient has a great influence over their efficiency. It shows which part of working time shift, the machinery works at full load without any visible or hidden interruption (Ajdinaj and Marku, 2014).

The wood processing machineries' utilization coefficient (k), consists of both k_1 and k_2 coefficients, from which the first is the coefficient of utilization or use of machinery's working time and the second is the coefficient of machinery's utilization or usage, otherwise known as time utilization coefficient for effective cutting.

2. MATERIAL AND METHODS

The study of wood processing machineries' utilization coefficient is carried out at Ardeno furniture manufacturing company. Ardeno was established in the year 2000, and is currently located in Tirana-Durres road. Its activity consists mainly in the manufacturing of chairs, tables, sofas, bedrooms, bar restaurants furniture etc. From a huge range of wood processing machineries used by this company, we choose to focus on the disk chainsaw machinery, the drilling machinery, the four-faceted (skoniatrice) machinery, and the wide tape calibration machinery.

The productivity of such machineries is given through the following basic formula (Dimoshi, 2006):

$$P = T \times U \times k_1 \times k_2 \text{ (ml/shift)}$$

Where:
T – the working shift time of 480 minutes;
U – the machinery's advance speed m/min;
K_1 – the machinery's working time utilization coefficient; &
K_2 – the machinery's utilization coefficient.

As shown by the formula, productivity depends on the working shift time; the machinery's advance speed; the machinery's working time utilization coefficient and the machinery's utilization coefficient (Mokovskovo, 1990).

Thus, there are two coefficients that need to be taken into account while calculating the wood processing machineries' productivity (Heurtematte, 1995):

K_1 – the machinery's working time utilization coefficient;

K_2 – the machinery's utilization coefficient, otherwise known as time utilization coefficient for effective cutting.

The K_1 coefficient represents the ratio between the machinery's effective working time (t_1) and the shifts' total time (T):

$$K_1 = \frac{t_1}{T}$$

This coefficient takes into account the machinery's apparent time-outs (stops) in order to repair something broken or not functioning, to control the detail size of, to change the instrument cutting stone, to deal with blackouts, to provide for worker's needs etc. (Bajraktari and Marku, 2006).

The K_2 coefficient represents the ratio between the machinery's useful time ($t_{3)}$ and machinery's effective working time ($t_{1)}$.

$$K_2 = \frac{t_3}{t_1}$$

This coefficient takes into account the hidden losses from the machinery's usage such as the necessary time to turn it back to make another detail (work-piece); the necessary time to rely the detail in the machinery; the time of placing the detail in the respective pile etc. So this coefficient takes into account the time that the machinery is working but not cutting the wood.

The machinery's utilization coefficient is calculated:

$$K = k_1 \times k_2$$

As mentioned earlier in this presentation, measurements of k_1 and k_2 coefficients were performed at Ardeno company.

Measurements have determined:

- Working time on which measurements are carried out T = 240 minutes;
- Machinery’s working time t_1;
- Time of the machinery’s visible stops during working shifts t_2;
- Machinery’s useful time t_3; &
- Time of the machinery’s hidden losses during working shifts t_4.

3. RESULTS AND DISCUSSION

The results of measurements performed in the Ardeno company wood processing machineries are provided in Tables 1, 2, 3 and 4. Graphically, the measurement results are shown in Figures 1, 2, 3 and 4.

The total time of the shifts is:

$$T = t_1 + t_2$$

On the other hand the machinery’s working time is:

$$t_1 = t_3 + t_4$$

from which it results that:

$$T = t_2 + t_3 + t_4$$

The machinery’s working time utilization coefficient will be:

$$K_1 = \frac{t_1}{T} = \frac{t_1}{t_1 + t_2}$$

Whereas the machinery’s time utilization coefficient will be:

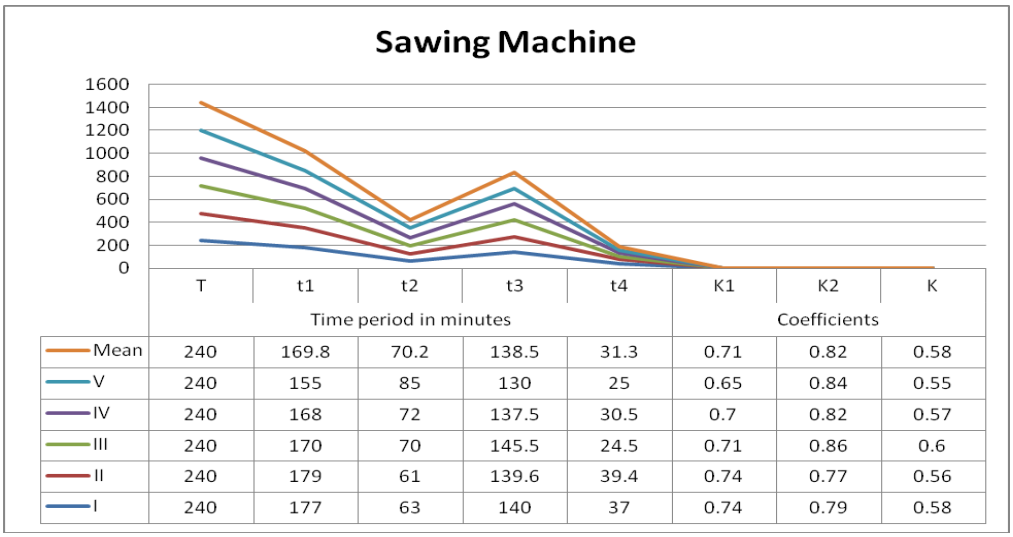
$$K_2 = \frac{t_3}{t_1} = \frac{t_3}{t_3 + t_4}$$

And the machinery’s utilization coefficient will be:

$$K = k_1 \; k_2 = \frac{t_1 \, t_3}{T \; t_1} = \frac{t_3}{T}$$

Table 1. *Disk chainsaw machinery*

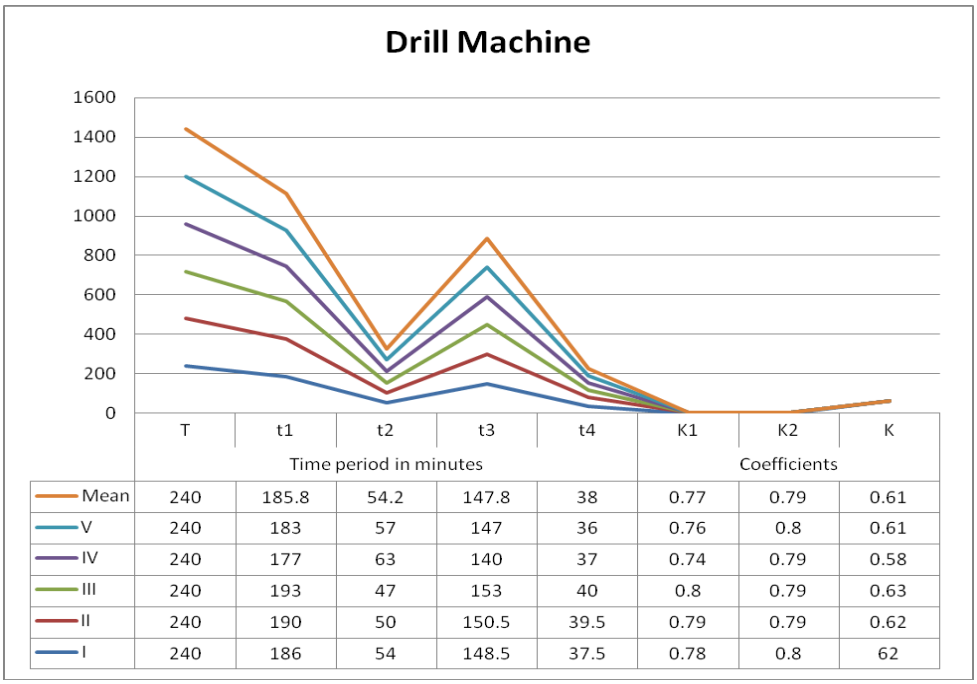
Measurements	Time period in minutes					Coefficients		
	T	t_1	t_2	t_3	t_4	K_1	K_2	K
I	240	177	63	140	37	0.74	0.79	0.58
II	240	179	61	139.6	39.4	0.74	0.77	0.56
III	240	170	70	145.5	24.5	0.71	0.86	0.60
IV	240	168	72	137.5	30.5	0.70	0.82	0.57
V	240	155	85	130	25	0.65	0.84	0.55
Average	**240**	**169.8**	**70.2**	**138.5**	**31.3**	**0.71**	**0.82**	**0.58**



Fugure 1. *Sawing Machine*

Table 2. *Drilling machinery*

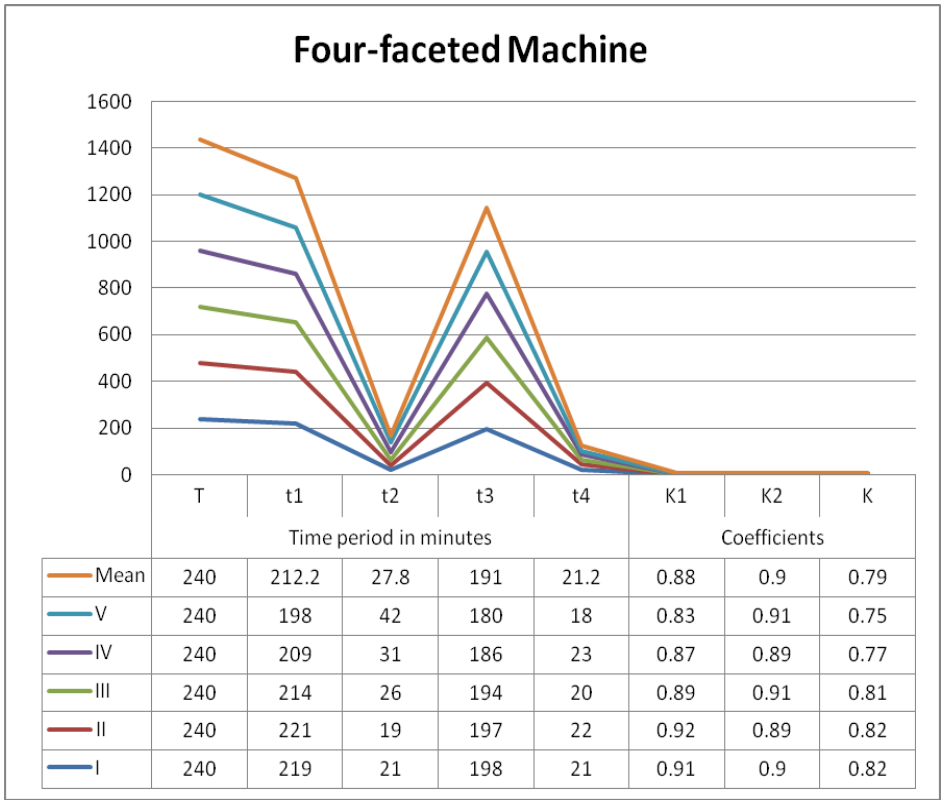
Measurements	Time period in minutes					Coefficients		
	T	t_1	t_2	t_3	t_4	K_1	K_2	K
I	240	186	54	148.5	37.5	0.78	0.80	062
II	240	190	50	150.5	39.5	0.79	0.79	0.62
III	240	193	47	153	40	0.80	0.79	0.63
IV	240	177	63	140	37	0.74	0.79	0.58
V	240	183	57	147	36	0.76	0.80	0.61
Average	**240**	**185.8**	**54.2**	**147.8**	**38**	**0.77**	**0.79**	**0.61**



