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CONTENTS

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COMPUTATION OF THE ENERGY AND HEAT FLUX NEEDED FOR COVERING OF THE EMISSION IN THE SURROUNDING AIR OF SUBJECTED TO UNILATERAL CONVECTIVE HEATING WOOD DETAILS BEFORE LACQUERING

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ABSTRACT

An approach for the computation of the specific (for 1 m^2) energy consumption, q_e, and the specific heat flux, dq_e/dτ, needed for covering of the emission in the surrounding environment of the subjected to unilateral convective heating flat wood details before lacquering, has been suggested in the present paper. The approach is based on the use of numerical solutions of the second from two mutually connected 1D linear mathematical models, which has been suggested by the authors earlier. The first model allows the computation of the non-stationary temperature distribution along the thickness of subjected to unilateral convective heating wood details before their subsequent lacquer coating. The second model, whose solutions are used for determination of q_e and dq_e/dτ, allows the computation of the non-stationary distribution of the temperature along the thickness of the carrying rubber band, on which the non-heated surface of the wood details lies.

For simultaneously numerical solution of the both models aimed at the determination of q_e and dq_e/dτ software program has been prepared, which was input in the calculation environment of Visual Fortran Professional. Using the program, computations have been carried out for the determination of the change in the heat energy q_e and in the flux dq_e/dτ, which are consumed by oak details with an initial temperature of 20 °C, moisture content of 8 %, thickness of 16 mm, width of 0.6 m, and length of 1.2 m during their 10 min unilateral convective heating by hot air with temperature of 100 °C, which circulates above the details with a velocity of 2 m.s^{-1}, 5 m.s^{-1}, and 8 m.s^{-1} aimed at improvement of the conditions for the subsequent lacquering. The rubber band had thickness of 4 mm, width of 0.8 m, initial temperature of 20 °C, and the temperature of the surrounding air from the non-heated surface of the band was 20 °C. The obtained results are graphically presented and analyzed.

Key words: oak details, convective heating, lacquering, heat emission, specific heat energy, heat flux

1. INTRODUCTION

The pre-heating of subjected to lacquering wood details is done with the aim to speed up the hardening of thin coatings of lacquering systems with organic solvents. During the application of the lacquer coatings onto the heated wood's surfaces, the evaporation of the solvents is speeded up and the air is removed from the pores of the wood (Zhukov and Onegin 1993, Rüdiger *et al.* 1995, Jaić and Živanović-Trbojević 2000).

Unilateral convective heating used prior to lacquering is mostly applied on flat wood details with thickness from 4 to 35 mm and moisture content of 8 ÷ 10 % (Kavalov and Angelski 2014) The equipment for preliminary heating of the details is formed usually as a tunnel section, which can be part of an assembly line for protective and decorative film application (Skakić 1992, Kavalov and Angelski 2014).

In the accessible specialized literature there is very limited information about the temperature distribution in wood details during their unilateral convective heating (Deliiski *et al.* 2016a, 2016b) and there is no information at all about the energy consumption needed for realizing of such heating. That is why each research in this aria has both a scientific and a practical interest.

The aim of the present paper is to suggest an approach for the computation of the specific energy and specific heat flux, which are needed for covering of the emission in the surrounding environment of the subjected to unilateral convective heating flat wood details before their lacquering.

2. MATERIAL AND METHODS

2.1. Mechanism of the 1D heat distribution in flat wood details during their convective 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 during their unilateral convective heating (i.e. along the coordinate x, which coincides with the details' thickness) can be carried out with the help of the following 1D mathematical model (Deliiski 2011, 2013b, Deliiski *et al.* 2016a):

$$\frac{\partial T_{\mathrm{w}}(x,\tau)}{\partial \tau} = a_{\mathrm{w}}(T,u,u_{\mathrm{fsp}},\rho_{\mathrm{b}})\frac{\partial^2 T_{\mathrm{w}}(x,\tau)}{\partial x^2} \tag{1}$$

with an initial condition

$$T_{\mathrm{w}}(x,0) = T_{\mathrm{w0}} \tag{2}$$

and following boundary conditions:

• from the side of the details' heating – at conditions of forced convective heat exchange between their upper surface and the circulated hot air with temperature T_{ha} and speed v_{ha} (see Fig. 1 below):

$$\frac{\mathrm{d}T_{\mathrm{w}}^{\mathrm{hs}}(\tau)}{\mathrm{d}x} = -\frac{\alpha_{\mathrm{w}}^{\mathrm{hs}}(\tau)}{\lambda_{\mathrm{w}}^{\mathrm{hs}}(0,\tau)}\left[T_{\mathrm{w}}^{\mathrm{hs}}(\tau) - T_{\mathrm{ha}}(\tau)\right], \tag{3}$$

• from the opposite non-heated side of the wood details – at temperature, which is equal to the temperature of the upper (heated) side of the carrying rubber band, on which the non-heated surface of the details lies (see Fig. 1 below):

$$T_{\mathrm{w}}^{\mathrm{nhs}}(\tau) = T_{\mathrm{B}}^{\mathrm{hs}}(\tau)\,, \tag{4}$$

where x is the coordinate along the thickness of the details and the carrying rubber band: $0 \le x \le X = h_{\mathrm{w}} + h_{\mathrm{B}}$, m; h_{w} – thickness of the details, m; h_{w} – thickness of the rubber band, m; a_{w} – temperature conductivity of the details' wood, $\mathrm{m^2 \cdot s^{-1}}$; u – moisture content of the details' wood, $\mathrm{kg \cdot kg^{-1}}$; u_{fsp} – fiber saturation point of the details' wood, $\mathrm{kg \cdot kg^{-1}}$; ρ_{b} – basic density of the details' wood specie, equal to the dry mass divided to green volume, $\mathrm{kg \cdot m^{-3}}$; T – temperature, K; T_{w} – temperature of the wood, K; T_{w0} – initial temperature of the subjected to heating wood details, K; $T_{\mathrm{w}}(x,0)$ – temperature of all points along the detail's thickness at the beginning (i.e. at $\tau = 0$) of the heating process, K; $T_{\mathrm{w}}^{\mathrm{hs}}$ – temperature of subjected to heating upper surface of the details, K; $T_{\mathrm{B}}^{\mathrm{hs}}$ – temperature of the upper (heated) surface of the rubber band, K; T_{ha} – temperature of the hot air near the heated details' surface during the heating, K; $\alpha_{\mathrm{w}}^{\mathrm{hs}}$ – convective heat transfer coefficient of the heated details' surface, $\mathrm{W \cdot m^{-2} \cdot K^{-1}}$; $\lambda_{\mathrm{w}}^{\mathrm{hs}}$ – thermal conductivity of the wood on the heated details' surface, $\mathrm{W \cdot m^{-1} \cdot K^{-1}}$; τ – time, s.

Because of the tight contact between the wood details and the thin carrying rubber band on which they lie during the heating process, the temperature of the non-heated surface of the details is assumed to be equal to the temperature of the band's upper surface.

2.2. Mechanism of the 1D heat distribution in the carrying rubber band during details' heating

Analogously to the model presented above, the calculation of the change in the temperature along the thickness of the carrying rubber band during details' unilateral heating (i.e. along the coordinate x, which coincides with the thicknesses of the details and of the band – see Fig. 1 below) can be carried out with the help of the following 1D mathematical model:

$$\frac{\partial T_{\mathrm{B}}(x,\tau)}{\partial \tau} = a_{\mathrm{B}}(T)\frac{\partial^2 T_{\mathrm{B}}(x,\tau)}{\partial x^2} \tag{5}$$

with an initial condition

$$T_{\mathrm{B}}(x,0) = T_{\mathrm{B0}} \tag{6}$$

and following boundary conditions:

• from the upper (heated by the wood details) surface of the band – at temperature, which is equal to the temperature of the bottom (non-heated) surface of the details:

$$T_{\mathrm{B}}^{\mathrm{hs}}(\tau) = T_{\mathrm{w}}^{\mathrm{nhs}}(\tau)\,, \tag{7}$$

• from the bottom (non-heated) surface of the band – at conditions of free convective heat exchange between the band and the surrounding air environment:

$$\frac{\mathrm{d}T_{\mathrm{B}}^{\mathrm{nhs}}(\tau)}{\mathrm{d}x} = -\frac{\alpha_{\mathrm{B}}^{\mathrm{nhs}}(\tau)}{\lambda_{\mathrm{B}}^{\mathrm{nhs}}(0,\tau)}\left[T_{\mathrm{B}}^{\mathrm{nhs}}(\tau) - T_{\mathrm{nha}}(\tau)\right], \tag{8}$$

where a_{B} is the temperature conductivity of the rubber band perpendicular to the textile fibres by which it is reinforced, $\mathrm{m^2\cdot s^{-1}}$; T_{B} – temperature of the band, K; $T_{\mathrm{B}}(x,0)$ – temperature of all points along the band's thickness at the beginning of the details' heating process, K; T_{B0} – initial temperature of the rubber band, K; $T_{\mathrm{B}}^{\mathrm{hs}}$ – temperature of the upper (heated) surface of the rubber band, K; $T_{\mathrm{w}}^{\mathrm{nhs}}$ – temperature of the bottom (non-heated) surface of the wood details, K; $T_{\mathrm{B}}^{\mathrm{nhs}}$ – temperature of bottom (non-heated) surface of the band, K; T_{nha} – temperature of the air near the bottom surface of the band during the heating, K; $\alpha_{\mathrm{B}}^{\mathrm{nhs}}$ – convective heat transfer coefficient of the non-heated band's surface, $\mathrm{W\cdot m^{-2}\cdot K^{-1}}$; $\lambda_{\mathrm{B}}^{\mathrm{nhs}}$ – thermal conductivity of the rubber on the non-heated band's surface, $\mathrm{W\cdot m^{-1}\cdot K^{-1}}$.

2.3. Modelling of the specific energy consumption for covering of the heat emission from the non-heated side of the rubber band

The change in the specific energy consumption q_{e}, which is needed for covering of the heat emission from 1 $\mathrm{m^2}$ of the non-heated side of the rubber band to the surrounding air environment during the time $\Delta\tau$, can be calculated according to the following equation:

$$\Delta q_{\mathrm{e}} = \frac{\alpha_{\mathrm{B}}^{\mathrm{nhs}}(\tau)\Delta\tau}{3.6\cdot 10^3}\left[T_{\mathrm{B}}^{\mathrm{nhs}}(\tau) - T_{\mathrm{nha}}\right]. \tag{9}$$

The specific energy needed for the covering of the heat emission from 1 $\mathrm{m^2}$ surface of the rubber band during unilateral convective heating with duration $\tau_{\mathrm{p}} = N\cdot\Delta\tau$ is equal to

$$q_{\mathrm{e}} = \sum_{n=1}^{N}\Delta q_{\mathrm{e}\text{-}n}\,, \tag{10}$$

where $\Delta\tau$ is the value of the step along the time coordinate, by which the mathematical models (1) ÷ (4) and (5) ÷ (8) are solving, s; N – current number of the steps $\Delta\tau$: n = 1, 2, 3, ….., N_{E}.

The multiplier $3.6\cdot 10^3$ in the denominator of eq. (9) ensures that the values of Δq_{e} and q_{e} are obtained in $\mathrm{Wh\cdot m^{-2}}$, instead of in $\mathrm{J\cdot m^{-2}}$.

The change in q_{e} during the time $\Delta\tau$, i.e. the heat flux needed for the covering of the heat emission from the non-heated side of 1 $\mathrm{m^2}$ of the subjected to unilateral heating wood details, $\mathrm{d}q_{\mathrm{e}}/\mathrm{d}\tau$ (in $\mathrm{W\cdot m^{-2}}$), can be calculated according to equation

$$\frac{\mathrm{d}q_{\mathrm{e}}}{\mathrm{d}\tau} \approx \frac{3600\Delta q_{\mathrm{e}}}{\Delta\tau}\,. \tag{11}$$

The heat transfer coefficient $\alpha_{\mathrm{B}}^{\mathrm{nhs}}$ in eq. (9) can be calculated according to the following equations, which are valid for the cases of heating or cooling of horizontally situated rectangular surfaces in conditions of free air convection (Telegin *et al.* 2002, Deliiski *et al.* 2016b):

$$\alpha_{\mathrm{B\text{-}nhs}} = \frac{1.3\mathrm{Nu}_{\mathrm{nha}}\lambda_{\mathrm{nha}}}{b_{\mathrm{B}}}, \tag{12}$$

where the Nusselt's number of similarity is calculated with the help of the thermo-physical characteristics of the air from the non-heated side of the rubber band according to following equation:

$$\mathrm{Nu}_{\mathrm{nha}} = 0.5\left(\mathrm{Gr}_{\mathrm{nha}} \cdot \mathrm{Pr}_{\mathrm{nha}}\right)^{0.25}\left(\frac{\mathrm{Pr}_{\mathrm{nha}}}{\mathrm{Pr}_{\mathrm{nhs}}}\right)^{0.25} \quad @ \quad 10^3 < \mathrm{Gr}_{\mathrm{nha}} \cdot \mathrm{Pr}_{\mathrm{nha}} < 10^9. \tag{13}$$

The Grashoff's number of similarity $\mathrm{Gr}_{\mathrm{nha}}$ and the Prandtl's numbers of similarity $\mathrm{Pr}_{\mathrm{nha}}$ and $\mathrm{Pr}_{\mathrm{nhs}}$ in eq. (13) are calculated according to the equations (Milchev *et al.* 1989, Telegin *et al.* 2002)

$$\mathrm{Gr}_{\mathrm{nha}} = \frac{g \cdot \beta_{\mathrm{nha}} b_{\mathrm{B}}^3}{w_{\mathrm{nha}}^2}\left(T_{\mathrm{B}}^{\mathrm{nhs}} - T_{\mathrm{nha}}\right), \tag{14}$$

$$\mathrm{Pr}_{\mathrm{nha}} = \frac{w_{\mathrm{nha}}}{a_{\mathrm{nha}}}, \tag{15}$$

$$\mathrm{Pr}_{\mathrm{nhs}} = \frac{w_{\mathrm{nhs}}}{a_{\mathrm{nhs}}}. \tag{16}$$

where b_{B} is the width of the rubber band, m; g - acceleration of gravity (g = 9.81 $\mathrm{m \cdot s^{-2}}$); λ - thermal conductivity, $\mathrm{W \cdot m^{-1} \cdot K^{-1}}$; a - temperature conductivity, $\mathrm{m^2 \cdot s^{-1}}$; β - coefficient of the volume expansion, $\mathrm{K^{-1}}$; w - kinematic viscosity, $\mathrm{m^2 \cdot s^{-1}}$.

The indexes "nha" and "nhs" of the variables and of the numbers of the similarity in equations (12) to (16) mean that these variables and numbers must be calculated depending on the temperature of the **n**ot **h**eating **a**ir and of the **n**ot **h**eated **s**urface of the rubber band, respectively.

3. RESULTS AND DISCUSSION

The mathematical models, which are presented in common form by the eqs. (1) ÷ (8), have been solved with the help of explicit schemes of the finite difference method. This has been done in a way, analogous to the one used and described in (Deliiski 2011, Deliiski and Dzurenda 2010) for the solution of a model of the heating process of prismatic wood materials. The presenting of eqs. (1) and (5) from the mathematical models through their discrete analogues corresponds to the shown in Figure 1 setting of the coordinate system and the positioning of the nodes in the mesh, in which the 1D non-stationary distribution of the temperature along the thicknesses of the wood details and the carrying rubber band during the unilateral convective heating of the details is calculated.

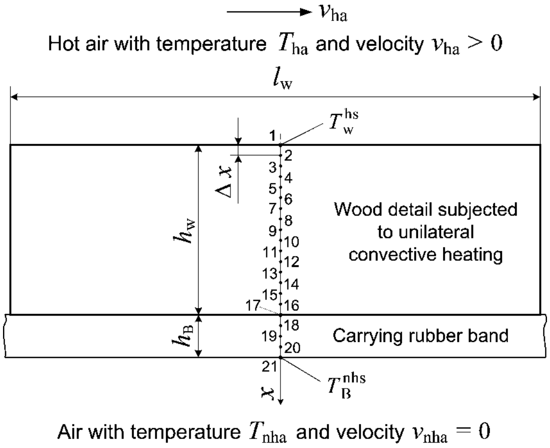

Figure 1. *Positioning of the nodes of the 1D calculation mesh along the thicknesses of the wood details and carrying rubber band*

For the solution of the models a software program has been prepared in FORTRAN in the calculation environment of Visual Fortran Professional. With the help of the program, as an example, computations have been made for the determination of the 1D change of the temperature in flat oak (*Quercus petraea* Libl.) details with thickness of 16 mm, width of 0.6 m, length l_w = 1.2 m, initial temperature t_{w0} = 20 °C, moisture content u = 8 % during their 10 min unilateral convective heating by hot air with temperature t_{ha} = 100 °C and velocity $v_{ha} = 2\ m\cdot s^{-1}$, $v_{ha} = 5\ m\cdot s^{-1}$, and $v_{ha} = 8\ m\cdot s^{-1}$.

The calculations of the temperature distribution along the details' thickness have been done with average values of the wood temperature conductivity $a_w = 1.9337\cdot 10^{-7} m^2\cdot s^{-1}$ and of the wood thermal conductivity cross-sectional to the fibers of the details $\lambda_w = \lambda_w^{hs} = 0.2738\ W\cdot m^{-1}\cdot K^{-1}$ in the temperature range from 20 °C to 60 °C for oak wood with basic density $\rho_b = 670\ kg\cdot m^{-3}$, moisture content $u = 0.08\ kg\cdot kg^{-1}$, fiber saturation point $u_{fsp} = 0.29\ kg\cdot kg^{-1}$ (i.e. 29 %), and volume shrinkage S_v = 11.9 % (Nikolov and Videlov 1987). These average values if a_w and λ_w have been obtained using the mathematical description of a_w and λ_w depending on t, u, u_{fsp}, and ρ_b of the wood species (Deliiski 2013a, Deliiski and Dzurenda 2010, Deliiski *et al.* 2016a).

With the help of the program simultaneously with the above described 1D calculations, computations have been carried out for the determination of the 1D change in the temperature along the thickness of the carrying rubber band reinforced by textile fibers, on which the non-heated surfaces of the subjected to unilateral heating wood details lie (see Fig. 1). The band was accepted to be with thickness h_B = 4 mm, width b_B = 0.8 m, and initial temperature t_{B0} = 20 °C. The temperature of the surrounding air from the non-heated surface of the band during the details' heating was accepted to be equal to t_{nha} = 20 °C. The computations have been done with average values of the band's temperature conductivity perpendicular to the textile fibers $a_B = 1.1655\cdot 10^{-7}\ m^2\cdot s^{-1}$ (Juma *et al.* 2000) and of the thermal conductivity of the band $\lambda_B = \lambda_B^{nhs} = 0.281\ W\cdot m^{-1}\cdot K^{-1}$ (www.axelproducts.com).

All computations have been carried out with 21 nodes of the calculation mesh, i.e. with a step along the thicknesses of the furniture elements and the band, equal to 1.0 mm (see Fig. 1).

Figure 2 presents the calculated change in the heat transfer coefficient and surface temperature of the non-heated side of the rubber band during 10 min unilateral convective heating of the studied oak details, depending on the speed v_{ha} of the circulated hot air, which heated the details.

Figure 3 presents the calculated change in the specific energy q_e and specific heat flux $dq_e/d\tau$ during 10 min unilateral convective heating of the studied oak details, depending on v_{ha}.