Fugure 2. *Drill Machine*

Table 3. *Four-faceted machinery*

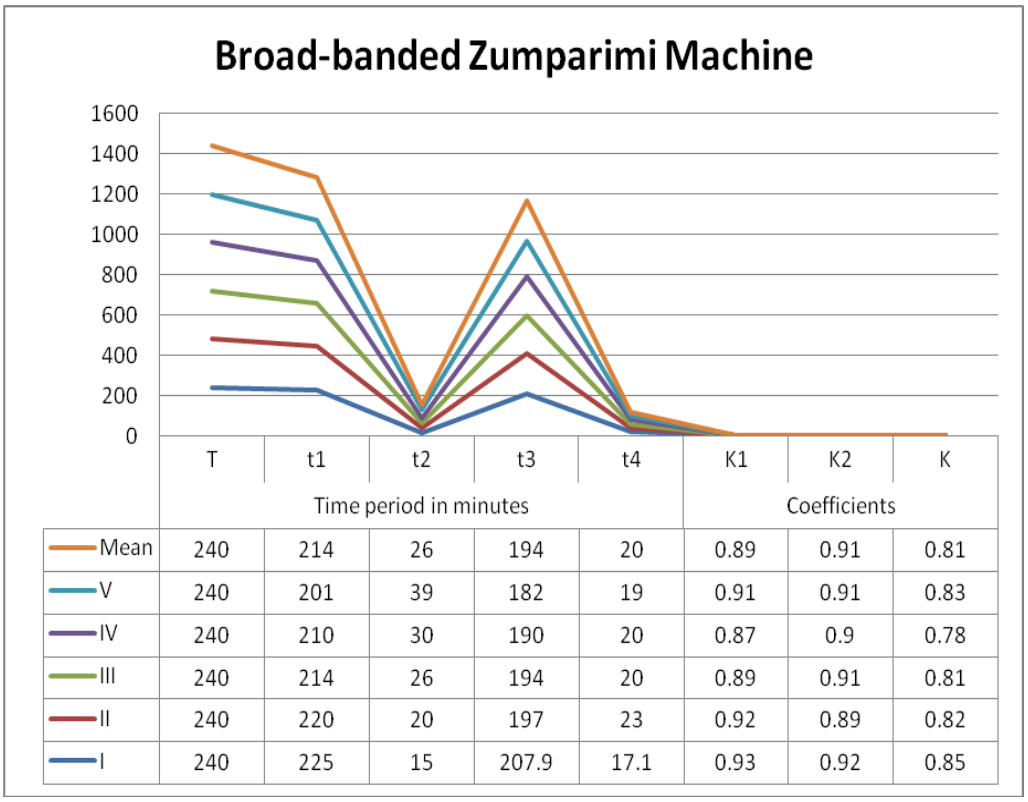
Measurements	Time period in minutes					Coefficients		
	T	t_1	t_2	t_3	t_4	K_1	K_2	K
I	240	219	21	198	21	0.91	0.90	0.82
II	240	221	19	197	22	0.92	0.89	0.82
III	240	214	26	194	20	0.89	0.91	0.81
IV	240	209	31	186	23	0.87	0.89	0.77
V	240	198	42	180	18	0.83	0.91	0.75
Average	**240**	**212.2**	**27.8**	**191**	**21.2**	**0.88**	**0.90**	**0.79**



Fugure 3. *Four-faceted Machine*

Table 4. *Wide tape calibration machinery*

Measurements	Time period in minutes					Coefficients		
	T	t_1	t_2	t_3	t_4	K_1	K_2	K
I	240	225	15	207.9	17.1	0.93	0.92	0.85
II	240	220	20	197	23	0.92	0.89	0.82
III	240	214	26	194	20	0.89	0.91	0.81
IV	240	210	30	190	20	0.87	0.90	0.78
V	240	201	39	182	19	0.91	0.91	0.83
Average	**240**	**214**	**26**	**194**	**20**	**0.89**	**0.91**	**0.81**



	T	t1	t2	t3	t4	K1	K2	K
	Time period in minutes					Coefficients		
Mean	240	214	26	194	20	0.89	0.91	0.81
V	240	201	39	182	19	0.91	0.91	0.83
IV	240	210	30	190	20	0.87	0.9	0.78
III	240	214	26	194	20	0.89	0.91	0.81
II	240	220	20	197	23	0.92	0.89	0.82
I	240	225	15	207.9	17.1	0.93	0.92	0.85

Fugure 4. *Brend-banded Zumparimi Machine*

As can be seen from the measurements, the machinery’s utilization coefficient on disk chainsaw is 0.58, lower than in the three other machineries for several reasons:

- Work process itself in this machinery is as such that requires time to take and place the panel on the bank of the machinery.
- More time is spent again to place another panel for the next cutting;
- Panel advance is done manually and it requires special attention to be protected from the cutting instrument, etc.

Even in the drilling machinery, the utilization coefficient resulted low (0.61), because even here the panel advance is done manually, time is lost while for receiving the next work piece, and the work piece produced is placed in the respective pile etc.

The utilization coefficient was 0.79 at four-faceted machinery, higher than in the first two cases, but even here, the rate could be higher, if we consider that this is a completely mechanized machinery, in which only details supply is done manually. But even here there are losses because this machinery has a special comb for details’ loading, from where they are taken one by one for processing. There are often cases when the mouth of the supplying machinery remains empty from the necessary material.

Major stops may occur in this machinery from various failures or when the processing type is changed (when the detail size is changed, etc.).

The utilization coefficient at broad-banded calibration machinery (with wide stripe-calibration), resulted 0.81, higher than in other machineries included in the study. But even here there is room to increase this ratio and hence the productivity of the machinery, as happens that the machinery is not regularly supplied with details, various breakdowns occur, etc.

Besides the type of machinery, the size of the wood processing machineries’ utilization coefficient is affected by other factors such as:

- The technical characteristics of wood processing machineries that the manufacturing companies posses (cutting speed, advance speed, the rotational number, electric motor power, etc.)
- The condition of the machinery and the equipments related to it, as the rollers of the advance, the different conveyors etc.
- The degree of mechanization job in machineries, as well as ways of organizing work.

- Quality of the cutting instrument, profiles of the teeth, the degree of sharpening, etc.
- Type, size and shape of details to be processed, the degree of surface purity, wood humidity, lack of or frequency of joints, etc.

4. CONCLUSIONS

By analyzing the conducted study, the following conclusions can be drawn:

- The disk chainsaw machinery and the drilling machinery have a machinery’s utilization coefficient lower when compared to the four-faceted (skoniatrice) machinery and the wide tape calibration machinery included in the study. This comes mainly from their construction and the production technology.
- The wood processing machinery productivity depends on the working shift time; the machinery’s advance speed; the machinery’s working time utilization coefficient and the machinery’s utilization coefficient. Both the wood processing machinery productivity and utilization coefficient are greatly affected by the machinery’s working time utilization coefficient and the machinery’s utilization coefficient, otherwise known as time utilization coefficient for effective cutting.
- Albanian furniture production companies should further carry out investments for the introduction of new technologies, especially in terms of new machineries and related equipments. This way, they will be able to boost production, improve the quality and face competition in this area.

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The Authors’ Addresses:

Elva Çaushi, M.Sc.
Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz, Tirana
ALBANIA
e-mail: alcaushi@abcom.al

Pandeli Marku,
Professor
Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz, Tirana
ALBANIA

Entela Lato,
Professor
Wood Industry Departament, Forest Sciences of Faculty
Agricultural Universitety of Tirana, Kodër Kamëz, Tirana
ALBANIA
e-mail: entela.lato@yahoo.com

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ISOLATION AND CHEMICAL MODIFICATION OF NANOCELLULOSE NANOCRYSTALS FOR REINFORCEMENT OF NANOCOMPOSITES

Milica Rančić[1], Jelena D. Rusmirović[2], Ivana Popović[3], Aleksandar D. Marinković[3]

[1] *Faculty of Forestry, University of Belgrade, Serbia,*
e-mail: milica.rancic@sfb.bg.ac.rs
[2]*Innovation center, Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia,*
e-mail: jrusmirovic@tmf.bg.ac.rs
[3]*Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia*
e-mail: marinko@tmf.bg.ac.rs

ABSTRACT

Owing to environmentally friendly attributes, good mechanical properties, low density, biodegradability and abundant availability of renewable resources, the production of nanocellulose and its application in composite materials has gained increasing attention in recent times. The most important potential application of nanocellulose is its incorporation as a reinforcing agent in polymer based composite materials. The outstanding mechanical properties displayed by these nanocomposites are ascribed to the formation of a continuous network formed by the cellulosic nanoparticles connected by hydrogen bonding. Nanocellulose nanocrystals (NC) have a perfect crystalline structure and high modulus, close to the theoretical modulus of cellulose. Due to their hydrophilic character along with inherent tendency to form strong network held through hydrogen bonding, nanocellulose nanocrystals cannot uniformly be dispersed in most non-polar polymer matrices. Therefore, surface modification was used in order to improve compatibility and homogeneous dispersion within polymer matrices.

The purpose of this work is to prepare cellulose nanocrystals by sulfuric acid hydrolysis of cellulose. The factors that varied during the process were the concentration of sulfuric acid, the hydrolysis time and temperature, and the ultrasonic treatment time. In order to to improve the interface between matrix and nanocellulose, and to develop composites with better mechanical properties and environmental performance by increasing the hydrophobicity of NC, the surface modification of nanocellulose with different acid anhydrides and fat acids was performed. The unmodified and modified samples were characterized by using thermogravimetric analysis and FT-IR spectroscopy and acid numbers were determined.

Key words: nanocellulose, nanocrystals, nanocomposites, acid hydrolysis, chemical modification

1. INTRODUCTION

Nowadays, nanotechnology is recognized as one of the most promising areas for technological development. In line with the development of nanotechnology and recent concern about environmental issues, it has been paid more attention to utilizing biobased materials. In this regard, natural fibers have been gaining much more interest because of their promising characteristics such as biodegradable nature, renewability and lower price. Among these natural fibers, cellulose as the most plentiful biopolymer which exists in a wide variety of living species including plants, bacteria and some animal species like tunicates, has been the subject of extensive research in nanotechnology. The impressive mechanical properties, reinforcing capabilities, abundance, low density, and biodegradability of these

nanoparticles make them ideal candidates for the processing of polymer nanocomposites. With a Young's modulus in the range 100–130 GPa and a surface area of several hundred m^2g^{-1}, new promising applications can be considered for cellulose (Dufresne, 2013).

A lot of research works have been performed all over the world on the use of cellulose fibers as a reinforcing material for the preparation of various types of composites. However, lack of good interfacial adhesion, low melting point, and water sensitivity make the use of cellulose-fiber reinforced composites less attractive. Pretreatments of the cellulose fibers can modify the fiber surface, such as chemical functionalization, stop the moisture absorption process and increase the surface roughness (Kalia, Kaith, Kaur, 2009). The production of nanoscale cellulose fibers and their application in composite materials have gained increasing attention due to their high strength and stiffness combined with low weight, biodegradability, and renewability. Application of cellulose nanofibers in polymer reinforcement is a relatively new research field (Siro, Plackett, 2010). The main reason to utilize cellulose nanofibers in composite materials is potential exploitation of the high stiffness of the cellulose crystal for reinforcement. This can be done by breaking down the hierarchical structure of the plant into individualized nanofibers of high crystallinity, with a reduction of amorphous parts (Eichorn, Dufresne, Aranguren, 2010).

In the case of application of cellulose in nanotechnology, two general types of nanocelluloses are recognized, namely cellulose nanocrystals and cellulose nanofibers. These two types of nanocelluloses can be distinguished by their different production processes and structures. Cellulose nanofibers, having a high aspect ratio in both amorphous and crystalline regions, can be produced using some techniques such as electrospinning, refining, homogenization, grinding, cryocrushing, ultrasonication and steam explosion (Siro, Plackett, 2010). While cellulose nanocrystals are the whisker form of nanocellulose, their amorphous part can be completely removed by acid hydrolysis (Siqueira, Bras, Dufresne, 2010). These nanocellulose structures have attracted attention as a potential material in reinforced nanocomposites. Insertion of these nanoscale compounds into polymers, even in small quantities, improve the properties of polymers; however, it depends on the type of nanocellulose used in the applications. However, composites reinforced with natural fibers are not widely used in industrial applications, mainly due to the following drawbacks: (1) cellulose fibers are polar and hydrophilic, so they are not compatible with non-polar and hydrophobic thermoplastics, which result in inefficient dispersion of the reinforcement and weak interaction between the matrix and reinforcement; (2) processing temperature limits the compounding of cellulose fibers with major engineering plastics such as polyethylene, polypropylene, polystyrene, and poly(vinyl chloride); (3) cellulose fiber-reinforced composites can be hygroscopic and swell causing a decrease in mechanical properties.