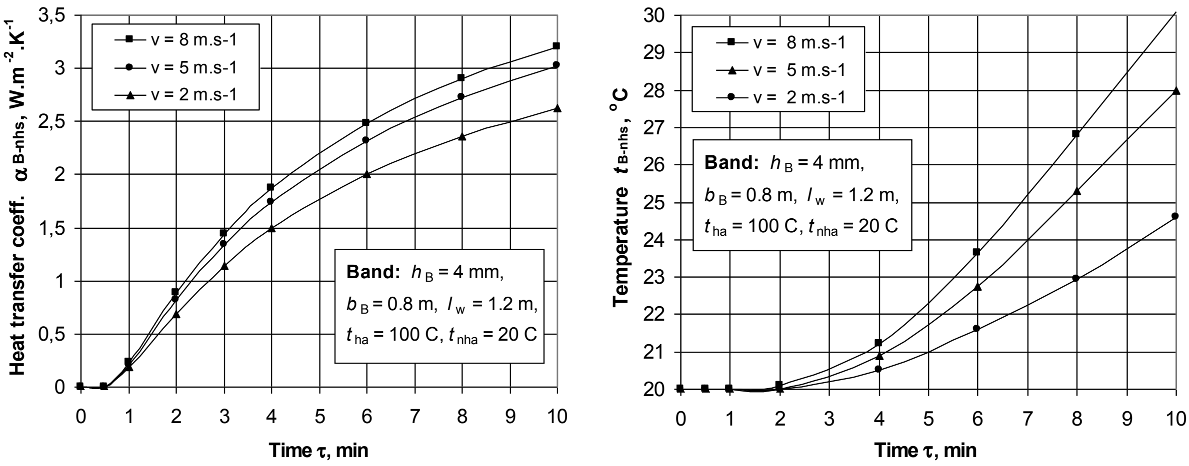

Figure 2. *Change in α_B^{nhs} (left) and t_B^{nhs} (right) during 10 min convective heating of the studied oak details, depending on v_{ha}*

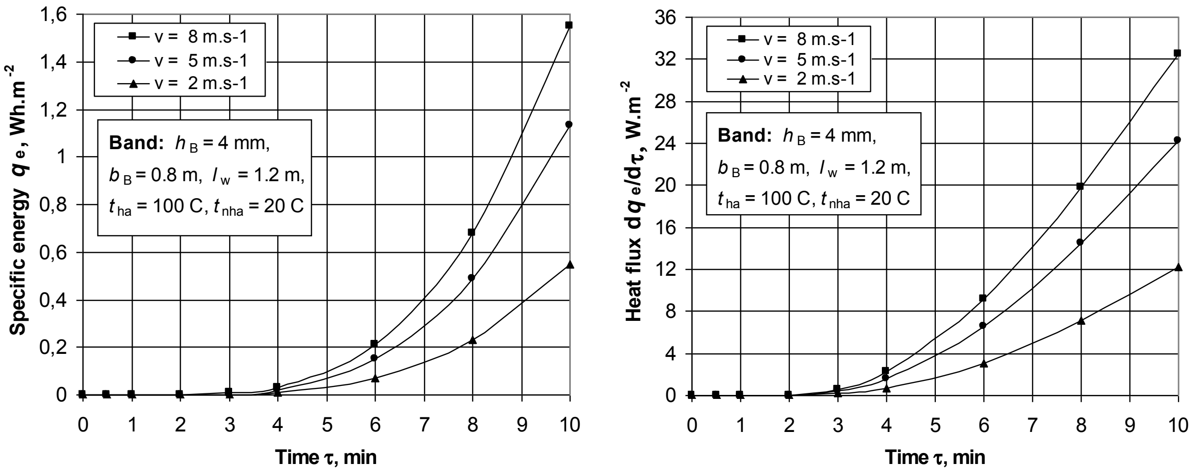

Figure 3. *Change in q_e (left) and $dq_e/d\tau$ (right) during 10 min convective heating of the studied oak details, depending on v_{ha}*

The analysis of the obtained results leads to the following conclusions:

1. The convective heat transfer coefficient of the non-heated surface of the carrying rubber band, α_B^{nhs}, increases curvilinearly depending on the heating time and non-linearly depending on the velocity of the hot air v_{ha}. This coefficient according to eq. (14) depends on the temperature difference $T_B^{nhs} - T_{nha}$. At the beginning of the heating process there is no difference between T_B^{nhs} and T_{nha}. That is why then the coefficient α_B^{nhs} is equal to zero. After 6 min and 10 min of convective heating of the oak details this coefficient reaches the following values:
   - at at $v_{ha} = 2$ m·s^{-1}: 2.00 W·m^{-2}·K^{-1} and 2.63 W·m^{-2}·K^{-1} respectively;
   - at at $v_{ha} = 5$ m·s^{-1}: 2.32 W·m^{-2}·K^{-1} and 3.02 W·m^{-2}·K^{-1} respectively;
   - at at $v_{ha} = 8$ m·s^{-1}: 2.48 W·m^{-2}·K^{-1} and 3.20 W·m^{-2}·K^{-1} respectively.

2. During the details' heating, the curve of the temperature on the non-heated surface of the rubber band is concave inwardly. After 6 min and 10 min convective heating of the details the temperature on the non-heated surface of the carrying band obtains the following values:
   - at $v_{ha} = 2$ m·s^{-1}: $t_B^{nhs} = 21.6$ °C and $t_B^{nhs} = 24.6$ °C respectively;
   - at $v_{ha} = 5$ m·s^{-1}: $t_B^{nhs} = 22.8$ °C and $t_B^{nhs} = 28.0$ °C respectively;
   - at $v_{ha} = 8$ m·s^{-1}: $t_B^{nhs} = 23.7$ °C and $t_B^{nhs} = 30.1$ °C respectively.

3. By increasing the heating time, the specific energy q_e and the heat flux dq_e/dτ increase according to curvilinear dependences, which are similar to the change of the surface temperature of the non-heated side of the rubber band. The both variables increase non-linearly depending on v_{ha}.

The energy q_e according to eq. (9) depends on the temperature difference $T_B^{nhs} - T_{nha}$. At the beginning of the heating process there is no difference between T_B^{nhs} and T_{nha}. That is why then the specific energy q_e and the heat flux dq_e/dτ are equal to zero.

After 10 min of convective heating of the oak details q_e and dq_e/dτ reach the following values:
- at $v_{ha} = 2$ m·s^{-1}: $q_e = 0.55$ Wh·m^{-2} and dq_e/dτ = 12.2 W·m^{-2};
- at $v_{ha} = 5$ m·s^{-1}: $q_e = 1.13$ Wh·m^{-2} and dq_e/dτ = 24.2 W·m^{-2};
- at $v_{ha} = 8$ m·s^{-1}: $q_e = 1.55$ Wh·m^{-2} and dq_e/dτ = 32.5 W·m^{-2}.

4. CONCLUSIONS

The present paper describes the suggested by the authors approach for the computation of the specific (for 1 m^2) energy consumption, q_e, and the specific heat flux, dq_e/dτ, which are needed for covering of the emission in the surrounding environment of the subjected to unilateral convective heating flat wood details before their lacquering. The approach is based on the use of numerical solutions of the second from two mutually connected 1D linear mathematical models, which has been suggested by the authors earlier. The first model allows the computation of the non-stationary temperature distribution along the thickness of subjected to heating wood details before their subsequent lacquer coating. The second model, whose solutions are used for determination of q_e and $dq_e/d\tau$, allows the computation of the non-stationary distribution of the temperature along the thickness of the carrying rubber band, on which the non-heated surface of the wood details lies.

For simultaneously numerical solution of the both mathematical models aimed at the determination of q_e and $dq_e/d\tau$ software program has been prepared, which was input in the calculation environment of Visual Fortran Professional. Using the program, computations have been carried out for the determination of the change in the heat energy q_e and in the heat flux $dq_e/d\tau$, which are consumed by oak details with an initial temperature of 20 ^{o}C, moisture content of 8 %, thickness of 16 mm, width of 0.6 m, and length of 1.2 m during their 10 min unilateral convective heating by hot air with temperature of 100 ^{o}C, which circulates above the details with a velocity of 2 m.s^{-1}, 5 m.s^{-1}, and 8 m.s^{-1} aimed at improvement of the conditions for the subsequent lacquering. The rubber band had thickness of 4 mm, width of 0.8 m, initial temperature of 20 ^{o}C, and the temperature of the surrounding air from the non-heated surface of the band was 20 ^{o}C.

The obtained results show that during the unilateral convective heating of the wood details, the change in the heat energy q_e and in the flux $dq_e/d\tau$ goes on according to complex curves, increasingly and non-linearly depending on the velocity of the circulated hot air v_{ha}, which heated the details.

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YIELD OF CUTTING OF EDGED BEECH TIMBER INTO ELEMENTS FOR DECKCHAIRS

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ABSTRACT

Goal of this research was to determine quantitative yield of short (1,2 – 1,6 m) beech timber in production of elements for deckchairs. Edged beech timber was divided into four groups, by quality (classes "1" and "2") and by length (1.2–1.3 m and 1.4–1.6 m). Technological process of cutting of elements for deckchair consisted of planing, ripping and crosscutting. Needed elements were planned out by quantity, i.e. the goal was to construct complete deckchairs with as few leftover parts as possible.

Quantitative yield was between 42.62% and 55.62%. Timber of class "1" had a higher yield than class "2" timber, as was expected. However, it was not expected that shorter boards would have higher quantitative yield than longer ones. This can be explained by the fact that lengths of shorter boards fitted the lengths of longest elements produced.

By analyzing the value of timber on the market, it was determined that the least amount of material per unit of product would be sawn by cutting quality "2" timber that is 1.2–1.3 m long.

Key words: beech, timber, cutting, elements for deckchairs

1. INTRODUCTION

Sawing timber into elements for wood products can be conducted in a sawmill or at a company which specializes in final products. Technological process in a sawmill can be organized as traditional, when sawn timber is produced in maximal possible dimensions, and cutting is conducted at a company specialized in final products. It can also be organized as dimension stock process when timber is produced to specific dimensions for a particular user.

Desired widths of cut elements can be obtained in two ways. Most often they are formed by ripping of timber. However, especially with elements with small widths, a process is applied in which timber thickness represents its future width, and thicknesses are defined by arranging the cuts on the ripper. Depending on the desired manufacturing precision, planers can also be used in this process.

Timber cutting was discussed by numerous authors. Zubčević (1973) compared yields in various methods of obtaining widths. Dimension stock processing of beech wood was researched by Skakić (1985) who examined yield of beech timber in manufacturing of elements for tables and chairs, Brežnjak (according to Ištvanić, 2003) who compared quantitative yield of beech wood and other hardwoods in traditional and dimension stock technologies, and Clément and Bond (2005) who examined the influence of timber widths on yield in manufacturing of elements. The influence of the order of operations and the type of technological process was researched by Shepley, Wiedenbeck, Smith (2004), Hoff (2000), and Thomas and Buehlmann (2016), while the influence of workers' errors or technological errors on yield was researched by Regalgado, Kline, Araman (1992), and Buehlmann and Thomas (2007).

Goal of this paper is to assess the influence of length and quality of short beech timber on quantitative yield in a specific technological process of making elements for deckchairs. This product was chosen for research because it consists of long and narrow elements. A specific technological process was conducted, starting with planing, which ensures that thickness of timber will become the width of elements. After that, cutting was used on ripper and cutter to define the final thickness and length of each element.

2. METHOD

Deckchair is a chair for sunbathing, and is used outdoors, at a swimming pool, on the beach, or in the garden. It can be folded and the backrest can be adjusted in three positions. It is assembled of beech elements of equal thicknesses (23 mm) and widths (45 mm) in various lengths. It consists of five groups of pieces (Figure 1).

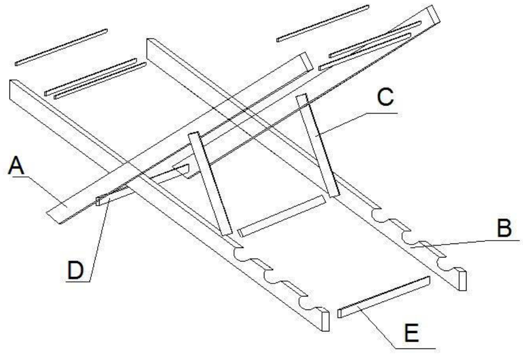

Figure 1. *Deckchair, appearance and assembly*

Elements "A", "B", and "C" obtain their final dimensions in the cutting department, while "D" and "E" are subsequently cut into pieces for top bar, bottom bar, and canvas holder, with cross sections of 20x20 mm. Elements needed for one deckchair, and their dimensions, are shown in Table 1.

Table 1. *Elements needed for one deckchair*

Group	Length (mm)	Width (mm)	Thickness (mm)	Number of pieces
A	1200	47	23	2
B	1050	47	23	2
C	550	47	23	3
D	500	47	23	2
E	450	47	23	3

This specification was made from 50 mm thick edged beech timber, 1.2 to 1.6 m long, without knots, cracks and rotten red heartwood. Timber was divided into two groups according to length (1.2 – 1.3 m and 1.4 – 1.6 m), and into two groups according to quality: without red heartwood (class "1") and with red heartwood (class "2"). Class "1" approximately corresponds to F-F1, and class "2" to F-F1R of EN 975-1 standard. As in the mentioned standard, minimal width of the board of the class "1" was 12 cm, but boards of class "2" were allowed to be narrower, and their minimal width was 8 cm. Also, maximum percentage of red heartwood was 50% of the surface, because it is not tolerated in final elements. Approximate volume of boards in each group was 0.55 m^3.`

Technological process of cutting of elements for deckchair consists of planing, ripping and crosscutting. The kiln-dryed, edged beech timber was planed on both wider and one narrower sides, and its thickness was made to 47 mm, in order to match the future width of elements (an overmeasure of 2 mm was left for further processing). Next, timber was marked with chalk and a cutting plan was laid out, considering the number of needed elements, with as few excess pieces as possible. Elements were then cut in a ripping-crosscutting technological process.

Calculation of quantitative yield was conducted in two ways: as a ratio between volumes of timber needed to produce complete deckchairs and that of the timber used, and as a ratio between volumes of all the elements produced and that of the timber used. The analysis conducted was based on the latter. Apart from the quantitative yield, the market prices of timber were introduced to calculate the cost price of material needed to produce a deckchair unit.

3. RESULTS AND DISCUSSION

By cutting the 1.2 m to 1.3 m long class "1" timber, elements for 34 complete deckchairs were produced. Also, two E elements were produced, along with one element A and one element B. Results are shown in Table 2.

Table 2. *Resulting yield of 1.2 m – 1.3 m long class "1" timber*

	Quantity (m^3)	Quantitative yield (%)
Processed edged timber	0.5435	
Total volume of produced elements	0.3024	55.62
Volume of elements for 34 deckchairs	0.2991	55.03

By processing the 1.4 m – 1.6 m long class "1" timber, elements for 32 complete deckchairs were produced, along with two additional D elements. Results are shown in Table 3.

Table 3. *Resulting yield of 1.4 m – 1.6 m long class "1" timber*

	Quantity (m^3)	Quantitative yield (%)
Processed edged timber	0.5480	
Total volume of produced elements	0.2826	51.57
Volume of elements for 32 deckchairs	0.2815	51.37

By cutting the 1.2 m – 1.3 m long class "2" timber, elements for 27 complete deckchairs were produced, along with one element C and one element E. Results are shown in Table 4.

Table 4. *Resulting yield of 1.2 m – 1.3 m long class "2" timber*

	Quantity (m^3)	Quantitative yield (%)
Processed edged timber	0.5570	
Total volume of produced elements	0.2386	42.84
Volume of elements for 27 deckchairs	0.2375	42.64

By processing the 1.4 m – 1.6 m long class "2" timber, elements for 26 complete deckchairs were produced. Also, an additional element of each group was produced, except for group C which got two additional elements. Results are shown in Table 5.

Table 5. *Resulting yield of 1.4 m – 1.6 m long class "2" timber*

	Quantity (m^3)	Quantitative yield (%)
Processed edged timber	0.5471	
Total volume of produced elements	0.2332	42.62
Volume of elements for 26 deckchairs	0.2287	41.8

The results show that during planning it was attempted to cut the exact number of elements to produce complete deckchairs, without leftover elements. This is why the differences in yields are small, with single extra pieces produced only to use up as much of material as possible.

Figure 2 shows the yields of beech timber in cutting the elements for deckchairs.

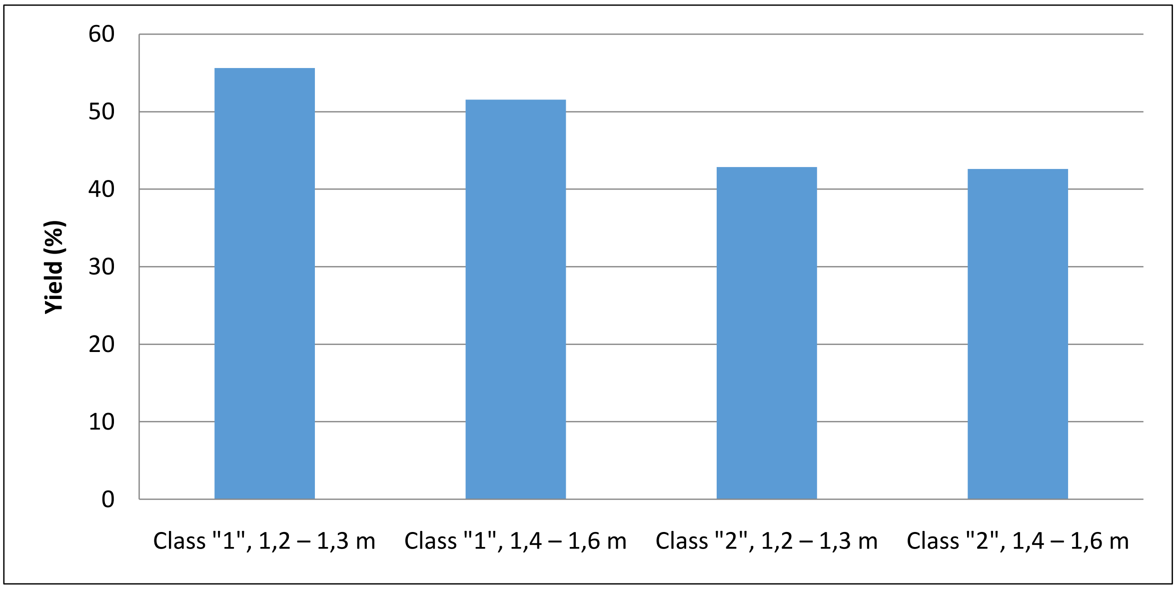

Figure 2. *Quantitative yield of beech timber in elements for deckchairs*

Figure 2 indicates that cutting timber of higher quality produced a higher yield. Since the basic difference in quality was based on the presence of red heartwood, which is not tolerated in products, these results are expected and they completely corroborate the results reported by other authors (Zubčević 1973, Skakić 1985, Wang et al. 2009).

However, the higher quantitative yield of shorter timber as compared to that of longer timber (noticeable in processing of class "1" timber) was not expected. This can be explained by the fact that the lengths of final elements (around 0.5 m or 1 – 1.2 m) represented a better fit for the 1.2 – 1.3 m timber than for the longer one. The inappropriate length of longer timber was the reason why such timber yielded more waste. This was especially noticeable with the longest elements (A), in which the shorter timber was almost perfectly used up, while in most of longer products there was a greater amount of waste because it was impossible to yield any other elements.

Value of timber needed for one deckchair, depending on its length and quality, is shown on Figure 3. It is visible that the longer quality "1" timber had the highest cost of material used to make one deckchair, while the shorter quality "2" timber had the lowest cost. This result is probably caused by the great difference in market prices between beech wood with red heartwood and without it. Also, red heartwood in used timber was limited to 50% of surface, and most of boards contained much less of it. Also, the applied technological process enabled a relatively easy fitting of elements, which was further facilitated by the fact that the elements differed only in their length.

Value of timber of which constitutes a product is just one of the indicators of total production costs. Working with lower quality timber is more complicated and it demands more work by the workers and machines, decreasing the total productivity of a system and therefore increases total production costs. Similar conclusions were reported by Clément and Bond (2005) who also considered that, in order to assess the influence of these factors on total production costs, further research must be conducted.

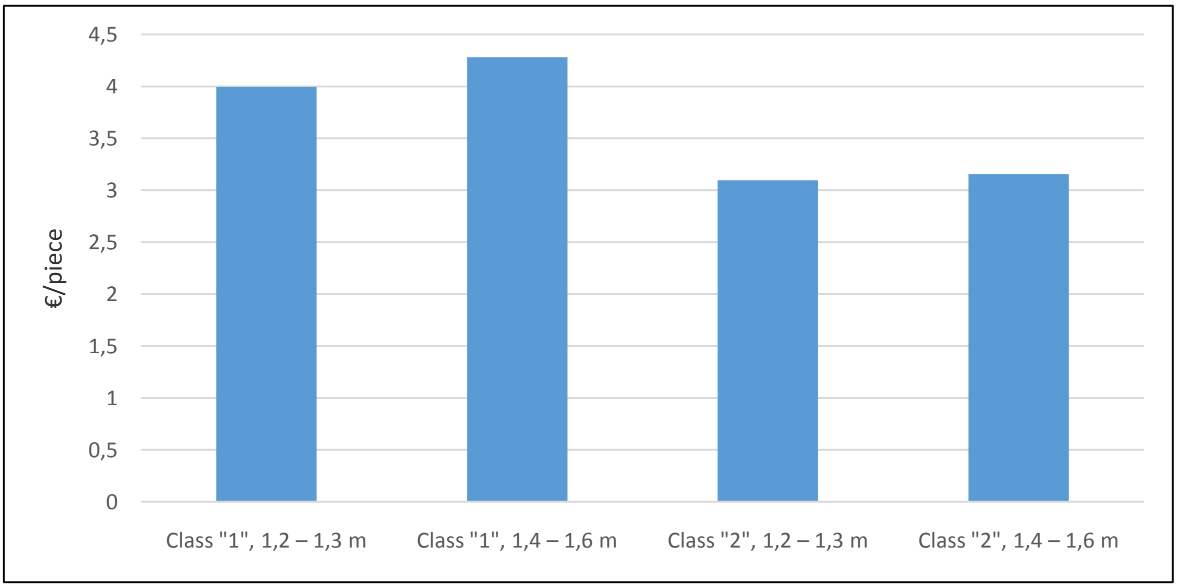

Figure 3. *Influence of length and quality of timber on value of material needed for one deckchair*

4. CONCLUSIONS

Examined was the influence of length and quality of short (1.2 to 1.6 m long) beech timber in production of elements for deckchairs. A specific technological process was applied, starting with planing timber and making the thicknesses into the size of future widths. Then, timber was cut in the ripping-crosscutting process into elements according to a specification of dimensions and numbers of pieces. The results indicate the following:

1. Quantitative yield of beech in production of elements for deckchairs was between 42.64% and 55.62% and depends upon timber length and quality;
2. Higher quantitative yield was achieved out of higher-quality timber;
3. Higher quantitative yield was achieved from shorter timber (1.2 – 1.3 m) as compared to longer timber (1.4 – 1.6 m), which was caused by the better fitting of shorter timber into desired lengths;
4. Highest value of timber needed for one deckchairs was in processing the 1.4 – 1.6 m long class "1" timber, and the lowest in processing of 1.2 – 1.3 m long class "2" timber. The greatest influence on this result was the significant price difference between beech timber with red heartwood and without it;
5. Price of raw material is just one of the indicators of total production costs and further research is needed in order to completely assess the influence of length and quality of timber on the cost-effectiveness of processing.

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INFLUENCE OF CONDITIONING PHASE AT THE END OF CONVENTIONAL DRYING ON DRYING QUALITY OF OAK TIMBER

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ABSTRACT

This study aimed to investigate the influence of different climates in the conditioning phase of conventional drying on drying quality of oak timber. The results of drying cycle with "traditional" conditioning were compared with results of the drying cycle where the equilibrium moisture content was higher (by 2%), while the duration of the conditioning phase was shortened by 24 hours. At the end of drying the final moisture content, moisture content difference across thickness and case-hardening were determinated. The examined boards from drying cycle with modified conditioning phase had higher final moisture content (but still below target value) and higher moisture content gradient. Gap values – which are a measure of case-hardening – were significantly lower in this drying cycle. This confirms that applying higher EMC value during conditioning phase, even with shorter time, gives better results in reducing case-hardening. It can be expected that timber after modified conditioning phase has lower internal stresses, i.e. that it is more stable during further processing. No direct relationship between gap values and final moisture content, nor between gap values and moisture content difference across thickness was found.

Key words: conventional drying, conditioning phase, oak timber, drying quality

1. INTRODUCTION

Oak, together with beech, is the most important and certainly the most expensive European wood species. However, above all, the non-permeability of oak leads to the fact that this species is the most difficult to dry, i.e. that the drying of oak timber lasts very long. Almost all quantities of oak timber in Europe are dried in conventional kilns. During conventional drying and due to wood shrinkage, tensile stress will develop in the surface layer of the boards. This stress combined with the change in MC causes mechanosorptive creep. At the end of drying - especially at the end of drying of oak timber - there will be a considerable internal MC gradient and the creep deformation will cause distortions in subsequent machining. For this reason, the conditioning phase at the end of drying, with the aim to reduce this problem, has been recommended for decades.

Despite its significance for drying quality, it is not uncommon in industrial praxis to skip the conditioning phase at the end of conventional drying. The main reason for this is lack of knowledge, and only sometimes the intentional saving of time and energy. In companies where this phase is not skipped, conditioning is often conducted inadequately, mostly because of inadequate conditioning climate recommended by kiln manufacturers. This usually results in inadequate drying quality. The expected result of conditioning should be equalized moisture content across the timber thickness and reduced case-hardening. However, results of this phase are strongly influenced by its duration and conditions (Milić and Kolin, 2008a, Milić and Kolin, 2008b), but also by initial moisture content of timber, drying schedule, and the state of the kiln (Denig, Wengert, Simpson, 2000).

The objective of this study was to compare the effect of the conditioning time and conditions on drying quality of oak timber.

2. MATERIAL AND METHODS

The research was done under industrial conditions (company Grakom SN), in conventional kilns with capacity 80 m^3, on square-edged sessile oak (*Quercus petrea* L.) timber. Sawn thickness of timber was 29 mm and width 125 – 170 mm. Two drying cycles were examined, and drying schedule recomended by kiln manufacturer (Table 1) was applied in both runs with the exception of conditioning phase. During the conditioning of the first cycle, the air parameters were scheduled as recommended by the kiln manufacturer. This cycle was compared with the results of the second drying cycle, where the set equilibrium moisture content (EMC) was higher (10%), while the duration of the phase was shortened (Table 2). During the conditioning phase, humidifying of air was performed with cold water.

Table 1. *Conventional drying schedule (oak, sawn tichkness 29 mm)*

MC (%)	T_d (°C)	ΔT (°C)	T_w (°C)	φ (%)	EMC (%)	FS (%)
>60	35	2.5	32.5	85	17	100
60	35	3	32	83	16	100
50	36	3.5	32.5	78	14.5	100
40	37	4	33	76	14.0	100
35	39	4.5	34.5	75	13.5	100
30	41	5	36	71	12.5	98
27	42	6.5	35.5	65	11.0	96
24	46	9.5	36.5	54	9.0	94
20	50	13.5	36.5	41	7.0	92
16	55	18	37	32	5.2	90
12	58	22	36	24	4.0	88
10	60	26	34	18	3.0	86

Table 2. *Conditioning phase settings*

Drying cycle	T (°C)	EMC(%)	Duration (h)
1	60	8	48
2	60	10	24

Timber was dried from green state to 8.5% MC, measured by the probes in the kiln. Six randomly selected boards (from the stacks positioned in the same place in both runs) were analysed at the end of drying. All examined boards were 170 mm wide. From each board three 15-mm thick specimens were sliced and marked A, B, C (Figure 1).

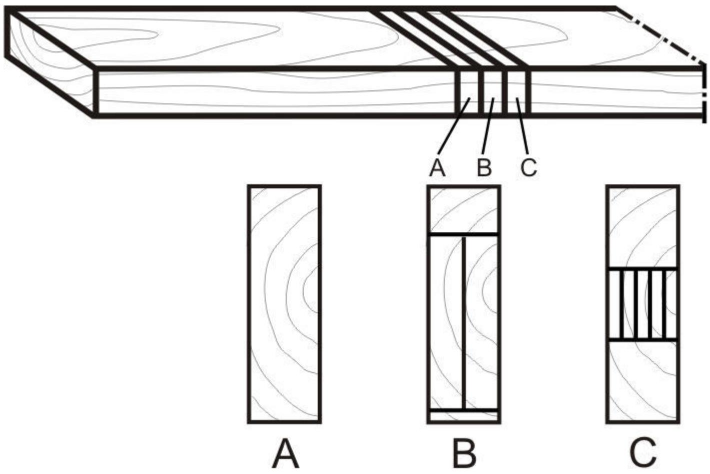

Figure 1. *Samples for determination of final MC (A), gap measuring (B) and MC profile (C)*

Test specimens A were taken for the final MC determination by means of the oven-dry method. Gap measurements (CEN/TS 2010) were done on specimens B after 48 h of acclimatization. Initially, specimens B were 150 mm long and after gap measurings they were shortened to standardised 100 mm and measured again. Five lamellae were sliced from specimen C, and their MC was determined gravimetrically to find out the MC distribution across thickness. MC difference (ΔMC) was calculated as the difference between the MC in the core (MC of lamella 3) and the mean MC in the surface (MC of lamellae 1 and 5):

$$\Delta MC_i = MC_c - \frac{MC_{s1} + MC_{s5}}{2} \qquad (1)$$

ΔMC_i – moisture content difference across thickness of control board (%),
MC_c – moisture content in the centre in % (moisture content of lamella 3),
$MC_{s1,5}$ – moisture content in the surface layer in % (moisture content of lamella 1 and lamella 5).

The mean and standard deviations for the three basic parameters of quality (MC, ΔMC, gap test) were calculated to allow comparison between the runs.

3. RESULTS AND DISCUSSION

Drying time of Cycle 1 was 30 days, while the second drying cycle lasted 27 days. Both cycles were dried at the same time – during the month of June – in two identical chambers. The reason for this was to conduct the drying with two sets of timber with similar characteristics (cut at the same time, with similar initial MC,...). The difference in durations of the two cycles was small which was expected because both used the same drying schedules. Cycle 2 also lasted shorter because of shorter conditioning time (24 h as compared to 48 h in Cycle 1).

The average final MC was 5.8% in drying cycle 1 and 6.6% in the second cycle (Table 3). In both cycles the timber was clearly over-dried (target MC was 8.5%). The final MC is influenced by many factors (Gu et al. 2004), but the somewhat higher final MC in Cycle 2 was probably caused by the active drying phase being shorter by two days, and also by the higher EMC during conditioning phase. Higher values of EMC during this phase usually cause a higher final MC by 1% on average. In production of wood flooring, which is the case here, it is a very common practice to overdry the timber in order to avoid problems with any single board having a higher MC. By applying a higher EMC during conditioning, the overdried boards can closely approach the target MC. It is important to note that low average final MC indicates that the probes in the kiln are not completely reliable even in this drying phase, because they show values higher than real (for about 2-3%). Knowing this, in this case it was possible to end the active drying 2-3 days sooner, without fear that the MC would be higher than the target 8.5%.

Table 3. *Parameters of drying quality*

Drying cycle	Final MC (%)	ΔMC (%)	Gap_{150}* (mm)
1	5.8 (0.4)	0 (0.7)	3.8 (0.8)
2	6.6 (0.7)	0.5 (0.3)	2.8 (0.9)

*Gap_{150} – gap measured on specimens 150 mm long
SD in parentheses

Moisture content difference was lower in the first drying cycle as compared to second. This is probably caused by longer drying time – longer drying time and lower final MC generally produce lower MC difference across thickness. Also, longer conditioning phase in the first cycle could have contributed to fllatter MC profile. Some boards from Cycle 1 had a negative MC difference (MC of surface layers was higher than in the center), which was not the case in Cycle 2.

Gap values measured on 150 mm specimens were significantly lower in second drying cycle. Values obtained on 100 mm specimens showed similar trend (Fig. 2). These results were expected and they corroborated some of the previous results (Sandland, 2001; Milić and Kolin 2008b). They indicate that applying higher EMC during conditioning, even with a shorter duration of this phase, results in lower case-hardening. In other words, after such conditioning phase, timber contains lower inner stresses and behaves better in subsequent machining. This also means less waste in further processing and, thus, a better financial result. At the same time, some drying time is saved (24 h), as is some of the energy – both electrical (for fans) and heat. It can be expected that such conditioning phase will also produce good results regarding case-hardening in other kilns in companies that process oak wood. This is especially true for a large number of companies that produce oak flooring, which utilize 48 hour long conditioning – they could save both time and energy consumption.

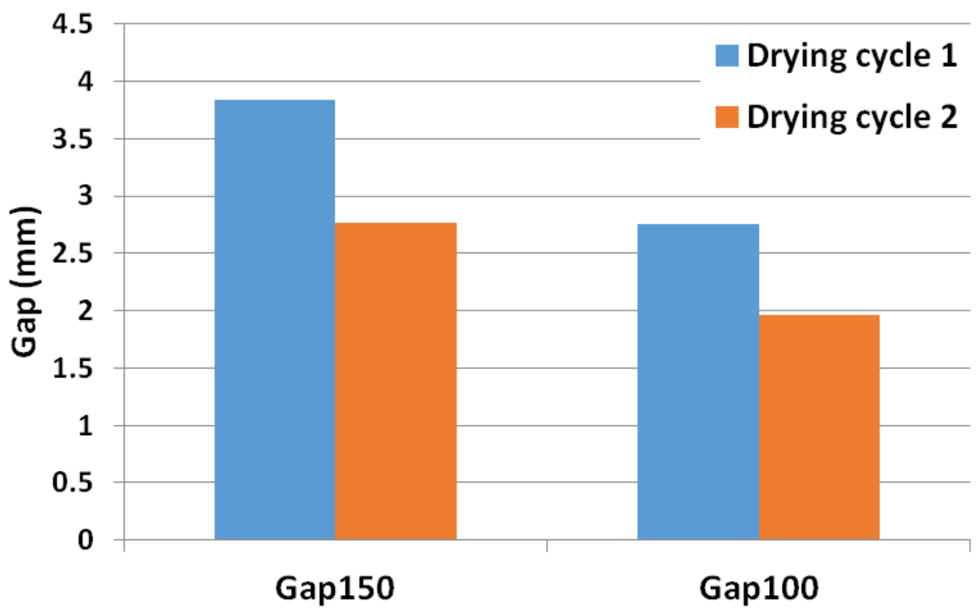

Figure 2. *Gap values measured on 150 mm and 100 mm specimens*

It is known that, during the conditioning phase, MC across wood thickness equalizes while case-hardening decreases. Although these two processes occur simultaneously, results show that the flattening of MC profiles can also be completely achieved with an unchanged conditioning phase, however this is not the case with case-hardening. This is visible in Cycle 1 where there were no differences in MC on the surface and in the center, but where case-hardening was significant. On the other hand, the shorter conditioning phase in the second cycle did not completely eliminate the differences in MC across thickness, but case-hardening was much lower. This case-hardening reduction confirms that mechanosorptive creep – which "is the most fundamental deformation component by which the shrinkage-induced drying stress could be released effectively" (Zhan and Avramidis, 2011) – strongly depends of EMC during conditioning phase. Further research is needed to assess whether even higher EMC (e.g. 11% or 12%) during 24 h or less can produce even better results. Varying climate during this phase (Salin, 2001) is also one of the possibilities.

4. CONCLUSIONS

The research confirmed the results of some previous works according to which the higher EMC values during the conditioning phase lead to a more significant reducing of case-hardening. Considering that the overdrying of oak timber is so frequent, by applying higher EMC during conditioning, MC can be brought closer to the target MC.

Although average moisture content difference across thickness was lower in the drying cycle with common conditioning settings – probably due to longer conditioning time, the case-hardening was significantly higher. Lower gap values in the drying cycle with high EMC value during conditioning phase potentially mean less waste in further processing, which is especially significant for oak flooring manufacturers. Additionally, such (shorter) conditioning leads to saving of drying time and energy consumption.

It was not found that there is a direct correlation between the gap values and final MC, nor between gap values and ΔMC. Further research is needed to reveal whether even higher EMC values and shorter conditioning times can give even better results.

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COMPUTATION OF THE ICING DEGREE OF LOGS DURING MELTING OF THE FROZEN FREE WATER IN THEM

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ABSTRACT

An approach for the computation of the relative icing degree of frozen logs during their heating until reaching of temperatures, at which the melting of the frozen free water in them occurs, has been suggested in the present paper. The approach is based on the use of numerical solutions of personal mathematical model of the logs' defrosting process, which consist of non-linear differential equation of the thermo-conductivity and of equations of the initial and boundary conditions of this process.

For numerical solution of the model an explicit form of the finite-difference method in the computing medium of Visual Fortran Professional has been used. After application of this method, the temperature distribution in the nods of the calculation mesh is obtained, which is built on the longitudinal section of the logs. Synchronously with the computation of the change in the temperature field in logs during their heating, a count of the nods of the calculation mesh is carried out, in which the temperature above –1 ^{o}C is already increased and a melting of the frozen free water in them occurred. The current relationship between these "defrosted" nods and the whole nods' number of the calculation mesh gives the current icing degree of the logs for each moment of the defrosting process.

The information about the relative logs' icing degree is needed for the computation of the energy consumption of the defrosting of logs aimed at their plasticizing in the production of veneer.

Key words: logs, modelling, defrosting, frozen free water, computation, relative icing degree

1. INTRODUCTION

It is known that the duration of the thermal treatment of frozen logs in the winter aimed at their plasticizing for the production of veneer and also the energy consumption needed for this treatment depend on the degree of the logs' icing (Cudinov 1968, Videlov 2003, Pervan 2009, Deliiski and Dzurenda 2010). In the specialized literature there are limited reports about the temperature distribution in subjected to defrosting frozen logs (Steinhagen 1986, 1991, Khattabi and Steinhagen 1992, 1993, Deliiski 2004, 2009, Deliiski and Dzurenda 2010, Hadjiski and Deliiski 2015, 2016). That is why the experimental research and also the modelling and the multi-parameter study of the defrosting process of logs are of considerable scientific and practical interest.

For different engineering calculations it is needed to be able to determine the icing degree of the wood materials depending on the temperature of the influencing on them gas or liquid medium and on the duration of their staying in this medium. Such calculations are carried out using mathematical models, which describe the complex process of the wood defrosting.

The aim of the present paper is to suggest a numerical approach for the computation of the relative icing degree of logs during melting of the frozen free water in them using personal 2D non-linear mathematical model of the logs' defrosting process.