In order to utilize nanocellulose as reinforcement in nanocomposites, the strong hydrogen bonds between nanocellulose, which make it hydrophilic, must be broken down for good dispersion in the polymers with hydrophobic nature. Surface modification is the most common way to make the surface of nanocellulose hydrophobic and to incorporate it homogenously in different polymers, including by grafting, silylation, acetylation, etc. (Habibi, 2014).

As the skeletal component in all plants, cellulose is organized in a cellular hierarchical structure. The cell walls of plants are divided by a middle lamella from each other, followed by the primary cell wall layer. Cellulose is predominantly located in the secondary wall and consists of roughly 6,000 glucose units in the primary cell wall (Fengel, Wegener, 1984). Cellulose is a linear biopolymer, having β-D-glucopyranose repeating units in both crystalline and amorphous region (Fengel, Wegener, 1984) that are covalently linked through acetal functions between the equatorial OH group of C4 and the C1 carbon atoms forming bundles of fibrils (also called microfibrillar aggregates), which allows the creation of highly ordered regions (i.e., crystalline phases) alternating with disordered domains (i.e., amorphous phases). Figure 1 presents a schematic wood hierarchical structure from biomass to cellulose nanocrystal (CNC) and nanofibrillated cellulose (NFC).

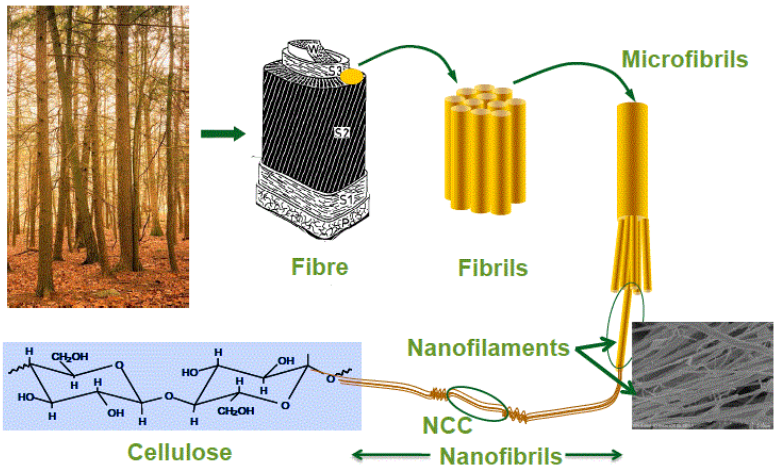

Figure 1. *Hierarchical structure of cellulose forming nnaofibrils, microfibrils, fibrils and fibre*

The main chemical process to produce nanocrystalline cellulose is acid hydrolysis by either sulphuric acid (H_2SO_4) (Siqueira et al., 2010), hydrochloric acid (HCl) (Braun, Dorgan, Chandler, 2008) or a combination of these two acids (Zhang et al., 2007) at various concentrations. In the case of CNC obtained by H_2SO_4 hydrolysis, the surface of the material becomes negatively charged with sulfonate ester groups, causing the easy dispersion of CNC in aqueous solvents, whereas those produced using HCl have weaker charge density and show a higher tendency of flocculation in organic solvents (Eichhorn, 2011). Native cellulose consists of crystalline and amorphous regions, and when cellulosic fibers were subjected to insensitive acid treatment, the amorphous parts break up and just the individual crystallites remain. So, the characterization of CNC is dependent on various parameters, such as reaction time, cellulose sources, type of acid and reaction temperature (Peng et al., 2011).

2. MATERIALS AND METHODS

Sample preparations

Nanocellulose nanocrystals were obtained from cotton by acid hydrolysis with sulfuric acid. In a Erlenmeyer flask of 250 ml 10 g of cotton and 200 ml of sulfuric acid solution of different concentrations (H_2SO_4) were added dropwise in an ice bath and stirred. The suspension was heated while stirred if nessesery to reach the temperature of 40^0C. Afterwards, the cotton dispersion was washed with deionized water using repeated centrifuge (n=5000 rpm/min) and sonification cycles, *i. e.* the supernatant was removed from the sediment and replaced by new deionized water and mixed. The centrifuge step was repeated until pH value of 4 is achieved or the supernatant became turbid. The last wash was conducted using dialysis with deionized water until the wash water maintained at constant pH. and washed with deionized water until the pH value reached 4-5. In this work, nanocellulose was obtained using four different concentrations of sulfuric acid: 64 %, 48 %, 32 % and 22 %, (i.e. H_2O/ H_2SO_4 *conc* = 1:2, 1:1, 2:1, and 3:1, v/v).

Chemical modification of nanocellulose with acid anhydrides

In order to change solvent for the modification, the obtained cellulose nanoparticles (*method 2.2.*) were washed with acetic acid, glacial (GAA), and 2 g of purified NC was charged into an Erlenmeyer flask of 250 ml. The 20 ml of GAA and 25 ml of toluene were added to purified nanocellulose and mixture was homogenized on ultrasonic bath (Bandelin electronic, Berlin, Germany, power 120 W, frequency 35 kHz) for 10 minutes. After homogenization, 0.1 ml of 60 wt.% perchloric acid and 0.5 g of corresponding acid anhydride were added into the mixture and left in ultrasonic bath for one hour. Figure 1 shows chemical structures of MA (a), PMDA (b) and THPA (c). The modifications of nanocellulose are presented in Table 2. After completion of the reaction, the reaction product

(modified NC) was centrifuged and washed three times with toluene. Figure 2 shows the schematic review of nanocellulose modification with MA.

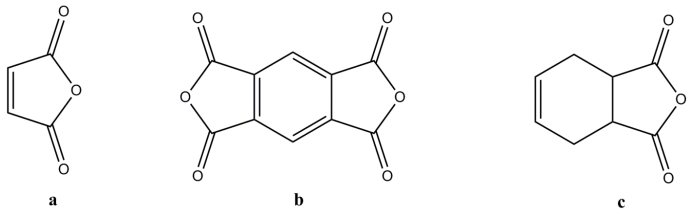

Figure 2. *Chemical structures of MA (a), PMDA (b) and THPA (c)*

Chemical modification of nanocellulose by esterification with fat acids

Nanocellulose obtained by acid hydrolysis method was modified by esterification with fat acidsisolated from sunflower and linseed oil and oleic acid. 2 g of nanocellulose was measured and put in three-necked round-bottomed flask equipped with nitrogen inlet tube. Afterwards, 100 ml of pyridine, 3.5 g p-toluenesulfonyl chloride and 5 ml of fatty acids isolated from corresponding oil were added in the flask. The reaction mixture was stirred and heated for 2 h on the magnetic stirrer at temperature of 50°C. After the completion of the reaction, about 100 ml of ethanol was added and the reaction was terminated.

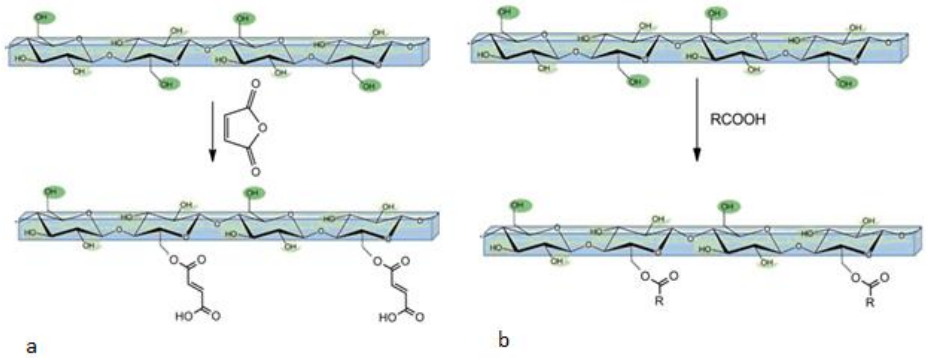

Figure 3. *Schematic review of nanocellulose modification with a) MA and b) fat acids*

Characterization method

The structural analysis of the obtained cellulose nanoparticles and obtained composites materials were performed by FT-IR (Bomem MB-102) spectroscopy, within a range of 400-4000 cm^{-1}, at a resolution of 4 cm^{-1}. The spectra were recorded at room temperature.

The acid value (*AV*) was determined by titration of the sample solution in mixture of isopropyl alcohol/toluol (50%) with standard (0.5 M) alcoholic KOH solution (ASTM D3644).

Thermogravimetric analysis (TGA) was performed using a Seteram Setsys Evolution-1750 instrument. The TGA experiments were run in a nitrogen atmosphere (flow rate 25 cm^3/min) from 30 to 600 ^oC, with a heating rate of 10 ^oC/min.

3. RESULTS AND DISCUSSION

Production of nanocellulose

In this study, nanocellulose was obtained by acid hydrolysis of cotton with sulfuric acid. The factors which were varied in order to optimimize the production of nanocellulose were: the sulfuric acid concentration, the duration and temperature of hydrolysis. The responses measured were median

size, dispersiability and yield of the hydrolyzed cellulose. The reaction parameters and yields are presented in Table 1.

Table 1. *Reaction parameters and yields for acid hydrolysis of cotton*

Sample	***Concentration H_2SO_4 (%)***	***Time (min)***	***Temperature (^0C)***	***Yield (%)***
NC1	64	20	40	98
NC2	48	60	60	80
NC3	32	90	60	75
NC4	22	120	60	70

The results presented in Table 1. undoubtedely indicate that the best procedure for nanocellulose production from cotton is acid hydrolysis with sulfuric acid of concentration 64% with the highest yield (98%) and for shortest time (20 min) but at lowest temperature (40^0C). Besides, procedure used give very stable colloidal water suspension which is attributed to negatevely charged sulfate groups at the nanocellulose surface. Decreased yield in procedures in which lower concentrations of sulfuric acid are used can be explained by desintegration of not only amorphous, but also crystall regions because nanocellulose is exposed to higher temperatures in longer time. It is also expected that nanocrystal particals obtained this way are of smaller size.

Characterisation of nanocellulose samples

From FT-IR spectrum (Figure 4) of unmodified and modified cellulose nanoparticles, it can be observed absorption peak about 1750 cm^{-1} derived from the ester carbonyl group after the modification with anhydrides. Also, it can be seen the reduction of the intensity strip stretching OH vibrations at around 3300-3400 cm^{-1}. All samples show the absorption peak at 1640 cm^{-1}, which originates from symmetric deformational vibrations of water molecules absorbed at the surface, though FT-IR spectra were recorded with samples dried at 105^0C. Intensity of those peaks decreases with introduction of non-polar groups (increase in hydrophobicity). The bands at 3410, 2923, 1640, 1490, 1321 i 1069 cm^{-1} in Fig. 5 are associated with native NC (Hu et al., 2011). This decreasing phenomenon occurs because the hydroxyl groups in NC are partially substituted by acyl groups in the reaction. In addition, no absorption was observed in the region between 1840 and 1760cm−1 in the spectra. It demonstrated that the product was free of unreacted anhydride.