2. MATERIAL AND METHODS

2.1. Modelling of the 2D heat distribution in logs during their defrosting

The mechanism of the heat distribution in frozen logs during their heating can be described by the equation of the heat conduction. When the length of the logs does not exceed their diameter by at least 3 ÷ 4 times, then the heat transfer through the frontal sides of the logs can not be neglected, because it influences the change in temperature of their cross sections, which are equally distant from the frontal sides (Chudinov 1968, Deliiski 2011, Deliiski *et al.* 2014). In such cases, for the calculation of the change in the temperature in the longitudinal sections of the logs (i.e. along the coordinates r and z of these sections) during their defrosting in air medium the following 2D non-linear model can be used:

$$c_{\mathrm{we}}\rho_{\mathrm{w}}\frac{\partial T(r,z,\tau)}{\partial\tau}=\lambda_{\mathrm{wr}}\left[\frac{\partial^2 T(r,z,\tau)}{\partial r^2}+\frac{1}{r}.\frac{\partial T(r,z,\tau)}{\partial r}\right]+\frac{\partial\lambda_{\mathrm{wr}}}{\partial T}\left[\frac{\partial T(r,z,\tau)}{\partial r}\right]^2+ \lambda_{\mathrm{wz}}\frac{\partial^2 T(r,z,\tau)}{\partial z^2}+\frac{\partial\lambda_{\mathrm{wz}}}{\partial T}\left[\frac{\partial T(r,z,\tau)}{\partial z}\right]^2, \qquad (1)$$

with an initial condition

$$T(r,z,0)=T_0 \qquad (2)$$

and boundary conditions for convective heat transfer:

- along the radial coordinate *r* on the logs' frontal surface during defrosting process:

$$\frac{\mathrm{d}T(r,0,\tau)}{\mathrm{d}r}=-\frac{\alpha_{\mathrm{p\text{-}dfr}}(r,0,\tau)}{\lambda_{\mathrm{wp}}(r,0,\tau)}\left[T(r,0,\tau)-T_{\mathrm{m\text{-}dfr}}(\tau)\right], \qquad (3)$$

- along the longitudinal coordinate *z* on the logs' cylindrical surface during defrosting process:

$$\frac{\mathrm{d}T(0,z,\tau)}{\mathrm{d}z}=-\frac{\alpha_{\mathrm{r\text{-}dfr}}(0,z,\tau)}{\lambda_{\mathrm{wr}}(0,z,\tau)}\left[T(0,z,\tau)-T_{\mathrm{m\text{-}dfr}}(\tau)\right], \qquad (4)$$

where c_{we} is the effective specific heat capacity of the wood in respective temperature ranges, in which the frozen free and the frozen bound water melts (Chudinov 1968, Deliiski 2011, 2013b), $\mathrm{J\cdot kg^{-1}\cdot K^{-1}}$;

λ_{wr} and λ_{wp} – thermal conductivity of the wood in radial and longitudinal direction respectively, $\mathrm{W\cdot m^{-1}\cdot K^{-1}}$;

ρ_{w} – wood density, $\mathrm{kg\cdot m^{-3}}$;

r – coordinate of the separate points along the log's radius, m;

z – coordinate of the separate points along the log's length, m;

τ – time, s;

T – temperature, K;

T_0 – initial mass temperature of the subjected to defrosting log, K;

$T(r,z,0)$ – temperature of all points in the log's volume in the beginning of the defrosting, K;

$T(r,0,\tau)$ – temperature of all points on the log's frontal surface, K;

$T(0,z,\tau)$ – temperature of all points on log's cylindrical surface, K;

$T(r,z,\tau)$ – current temperature in the separate points of the log during its defrosting, K;

$T_{\mathrm{m\text{-}dfr}}$ – temperature of the surrounding air environment during the log's defrosting, K;

$\alpha_{\mathrm{r\text{-}dfr}}$ and $\alpha_{\mathrm{p\text{-}dfr}}$ – convective heat transfer coefficients between the log's surfaces and the surrounding air environment in radial and longitudinal direction respectively, $\mathrm{W\cdot m^{-2}\cdot K^{-1}}$.

The mathematical model of the logs' defrosting process, which consists of eqs. (1) ÷ (4) can be solved without any simplification with the help of an explicit form of the finite-difference method (Deliiski 2004, 2011, Deliiski and Dzurenda 2010). For this purpose the calculation mesh can be built on ¼ of the longitudinal section of the log due to the circumstance that this ¼ is mirror symmetrical towards the remaining ¾ of the same section.

2.2. Mathematical description of the relative icing degree of logs, caused by the freezing of the free water in the wood

The relative icing degree of logs, which is caused by the freezing only of the free water in them, $\Psi_{\text{ice-fw}}^{n}$, can be calculated for each moment $n{\cdot}\Delta\tau$ of the freezing process according to the equation

$$\Psi_{\text{ice-fw}}^{n} = \frac{S_{\text{ice-fw}}^{n}}{S_{\text{w}}}, \tag{5}$$

where $S_{\text{ice-fw}}^{n}$ is that part of the ¼ of the log's longitudinal section area, in which up to the present moment $n{\cdot}\Delta\tau$ the free water is in the frozen state, m^2;

S_{w} – area of the entire ¼ of log's longitudinal section, m^2;

$\Delta\tau$ – step along the time coordinate, by which the mathematical model is solving, s;

n – time level during the solving of the model: n = 0, 1, 2, 3, ……

For the use of equation (5) it is needed for each moment $n{\cdot}\Delta\tau$ of the log's defrosting process to know the current value of $S_{\text{ice-fw}}^{n}$. Unfortunately, there are no instrumental methods for measurement of this area. Therefore, the only possible way to estimate $S_{\text{ice-fw}}^{n}$ is to use the current solution of the mathematical model of the log's defrosting process.

The solution of the model gives the non-stationary distribution of the temperature field in the knots of the calculation mesh (Deliiski 2004, 2011). The model solutions are obtained for any point in time, which is a multiple of the step $\Delta\tau$. It is not difficult to put a logical condition in the software for the model's solution, which registers and records the moments when the temperature of each of the knots increases above 272.15 K (i.e. above –1 $^{\text{o}}$C) and then temperature conditions for melting of the frozen free water separately for each knot arise (Deliiski andTumbarkova 2016).

This means that synchronously with the obtaining of the temperature distribution it is possible to determine the current number of the knots, $N_{\text{ice-fw}}^{n}$, in which the frozen free water already "starts to melt". The relationship between $N_{\text{ice-fw}}^{n}$ and the total number of knots of the entire calculation mesh, N_{total}, can be used for estimation of the current icing degree of logs, which occurs during the melting of the frozen free water in them up to the present moment $n{\cdot}\Delta\tau$, i.e.

$$\Psi_{\text{ice-fw}}^{n} = \frac{N_{\text{ice-fw}}^{n}}{N_{\text{total}}}. \tag{6}$$

2.3. Experimental research of the logs' defrosting process

For application and verification of the suggested above approach for the computation of the icing degree of logs we needed experimentally obtained data about the change in the temperature field in logs during their defrosting. That is why we carried out such experiments.

The logs subjected to experimental research were with a diameter D = 240 mm and a length L = 480 mm. They were produced from the sap-wood of freshly felled poplar trunk (*Populus nigra* L.). Before the experiments, 4 holes with diameters of 6 mm and different lengths were drilled in each log. Sensors with long metal casing were positioned in these 4 holes for the measurement of the wood temperature during the experiments. The coordinates of the points of the logs are, as follows:

Point 1: along the radius r =30 mm and along the length z =120 mm;
Point 2: along the radius r =60 mm and along the length z =120 mm;
Point 3: along the radius r =90 mm and along the length z =180 mm;
Point 4: along the radius r=120 mm and along the length z=240 mm.

These coordinates of the characteristic points allow covering the impact of the heat fluxes simultaneously in radial and longitudinal directions on the temperature distribution in logs during their defrosting. For the freezing of the logs before their defrosting a horizontal freezer was used with length of 1.1 m, width of 0.8 m, depth of 0.6 m and an adjustable temperature range from –1 $^{\text{o}}$C to –30 $^{\text{o}}$C (Deliiski and Tumbarkova 2016).

The automatic measurement and record of the temperature and humidity of the air processing medium and also of the temperature in the 4^{th} points in logs during the experiments was carried out with the help of Data Logger type HygroLog NT3 produced by the Swiss firm ROTRONIC AG (http:/www.rotronic.com). On Fig. 1, as an example, the change in the temperature of the processing air medium, t_m and in its humidity, φ_m, and also in the temperature in 4^{th} characteristic points of a poplar log with an initial temperature t_0 = –29.5 °C, moisture content u = 1.63 kg·kg^{-1}, and basic density ρ_b = 361 kg·m^{-3} during its 70 h defrosting (after its preceding 50 h freezing) is presented. The record of all data was made automatically by Data Logger with intervals of 5 min.

2.4. Mathematical description of the air medium temperature during log's defrosting

The curvilinear change in the shown on Fig. 1 freezing air medium temperature, $T_{\mathrm{m-dfr}}$, with very high accuracy (correlation 0.98 and Root Square Mean Error 0.77 °C) has been approximated with the help of the software package Table Curve 2D (http://www.sigmaplot.co.uk/products/tablecurve2d/tablecurve2d.php) by the following equation:

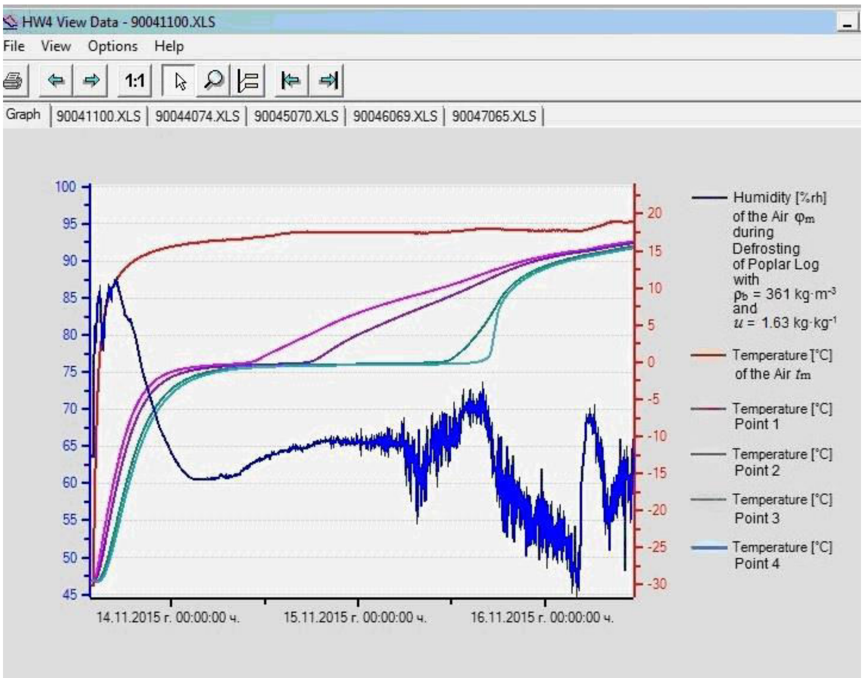

Figure 1. *Experimentally determined change in t_m, φ_m, and t in 4 points of poplar log with D = 0.24 m, L = 0.48 m, u = 1.63 kg·kg^{-1}, ρ_b = 361 kg·m^{-3} (i.e. ρ_w = 949 kg·m^{-3}), and t_0 = –29.5 °C during its 70 h defrosting at 18.9 °C*

$$T_{\mathrm{m-dfr}} = \frac{a_{\mathrm{dfr}} + c_{\mathrm{dfr}}\tau^{0.5}}{1 + b_{\mathrm{dfr}}\tau^{0.5}}, \qquad (7)$$

whose coefficients are equal to: a_{dfr} = 292.2975534, b_{dfr} = –0.00237555, c_{dfr}= –0.69350256, and τ is the current time, starting from the beginning of the 50 h preceding freezing process of the log, s.

Equation (7) was used for the solving of eqs. (3) and (4) of the model.

3. RESULTS AND DISCUSSION

For the numerical solution of the above presented mathematical model aimed at usage of the suggested approach for the calculation of $N_{\text{ice-fw}}$ and $\Psi_{\text{ice-fw}}$ 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 an example, computations were made for the determination of the 2D non-stationary change of the temperature in ¼ of the longitudinal section of the poplar log, whose experimentally determined temperature distribution is shown on Fig. 1. The model was solved with step $\Delta r = \Delta z = 6$ mm along the coordinates r and z and with the same initial and boundary conditions, as they were during the experimental research.

During the solving of the model, the mathematical descriptions of the thermo-physical characteristics of poplar wood with fiber saturation point 0.35 kg·kg^{-1}, presented in (Deliiski 2011, 2013a, 2013b, Deliiski *et al.* 2015) were used.

Figure 2 presents the calculated change in $t_{\text{m-dfr}}$, log's surface temperature t_s, and t of 4 points of the studied poplar log, which have the same coordinates, as during the experimental research.

The comparison to each other of the analogical curves on Fig. 1 and Fig. 2 shows good qualitative and quantitative conformity between the calculated and experimentally determined changes in the temperature field of the studied log during its defrosting. It was calculated that the average Root Mean Square Error for all studied 4 points in the log is $\sigma_{avg} = 1.09$ °C.

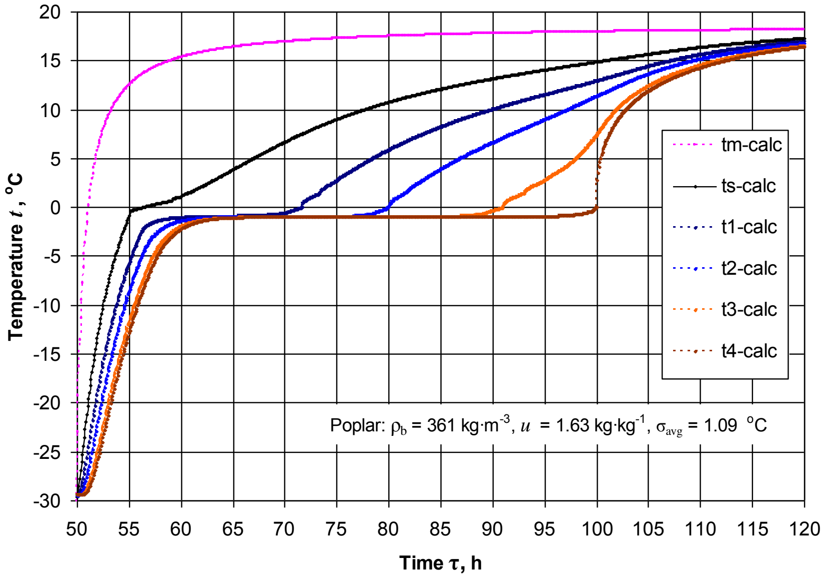

Figure 2. *Calculated with the model change in $t_{m\text{-}dfr}$, t_s, and t of 4 characteristic points of the studied poplar log during its 70 h defrosting at room temperature*

Figure 3 presents the change of the number of knots of the calculation mesh $N_{\text{ice-fw}}$ and $N_{\text{ice-fwE}}$ during the 70 h defrosting process of the studied log after completion of 50 h freezing of this log before that. The number of $N_{\text{ice-fw}}$ is counted when the temperature of each of the knot of the calculation mesh reaches a value of 272.15 K (i.e. –1 °C) and the melting of the frozen free water in it starts. The number of $N_{\text{ice-fwE}}$ is counted when the temperature of each knot reaches a value of 273.15 K (i.e. 0 °C) and the melting of the frozen free water in it ends.

Figure 4 presents the calculated change of the log's relative icing degrees $\Psi_{\text{ice-fw}}$ during the 70 h defrosting process of the studied log.

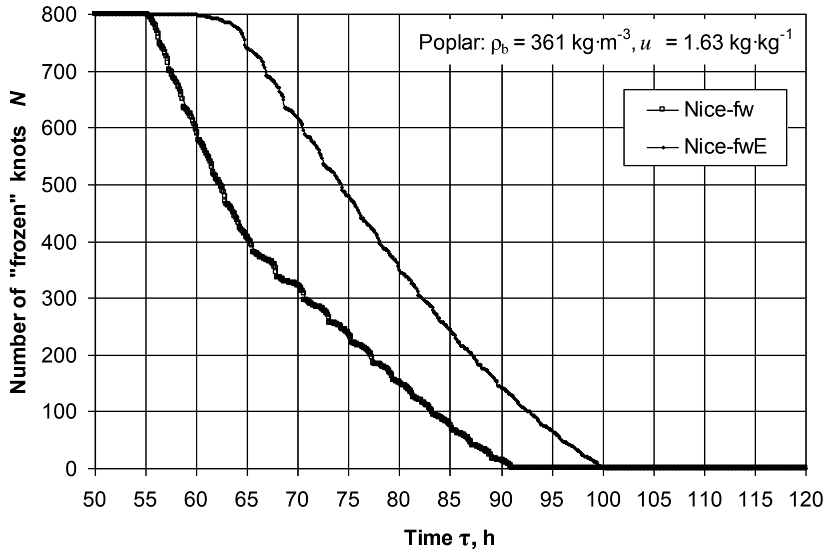

***Figure 3.** Change in the knots $N_{ice\text{-}fw}$ and $N_{ice\text{-}fwE}$ of the calculation mesh during the defrosting of the studied poplar log*

The graphs on Fig. 3 and Fig. 4 show that the change of $N_{\text{ice-fw}}$, $N_{\text{ice-fwE}}$, and $\Psi_{\text{ice-fw}}$ is happening according to complex dependences on the defrosting time. The first 5.1 h of the defrosting $N_{\text{ice-fw}}$ is equal to 0 due to the circumstance that the melting of the frozen free water even in the peripheral log's layers is still not started. During these 5.1 h the free water in all knots of the calculation mesh is still in frozen state (i.e. $N_{\text{ice-fw}} = N_{\text{total}}$) and subsequently the icing degree $\Psi_{\text{ice-fw}}$ is equal to 1.

The number of knots $N_{\text{ice-fw}}$ becomes equal to 0 after 41.1 h of the log's defrosting process, when the melting of the frozen free water even in the log's centre starts. Then the calculated according to eq. (6) value of icing degree $\Psi_{\text{ice-fw}}$ becomes equal to 0 (see Fig. 4).

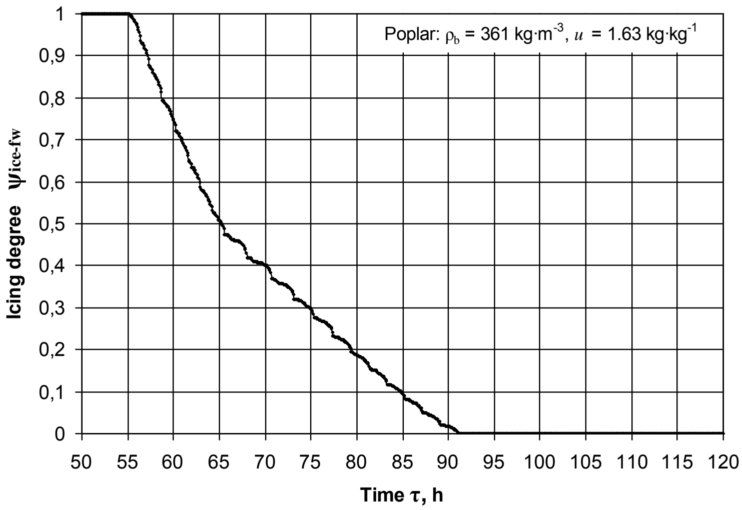

***Figure 4.** Change in $\Psi_{ice\text{-}fw}$ during the defrosting of the studied poplar log*

The horizontal distance between the both graphs on Fig. 3 indicates the time that the temperature in the one and the same knots increases from –1°C to 0 °C. During this time the melting of the frozen free water is carried out. In the peripheral log's layers this melting ends 9.2 h after the beginning of the defrosting process. This means that the melting of the frozen free water in these layers lasts 9.2 – 5.1 = 4.1 h. In the log's center the melting ends 49.9 h after its beginning. This means that the melting of the frozen free water in the log's center lasts 49.9 – 41.1 = 8.8 h.

4. CONCLUSIONS

The present paper describes the suggested for the first time by the authors approach for the computation of the relative icing degree of logs $\Psi_{ice\text{-}fw}$, which is caused by the melting of the frozen free water in them during their defrosting. The approach is based on the use of the numerical solutions of personal 2D non-linear mathematical model of the logs' defrosting process.

For the solution of the model and practical application of the suggested approach, a software program was prepared in the calculation environment of Visual Fortran Professional. The paper shows and analyzes, as an example, diagrams of the change in the temperature distribution and in the icing degree for poplar log with a diameter of 0.24 m, length of 0.48 m, initial temperature of –29.5 ^{o}C, basic density of 361 $kg{\cdot}m^{-3}$, and moisture content of 1.63 $kg{\cdot}kg^{-1}$ during its 70 h defrosting in air environment with 18.9 ^{o}C. All diagrams are drawn using the results calculated by the model.