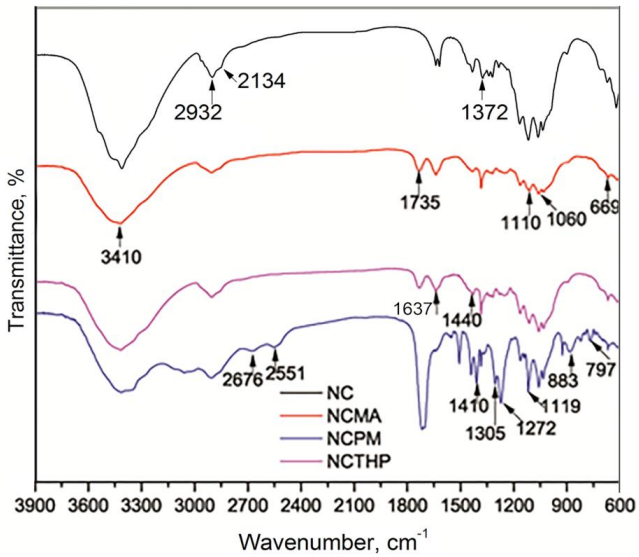

Figure 4. *FT-IR spectra of unmodified nanocellulose (NC), nanocelullose modified with maleic anhydride (NCMA), pyromellitic anhydride (NCPM) and tetrahydrophthalic anhydride (NCTHPA)*

The bands between 750 cm^{-1} i 1000 cm^{-1}, as well as the other bands around 1350 cm^{-1} and 1175 cm^{-1} show the presence of sulfonates in nanocelllulose samples (Socrates, 2004). FT-IR spectroscopy displays that NC samples modified with acid anhydrides show characteristic bands for carbonyl ester group at 1735 cm^{-1} for NCMA, 1718 cm^{-1} for NCPMDA and 1731 cm^{-1} for NCTHPA, as well as eter C-O vibrations around 1060 cm^{-1}.

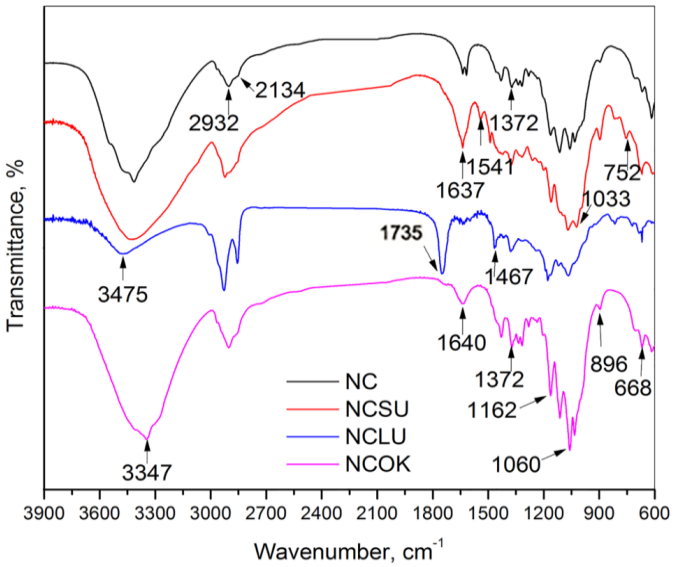

Figure 5. *IR-FT spectra of nanocellulose modified with fat acids isolated from sunflower oil (NCSU), linseed oil (NCLU) and oleic acid (NCOK)*

TGA analysis

TGA curves (Figure 6) of unmodified and modified cellulose nanoparticles are very similar, and the thermal degradation of all samples take place in three stages. The unmodified NC show a weight loss between room temperature and 130 °C which originates from the moisture content or solvent residues. This effect is reduced for modified NC with various anhydrides (NCMA, NCPMDA, NCTHPA), due to lower availability of surface OH groups. Since the crystal structure destruction of the NC begins from 230°, the peak of the unmodified NC occurs at 230°C. The peak of the chemically modified NC occurs at lower temperatures. A weight loss occuring at about 430°C originates from sulfonic groups present at the surface NC.

It can also be seen that the onset of degradation (defined as temperature at which 10% mass loss occurred) is shifted to lower temperature with increasing carbon chain length of organic acids attached to the surface of NC Similar results were also obtained by other authors (Menezesa et al., 2009), who modified pulp fibres with oleic and stearic acids. By increasing the carbon chain length, the temperature at which the maximum rate of weight loss (the peak of the derivative curves) decrease. This is thought the due to the reduced number of effective hydrogen bonds between NC nanofibres, as the nanofibres can then not be closely packed. In addition to this, as the amount of hydroxyl groups decreased due to the esterification reaction, the number of potential hydrogen bonds that can be formed decrease, too. This results in the reduction of hydrogen bonds formation between nanofibres, which further reduces the thermal stability when compared to neat NC.

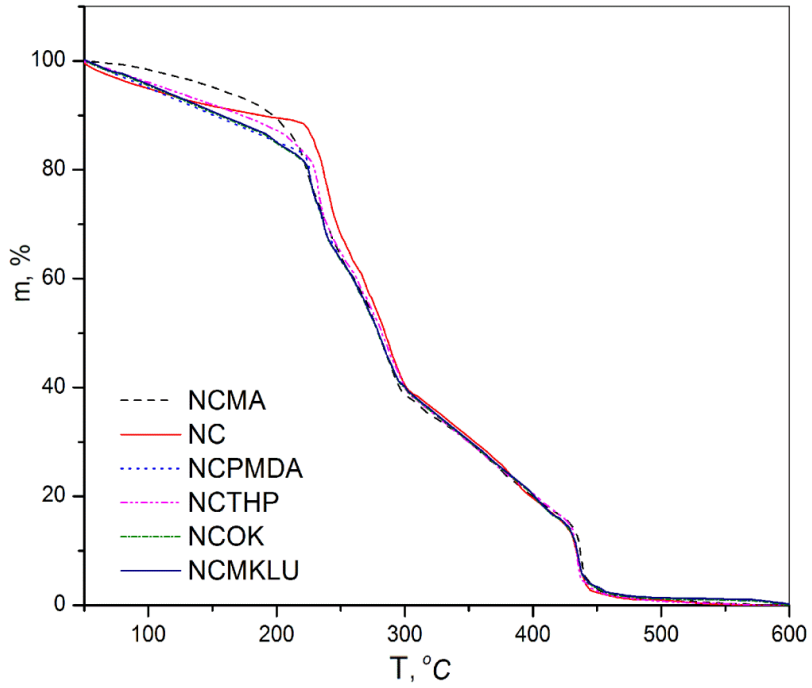

Figure 6. *TGA curves of unmodified nanocellulose nanoparticles modified (NC), nanocellulose modified with nanocelullose modified with maleic anhydride (NCMA), pyromellitic anhydride (NCPM) and tetrahydrophthalic anhydride (NCTHPA), nanocellulose modified with fat acids from sunflower oil (NCSU), linseed oil (NCLU) and oleic acid (NCOK)*

Acid value

The acid value (*AV*) of unmodified and modified nanocellulose samples was determined by standard procedure of titration of the sample solution in mixture of isopropyl alcohol/toluol (50%) with standard (0.5 M) alcoholic KOH solution (ASTM D3644) and results are presented in Table 2.

Table 2. *Acid value results*

Sample	***AV (mg/g)***
NC	28
NCMA	150
NCPMDA	112
NCTHP	150
NCOK	18
NCLU	15
NCSU	14

Results of the AV determination (Table 2) show that the AV of modified NC increases relative to the unmodified NC and it is in the range of 112-150 as expected because of introducing free carboxyl groups into nanocellulose molecule. Somewhat lower value for NCPMDA (112) can be explained by decreased degree of functionalisation due to molecule size. Nanocellulose samples modified with fat acids have AV in the range of 14-18.

4. CONCLUSIONS

The main goal of this study has been to optimize process conditions using the sulfuric acid hydrolysis method to separate individual crystallites/whiskers and prepare a stable colloidal water suspension of nanocellulose with a negative surface charge. Acid hydrolysis of cellulose is a well-known process for the production of nanocellulose nanocrystals, but the production is often limited to

amounts only sufficient for lab scale usage. However, the use of nanocellulose as a nanoreinforcement in biopolymers requires a compounding process that consumes larger quantities. This necessitates the optimization of production capacity in terms of both time and yield. Nanocellulose was obtained by acid hydrolisis with sulfuric acid. The factors which were varied in order to optimimize the production of nanocellulose were: the sulfuric acid concentration, the duration and temperature of hydrolysis. Futhermore, in order to improve the processability and performances of nanocellulose-based materials and more specifically to obtain nanocellulose derivatives that disperse well in apolar organic media (solvents and polymermatrices), nanocellulose was chemically modified with different acid anhydrides, as well as fat acids and all samles were characterized by Ft-IR spectra, thermogravimetric analysis and acid value.

The results obtained undoubtedely indicate that the best procedure for nanocellulose production from cotton is acid hydrolysis with sulfuric acid of concentration 64% that gives the highest yield (98%) for shortest time (20 min) but at lowest temperature (40^0C). The appearance of new bands around 1750 cm^{-1} in FT-IR spectra that originate from carbonyl groups showed that chemical modification with anhydrides and fat acids was successful. The reduction of intensity of the band at around 3300-3400 cm^{-1}originating from stretching OH vibrations also indicates functionalisation i.e. decreased number of hydroxyl groups.

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The Authors' Addresses:

Dr Milica Rančić,
assistant professor
Faculty of Forestry,
University of Belgrade,
Kneza Višeslava 1, 11030 Belgrade, SERBIA,
e-mail: milica.rancic@sfb.bg.ac.rs

Jelena D. Rusmirović,
PhD student
Innovation center, Faculty of Technology and Metallurgy,
University of Belgrade,
Karnegijeva 4, 11000 Belgrade, SERBIA,
e-mail: jrusmirovic@tmf.bg.ac.rs

Ivana Popović,
PhD student
Faculty of Technology and Metallurgy,
University of Belgrade,
Karnegijeva 4, 11000 Belgrade, SERBIA,
e-mail: ivana.popovic143@gmail.com

Dr Aleksandar D. Marinković,
assistant professor
Faculty of Technology and Metallurgy,
University of Belgrade,
Karnegijeva 4, 11000 Belgrade, SERBIA,
e-mail: marinko@tmf.bg.ac.rs

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OPTIMAL CAPACITY ANALYSIS OF WOODWORKING MACHINES FOR SOLID WOOD BOARDS PRODUCTION

Zoran Trposki[1], Vladimir Koljozov[1], Branko Rabadjiski[1], Sashko Tasev[2]

[1]Ss. Cyril and Methodius University in Skopje,Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje,
e-mail: trposki@fdtme.ukim.edu.mk; koljozov@fdtme.ukim.edu.mk;
rabadziski@fdtme.ukim.edu.mk
[2]Mebel-Vi doo Vinica, Republic of Macedonia,
e-mail:sasko@mebel-vi.com

ABSTRACT

Machine capacity is one very important parameter for machines operation mode determining. It is a feature for production power measurement and it shows the amount of products that can be produced under certain conditions, for a certain period of time. In this scientific work a capacity of the machines that are part of the technology for solid wood boards production is determined, taking into account the raw material that enters the production process (oak boards and oak planks, I and II class quality).

The capacity of each machine of the production process is determined. Technical characteristics of the machines are presented. The coefficient of utilization of the machine and the coefficient of the production time ratio are calculated.

According to the selected formula machine's output capacity is calculated. According to the results values, cumulative capacity is calculated and charts are prepared. These charts can practically be used in production of solid wood boards.

Key words: machine capacity, cumulative machine capacity, solid wood boards

1. INTRODUCTION

The capacity is the one of the most important features for determoning the operation of machines. It is the production capacity of the machine showing the quantity of products that can be produced under certain conditions, for a certain period of time.

There are three known types of capacity: 1/ theoretical or installed capacity, 2/ detailed or realistic capacity and 3/ optimal capacity.

Optimum capacity can be reached depending on the wood quality. Better raw material quality reduces the direct prodiuction costs. Since the capacity of the machine depends on a number of factors that define the production, in order to achieve optimal capacity, it is important that individual elements are analyzed. The quality of timber (logs, boards, planks, beams, etc.) is very important factor in analyzing the capacity of the machines.

2. AIM

The purpose of this research is to show relevant results from surveys for optimal machine capacity that are used in production of solid wood boards with thickness of 18 mm and 43 mm. Production technology will not be analyzed, as the focus will be exclusively on the calculation of the capacity of individual machines, finally shown the cumulative capacity.

3. MATERIALS AND METHODS

In order received data to be scientifically credible, an appropriate methodology of research has been applied to:

- Analyze the raw material in quality class,
- Measure the volume of sawn timber assortments and volume at each stage of mechanical treatment.
- Calculate the capacity of the machines on the basis of the previous two points.

Cumulative diagrams were created based on the capacity of each machine.

The raw material is steamed beech sawn planks of I/II class quality. The thickness of the material is 25,0 mm and 50,0 mm. The length is approximately constant and belongs to the second longitudinal band, from 1,0 to 1,7 m. Specifically, ranges from 1100 to 1200 mm, or 1,1÷1,2 m. Boards and planks with a minimum width of 120 mm. Moisture in the raw material is about 10,0 %.

4. RESULTS

On the basis of the objective and the adopted methodology of research, using data on the technical characteristics of the machinery, the input data for sawn lumber okrajchena beech and applied mathematical models of the formulas in this chapter we show the results of the conducted research.

The results are the product of research for a better view in the analysis will be shown as:

- Results in optimum capacity of machines for the preparation of plates with thickness of 25 and 50 mm,
- The results of cumulative optimal capacity machines for the construction of plates with a thickness of 18 mm and
- The results of cumulative optimal capacity machines for the construction of plates with a thickness of 43 mm.

The results of research on the optimal capacity machines in the preparation of plates of solid wood thickness 18 and 43 mm, are shown in Table 1 and 2.

The table shows the technological operations, such as working machines, the thickness of the plates and optimum capacity. The general conclusion is that according to the values obtained for optimal capacity, type machines, as well as their technical characteristics sound selected for a specific production such as panels of solid wood.

It can be concluded that optimal capacity in the production of plates with a thickness of 43 mm in individual machines refers to double compared with those whose thickness is 18 mm. For example, cross-cutting machine (E-001) in the thickness of the plates of 43 mm, yielding an optimal capacity of 18.14 (m^3/8h), and for plates with a thickness of 18 mm is 9.10 (m^3/8h). The analysis results show quite close to both the thickness of the plates in the technological process of pressing plates, where the optimal capacity for plates with a thickness of 18 mm is 13.23 (m^3 /8h), and 43 mm thick 14.34 (m^3/8h).

The graphic display of data from Table 1 and 2 is shown in Figure 1 and 2. The vertical axis shows the volume of the finished product-sheets of solid wood (left) and volume of incoming materials needed to prepare the requested amount of records. For example, to prepare 4m^3 massive plates per shift to be processed from 8.96 to 11,20m^3 timber, depending on the quality class of the material. The difference is about 2,20m^3. On the other hand to develop 10m^3 massive plates per shift to be processed from 22.39 to 28,00m^3 timber, depending on the quality class of the material. The difference is significant and is about 5,40m^3.

The optimal capacity of the machines (individual calculation) indicates that the selected machines have different capacity depends on the method of processing and speed of movement.

The results apply to cumulative optimum capacity of the machines in the preparation of plates of solid wood with a thickness of 43 mm, are shown in Table 2.

It shows machines Inventory number, their technological operations, the cumulative rate of abuse after surgery and required cumulative volume of the tree.

The coefficient of utilization is in operation with a value "from-to". Smaller values of the coefficient relating to goods of first-class quality and conversely, larger values of the coefficient relating to second-class timber quality.

In the table, the position of the machines is the reverse flow or, in the calculations start from the last machine (leveling + grinding) and move to the first machine (cut).

The box "required capacity" shows 13 columns, starting with 4.0 and ending with 10,0m3 final processed plates. In the bottom row of the numerical values input amount of material to obtain the required amount of final treated plates. In each cell has two number values. The smaller value of timber and the first larger timber for second-class quality.

Table 1. *Cumulative calculation capacity of individual machines set final capacity of the technological line, for plate thickness of 25 mm*

	MACHINE	rate	Required volume (m3)												
	Final processed plate		**4,0**	**4,5**	**5,0**	**5,5**	**6,0**	**6,5**	**7,0**	**7,5**	**8,0**	**8,5**	**9,0**	**9,5**	**10,0**
E-010		1,11	4,44	5,00	5,55	6,11	6,66	7,22	7,77	8,33	8,88	9,44	9,99	10,55	11,10
	TEHNOSAND K 1350 C-HP-DMC	to 1,13	4,52	5,09	5,65	6,22	6,78	7,35	7,91	8,48	9,04	9,61	10,17	10,74	11,30
E-009		1,02	4,53	5,09	5,66	6,23	6,79	7,36	7,93	8,49	9,06	9,62	10,19	10,76	11,32
	PF 1350/50	to 1,05	4,75	5,34	5,93	6,53	7,12	7,71	8,31	8,90	9,49	10,09	10,68	11,27	11,87
E-006		1,15	5,21	5,86	6,51	7,16	7,81	8,46	9,11	9,77	10,42	11,07	11,72	12,37	13,02
	SUPERSET XL	to 1,18	5,60	6,30	7,00	7,70	8,40	9,10	9,80	10,50	11,20	11,90	12,60	13,30	14,00
E-005		1,06	5,52	6,21	6,90	7,59	8,28	8,97	9,66	10,35	11,04	11,73	12,42	13,11	13,80
	SPANA VELO HERON-SA	to 1,10	6,16	6,93	7,70	8,47	9,24	10,01	10,78	11,55	12,32	13,09	13,86	14,63	15,40
E-004		1,22	6,74	7,58	8,42	9,26	10,10	10,94	11,79	12,63	13,47	14,31	15,15	16,00	16,84
	SUPERSET XL	to 1,25	7,70	8,66	9,63	10,59	11,55	12,51	13,48	14,44	15,40	16,36	17,33	18,29	19,25
E-003		1,10	7,41	8,33	9,26	10,19	11,11	12,04	12,97	13,89	14,82	15,74	16,67	17,60	18,52
	SALVADOR Supercut 300 SIGNUS	to 1,13	8,70	9,79	10,88	11,96	13,05	14,14	15,23	16,32	17,40	18,49	19,58	20,67	21,75
E-002		1,07	7,93	8,92	9,91	10,90	11,89	12,88	13,87	14,86	15,85	16,85	17,84	18,83	19,82
	COSMEC SM 400-LLM	to 1,10	9,57	10,77	11,96	13,16	14,36	15,55	16,75	17,95	19,14	20,34	21,54	22,73	23,93
E-001		1,13	8,96	10,08	11,20	12,32	13,44	14,56	15,68	16,80	17,92	19,04	20,16	21,27	22,39
	STROMAB PS 600/P	to 1,17	11,20	12,60	14,00	15,40	16,80	18,20	19,60	21,00	22,40	23,80	25,20	26,60	28,00

Utilization thickness boards of 25 mm, from beginning to end of the line is from 35,7 % to 44,6 %.

Table 2. *Cumulative calculation capacity of individual machines set final capacity of the technological line, for plate thickness of 50 mm*

	MACHINE	rate	Required volume (m3)												
	Final processed plate		**4,0**	**4,5**	**5,0**	**5,5**	**6,0**	**6,5**	**7,0**	**7,5**	**8,0**	**8,5**	**9,0**	**9,5**	**10,0**
E-010		1,08	4,32	4,86	5,40	5,94	6,48	7,02	7,56	8,10	8,64	9,18	9,72	10,26	10,80
	TEHNOSAND K 1350 C-HP-DMC	to 1,10	4,40	4,95	5,50	6,05	6,60	7,15	7,70	8,25	8,80	9,35	9,90	10,45	11,00
E-009		1,02	4,41	4,96	5,51	6,06	6,61	7,16	7,71	8,26	8,81	9,36	9,91	10,47	11,02
	PF 1350/50	to 1,05	4,62	5,20	5,78	6,35	6,93	7,51	8,09	8,66	9,24	9,82	10,40	10,97	11,55
E-006		1,12	4,94	5,55	6,17	6,79	7,40	8,02	8,64	9,25	9,87	10,49	11,10	11,72	12,34
	SUPERSET XL	to 1,14	5,27	5,93	6,58	7,24	7,90	8,56	9,22	9,88	10,53	11,19	11,85	12,51	13,17
E-005		1,06	5,23	5,89	6,54	7,19	7,85	8,50	9,15	9,81	10,46	11,12	11,77	12,42	13,08
	SPANA VELO HERON-SA	to 1,10	5,79	6,52	7,24	7,97	8,69	9,41	10,14	10,86	11,59	12,31	13,04	13,76	14,48
E-004		1,16	6,07	6,83	7,59	8,34	9,10	9,86	10,62	11,38	12,14	12,90	13,65	14,41	15,17
	SUPERSET XL	to 1,18	6,84	7,69	8,55	9,40	10,25	11,11	11,96	12,82	13,67	14,53	15,38	16,24	17,09
E-003		1,10	6,68	7,51	8,34	9,18	10,01	10,85	11,68	12,52	13,35	14,18	15,02	15,85	16,69
	SALVADOR Supercut 300 SIGNUS	to 1,13	7,73	8,69	9,66	10,62	11,59	12,55	13,52	14,48	15,45	16,42	17,38	18,35	19,31
E-002		1,05	7,01	7,88	8,76	9,64	10,51	11,39	12,27	13,14	14,02	14,89	15,77	16,65	17,52
	COSMEC SM 400-LLM	to 1,08	8,34	9,39	10,43	11,47	12,51	13,56	14,60	15,64	16,69	17,73	18,77	19,81	20,86
E-001		1,13	7,92	8,91	9,90	10,89	11,88	12,87	13,86	14,85	15,84	16,83	17,82	18,81	19,80
	STROMAB PS 600/P	to 1,17	9,76	10,98	12,20	13,42	14,64	15,86	17,08	18,30	19,52	20,74	21,96	23,18	24,40

Utilization thickness boards of 50 mm, from beginning to end of the line is from 41,0 % to 50,5 %.

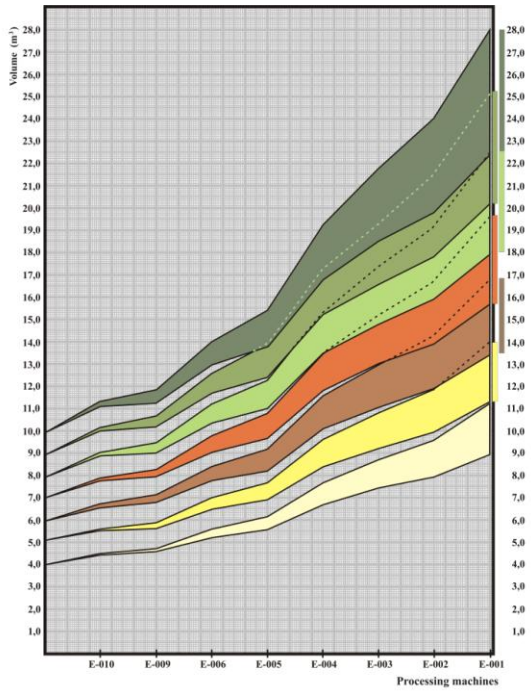
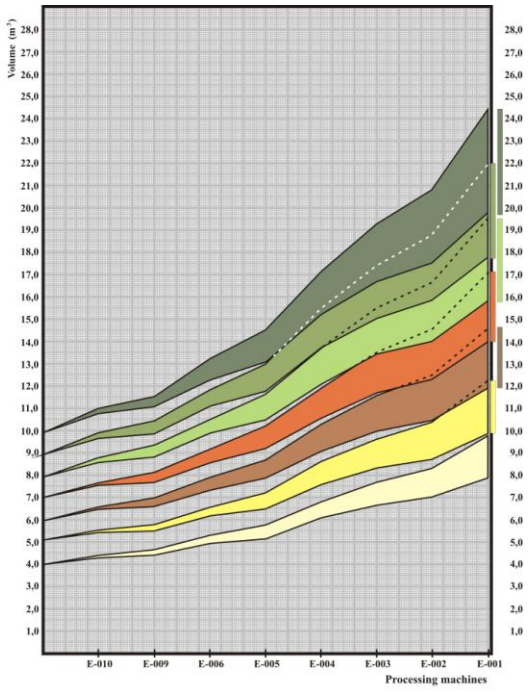


Figure 1



Fugure 2

Figure 1. *Cumulative optimum capacity for plates of solid wood (thickness – 25 mm)*

Figure 2*. Cumulative optimum capacity for plates of solid wood (thickness – 50 mm)*

5. DISCUSSION AND CONCLUSIONS

It can be concluded that optimal capacity in the production of boards with a thickness of 50 mm in individual machines refers to double compared with those whose thickness is 25 mm. For example, cross-cutting machine (E-001) in the thickness of the boards of 50 mm, yielding an optimal capacity of 18,14 (m^3/8h), and for boards with a thickness of 25 mm is 9,10 (m^3/8h). The analysis results show quite close to both the thickness of the boards in the technological process of pressing boards, where the optimal capacity for boards with a thickness of 25 mm is 13,23 (m^3/8h), and 50 mm thick 14,34 (m^3/8h).