It has been determined, that the value of the relative icing degree $\Psi_{ice\text{-}fw}$ of the studied log changes according to complex relationship in the range from 1 to 0 during the time from 5.1^{sh} h to 41.1st h of the defrosting process.

The approach that was suggested in the present paper for the computation of the mentioned logs' icing degree could be further applied in the development of analogous models, for example, for the calculation of the temperature fields and the energy consumption during defrosting of different wooden and other capillary-porous materials.

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REGIMES FOR AUTOCLAVE STEAMING OF NON-FROZEN BEECH VENEER PRISMS WITH A LIMITED POWER OF THE HEAT GENERATOR

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ABSTRACT

An approach for the computation of the processing medium temperature of the steaming process of wood prisms in autoclave, depending on the available limited power of the heat generator has been suggested. The approach is based on the use of the optimized method called "variable return step", together with own summarized 2-dimensional mathematical model for the transient non-linear heat conduction and energy consumption in non-frozen prismatic wood materials at arbitrary, encountered in the practice initial and boundary conditions, which has been created by the first co-author earlier.

An application of the suggested approach is presented in the present paper for the case of scientifically based computation of regimes for autoclave steaming of non-frozen beech veneer prisms with different thicknesses and moisture content of 0.6 $kg \cdot kg^{-1}$ aimed at their plasticizing in the production of veneer, when the power of the steam generator is equal to 500 kW.

The obtained results can be used for the creation of a system for optimized model based automatic control of the duration and energy consumption of the steaming process of wood materials.

Key words: autoclave steaming, wood materials, limited power, heat generator, optimization

1. INTRODUCTION

The steaming of wooden materials is an important part of the technological processes in the production of veneer, plywood, parquet, layered articles, etc.

The wood materials with prismatic shape are subjected to steaming with the aim of plasticization in the production of veneer, as well as when have to receive bent parts in the production of chairs and sporting equipment. This is determined by the circumstance that the heated moist wood has an increased deformation capability and is susceptible to cutting and spatial configuration.

Traditionally, for many past decades applied without changes, equipment and technologies for steaming wood materials are characterized by long durability (till some days) and extremely low energy efficiency. During the last couple of decades the utilization of intensive steaming of wood materials under increased pressure of the steam in encapsulated autoclaves started (Deliiski 2003, Deliiski and Sokolovski 2007, Sokolovski, Deliiski, and Dzurenda 2007). The higher temperature of the steaming medium on one side, and the good heat insulation of the autoclaves on the other side, allow the reduction by several times of the continuity and the specific energy expenditures of the process by comparison with the traditional technologies for steaming wood materials under atmospheric pressure (Trebula and Klement 2002, Videlov 2003, Pervan 2009).

The aim of the present work is to suggest and an algorithm for the computation of the processing medium temperature of the steaming process of wood prisms in autoclave, depending on the available limited power of the heat generator.

2. MATERIAL AND METODS

2.1. Modelling of the 2D heat distribution in the wood prisms during their steaming

Mathematical model of the heating processes of prismatic wood materials during their steaming at atmospheric and increased pressure are created, solved and verified earlier by the first co-author (Deliiski 2003, 2011). The 2D heat distribution mechanism in subjected to steaming prismatic wood materials during their steaming is described by the following system of equations:

$$c(T,u)\rho(T,u)\frac{\partial T(x,y,z,\tau)}{\partial \tau}=\frac{\partial}{\partial x}\left[\lambda_{\mathrm{r}}(T,u)\frac{\partial T(x,y,z,\tau)}{\partial x}\right]+\frac{\partial}{\partial y}\left[\lambda_{\mathrm{t}}(T,u)\frac{\partial T(x,y,z,\tau)}{\partial y}\right], \qquad (1)$$

with an initial condition:

$$T(x,y,0)=T_0 \qquad (2)$$

and the following boundary conditions:

$$T(0,y,\tau)=T(x,0,\tau)=T_{\mathrm{m}}(\tau), \qquad (3)$$

where

T is the wood temperature, K;

T_0 – initial temperature of the subjected to steaming wood materials, K;

T_{m} – temperature of the steaming medium in the autoclave, K;

c – specific heat capacity of the wood, J.kg^{-1}.K^{-1};

ρ – wood density, kg.m^{-3};

u – wood moisture content, kg.kg^{-1};

λ_{r} – thermal conductivity of the wood in radial direction, W.m^{-1}.K^{-1};

λ_{t} – thermal conductivity of the wood in tangential direction, W.m^{-1}.K^{-1};

x – coordinate on the thickness of subjected to steaming prismatic materials;

y – coordinate on the width of subjected to steaming prismatic materials;

τ – time, s.

The thermo physical characteristics of the wood, which participate in eq. (1) are mathematically described in (Deliiski 2003, 2011, 2013a, 2013b, Deliiski and Dzurenda 2010, Deliiski *et al.* 2015).

2.2. Modeling of the energy consumption of the autoclave

The heat energy Q_{ha}, which is supplied into the autoclave by the introduced in it water steam is consumed for:

- heating the subjected to steaming wood materials (Q_{hw});
- heating of the body of the autoclave and of the situated in it metal trolleys for positioning of the wood materials (Q_{hf});
- heating of the heat insulating layer of the autoclave (Q_{hil});
- covering of the heat emission from the autoclave in the surrounding aerial space (Q_{he});
- filling in with steam the free (unoccupied by wood materials) part of the working volume of the autoclave (Q_{hfv});
- accumulating heat in the gathered in the lower part of the autoclave condensed water (Q_{hcw}).

On the grounds of the performed analyses, a structural model of distribution of the heat in the autoclaves for steaming of wood materials is suggested. By using this model, a mathematical description of the heat energy consumption and its equivalent of water steam are made, and also a mathematical description of the heat balance and its corresponding steam balance of the autoclaves (Deliiski 2003, Deliiski and Dzurenda 2010).

2.3. Heat balance of the autoclave

The total specific heat energy needed for steaming of 1 m^3 wood materials in autoclave for any moment $n\cdot\Delta\tau$ of the thermal treatment, q_{ha}^{n}, is equal to (in kWh·m^{-3}):

$$q_{\text{ha}}^{n} = q_{\text{hw}}^{n} + w_{\text{hf}}^{n} + q_{\text{hil}}^{n} + q_{\text{he}}^{n} + q_{\text{hfv}}^{n} + q_{\text{hcw}}^{n}, \tag{4}$$

where $\Delta\tau$ is the step along the time coordinate, by which the mathematical model is solving, s;

n – time level during the solving of the model: $n = 0, 1, 2, 3, \ldots\ldots$

The total specific heat flux, $\frac{dq_{\text{ha}}^{n}}{d\tau}$, which provides the energy q_{ha}^{n} for any moment $n\cdot\Delta\tau$ of the steaming process can be determined (in kW) according to the following equation:

$$\frac{dq_{\text{ha}}^{n}}{d\tau} \approx \frac{3600 q_{\text{ha}}^{n}}{\Delta\tau}. \tag{5}$$

2.4. Calculation of the temperature of the steaming medium in the autoclave when the heat generator has a limited power

For the realization of automatic control of the wood steaming process with limited power of the heat generator, q_{source} (in kW), the following problem occurs: depending on the present limited heat power it is needed to determine the real law of increase in the temperature of the heating medium T_{m} in the autoclave during the initial part of the thermal treatment processing (TTP) of the wood materials.

For the solution of such problem, an approach for the calculation of the change in T_{m} after submission of the limited heat power to autoclave at the beginning of TTP until reaching of the technological acceptable maximal value of $T_{\text{m}}^{\max}$ is needed.

It is known that at the beginning of TTP the temperature T_{m} increases to curvilinear dependence. The separate sections of this dependence can be approximated by a part of exponent with respective time constant τ_{e} for each step $\Delta\tau$ of the steaming process. This allows describing the increase of T_{m} during the initial part of TTP by the following equation:

$$T_{\text{m}}^{n} = T_{\text{m}}^{\max} - \left(T_{\text{m}}^{\max} - T_{\text{m}0}\right)\exp\left(-\frac{\tau}{\tau_{\text{e}}}\right), \tag{6}$$

where T_{m}^{n} is the current value of the processing medium temperature in the autoclave for each moment $n\cdot\Delta\tau$ of TTP, K, and:

T_{m0} – initial medium temperature in the autoclave, K;

$T_{\text{m}}^{\max}$ – maximal technologically allowable medium temperature in the autoclave, K;

τ – current time of TTP, equal to $n\cdot\Delta\tau$, s;

τ_{e} – time constant of the exponential increase of separate sections of T_{m} during the initial part of TTP, s.

For determination of τ_{e} and computation of $T_{\text{m}}^{\max}$ for each moment $n\cdot\Delta\tau$ of the initial part of TTP the method for optimization with variable reverse step (Stoyanov 1983, Deliiski 2003) is suitable for use. For this purpose the following optimization criteria can be used:

$$q_{\text{source}} - \partial_{\text{h}} \le \frac{dq_{\text{ha}}^{n}}{d\tau} \le q_{\text{source}} + \partial_{\text{h}}, \tag{7}$$

where by ∂_{h} (in kW) the setting of the limits of localization of $\frac{dq_{\text{ha}}^{n}}{d\tau}$ is carried out.

For the determination of the time constant τ_{e} in eq. (6), an algorithm and a subroutine to the software package were created. Depending on the limited power of the heat generator, q_{source}, they realize the optimization procedures for the calculation of T_{m}^{n} during the initial part of TTP.

When the condition (7) is satisfied that means that during the next step $\Delta\tau$ of TTP the energy $\Delta\tau\cdot q_{\text{ha}}$, which with the determined true value of T_{m}^{n} is calculated will be equal to the energy $\Delta\tau\cdot q_{\text{source}}$.

3. RESULTS AND DISCUSSION

For numerical solution of the above mentioned mathematical models aimed at usage of the suggested approach for the calculation of T_m during the initial part of TTP a software package was prepared in FORTRAN (Dorn and McCracken 1972), which was input in the calculation environment of Visual Fortran Professional. For the preparation of the models for programming an explicit form of the finite-difference method has been used, which allows for the exclusion of any simplifications in the models (Deliiski 2003, 2011).

With the help of the software package, as an example, computations were made for the determination of T_m and also of the 2D non-stationary change of the temperature in 4 characteristic points of ¼ of the square cross section of beech prisms with thickness d and width b respectively, during their steaming in an autoclave with a diameter D = 2.4 m and length of its cylindrical part L = 9.0 m (Deliiski and Sokolovski 2007). The dimensions of the prisms' cross sections were equal to 0.3 x 0.3 m, 0.4 x 0.4 m, 0.5 x 0.5 m, and the coordinates of their characteristic points were, as follow: Point 1: d/8, b/8; Point 2: d/4, b/4; Point 3: d/2, b/4; and Point 4: d/2, b/2. During the solving of the models, the mathematical descriptions of the thermo-physical characteristics of beech wood (*Fagus Sylvatica* L.) with basic density 560 $kg.m^{-3}$ and fiber saturation point 0.31 $kg \cdot kg^{-1}$ (Nikolov and Videlov 1987) were used, which have been presented in (Deliiski 2011, 2013a, 2013b). The initial temperature and the moisture content of the prisms were equal to 0 ^oC and 0.6 $kg \cdot kg^{-1}$ respectively.

During the numerical simulations 3-stage regimes for autoclave steaming of the prisms (Фиг. 1) were used (Deliiski 2003, Deliiski and Dzurenda 2010).

During the first stage of the TTP regime input of water steam is accomplished in the autoclave, with situated inside wooden materials, until the temperature t_m = 130 ^oC is reached. The time for increasing t_m up to t_m = 130 ^oC depends on the heat power of the steam generator. As higher this heat power is as fast is the increasing of t_m. This assures less duration of the TTP regimes and increased production capacity of the autoclave.

After reaching t_m = 130 ^oC, this temperature is maintained unchanged by reducing the input of steam inside the autoclave until the calculated by the model average mass temperature of the wood, t_{avg}, reaches a value of 95 ^oC. The TTP at t_m = 130 ^oC does not cause thermal destruction in wood, which ensures keeping its mechanical characteristics.

After reaching t_{avg} = 95 ^oC the input of steam in the autoclave is terminated and the second stage of the steaming regime begins. During this stage, by using the accumulated heat in the autoclave, the further heating and plasticizing of the prisms is accomplished, thus resulting in gradual reduction of the temperature t_m for about 2 hours down to around 115^oC.

Afterwards, the cranes directing the steam and condensed water out of the autoclave are opened, which initiates the third stage of the steaming regime. This stage ends after about an hour and a half, when t_m reaches approximate value of around 80 ^oC.

The end of the third stage defines the finish of the whole steaming regime and then the plasticized prisms are taken out of the autoclave. At the end of the third regime stage the temperature at the characteristic points of the cross section of the prisms falls entirely in the range of the optimum temperatures from 55 ^oC to 90 ^oC, needed upon cutting of veneer made of plasticized beech wooden prisms (Deliiski and Dzurenda 2010).

After taking the heated and plasticized prisms out of the autoclave, their air-conditioning (cooling) is executed at factory premises temperature during a certain period before cutting the veneer out them. During the air-conditioning additional homogenization of the temperature field occurs in the prisms volume, which ensures better quality veneer production.

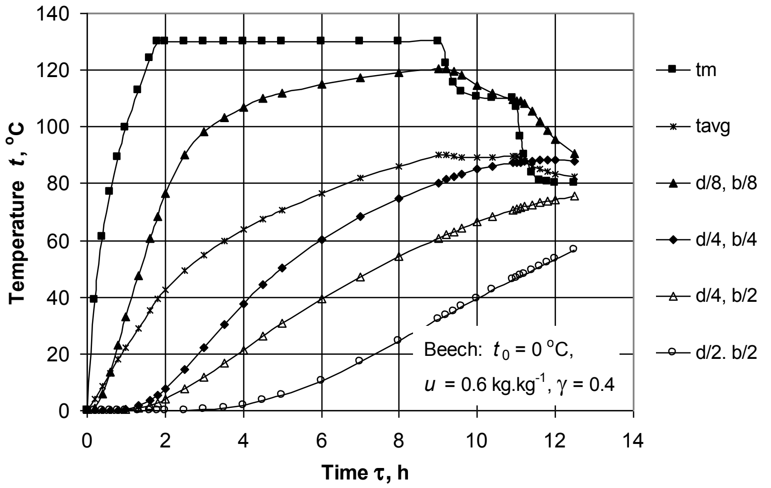

Figure 1. *Change in t_m and t in 4 characteristic points of beech prism with cross section 0.4 x 0.4 m during its TTP in an autoclave at a loading of 40%*

The increase of t_m at the beginning of the steaming regime is calculated by taking in mind the available heat power of the generator that produces steam. During simulations we have set limited power of the generator q_{source} = 500 kW. Two loading levels of the autoclave with filled in beech prisms for steaming, γ, have been investigated: $\gamma = 0.4\ m^3 \cdot m^{-3}$ and $\gamma = 0.5\ m^3 \cdot m^{-3}$ (i.e. γ = 40% and γ = 50%) and their influence over the change of t_m during the initial part of TTP, as well as over the entire duration of the prisms steaming regimes have been followed and analyzed.

Figures 2 and 3 present the calculated change in t_m during TTP of the studied beech prisms in an autoclave at γ = 40% and γ = 50%, respectively.

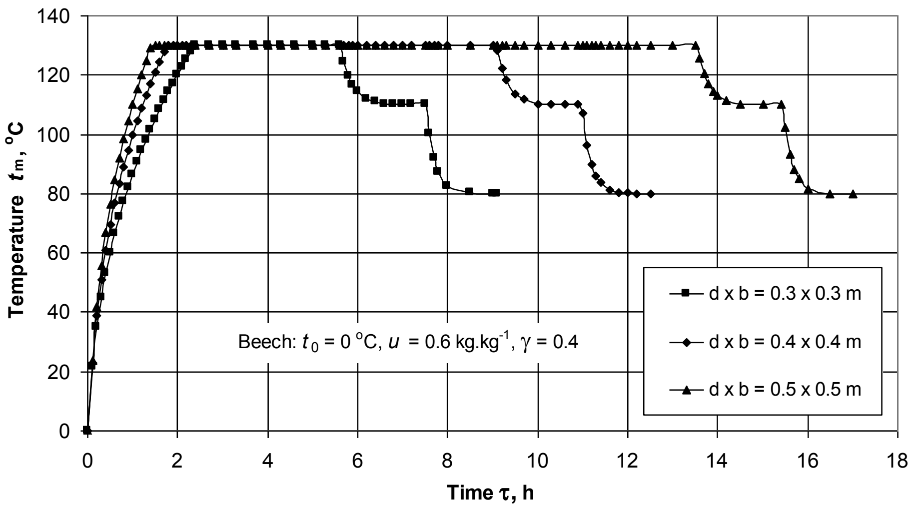

Figure 2. *Regimes for TTP of beech prisms in an autoclave at γ = 40%, depending on their dimensions*

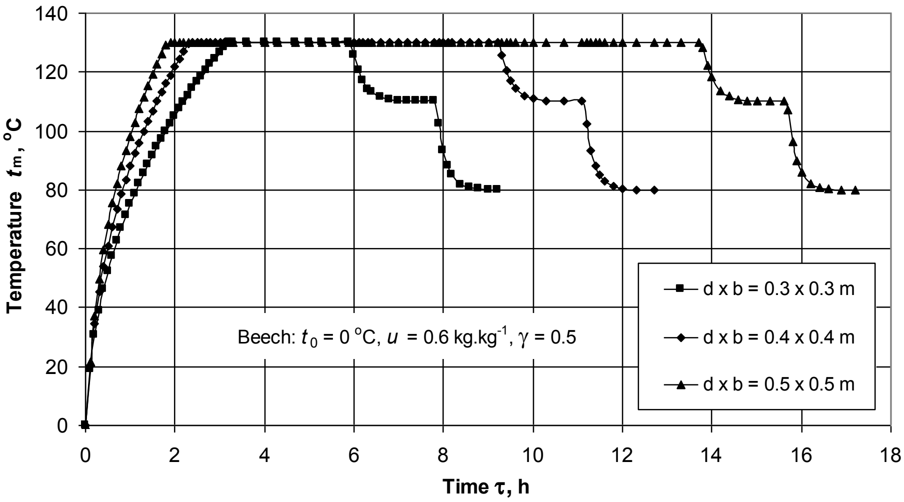

Figure 3. *Regimes for TTP of beech prisms in an autoclave at γ = 50%, depending on their dimensions*

Figure 4 presents the calculated change in the heat fluxes of the autoclave, q_{ha}, which are needed for the realization of the regimes shown on Fig. 2 and Fig. 3.

The analysis of the obtained simulation results, part of which are presented on Fig. 2, Fig. 3, and Fig. 4 lead to the following conclusions:

1. The main consumer of the heat energy in TTP are the wood prisms in the autoclave. That is why during the optimization procedure for the determination of the time constant τ_e in eq. (6) the current value of the total energy of the autoclave $\Delta\tau\cdot q_{ha}$ is most impacted by the change of the current value of the heat consumption of the wood $\Delta\tau\cdot q_{hw}$.

2. As the thickness of the wood materials d increases, the heat in the wood materials is distributed slower. This means that with an increase of d, a higher increase in t_m during any next step $\Delta\tau$ until warming up of the surface layers of the wood materials and reaching of the equality $\Delta\tau\cdot q_{ha} = \Delta\tau\cdot p_{source}$ is needed. This provides for a faster increase in t_m with an increase of d during the initial part of TTP.

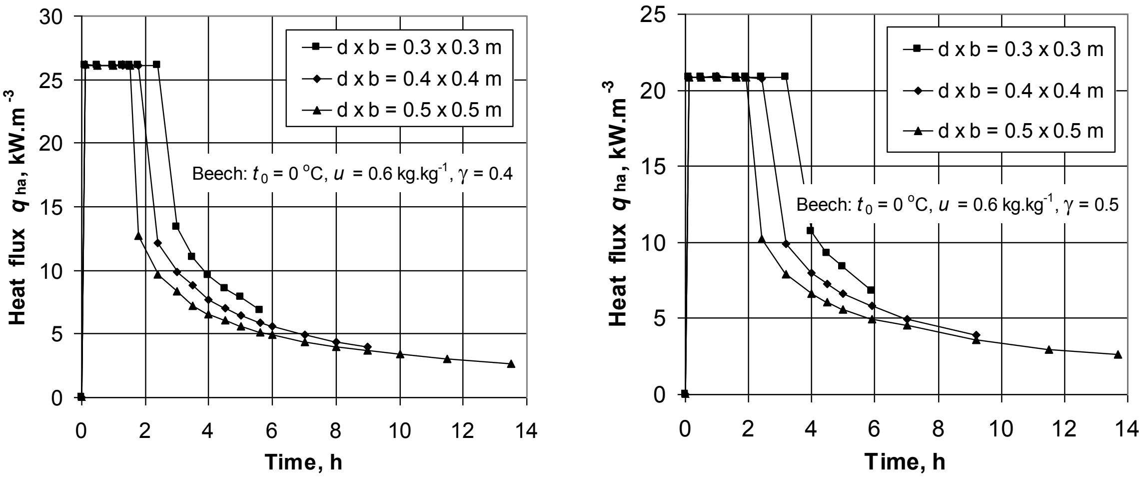

Figure 4. *Change in q_{ha} during TTP of beech prisms in an autoclave at γ = 40% (left) and γ = 50% (right), depending on their dimensions*

3. The larger loading of the autoclave means there is a presence of more heat capacity of the wood in the autoclave. This means that a smaller increase in t_m during any next step $\Delta\tau$ until reaching of the equality $\Delta\tau\cdot q_{ha} = \Delta\tau\cdot q_{source}$ in these cases is needed. This provides a slower increase in calculated according to eq. (6) values of t_m at the beginning of TTP with an increase of the autoclave's loading.

The presented on Fig. 2 and Fig. 3 durations of the increase of t_m from 0 °C to 130 °C at the beginning of TTP are in accordance with the conclusions given above. These durations are equal to, as follow:

• 1.5 h, 1.8 h, and 2.4 h for prisms with d = 0.5 m, d = 0.4 m, and d = 0.3 m respectively at autoclave's loading γ = 40%;

• 1.9 h, 2.4 h, and 3.2 h for prisms with d = 0.5 m, d = 0.4 m, and d = 0.3 m respectively at autoclave's loading γ = 50%.

4. The duration of the TTP regimes increases nonlinearly depending on the wooden prisms thickness. The duration of the first stage of the TTP regime, upon which time the autoclave is filled in with water steam until reaching average mass temperature of the beech prisms of 95 °C, is equal to:

• 5.6 h, 9.0 h, and 13.5 h for prisms with d = 0.3 m, d = 0.4 m, and d = 0.5 m respectively at autoclave's loading γ = 40%;

• 5.9 h, 9.2 h, and 13.7 h for prisms with d = 0.3 m, d = 0.4 m, and d = 0.5 m respectively at autoclave's loading γ = 50%.

The total duration of the investigated 3-stage TTP regimes, by the end of which the temperature at the characteristic points of the cross section of the beech prisms falls in the range of the optimum temperatures from 55 °C to 90 °C, which assures maximum plasticizing upon further veneer cutting, is equal to:

• 9.1 h, 12.5 h, and 17.0 h for prisms with d = 0.3 m, d = 0.4 m, and d = 0.5 m respectively at autoclave's loading γ = 40%;

• 9.4 h, 12.7 h, and 17.2 h for prisms with d = 0.3 m, d = 0.4 m, and d = 0.5 m respectively at autoclave's loading γ = 50%.

5. During the initial part of TTP when the heat power of the steam generator is limited at q_{source} = 500 kW, the specific heat fluxes q_{ha} are constant and equal to 26.07 kW.m^{-3} at γ = 40% and to 20.85 kW.m^{-3} at γ = 50% (Fig. 4).

These values of q_{ha} are received by the following way depending on these variables: generator power q_{source}, volume of the empty autoclave V_a and level of the autoclave's loading with wooden materials γ. By autoclave dimensions D = 2.4 m and L = 9.0 m its inside volume is equal to V_a = 47.95 m^3. The multipled volume V_a by γ results in the wooden materials volume V_w, at the respective level of loading: in our case V_w = 19.18 m^3 at γ = 40% and V_w = 23.98 m^3 at γ = 50%. In the analyzed example after dividing the generator power q_{source} = 500 kW by V_w, we get the presented in figure 4 constant values for heat fluxes q_{ha} = 26.07 kW·m^{-3} at γ = 40% and q_{ha} = 20.85 kW·m^{-3} at γ = 50% during the increase of t_m in the autoclave.

After reaching in the beginning of TTP t_m = 130 °C in the autoclave, the heat fluxes q_{ha} decrease considerably – initially at faster speed, gradually slowing down. The decrease of the fluxes q_{ha} is executed at curvilinear dependence on the duration of the steaming process and at the end of the first stage of TTP regimes they reach the following values:

• 6.82 kW.m^{-3}, 4.03 kW.m^{-3}, and 2.71 kW.m^{-3} at for prisms with d = 0.3 m, d = 0.4 m, and d = 0.5 m respectively at autoclave's loading γ = 40%;

• 6.76 kW.m^{-3}, 3.88 kW.m^{-3}, and 2.63 kW.m^{-3} at for prisms with d = 0.3 m, d = 0.4 m, and d = 0.5 m respectively at autoclave's loading γ = 50%.

4. CONCLUSIONS

The present paper describes the suggested by the authors approach for the computation of the temperature increase of the steaming environment, t_m, in the beginning of TTP of wooden materials at limited heat power of the steam generator. The approach is based on the use of the numerical solutions of personal 2D non-linear mathematical model of the steaming process of prismatic wood materials. For computation of t_m for each moment of the initial part of TTP the method for optimization with variable reverse step is used.

For the solution of the model and practical application of the suggested approach, a software program was prepared in the calculation environment of Visual Fortran Professional.

The paper shows and analyzes, as an example, diagrams of the change in t_m and 2D temperature distribution in beech prisms log with cross sections 0.3 x 0.3 m, 0.4 x 0.4 m, and 0.5 x 0.5 m, initial temperature of 0 °C, basic density of 560 kg·m^{-3}, and moisture content of 0.6 kg·kg^{-1} during their steaming in an autoclave with a diameter of 2.4 m, length of 9.0 m and loading with wood materials 40% and 50%, until reaching of average mass temperature of 90 ^{o}C at limited heat power of the steam generator, equal to 500 kW. All diagrams are drawn using the results calculated by the model.

It has been determined, that the increase of the prisms' dimensions causes faster increase in t_m during the initial part of TTP. The duration of the regimes for TTP increases non-linear with the increase of the prisms' dimensions. This duration practically does not depend on the loading of the autoclave with subjected to TTP prisms at given their dimensions.

The obtained results can be used for the creation of a system for optimized model based automatic control (Hadjiski and Deliiski 2015, 2016) of the duration and energy consumption of the steaming process of wood materials.

The approach that was suggested in the present paper for the computation of the increase in t_m during the initial part of TTP and also of the total duration of the regimes for TTP at limited power of the heat generator could be further applied in the development of analogous models, for example, for the computation of the temperature fields and the energy consumption during TTP of different wooden and other capillary-porous materials in non-frozen and frozen state, and also for optimization and model based control of these processes.

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CURRENT CONDITION INDICATORS OF WOOD INDUSTRY IN THE REPUBLIC OF MACEDONIA

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ABSTRACT

The wood industry represents as one of the oldest sectors of the manufacturing in the Republic of Macedonia. It is a strategic branch of the Macedonian economy.

The condition with the wood industry is shown through the current indicators such as: number of active business entities, number of employees, average paid monthly net salary per employee, industrial production, export and import, i.e. foreign trade. The data were obtained from the State Statistical Office of the Republic of Macedonia for the period 2011-2016.

The business entities in the wood industry in the number of business entities from the manufacturing participate with approximately 14% on average for the period 2011-2015. The average share of the number of employees in the wood industry in the total number of employees in the manufacturing is about 6% in the period 2011-2016. The value of net wages, on average, in the manufacture of wood and wood products and furniture production are lower compared to the average net salary in the manufacturing and at the same time below the national average.

In the wood industry, after all analyzed production we have a tendency for production growth except for the production of sawn lumber from pine and beech, parquet and production of the category other which includes the production of pallets, crates and boxes in the period 2011-2016.

The total export and import of wood industry products has increased in the studied period. The products from the furniture production are increasingly exported, and the products from the manufacture of wood and wood products have higher import. The total balance of wood industrial production has a positive sign in the last two years of the analyzed period (2011-2016).

Key words: current indicators, condition, wood industry

1. INTRODUCTION

The wood industry in the Republic of Macedonia has always had an important place in the country's economy. It is a strategic branch of the Macedonian economy. The wood industry is characterized as a branch with a number of comparative advantages in relation to other industrial branches in the country, which as separate ones would distinguish: a large share of domestic raw materials in its products; finished products with a lasting consumer character; production with permanent export orientation; production facilities that engage relatively lower investments; production facilities dispersed throughout the country; engaging workforce from multiple profiles and environmentally-highly-affordable activity.

The Republic of Macedonia, although rich in raw materials, does not reach the required capacities in the production of wood products, and especially in the manufacture of furniture. Due to the existence of a large number of small and irrational sawmills, the country's wood sector faces insufficient processing and production of wood products. Since the saw mills had begun work without investing in their technology in the 90s of the last century, they worked with obsolete machines and equipment. If it is invested in modern technology and new equipment, sufficient profit could be realized with minimal investments.

Furniture production is the most important segment of the wood sector. The Republic of Macedonia belongs to the group of unprepared countries in which in recent years there is no systemic investment in this sector. On the whole, the Macedonian wood industry is a marginal supplier on the international market. Its products are relatively unknown among buyers, except for some exceptions. Therefore, in the last few years this sector faces a decline in production and employment, which is a consequence of the unfavorable synergistic effect of the economic crisis, the globalization of the market, and especially the domestic environment.

The main determination of the wood sector should be a multiple increase in the value of wood raw materials through products with a high degree of finalization, with a prefix for high quality, design and recognition, whose development and guidelines will be based on explicit analysis and use of standards.

The wood industry in the Republic of Macedonia, that is, the manufacture of wood and furniture production should be economically successful and profitable activities, with balanced competitive and sustainable development, following the world development trends and challenges.

2. SUBJECT AND AIM OF THE RESEARCH

The subject of research in the paper is an analysis of current condition indicators of the manufacture of wood and wood products, furniture production and the total wood industry in the Republic of Macedonia. The indicators are analyzed from the aspect of the number of business entities, the number of employees, the average paid net salary, industrial production, and the export and import of products, i.e. foreign trade.

The data for analyses are obtained from the publications of the State Statistical Office of the Republic of Macedonia for the period 2011-2016. Indicators on the state of the wood industry are analyzed according to the National Classification of Activities (NACE), Rev. 2, 2007.

The aim of the research is to recognize the trends in production, employees, net wages, active business entities, trade, both in the manufacture of wood and wood products, as well as in the production of furniture, and to determine the condition of these production, that is the wood industry in the Republic of Macedonia.

3. RESEARCH RESULTS

We determined the condition in the wood industry of the Republic of Macedonia through several indicators: number of active business entities, number of employees, average monthly net salary per employee, industrial production in natural data, export and import, and foreign trade. The data that are the subject of our research will be analyzed separately by activities, such as the manufacture of wood and wood products, furniture production and total for the wood industry for the period 2011-2016.

3.1 Active business entities in the wood industry

The number of active business entities is given in Table 1. It is shown the total number of business entities in the manufacturing as well as the participation of the business entities in the wood industry and individually by activities. The period 2011 - 2015 was analyzed.

On the territory of the Republic of Macedonia, on average, there were registered 1104 business entities from the wood industry for the period 2011-2015. The number of enterprises in the manufacture of wood and wood products is 477, while in the manufacture of furniture the number is higher (628) in the analyzed period.

The participation of business entities from the wood industry in the number of business entities in the manufacturing is about 14% on average for the given period.

The number of business entities has a decreasing trend in the wood industry, as well as in the processing of wood and wood products and furniture production. This trend was also followed by the number of business entities from the manufacturing.

Table 1. *Number of active business entities in the wood industry*

Year	2011	2012	2013	2014	2015	Average	AAR
Manufacturing	8155	8251	7918	7675	7639	**7928**	**- 1,6**
Wood industry (total)	1171	1184	1071	1045	1051	**1104**	**- 2,7**
Manufacture of wood and wood products	526	528	446	444	440	**477**	**- 4,4**
Furniture production	645	656	625	601	611	**628**	**- 1,3**

Of the total active business entities in the wood industry, micro enterprises have the largest share of around 55%, small enterprises account for 30%, while medium-sized enterprises with only 15%. In medium-sized enterprises, the number of employees is mostly represented (about 13%) by enterprises with up to 100 employees (Stankevik Shumanska, M., 2014).

3.2 Employees in the wood industry

The data on the number of employees refer to the manufacturing, total for the wood industry and separately by activities for the period 2011-2016. They are shown in Table 2.

Table 2. *Number of employees in the wood industry*

Year	Manufacturing	Wood industry	Manufacture of wood and wood products	Furniture production
2011	100878	5762	2349	3413
2012	101132	5760	2253	3507
2013	104214	5861	2257	3604
2014	111559	5924	2096	3828
2015	111208	5976	1920	4056
2016	111402	6270	1992	4278
Average	**106732**	**5926**	**2145**	**3781**
AAR	**2,0**	**1,7**	**- 3,2**	**4,6**

The number of employees in the manufacturing is increasing from 100878 to 111402 employees or an average annual with a rate of 2,0% in the analyzed period.

From the data shown in Table 2 we can see that the number of employees in the wood industry has a tendency to increase. Thus, from 5762 employees in 2011, this number in 2016 increases to 6270 workers and it has an average annual growth rate of 1,7%.

In the manufacture of wood and wood products it is characteristic that the number of employees drops with the average growth rate from -3,2% for the whole period. The number of employees in furniture production has a tendency to increase with an average growth rate of 4,6% in the given period.

The average share of the number of employees from the wood industry in the manufacturing is about 6% in the period 2011-2016.

3.3 Average net salary per employee in the wood industry

The salary received by the employee is compensation for labor, that is, for his physical and mental strain and spending. The labor costs, i.e. the gross salary cover the net salaries of the employees and various contributions and taxes payable to the net wages, as well as all the benefits that the employee receives during the use of annual leave, public holidays, est. The amount of the net salary represents a significant economic and social problem for every enterprise.

The dynamics of the average net salary per employee in MKD for the period 2011-2016 in the manufacturing and the wood industry, that is, the manufacture of wood and wood products and furniture production are shown in Table 3.

Table 3. *Average net salary per employee (in MKD)*

Year	Manufacturing	Manufacture of wood and wood products	Furniture production
2011	15176	11549	11781
2012	15300	11999	12144
2013	15747	12301	12840
2014	16177	12878	13046
2015	16594	13483	12994
2016	17096	13750	13715
Average	**16015**	**12660**	**12753**
AAR	**2,4**	**3,6**	**3,1**

The average net salary per employee in the manufacturing (16015 MKD) has tendency to increase with an average annual rate of 2,4% in the analyzed period (Table 3).

The average net salary per employee for manufacture of wood and wood products (12660 MKD) is also increasing on average annually with a rate of 3,6%. The amount of net salary per worker annually in the production of furniture is 12753 MKD and has positive dynamics with an average rate of 3,1%.

Despite the increase in the average net salary per worker in the wood industry in both productions it is still lower compared to the average net salary of the employees in the manufacturing for all years from the analyzed period (2011 - 2016).

3.4 Wood industry production volume

The physical volume of production is an expression of the produced usable values that satisfy certain needs of people. The volume of production has a strong impact on the economy of the wood industry. The volume of production and its relation to the capacity of the wood industrial enterprise depend very much on the costs per unit product and the quality of the wood industry enterprise economy (Stankevik, M., 2007).

The analysis of the physical volume of production refers to the manufacture of wood and wood products, as well as the production of furniture for the period 2011-2016. The data were obtained from the State Statistical Office of the Republic of Macedonia.

The activity manufacture of wood and wood products includes: sawn lumber from pine, sawn lumber from beech, veneer and plywood production, parquet, windows, doors and others (pallets, crates, boxes). The production volume data for manufacture of wood and wood products by structure are given in Table 4.

From the data in Table 4 it can be seen that the production of sawn lumber from pine decreases with an average annual rate of -5,0% in the analyzed period. The same tendency is followed by the production of sawn lumber from beech which declines at a lower average rate of -1,5%. The average production of sawn lumber from pine is 3883 m^3, while the average production of sawn lumber from beech is less than 2360 m^3 for the given period.

Besides the production of sawn lumber it was analyzed and manufacture of veneer and plywood – panels. It can be seen that this production is characterized by variable dynamics with a positive average annual rate of 10,5%. The average annual production is insignificant and amounts to 714 m^3 for the studied period.

The production of parquet on average is 5962 m^3 in the analyzed period. The same is characterized by a decreasing tendency with an average annual rate of -18,2%. The smallest volume can be seen in 2016 when the production of parquet is only 2851 m^3.

Table 4. *Production volume - manufacture of wood and wood products, according to NACE Rev.2*

Year	Sawn lumber from pine (m^3)	Sawn lumber from beech (m^3)	Veneer and plywood (m^3)	Parquet (m^3)	Windows (pieces)	Doors (pieces)	Other (pallets, crates, boxes) (m^3)
2011	-	2578	752	7760	2528	1158	8791
2012	5589	3827	355	4817	1425	743	13082
2013	2267	1566	553	10704	871	1064	8590
2014	1315	2146	680	5613	1667	2327	12733
2015	5701	1654	705	4024	1709	2057	9335
2016	4544	2390	1237	2851	4369	5356	7032
Average	**3883**	**2360**	**714**	**5962**	**2095**	**2118**	**9927**
AAR	**- 5,0**	**- 1,5**	**10,5**	**- 18,2**	**11,6**	**35,8**	**- 4,4**

The physical volume of doors and windows production is expressed in pieces. The two productions have tendency to increase. The doors have average annually rate from 35,8%, while the windows have smaller rate that is 11,6% for the given period (2011 - 2016). On average, 2118 doors and 2095 windows were produced annually.

The category other that includes the production of pallets, crates, boxes tends to decline with an average annual rate of -4,4%. The average annual production of the mentioned wood products is 9927 m^3 in the studied period.

The activity of furniture production includes: armchairs, two-seaters and sofa beds, seats and parts, office furniture, kitchen furniture, furniture for living and dining rooms, bedroom furniture and other wooden furniture. Data on the volume of furniture production, by structure, are given in Table 5.

The data in Table 5 shows that the production of armchairs and two-seater sofa has some variation. The most was manufactured in 2014 or 43996 pieces, and the lowest in 2011 only 13079 pieces. The total period tends to increase production with an average annual rate of 23,1%.

The production of seats and parts has uneven dynamics. This production also has an average annual increase of 106,2%. The largest production volume was realized in 2014 with a total of 1067953 pieces manufactured, while the smallest volume was produced in 2011 when it was only 23154 pieces. It was produced 727044 pieces of seats and parts average annual for the analyzed period.