The exploitation of timber with thickness of the boards of 25 mm, range from 35,7 to 44,6%. The smaller value refers to less quality timber and vice versa. To prepare 4 m^3 massive boards per shift to be processed from 8,96 to 11,20 m^3 boards, depending on the materials quality class. The difference is about 2,20 m^3. On the other hand, for production of 10 m^3 massive boards per shift, there has to be processed from 22,39 to 28,00 m^3 timber, depending on the materials quality class. The difference is significant and is about 5,40 m^3.

The exploitation of timber, the thickness of the boards of 50 mm, range from 41,0 to 50,5%. The smaller value refers to less quality timber and vice versa.
For example, to prepare 4 m^3 massive boards per shift, there has to be processed from 7,92 to 9,76 m^3 timber, depending on the quality class of the material. The difference is about 1,80 m^3.

On the other hand, to produce 10 m^3 massive boards with a thickness of 50 mm per shift, there has to be processed from 19,80 to 24,40 m^3 timber, depending on the quality class of the material. The difference is significant and is about 4,60 m^3.

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[6] Stefanovski, V., Rabadjiski, B. (1994): Pilanska prerabotka na drvoto, Skopje, (in Macedonian).

The Authors' Addresses:

Dr Zoran Trposki, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: trposki@fdtme.ukim.edu.mk

Dr Vladimir Koljozov, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: koljozov@fdtme.ukim.edu.mk

Dr Branko Rabadjiski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: rabadziski@fdtme.ukim.edu.mk

M.Sc. Sashko Tasev
Mebel-Vi doo Vinica, Republic of MACEDONIA
e-mail: sasko@mebel-vi.com

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COMPRESSIVE STRENGTH IN DIRECTION OF THE WOOD FIBRES FROM THE SPRUCE WOOD (PICEA ABIES KARST) IMPREGNATED WITH POLYRETHANE AND ACRYLIC VARNISHES

Konstantin Bahchevandjiev, Mitko Nacevski, Nikola Mihajlovski

Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje,
e-mail: bahchevandjiev@fdtme.ukim.edu.mk; nacevski@fdtme.ukim.edu.mk;
mihajlovski@fdtme.ukim.edu.mk

ABSTRACT

This research is focused on the impact of the impregnation of the spruce wood (Picea abies Karst) on the strength of the pressure and module of the wood elasticity in direction of the wood fibers. The wood is impregnated by double vacuum process with polyurethane and acrylic varnishes. The increase in mass after the impregnation is 36.3% of polyurethane and 28.3% for the acrylic coating. It’s significantly increased the strength of the pressure and module of elasticity in direction of the wood fibers.

Key words: spruce, impregnation, polyurethane varnishes, acrylic varnishes, percentage of increase in mass, pressure strength, modulus of elasticity

1. INTRODUCTION

Spruce wood (Picea abies Karst) has wide usage value as a building material, furniture, products in the interior and exterior, façade and floor coverings and more. Therefore, it’s been constantly working on improving of the physical and mechanical features, in other words modification of this traditional material.

The impregnation of the wood with resin, which is a viscous material entering through the lumens of the cells in the surface layer of the wood and is a method of its modification. The resins are materials that with polymerization are restrained in the intracellular lumens and cavities. In that way they reduce the porosity, increase the density of the wood, thereby changing its physics and mechanical features. Some tests show that in the process of drying the structure of the spruce wood forms closed pores leading to low permeability of the lumen (Gindl M. et al. 2006).

Double vacuum impregnation is applied to impermeable and difficult vent wood species such as spruce stands. In addition, the size of the pressure will not significantly impact the depth of penetration and fixation of the materials in the tree. Only the time of the vacuum action has an impact (Richardson BA 2003).

The purpose of this test is to determine the acting extent of the impregnation with varnishes based on artificial polyurethaneand acrylic resins on the strength of the pressure and the module of elasticity when under pressure in the direction of the wood fibers. In doing so, firstly it will be determined the amount of the two varnishes that will be fixed on the wood, which is a condition for achieving the modification of the wood surface layer. The treated material with the double vacuum method is simultaneously compared with the properties of the conventional timber that has coated surfaces of the two types of varnishes and native from the control probe.

2. MATERIALS AND METHODS

The test pieces were made of spruce wood (Picea abies Karst) with dimensions 20 x 20 x 30mm, material from the local sawmill from Macedonia. It is performed a conditioning of the material to equilibrium moisture content of the wood, according to ISO 554. The volume mass is determined as well as the percentage of moisture in the wood, ISO 3130 and ISO 3131.The material is divided and treated in two impregnated and two coated groups with every type of coating and one control group from the wood.

The varnishes based on polyurethane and acrylic resins are standard products from the range of renowned producer, prepared according to the manufacturer’s instructions without further dilution. The viscosity has been determined according to the standard ISO 2431, and the percentage of dry residue was according to ISO 1515th

The impregnation of the wood has been performed according to the double-vacuum procedure (Videlov 1980, Richardson 2003). Wooden test pieces were completely immersed in the coating material used as impregnation material. The impregnation regime with double vacuum is shown in the graph below.

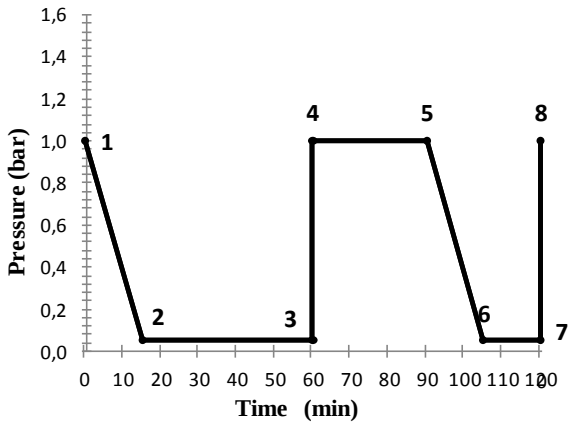


Figure 1. *Mode of samples’ treatment*

Polymerization process was followed up to the achievement of constant weight, under conditions prescribed by the standard ISO 554th.

The increase in mass - WPG is determined by the formula (Hill 2006)

$$WPG = \frac{m_m - m_u}{m_u} \cdot 100$$

m_m - mass of the treated sample (g)
m_u - weight of sample before treatment (g)

The pressure strength in the direction of wood fibers was determined according to ISO 3132, and the elasticity module of the pressure strength in the direction of the wood fiber is calculated according to the formula:

$$Epr = \frac{P \cdot l}{\Delta l \cdot b \cdot h}$$

Epr - modulus of the strength of the pressure (MPa)
P - compressive force (kg)
l - height of the sample before measuring (cm)

Δl - shortening of the sample per measurement (cm)
b and h - dimensions of the sides of the sample (cm)

Statistical data processing, check of the differences between two average values, significance, statistical collections for over 30 measurements are determined by:

$$T = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

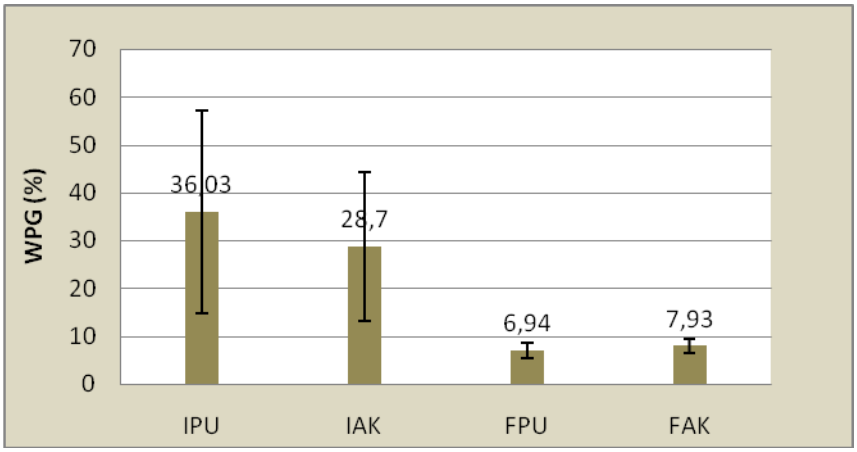
The level of significance of the test α = 0.01, in other words a degree of reliability of 99%, whereby the critical values are outside of the threshold ± 2.58.

3. RESULTS AND DISCUSSION

Sample pieces of spruce wood were with volumetric mass in absolutely dry conditions ρ_0 = 0.45g / cm3, and the percentage of moisture at the time of examination was W = 12%.

The viscosity of the polyurethane coating was v_{pu}=15" F_4/20°C with 49.3% dry residue and viscosity of the acrylic coating v_{ak}=27" F_4/20°C with 54.0% dry residue.

The increase in the wood mass impregnated with polyurethane coating does not differ significantly from the increase in wood mass impregnated with acrylic (S = 1:57). Also, the increase of the wood mass coated with acrylic is equal to the increase the wood mass coated with polyurethane coating (T = 1.5).



IPU – impregnated with polyurethane, IAK – impregnated with acryl,
FPU – coated with polyurethane , FAK – coated with acryl

Figure 2. *Graphical presentation of the mass increase*

The increasing of the wood impregnated mass with the polyurethane coating is 80.7% bigger than the coated for about five times. The increase in weight of the wood impregnated with an acrylic coating in terms of coated is about 72.3% or about 4 times.

Obtained differences of the increases of the impregnated wood mass and the high coefficients of variation confirm the fact that the spruce wood is impermeable in other words it’s hard for processing with impregnation (Militz 1993b, Mamonova 2000). The reason for this is the closure of the pores in the structure of the spruce wood that occur during the drying process, that leads to low permeability of the lumen (Gindl et al. 2006) and also is a cause of low penetration of the impregnation material in the wood.

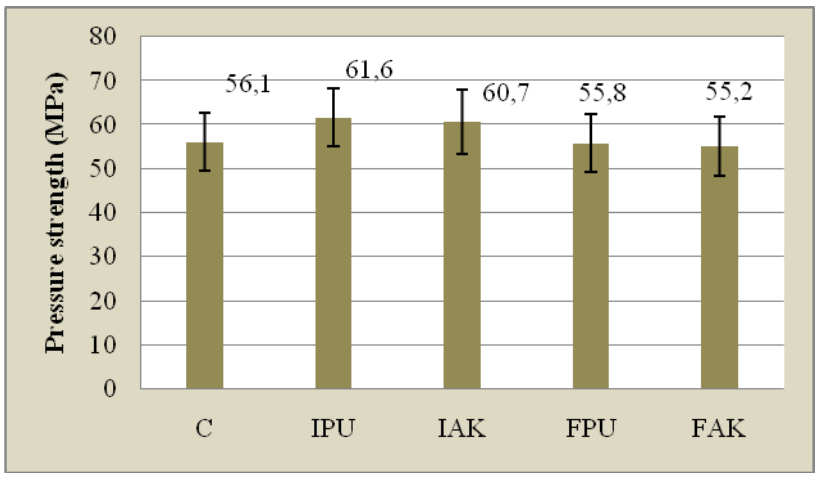
The pressure strength of the impregnated wood with polyurethane coating is equal to the strength of the impregnated wood with acrylic coating (T 0.53). Equal pressure strength have the polyurethane

coated wood as well as the acrylic coated wood (T = 0:34), and the native spruce wood. So, the coating has no effect on pressure strength.