Table 5. *Production volume - furniture production (per pieces), according to NACE Rev.2*

Year	Armchairs, two-seaters and sofa beds	Seats and parts	Office furniture	Kitchen furniture	Furniture for living and dining rooms	Bedroom furniture	Other wooden furniture
2011	13079	23154	154	259	9361	-	907
2012	26008	491875	455	628	12627	-	193
2013	31568	855330	773	704	12483	592	290
2014	43996	1067953	258	1013	12771	818	1514
2015	39646	1061861	205	1594	13291	1022	3912
2016	36927	826090	203	984	11792	611	5805
Average	**31871**	**727044**	**341**	**864**	**12054**	**761**	**2104**
AAR	**23,1**	**106,2**	**5,7**	**30,6**	**4,7**	**1,1**	**50,0**

There are variations in the production of office furniture from wood throughout the period. The general tendency has an increase, which is an average of 5,7% per year.

The kitchen furniture production has growth trend with an average annual rate of 30,6%. On average only 864 pieces of kitchen furniture were produced in the period 2011-2016.

The production of furniture for living and dining rooms is on average annually 12054 pieces of furniture. This production is characterized by a tendency of growth with an average annual rate of 4,7%.

In the analysis of the production of bedrooms we have registered production in the period 2013-2016. Like the other furniture production bedroom production there is a tendency of increase annually with rate of 1,1%, and average production of only 761 bedrooms in the given period.

In the manufacture of other wooden furniture is observed trend with growth dynamics annually with a rate of 50%. It was produced only 2104 pieces of wooden furniture on average in the analyzed period (2011-2016).

All the mentioned productions from the furniture production activity are characterized by a tendency of growth, which is most pronounced in the production of seats and parts in the studied period.

3.5 Foreign trade

Foreign trade is an area of total commodity turnover, which is carried out between companies from our country with economic entities from foreign countries, and it covers the import and export of goods. Through imports, the supply on the domestic market with finished products for consumption of the population is enriched, but it also supplies the economy with raw materials, raw materials, energy and equipment, which are necessary for the production. Through the export of goods, the surpluses of domestic products are sold, and thus the necessary foreign currency assets are acquired in order to be able to make the import. Thus, imports and exports are mutually dependent flows, which are very complex activities, which require knowledge of the international economic relations, payment instruments in the international trade, the foreign exchange and customs system of the country, the economic policy that the individual countries lead, the conditions of the world market and so on (Stankevik, M., 2007).

The export and import of the wood industry in the Republic of Macedonia will be analyzed in value through the manufacture of wood and wood products and furniture production, as well as total for the wood industry for the period 2011-2016. The data were obtained from the State Statistical Office of the Republic of Macedonia.

Export of wood industry by activity and total for the wood industry, according to NACE Rev.2, for the period 2011 - 2016 is shown in Table 6.

Table 6. *Export of wood industrial products, according to NACE Rev.2 (in 000 USD)*

Year	**Wood industry**		**Manufacture of wood and wood products**		**Furniture production**	
	Value	**(%)**	**Value**	**(%)**	**Value**	**(%)**
2011	97821	100	85972	78	11849	12
2012	84309	100	72032	75	12277	15
2013	57410	100	5402	9	52008	91
2014	90581	100	6076	7	84505	93
2015	121931	100	6258	5	115673	95
2016	153095	100	7945	5	145150	95
Average	**100858**		**30614**	**30**	**70244**	**70**
AAR	**9,4**		**- 37,9**		**65,1**	

The manufacture of wood and wood products is characterized by variable exports for the analyzed period (Table 6). The largest export was realized in 2011 from 85972000 USD, while the smallest export in 2013 was 5402000 USD. In addition to the variable dynamics of exports it has declining tendency for the total period with an average annual rate of -37,9%. The average export value is 30614000 USD. Furniture production has exports with dynamics of growth in the period 2011-2016. For the whole period, exports are characterized by a tendency of growth with an average annual rate of 65,1%. The average export value for this production for a period of six years is 70244000 USD.

As a result of the dynamics of exports in both productions, the total export of wood-based industrial products has a tendency to increase on average annually with a rate of 9,4% in the studied period (Table 6).

The average percentage share of export at manufacture of wood and wood products in the total export of wood-based industrial products is 30% and the participation of the export of furniture products is higher (70%) for the analyzed period.

The participation of the average export of wood industry (USD 105754000) in the total average export of products from the manufacturing (USD 4142287000) is 2,6% for the period 2013-2016.

Imports of wood-based industrial products by activity and total for the wood industry according to NACE Rev.2 for the period 2011-2016 is shown in Table 7.

Table 7. *Import of wood industry products according to NACE Rev.2 (in 000 USD)*

Year	Wood industry		Manufacture of wood and wood products		Furniture production	
	Value	(%)	Value	(%)	Value	(%)
2011	95550	100	77620	81	17930	19
2012	91916	100	78281	85	13635	15
2013	110613	100	67887	61	42726	39
2014	120273	100	73992	61	46281	39
2015	111306	100	69722	63	41584	37
2016	128704	100	74975	58	53729	42
Average	**109727**	**100**	**73746**	**68**	**35981**	**32**
AAR	**6,1**		**- 0,7**		**24,5**	

From the data in the previous table it can be seen that the import of products for manufacture of wood and wood products has a tendency to decline with an average rate of – 0,7%. The average value of imports is 73746000 USD for the total period. Furniture production has a tendency to increase imports annually with a rate of 24,5%. Average for the whole period, imports amounted to 35981000 USD.

The tendency of continuous increase of the import is accompanied by the total import of wood industry products with an average rate of 6,1% in the analyzed period. The total import is 1097727000 USD on average for the period 2011-2016.

The average percentage participation of imports of manufacture of wood and wood products in the total import of wood-based industrial products is 68%, while the share of the imports of furniture products is lower accounting for 32% for the analyzed period.

The participation of the average import of wood-based industrial production (71644000 USD) in the total average import of products from manufacturing (6225040000 USD) is 1,2% for the period 2013-2016.

Based on the analyzed data for the export and import of the total wood industry products has been made a balance for the period 2011 - 2016. The balance is shown in Table 8 and Graph 1.

Table 8. *Balance and coverage of imports with export to the wood industry*

Year	In 000 USD			Coverageof imports with export (%)
	Export	Import	Balance	
2011	97821	95550	2271	102
2012	84309	91916	-7607	92
2013	57410	110613	-53203	52
2014	90581	120273	-29692	75
2015	121931	111306	10625	110
2016	153095	128704	24391	119

As a result of the data on exports and imports in individual activities of wood-based industrial production the total balance of the wood industry is negative by 2015, with the exception of 2011 when the coverage of the import with the export is only 102%. In the last two years of the analyzed period, more precisely in 2015 and 2016, the balance gets a positive sign and the value of the export is slightly higher than the value of the import. For a better view of the condition the balance of exports and imports in the wood industry is shown in Figure 1.

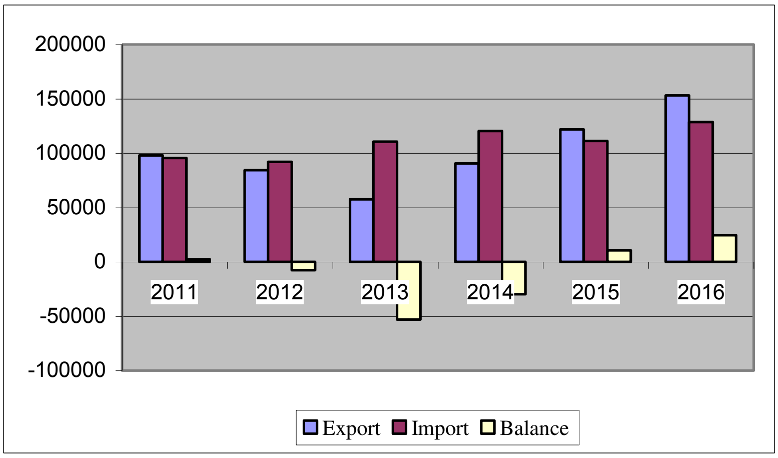

Figure 1. *Balance of export and import in the wood industry*

4. DISCUSSION AND CONCLUSIONS

The condition in the wood industry of the Republic of Macedonia is analyzed through the following indicators: number of active business entities, number of employees, average monthly net salary per employee, industrial production in natural data, export and import of wood industrial products. The period 2011-2016 was analyzed.

The participation of the enterprises in the wood industry (in 1104) in the number of business entities in the manufacturing (7928) is about 14% on average for the period 2011-2015 year.

The number of business entities has a decreasing trend in the wood industry, as well as in the manufacture of wood and wood products and furniture production. This trend was also followed by the number of business entities from the manufacturing.

The share of the number of enterprises from manufacture of wood and wood products in the total number of business entities in the wood industry is lower, amounting to 43%, while the number of enterprises from the furniture production is 57% in the given period.

The average participation of the number of employees in the wood industry (5926) in the total number of employees in the manufacturing (106732) is about 6% in the period 2011-2016.

The average number of employees in the wood industry has a tendency of growth with an average annual rate of 1,7%. The trend of growth has and the number of employees in furniture production, where the average rate is 4,6%. The number of employees in the manufacture of wood and wood products decline with an average annual rate of -3.2% during the studied period.

The average share of employees from the furniture production in the wood industry is 64%, while the employees of wood processing and wood products in the total number of employees in the wood industry are smaller and account for 36% for the analyzed period.

The average net salary per worker in manufacture of wood and wood products increases with an average annual rate of 3,6% for the period 2011-2016. The average salary - net salary per worker in furniture production have the same tendency to rise annually at a rate of 3,1%.

In the wood industry, the value of the net salary in the average amount, for all years of the analyzed period, in the manufacture of wood and wood products (12660 MKD) and furniture production (12753 MKD) are lower in relation to the average net - salary in the manufacturing (16015 MKD) and at the same time under the national average.

The production volume of manufacture of wood and wood products in the period 2011-2016 is characterized by the following production: sawn lumber from pine and beech, veneer and plywood production, parquet production, windows, doors and other (pallets, boxes, crates).

The average production of sawn lumber from pine is 3883 m^3, while the production of sawn lumber from beech is smaller than 2360 m^3. The average annual production of veneer and plywood boards is negligible with only 714 m^3. The parquet produced an average of 5962 m^3 in the analyzed period. The production of doors and windows is registered on a piece. Thus, the average annual production of windows was 2095, while 2118 doors were produced in the given period. The category other has the highest average production of 9927 m^3 which includes production of pallets, crates, boxes in the studied period.

For the production volume at manufacture of wood and wood products, it can be concluded that the production sawn lumber from pine and beech, the production of parquet and the category other (pallets, crates, crates and boxes) tend to decrease, while the production of parquet, windows and doors are characterized by a positive trend in the period 2011-2016.

The average volume of furniture production are 31871 pieces of armchairs, two-seaters and sofas, 727044 seats and parts, 341 pieces of office furniture, 864 kitchen furniture, 12054 pieces of furniture for living and dining rooms, 761 pieces for bedrooms and 2104 pieces of other wooden furniture in the period 2011-2016.

For the volume of furniture production, it can be concluded that, for all its holders, there is a tendency of increase in the analyzed period.

Export of products from manufacture of wood and wood products is characterized by an average decline rate of -37,9% in the period 2011-2016. The export of furniture products in the same period has an average growth rate of 65,1%. The movement of exports in separate production activities conditioned to the total export of wood-based industrial products has a tendency of increase on average annually with a rate of 9,4% in the studied period.

Regarding the average share in the total export of wood industry, for the analyzed period, the manufacture of wood and wood products is 30%, and the production of furniture with 70%.

The realized import of manufacture of wood and wood products drops on average annually with a rate of -0.7% in the period 2011-2016. Imports of furniture production increased with a growth rate of 24,5%. Based on the import trends in both productions, the total import of wood-based industrial products has an increase with an average rate of 6,1% in the given period.

On average imports of products from wood processing and wood products in the total import of wood industrial products account for 68%, while imports of furniture products are lower and amount to 32% for the studied period.

The total balance of wood-industrial production has a negative sign up to 2014, and by 2015 it will receive a positive sign. This means that from the year 2015 until the end of the period (2016) more exports were exported than they were imported into the wood industry.

Regarding the previous analysis, the manufacture of wood and wood products and furniture production have an important role in the national economy, which is reflected in the share of the total exchange of the country, the total number of employees in the processing industry, which contributes to harmonization of the total development processes of the country. According to the number of employees, the industrial enterprises are a recognizable part of the small business (micro, small and medium enterprises).

However, the Republic of Macedonia does not have enough skilled and educated staff in the wood sector, which with its knowledge and expertise will succeed in improving the existing production. Also, the wood industry in the Republic of Macedonia does not have an export chain for export of a national commodity mark (i.e. a brand), as have some successful European countries, for example, Sweden, Slovenia and Italy. One of the biggest problems is that the wood is exported as a raw material, and the products from that same wood are imported (Stankevik, M, 2007).

It is necessary for the competent state institutions to detect problems and by encouraging the production of the wood sector to ensure and promote domestic production. It should be noted, however, that the initiative should come from interested producers, who will set the real desire for change and vision to a higher level of processing of production, oriented towards export and new products.

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INFLUENCE OF THE NUMBER OF BELTS OVER THE PERFORMANCE OF THE CUTTING MECHANISM IN A WOODWORKING SHAPER

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ABSTRACT

This study presents the influence of the number of belts over the performance of the cutting mechanism in a woodworking shaper. The motion of the cutting mechanism was investigated by means of one and two V-belts. The vibration speed (r.m.s.) of the cutting mechanism was measured in three directions both empty and in stroke. The conducted experimental research provides a comparative analysis of the impact of the numbers of belts over the performance of the cutting mechanism.The obtained results can be used to optimize the number of the belts used to drive the cutting mechanism of the woodworking shapers.

Key words: woodworking shaper, number of V-belts, vibration

1. INTRODUCTION

Universal woodworking milling machines are one of the most common woodworking machines in the industry. With them details can be worked right, oblique and profiled. Placement of additional devices allows the user to perform a number of processes such as longitudinal plane milling, making teeth, knots, etc. (Filipov, 1979, Obreshkov, 1997). To be able to perform so many operations, the requirements for modern milling machines are high. They should be able to work in different conditions (modes), which influence the mechanisms, nodes and details of the machine. Contemporary wood spares should be able to work at different cutting speed depending on the material being processed. Most often the speed ranges between 30 m/s – 60 m/s (Gochev, 2005). This inevitably is associated with different cutting forces which load the cutting mechanism and cause forced vibrations of varying size. To create this cutting speeds, it is necessary the machine to work at different rotational speed. The change in rotation speed is achieved by changing the transmission ratio of the pulley diameters. Nowadays, the requirements for limiting the level of vibrations and noise accompanying the work of modern woodworking milling machines are increasing. Providing adequate measures to reduce the level of vibration and noise requires to have an insight in the nature of the phenomena typical of the machine and its individual elements (Vukov at all, 2016). It is necessary to look at specific studies, both theoretical and experimental, in which the machine can be considered as a mechanical shaking system with certain characteristics. The results can be used to formulate recommendations applicable to the design, production and operation not only for milling but also for other woodworking machines. The high requirements for reducing the level of vibration and noise accompanying the operation of modern woodworking machines requires a deep study of the dynamic processes in them. A subject of discussion in this study is a universal wood shaper with bottom location of the working shaft shown in Fig 1. The cutting mechanism is driven by classic V-belts. By using a specialized instrument to measure the vibration Bruel & Kjaer Vibrotest 60 the root-mean-square speed (r.m.s) is measured (ISO 10816-1:2002). The advantages and disadvantages of the machine using a number of belts at different speeds are discussed. The study is aimed at improving the reliability and efficiency of cutting mechanism to ensure the accuracy and quality of products.

Figure 1. *Universal wood shaper with bottom location of the working shaft*

2. CONSTRUCTION OF CUTTING MECHANISM

The construction of the cutting mechanism of the milling machine is relatively simple. A fitting mandrel is fitted on the machine shaft by a differential nut on which the cutting g tool is placed. The shaft of the machine is driven by an asynchronous electric motor with 3 kW power through the belt drive with classic V-belts. The mechanic-mathematical model is built by the authors on the basis of the cutting mechanism Fig 2.

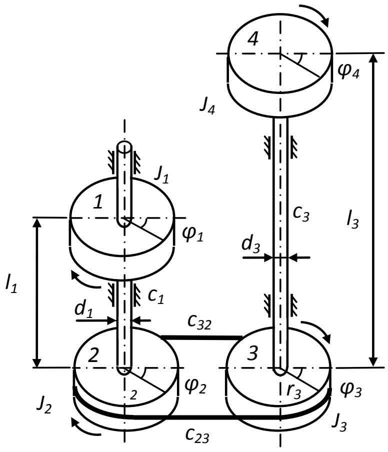

Figure 2. *Dynamic model*

This model includes four discrete mass connected with three massless elastic elements. The items considered as masses are the rotor of electric motor, the pulley mounted to the electric motor shaft, the pulley mounted to the shaft of the machine and the mandrel with the cutting tool. The elastic elements are the shaft of the electric motor, the shaft of the machine and the belt that drives the cutting mechanism. The angles of the rotation are φ_i, $i = 1, 2, 3, 4$ of the corresponding rotor. The elasticity coefficients of the electric motor's shaft, the belt and the spindle are taken into account. The elasticity angular coefficient of the electric motor's shaft is marked with c_1, and this one of the spindle – 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*). Reduced mass inertia moments of the cutting mechanism: J_1 – the mass inertia moment of the electric motor's rotor, J_2 - the mass inertia moment of the belt pulley on the electric motor's shaft, J_3 - the mass inertia moment of the belt pulley on the working shaft, J_4 - the mass inertia moment of the mandrel and tool. The other some symbols on fig. 2 are: d_1, d_3 – diameters of the electric motor's shaft and spindle, l_1, l_3 – computing length of the electric motor's shaft and spindle, r_2, r_3 – radius of the belt pullers on the electric motor's shaft and spindle, G – modulus of shearing. Using the presented model the authors numerically examine the natural frequencies and mode shapes of torsion vibration in the cutting mechanism of the machine (Vukov at all, 2013). The model presents features in the construction of a kind of wood shapers. Two most commonly used driving mechanisms are modeled – with a V-belt and with a ribbed belt. The results obtained from the numerical investigation are sufficient justification for going to experimental research. The present investigate examines how the number of belts influence over the operation of the cutting mechanism of the used milling machine.

3. OPERATION METHOD

To conduct the experimental part a universal wood shaper with bottom location of the working shaft is selected Fig.1. Before carrying out the practical part it is necessary to choose the factors in which the research will be conducted. These are rotation speed, cutting speed, feed rate, thickness of the wood removal layer and some others. The rotation speed which used for experiments was 6000 min^{-1}. This is one of the most commonly used in milling machines. The selected rotational speed is realized by pulleys mounted on the electric motor shaft and the machine shaft. The dimensions of the pulleys depend on the technical characteristics of the electric motor. The used engine has a power of 3 kW and speed of 2880 min^{-1}. The data is sufficient to pass calculation of diameters of the pulleys. Except diameters of the pulleys is necessary to specify the type of used V-belt.

The vertical section of the V-belts is determined by the transmitted power. In accordance with accepted standards, the required belt which can transmit 3 kW of power, is a belt with section A (Sokolovski, 2014). The experiment was performed with Z section belt. By default, these belts can be used to transmit power up to 2 kW. It should be noted that this can be achieved only at speed above 2000 min^{-1} (Sokolovski, 2014). The rotation speed of the electric motor allows this. It is known that each belt section requires a minimum diameter of the pulley. The minimum diameter provides the required traction coefficient, conforms the stresses that occur in the belt, provide the necessary belt durability and efficiency. The minimum diameter of the small belt pulley with section Z is 63 mm. For the present investigate this diameter was increased from 63 mm to 90 mm Fig 3. The larger minimum diameter increases the angle of coverage, increases the gearing capacity of the gear, the permissible power transmitted by a belt increases, the belt operates significantly more smoothly, and the stresses in it is also reduced.