The strength and pressure of the impregnated spruce wood is 5.6MRa or for 9.11% bigger than the strength of the native spruce wood as it’s proved as statistically significant difference (T = 3:31). Also the spruce impregnated wood has a higher compressive strength even than the coated wood (T = 3:51). The pressure strength in the direction of the wood fibers from the spruce wood, in accordance with the literature is about 45 MPa (Kretschmann 2010, Pejovski 1966). In our research the spruce wood we had a higher strength than the one in the literature, for about 18%, which is still permissible variation (Archer and Lebow 2006).

The pressure strength increase with the method of impregnation with resin, in this case with polyurethane and acrylic ones, is confirmed in the literature (Videlov 1980, Hill 2006). The pressure strength despite the variations in the mass increase is relatively steady, with the coefficients of variation below 10%. Samples with less mass increase have equal strength with the samples that have a greater mass increase. This leads to the conclusion that the mass increase has little influence on the pressure strength in the direction of the wood fibers.

It is likely that, to a certain percentage of the mass increase and strength there is a proportional increase, and the impact is still small. It is interesting data (Rowell 1976), that with the increase in wood mass there is over 35% destruction of the cell wall or damaging of the wood material.

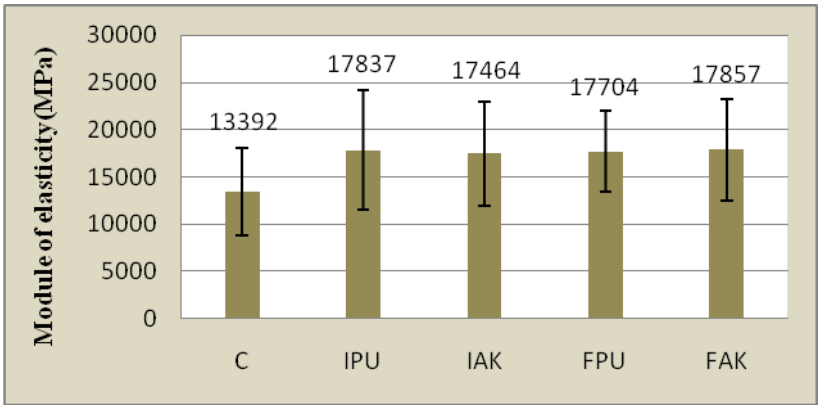


IPU – impregnated with polyurethane, IAK – impregnated with acryl,
FPU – coated with polyurethane, FAK – coated with acryl

Figure 3. *Graphic display of the pressure strength in the direction of the wood fibers*

The average values of the elasticity modulus under pressure are shown in Figure 3. The values of the modulus of elasticity under pressure with wood impregnated with polyurethane and acrylic coating and the wood coated regardless of the coating don’t show any significant differences. The impregnated spruce wood has 4445MRa or 24.9% higher modulus of elasticity than the native spruce wood. This difference is statistically significant
(T = 2.79). The coated timber has 4312MRa or 24.3% higher modulus of elasticity than the untreated wood (T = 3:26). The values for modulus of elasticity for pressure in our study are in accordance with the literature data (Pejovski 1966). According to the literature data (Stamm 1964, Pittman et al. 1994, Miroy et al. 1995, Rapp and Peek 1999, Gindl et al. 2004, Deka et al. 2007) during the wood impregnation with resins there is an increase of the mechanical features of the wood, thus the elasticity increase is expected.

The values of the elasticity module in all groups of wood are followed by large coefficients of variation of approximately 30%, but quite variable is also the increase in the mass of the impregnated wood. It is noticed that the samples with small percentage of increase in the weight have less elasticity and vice versa. Consequently it can be said that the wood elasticity depends largely on the percentage of the mass increase after the impregnation.



IPU – impregnated with polyurethane, IAK – impregnated with acryl,
FPU – coated with polyurethane, FAK – coated with acryl

Figure 4. *Graphic display of the module of elasticity in the strength of the pressure in the direction of the wood fibers*

It is important to note that the coating as a method does not increase the pressure strength of the wood, but increases the elasticity for 24.3%. This is probably due to the small dimensions of the test samples. With smaller dimensions of the wood, the coating forms a film that covers the surfaces, an effect of "sleeve", which in this case did not affect strength of the pressure, but increases or takes elasticity. For larger pieces, this impact would be lost.

In measuring of the strength of the pressure it was noticed an arbitrary violation of the test pieces. The coated test pieces that act under pressure are not deformed by sliding in the fracture plane with an angle of 40^{o} to 60^{o}, but only shorten the amount of sample and without the appearance of cracks characteristic for this type of fracture. This is probably a result of the effect of "sleeve", which forms the coated surfaces film.

4. CONCLUSIONS

The wood impregnation with polyurethane and acrylic varnishes, increase the strength of pressure and elasticity in the direction perpendicular to the wood fibers. At rates of mass increase of about 36.3%, the strength of the pressure in the direction perpendicular to the wood fiber is increased by 9.1% and the elasticity modulus of the strength of the pressure in the direction parallel to the wood fibers for 24.9%. The method of coating does not affect the strength of the pressure but increases the elasticity modulus of the pressure strength in the direction perpendicular to the wood fibers to 24.3%. The method of impregnation of wood with double vacuum, with varnishes increases the mechanical properties of wood and has potential application in the special final products in the industry. Further researches should be conducted in order to determine the hardness and abrasive permanence of such treated wood.

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The Authors' Addresses:

Dr Konstantin Bahchevandjiev, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: bahchevandjiev@fdtme.ukim.edu.mk

Dr Mitko Nacevski, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: nacevski@fdtme.ukim.edu.mk

M.Sc. Nikola Mihajlovski
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: mihajlovski@fdtme.ukim.edu.mk

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EXAMINATION OF THE COMFORT WHILE LYING ON A METTRESS WITH A SOFT POLYURETHANE FOAM CORE

Konstantin Bahchevandjiev, Gjorgi Gruevski, Nikola Mihajlovski

Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje,
e-mail: bahchevandjiev@fdtme.ukim.edu.mk; gruevski@fdtme.ukim.edu.mk;
mihajlovski@fdtme.ukim.edu.mk

ABSTRACT

The paper presents the results of the examination of the comfort while lying on a mattress with a soft polyurethane foams core. The areas of standing close by measurements with measurement of the multi- sensory appropriate cover and computer software were studied. For an indicator of comfort is taken the comfort index, according which within the limits of average height and weight of the group of users, the measurements match the recommended method of tabular values. The cases where the users are with low body weight and greater height, and users with greater body weight and short stature, deviate from the recommended method of tabular selection. The measurement with multi-sensory measuring cover is recommended as yet most realistic method for determining the comfort when lying on a mattress.

Key words: comfort, mattress, soft polyurethane foams, an index of comfort, pressure zones

1. INTRODUCTION

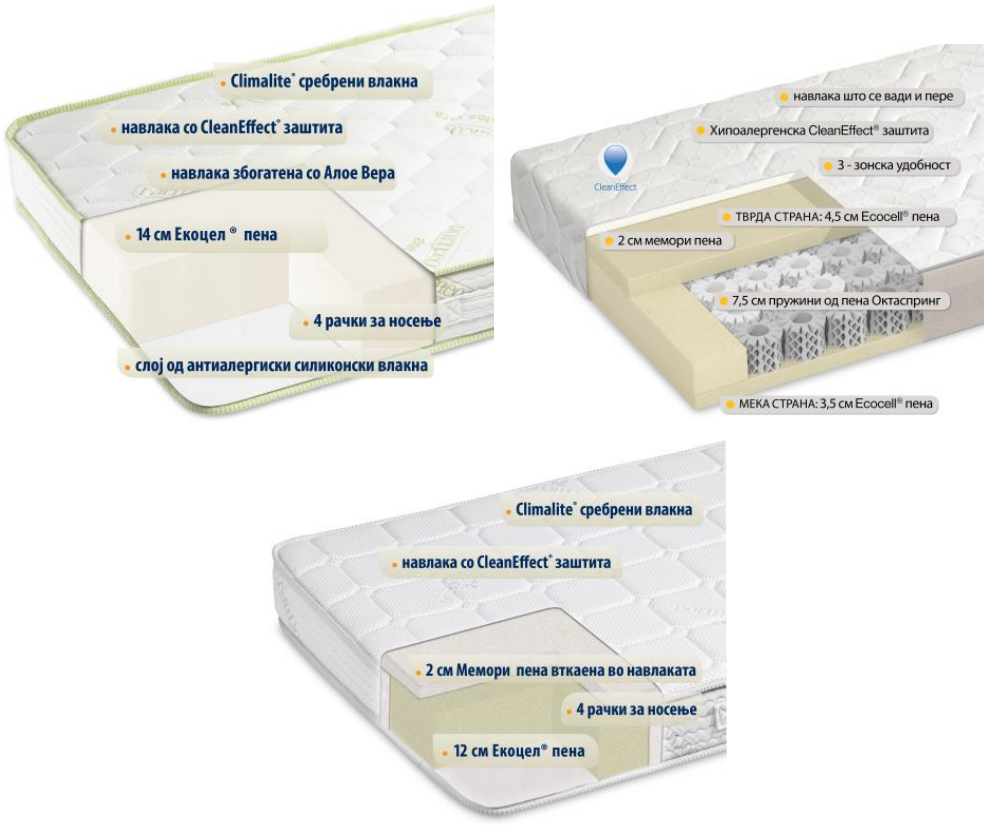
A good mattress has a direct impact on the human relaxation and a sense of comfort. When lying down - sleeping man should be completely relaxed, without muscle contractions, spine in the correct position and then he unconsciously feels comfort - comfort [1]. The basic requirement for achieving of this situation is fully and equally reliance on the human body in lying positions.

This study is also aimed to some of the causes of discomfort during sleeping which is manifested by the appearance of tonicity in some parts of the muscularity, tingling, pain and numbness of the user. Physiological and hygiene factors that affect the comfort as the conduction of heat - insulation and moisture migration which are freed by the human body at night, factors which also come to disruptions during the sleep, getting up at night and waking up, are not subject of this research .

The goal is to get more specific information about the three kinds of constructive solutions for mats with a core made of a combination of soft polyurethane foams. Furthermore what is the adaptability of the materials incorporated into the mattress, to the positions of the human body in the process of sleep, relying on the human body and the appearance of zones of excessive pressure?

2. MATERIALS AND METHODS

The tests are made with mats with a core of soft polyurethane foams with three levels of hardness: soft, semi hard and hard mattress. Two positions of man’s lying were investigated, on the back and on side - laterally. In determination of the index of comfort, it was relatively taken that during the user’s lying on the mattress, 70% of the time is lying on his back, and the remaining 30% are on side. Figure 1 shows cross-sections of the mattresses and their content.



1. Cilmalite silver fiber	1. Cover removable and washable	1. Cilmalite silver fiber
2. Cover with Clean Effect protection	2. Hypoallergenic Clean Effect protection	2. Cover with Clean Effect protection
3. Cover enriched with Aloe Vera	3. 3-zone comfort	3. 2cm memory foam woven into the cover
4. 14cm Eco-cell foam	4. Hard side: 4.5cm Eco-cell foam	4. Carrying handles
5. 4 Carrying handles	5. 2cm memory foam	5. 12cm Eco-cell foam
6. a layer of anti-allergic silicon fib	6. 7.5cm Spring foam	
	Soft side: 3.5cm Eco-cell foam	

Figure 1. *Sections and composition of soft semi hard and hard mattress*

Reliance in the supine position is defined by surface and intensity of reliance of the man lying on a mattress. In these trials, for the measurements it is used multi-sensory measurement cover placed on the mattress under the body, through which it is pressed into the mattress. The measurement system is composed of four main parts [4]: sensors in arrays outs - transducers A / D signals, micro control unit (MCU) and wireless controller to the PC.

The basic unit is a sensor that according to the principle of the piezoelectric effect transforms the pressure of the body into an electrical signal. The initial signal is converted and software corrected until reaching the correlation between the measurement points and arrays.

Figure 2. *Multi-sensory measurement cover*

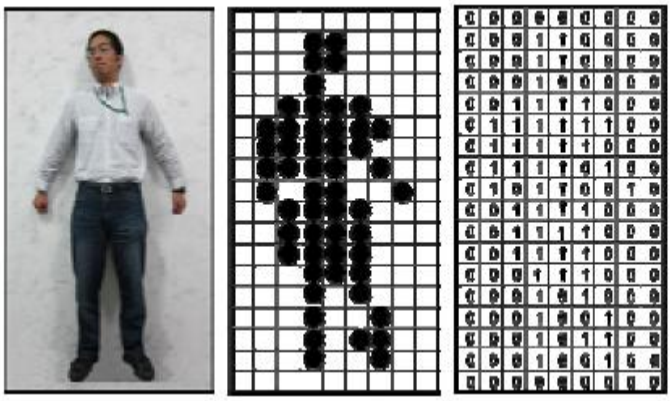


Figure 3. *Imprint and binary display of the imprint*

Multi-sensory cover (Figure 1) has a measuring area with dimensions 81.2 x 203.2 cm [8]. On it with regular arrays 1664 of sensors with the declared resolution lines is 3.17 cm are placed. With the cover and appropriate software support are marked the surfaces of the imprint of the man’s body, with differentiated zones of pressure, reliance on a mattress (Figure 2). The displayed image (Figure 3) graphically differentiated zones following pressures: p 1 - dark blue 0 to 3 mmHg, p 2 - Blue 3 to 8 mmHg, p 3- blue light 8 to 18 mmHg, p 4 - Green 18 to 26 mmHg, p 5 - yellow 26 to 33 mmHg, p 6 - orange 33 to 40 mmHg, and p 7 - Red 40 to 50 mmHg [2]. Then the S 1-7 - surface reliance of body areas of pressure p 1-7, S - total area of reliance of the body (cm2) and p max – average value of pressure in the zones with maximum pressure (mmHg) are marked and determined.

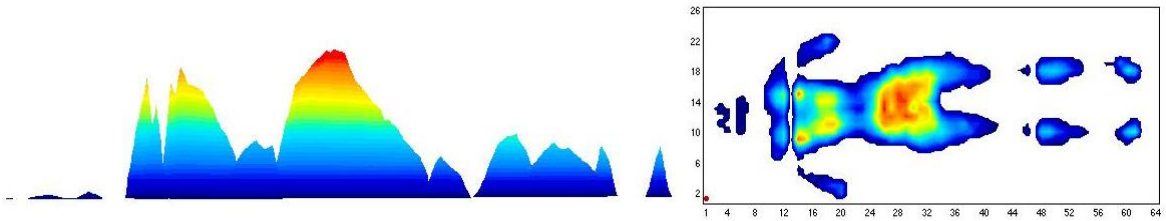


Figure 4. *Areas of reliance of the body in the zones of pressure*

The Indicator comfort is the index of comfort – E, defined by the ratio of the 65% IFD - under the burden at 65% deflection and 25% IFD - under the burden at 25% deformation [5].

E = 65% IFD / 25% IFD

3. RESULTS AND DISCUSSION

The results are grouped in five groups of tests made in three different constructive solutions for mattresses. [6] In all cases, the substrate on which the mattresses are placed is a frame with grid of concave oriented, resilient slats of glued veneer sheets – lato-flex base. Each group of test refers to a respondent with a distinctive weight and height marked from 1 to 5 (Table 1).

Table 1. *Average pressure value in the areas with maximum pressure, reliance on surface and an index of comfort*

No.	Weight kg.	High cm.	Mattress 1			Mattress 2			Mattress 3		
			p_{max} mmHg.	S cm^2	E %	p_{max} mmHg.	S cm^2	E %	p_{max} mmHg.	S cm^2	E %
1	2	3	4	5	6	7	8	9	10	11	12
1	54	158	43.03	2359	87	41.79	2238	54	48.56	2117	12
2	57	182	41.67	2429	33	40.96	2702	100	43.19	2308	14
3	75	181	44.61	3216	68	43.72	3145	81	46.19	3034	7
4	98	168	43.32	3720	90	42.29	3538	60	45.51	3327	0
5	97	184	49.2	4234	43	42.95	4425	100	46.31	3669	25

The data in Table 1 are shown graphically (Figure 5) as zones of pressure in reliance body on a mattress in the position of lying on back and on side.

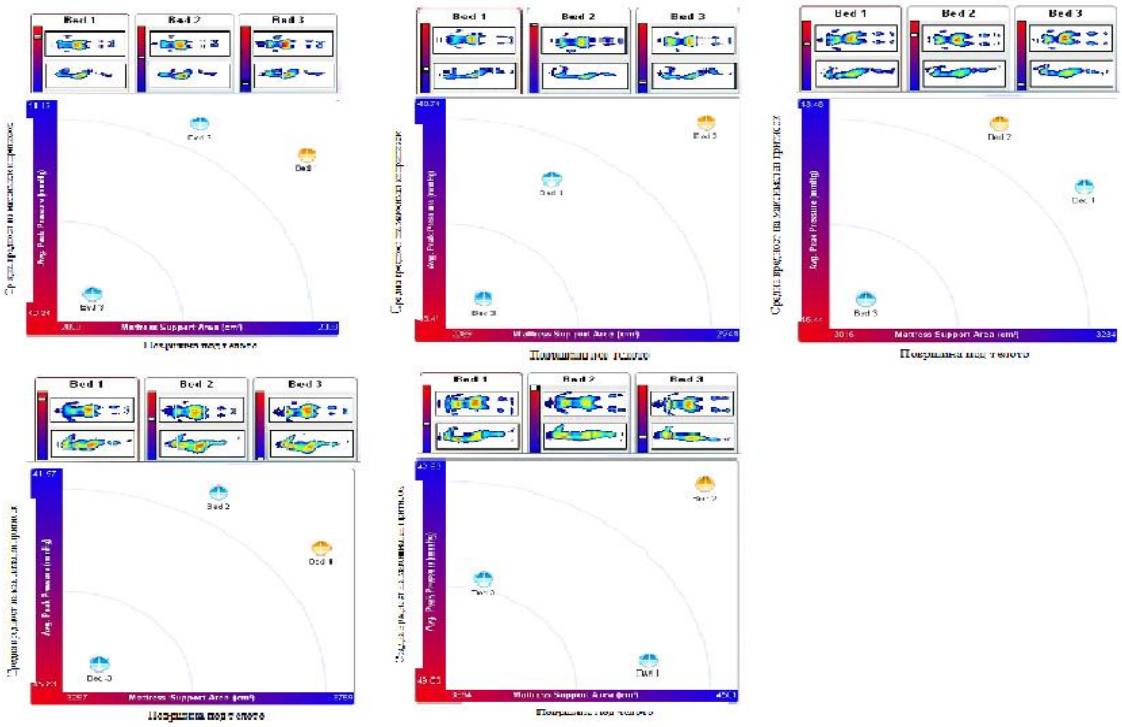


Figure 5. *Results of five sets of measurements of three types of mattresses*

The ratio of the total area of reliance of the body and the average pressure value in the zones with maximum pressures, five sets of measurements of three kinds of soft, semi hard and hard mattress are displayed separately for each respondent (Figure 5) and cumulative distribution on next image (Figure 6).

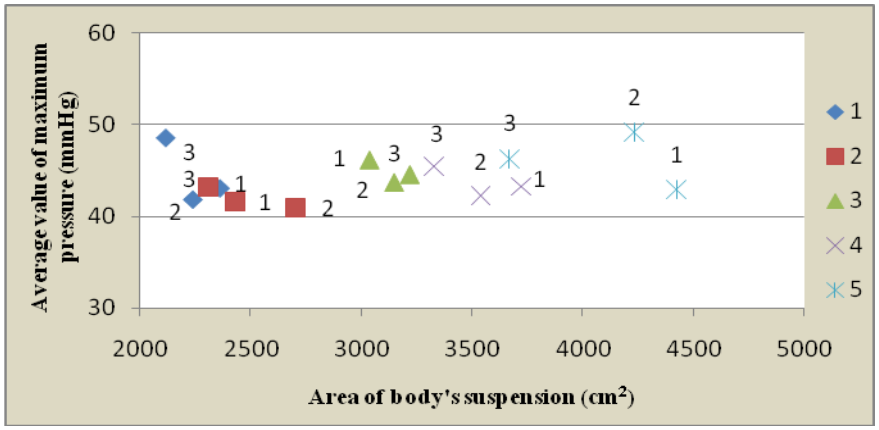


Figure 6. *Distribution area of suspension and the average pressure value in the zones with maximum pressure*

According to the values in Table 1 the soft mattress reached a high index of comfort with people with low growth and low weight E1 = 87% and with people of short stature and great weight E4 = 90%. For people with average height and weight the comfort is optimal, E3 = 68%.

The comfort while lying on semi hard s mattress filled with soft polyurethane foams stand out from the other two mattresses. The index of comfort of semi hard mattress for persons owith high growth and low weight and people with high growth and great weight is the highest, E2 and E5 100% = 100%. The index of comfort for people with average rat and weight, optimal E3 = 81%. The trials of semi hard mattress showed optimal values and also with people with short stature and low body weight E1 = 54%, as well as in case of people with short stature and great weight E4 = 60%. From the presented results, the ratio of the surface of the suspension of the body and the pressure that the body is imprinted on semi hard mattress is ideal.

The comfort of the hard mattress is low. The index of comfort regardless of the height and weight of the respondents ranges from 0% to 25%. With this mattress on small areas of the body suspension, great standing close occurs. Low index of comfort confirms that the hard mattress is not comfortable, which is a potential cause of deformities of the spine [3].

The areas with the highest pressure "red zone" while lying on the side occurs in the area of the hips and shoulders, and while lying on the back in the area of the pelvic bone and upper shoulders at scapula, data confirmed in literature [3]. In our research "yellow zones" appear at increased pressure with around half of respondents in the position of lying on the back, which is not characteristic according to the literature [3].

The way of selection of mattress [3, 7] according to which the person with physical weight to 60 kg is recommended a lying on a soft mattress, from 60 to 80 kg semi hard mattress and over 80 kg selection of hard mattress. This coincides with measurements of the users 1, 3 and 5. Deviation are the cases with users with low body weight and a greater height, respondent 2 wherein the comfort index E2 = 100%, in the next group of the mattress of medium hardness and users with higher body weight and stature, case 4, instead of hard mattress, the highest index of comfort E4 = 90% even two gradations below or the best suspension is on the soft mattress.

4. CONCLUSIONS

The examination of the comfort of using soft and semi hard and hard mattress with a core of soft polyurethane foams, results with the following conclusions.

- The soft mattress is comfortable for people with small or large weight and low and medium height, i.e. persons ranging in weight from 50 to 100kg and a height of 160 to 170cm.
- The semi hard mattress is convenient to be used by the majority of the population, customers with a wide range of weight from 50 to 100kg and a height of 150 to 200cm. This mattress is especially convenient for people with low and high weight and high growth. The semi hard mattress with a core of polyurethane flexible foams is the optimal choice
- The hard mattresses are of little comfort no matter the weight and height of the user.

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The Authors' Addresses:

Dr Konstantin Bahchevandjiev, Full professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: bahchevandjiev@fdtme.ukim.edu.mk

Dr Gjorgi Gruevski, Associate professor
Ss Cyril and Methodius University,
Faculty of Design and Technologies of Furniture and Interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: gruevski@fdtme.ukim.edu.mk

M.Sc. Nikola Mihajlovski
Ss Cyril and Methodius University,
Faculty of Design and Technologies of furniture and interior – Skopje
Ul. 16 Makedonska Brigada br. 3, PO box 8, 1130 Skopje, Republic of MACEDONIA
e-mail: mihajlovski@fdtme.ukim.edu.mk

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