The coverage angle is calculated by the formula 1 (Sokolovski, 2014).

$$\alpha_1^0 = 180^0 - 57,3\frac{d_2 - d_1}{a} \qquad (1)$$

where d_2 is the large pulley diameter, mm;
d_1 – small pulley diameter, mm;
a – wheelbase, mm;

The large diameter is calculated by the formula 2 (Sokolovski, 2014).

$$d_2 = i.d_1.(1-\varepsilon)\text{, mm} \qquad (2)$$

where d_2 is the large pulley diameter, mm;
i – gear's ratio;
έ – coefficient of elastic slip;

The required size of the large belt pulley to achieve s shaft rotation speed of 6000min^{-1} is 190 mm Fig 4.

Figure 3. *Spindle and small pulley*

Figure 4. *Electric motor with a pulley*

The number of belts required to drive the cutting mechanism of the milling machine is calculated by the formula 3 (Sokolovski, 2014).

$$z \geq \frac{P_1.K_5}{P_0.K_1.K_2.K_3.K_4} \qquad (3)$$

where P_1 is transmitted power, kW;
P_0 – permissible power transmitted by one belt, kW;
K_1 – coefficient which measures the influence of covered angle of the small pulley;
K_2 – coefficient reflecting the influence of the length of the belt;
K_3 – coefficient of the type of electric motor;
K_4 – coefficient for the number of belts;
K_5 – machine operating coefficient;

The larger minimum diameter of the small pulley increases the permissible transmission power. The number of belts decreases. The load on the bearings is also reduced. The calculations show that the number of belts required to drive the cutting mechanism are two.

To determine how exactly the number of belts influences the cutting mechanism, investigations have been made also with one belt. When the diameters of the pulleys have been calculated and the number of belts determined we can start with experimental studies. A cutter with diameter D = 125 mm was used and the cutting speed is 44 m/s Fig 5.

Figure 5. *Groove cutter*

By using a specialized instrument to measure the vibration Bruel & Kjaer Vibrotest 60 Fig.5 the root-mean-square speed (rms) is measured fig.6 (ISO 10816-1:2002). The measurement points are located on the bearing housing of the machine. It significantly responds to the dynamic state. The exact vibration state measurements need to make in three mutually perpendicular directions fig.7. Measurements are performed at idle state and during machine operation with test pieces of pine. The feed speed is U = 10 m/min and the thickness of the remove layer is h=12 mm.

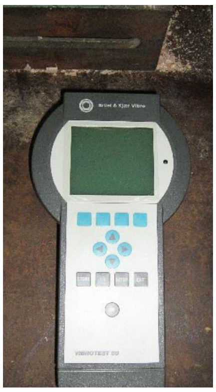

Figure 6. *Bruel & Kjaer Vibrotest 60*

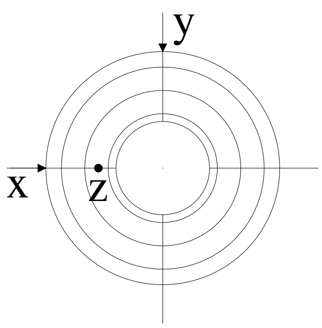

Figure 7. *Measurement points*

4. RESULTS

Table.1 shows the average values of vibration speed (r.m.s) at idle state. To drive the cutting mechanism a two classical V-belt section Z is used. Index A shows the measurements made in the different directions in the upper bearing. Index B shows the measurements made in the lower bearing.

Table 1. *Vibration speed at idle state*

Measurement points	A_x	A_y	A_z	B_x	B_y	B_z
Vibration speed (r.m.s)	2,5	3,4	2,4	1,1	2,5	2,6

Table.2 shows the average values of vibration speed (r.m.s) at idle state. To drive the cutting mechanism a single classical V-belt section Z is used.

Table 2. *Vibration speed at idle state*

Measurement points	A_x	A_y	A_z	B_x	B_y	B_z
Vibration speed (r.m.s)	2,5	2,9	2,6	1	1,8	3,5

Fig.8 shows the average values of vibration speed (r.m.s) at idle state close to the upper bearing.

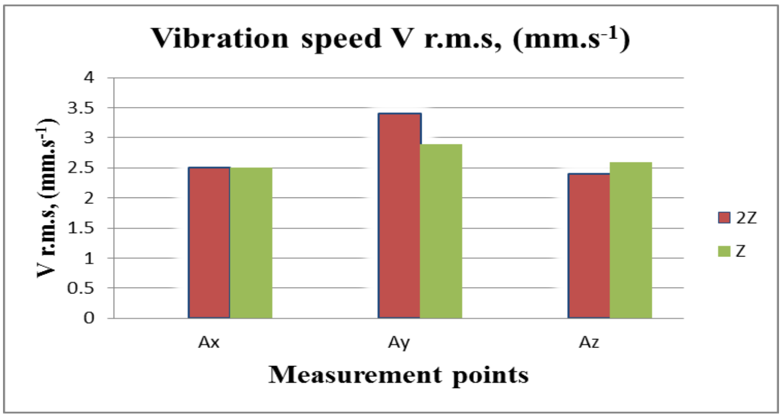

Figure 8. *Upper bearing vibration speed (r.m.s) at idle state*

Fig.9 shows the average values of vibration speed (r.m.s) at idle state close to the bottom bearing.

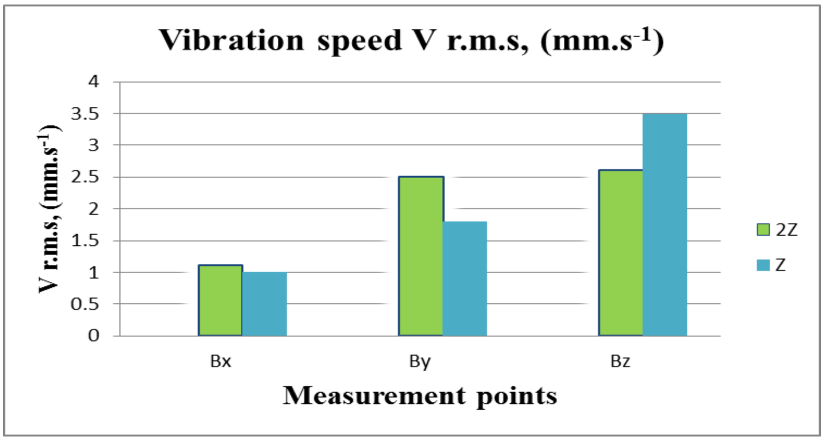

Figure 9. *Bottom bearing vibration speed (r.m.s) at idle state*

Table.3 shows the average values of vibration speed (r.m.s) during machine operation. To drive the cutting mechanism a two classical V-belt section Z is used.

Table 3. *Vibration speed during machine operation*

Measurement points	A_x	A_y	A_z	B_x	B_y	B_z
Vibration speed (r.m.s)	2,1	3,5	2,7	1	2,2	2,9

Table.4 shows the average values of vibration speed (r.m.s) during machine operation. To drive the cutting mechanism a single classical V-belt section Z is used.

Table 4. *Vibration speed during machine operation*

Measurement points	A_x	A_y	A_z	B_x	B_y	B_z
Vibration speed (r.m.s)	1,9	3	3,1	0,9	1,5	3,9

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Fig.10 shows the average values of vibration speed (r.m.s) during machine operation close to the upper bearing.

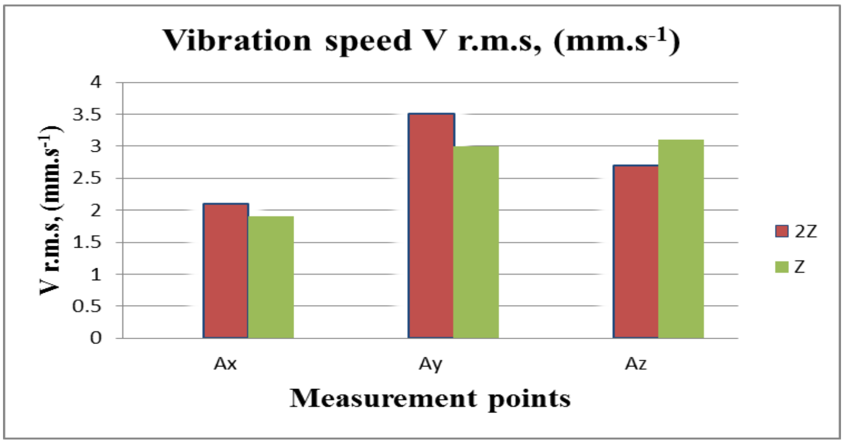

Figure 10. *Upper bearing vibration speed (r.m.s) during machine operation*

Fig.11 shows the average values of vibration speed (r.m.s) during machine operation close to the bottom bearing.

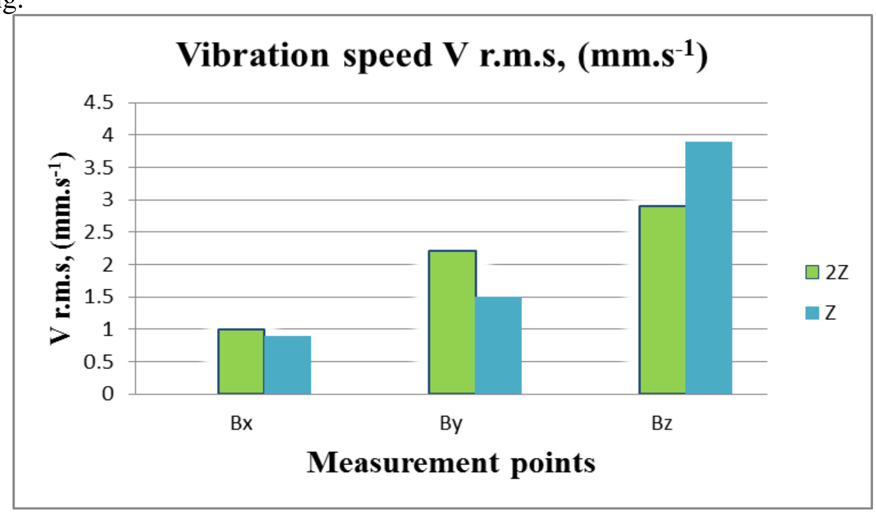

Figure 11. *Bottom bearing vibration speed (r.m.s) during machine operation*

5. CONCLUSION

As a result of research and analysis of the results the following conclusions can be made:

The measured vibration speed (r.m.s) at the Ax point (radial direction) and Az point (axial direction) coincide or is very close to each other regardless of the number of belts used. At Ay point (radial direction) is measured lower vibration speed (r.m.s) when single-belt drive used. Lower Bearing measurements show close vibration speeds (r.m.s) in the Bx direction with one and two belts. In the By direction measured lower vibration speeds (r.m.s) used a single belt and in the Bz direction the values are lower when the mechanism is driven by two belts. From the idling study, it can be seen that at three of the measuring points Ax, Az and Bx the values coincide or are close together. In two of the other points Ay and By measured lower vibration speed when using a single belt.

Measurements during machine operation running in the upper bearing at point Ax are almost the same for both belts. At the Ay point the vibration speeds is lower when one belt is used, and at the Az point when two belts are used. In the lower bearing the same tendency is observed as in the above.

From the made examinations, it can be seen that with the increase of the diameters of the pulleys, fewer belts can be used, as well as belts with less section. The tensioning forces of the belts decrease, which saves the machine bearings. It is always advisable to choose a larger diameter than the minimum allowed when it is possible. Larger pulleys diameters improve cutting mechanism performance and vibration speeds is lower. This is related the quality of the surfaces obtained, the reliability of the machines, the safety of the work, etc.

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STUDY ON THE VIBRATION SEVERITY GENERATED BY WOODWORKING SPINDEL MOULDER MACHINE

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ABSTRACT

The aim of this study was to investigate and determine the vibration severity, generated by a woodworking spindle moulder machine at different rotation frequencies and with different cutting tools. The assessment was based on the root mean square value of the vibration velocity (*v*) mm.s^{-1} (r.m.s.) measured in two mutually perpendicular radial directions in each of the bearing housings of the driving shaft of the machine (four measuring points).

Key words: wood shaper, vibration severity, vibration velocity

1. INTRUDUCTION

The dynamic behavior of a woodworking machine, determined by the magnitude of its vibrations, could be regarded as a benchmark for its manufacturing quality as well as for its technical condition as a result of its working load. In order to obtain better quality of the machined surfaces and at the same time to follow the hygienic standards, the magnitude of vibrations should be minimal (Vitchev, 2012).

The increased vibrations generated during milling frequently are a result of unbalanced rotating machine elements (shafts, rotors of electric motors and other) as well as of misalignment in the belt pulley (Vukov, 2008).

The use of unbalanced cutting tools is another reason for increased magnitude of the vibrations, generated in a given mechanical system. One of the main characteristics of the modern woodworking milling machines is the high cutting speed, accompanied by the respective high rotating frequency of the cutting tools. It is well-known that when the rotation speed of the working shaft of the machine increases, the magnitude of the overall vibrations increases as well (Bruel & Kjaer Vibro, 2011; Vukov et al, 2012).

As far back as 1959, it has been proven that when the unbalanced tables of the working shaft of a woodworking milling machine and the cutting tool caused unbalancing forces of 40 N, vibrations with a similar magnitude could be expected. Such vibrations could cause crash of the machine shaft which is due to the exceed permissible tire fatigue strength of the spindle.

To assess the vibrations, generated by a given machine, the highest vibration value measured at one of the measuring points where the measurements were made is used. According to the current Guidelines this maximal value is determined as vibration severity (ISO 10816-1).

The marginal values of the acceptable range of vibrations intensity of a given machine depend on a number of factors, such as type and dimensions of the machine, location, power of the motor etc.

The objective of the current study was to investigate the changes in the vibration severity of the woodworking spindle moulder machine at idling, measured at different rotation speeds and depending on the type of the cutting tool.

2. MATERIAL END METHODS

The experiments have been performed on the woodworking milling machine, type FD-3. The machine is equipped with a three phase electric motor with power N = 3 kW which, by means of a belt drive, provides the following rotational speeds of the machine shaft: 4000, 6000 and 8000 min^{-1}. The machine is presented in Figure 1.

Figure 1. *General view of the woodworking milling machine, type FD-3*

The vibrations magnitude was measured at all possible rotation frequencies of the working shaft of the machine at idling both without and with mounted four different cutting tools. The latter are presented in Figure 2.

Figure 2. *General view of the used cutting tools*
a – cutting tool F-1; b –cutting tool F-2; c – cutting tool N-1; d – cutting tool N-2.

The technical characteristics of the cutting tools are presented in Table 1, where *D* is the diameter of the milling cutter, *d* – diameter of the bore, *B* – milling width, β – angle of sharpening, γ – front angle of cutting, *z* – number of teeth.

Table 1. *Technical characteristics of the cutting tools*

Name	*D* mm	*d* mm	*B* mm	β °	γ °	*z* бр	*m* gr	Material of the teeth
Cutting tool *F*-1 (Fig. 2 *a*)	140	30	30	53	25	4	2275	HM
Cutting tool *F*-2 (Fig. 2 *b*)	100	30	30	55	23	4	1180	HM
Cutting tool *N*-1 (Fig. 2 *c*)	140	30	12	58	20	6	910	HM
Cutting tool *N*-2 (Fig. 2 *d*)	100	30	12	60	18	6	360	HM

The intensity pf the vibrations, generated by the tested machine depending on the rotation frequency of the working shaft and the mounted cutting tool is assessed on the basis of the root mean square value of the vibration velocity (v) mm.s^{-1} (r.m.s.) measured at different working modes of the machine. The measurements have been performed at four measuring points located on two bearing housings of the main shaft of the machine (two measurement points on each bearing housing). The measurement points on each bearing housing are located mutually perpendicular and radial to the main shaft of the machine (Fig. 3).

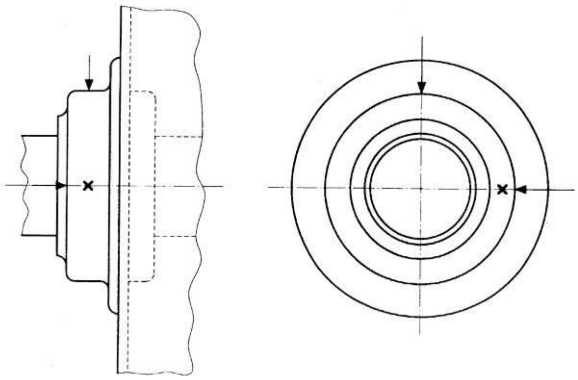

Figure 3. *Measurement points on one bearing housing*

In the current study, the measurement points are defined as follows:

- For the gearbox located in proximity to the driven belt pulley, hereinafter referred to as "lower bearing housing", the measurement points are indicated by D_x – in the direction parallel to the feed direction and D_y – in direction perpendicular to the feed direction;
- For the bearing housing located in proximity to the working top of the machine and the cutting tool, hereinafter referred to as "upper bearing housing ", the measurement points are indicated by G_x – in direction parallel to the feed direction and G_y – in direction perpendicular to the feed direction.

The requirements given in BDS ISO 10816-1 were strictly followed throughout the experiments.

For the measurement of the vibration velocity a vibration meter, model *Vibrotest* 60 (*Bruel & Kjaer Vibro*) has been used. The vibration meter is equipped with a sensor picking up vibration accelerations, model AS-065 (*Bruel & Kjaer Vibro*) (Fig. 4).

Figure 4. *General view of the vibration meter, model Vibrotest 60, equipped with a sensor for vibration accelerations*

A magnet is used for fixing the sensor to the bearing housings of the predetermined measurement points. To ensure the good fixation, the bearing housings have been cleaned out of paint, dust and other contaminants.

3. RESULTS AND DISCUSSION

The results obtained from the root mean square value of the vibration velocity (v) mm.s^{-1} (r.m.s.), measured at idling mode of the milling machine with and without cutting tools (Fig. 2) are shown in table 2. The values of the vibration magnitude, assessed in four measuring points at three rotation frequencies (n) – 4000, 6000 and 8000 min^{-1} are presented.

Table 2. *Values of vibration velocity (v), measured at different rotation frequencies of the working shaft at idling mode, with and without cutting tools*

Idling mode	**Vibration velocity *v*, mm.s^{-1} (r.m.s)**											
	n = 4 000 min^{-1}				**n = 6 000 min^{-1}**				**n = 8 000 min^{-1}**			
	G_x	G_y	D_x	D_y	G_x	G_y	D_x	D_y	G_x	G_y	D_x	D_y
Without cutting tool	0,76	0,68	0,55	0,62	2,04	2,76	0,74	1,92	1,74	3,42	2,17	3,32
With cutting tool *F*-1	2,56	1,39	0,48	0,98	1,17	1,68	0,49	0,85	3,52	3,05	2,15	2,82
With cutting tool *F*-2	2,39	0,81	0,77	0,82	1,72	1,87	0,72	0,97	3,24	3,20	1,70	2,15
With cutting tool *N*-1	1,76	0,62	0,72	0,96	1,38	1,68	1,10	0,92	3,35	2,75	1,37	2,35
With cutting tool *N*-2	1,53	0,96	0,48	0,85	0,95	0,80	0,65	0,76	3,81	2,90	1,25	2,55

From the experimental study and the results obtained we observed significantly higher vibration values at measurement points G_x and G_y which are located on the bearing housing in proximity of the cutting tool (upper bearing housing) compared to the vibrations measured at points D_x and D_y (lower bearing housing). The vibration intensity is determined by the maximal root square value of vibration velocity, measured at the respective working mode of the machine and the specific value is underlined in the table above.

The vibration intensity values, measured at different rotation frequencies of the working shaft and in accordance with the type of the cutting tool are presented in Figure 5. In the same figure, the upper limit values of the assessment zones of the machine performance in relation to the vibration intensity with electric power of the main motor up to 15 kW (ISO 10816-1:2002) are also presented.

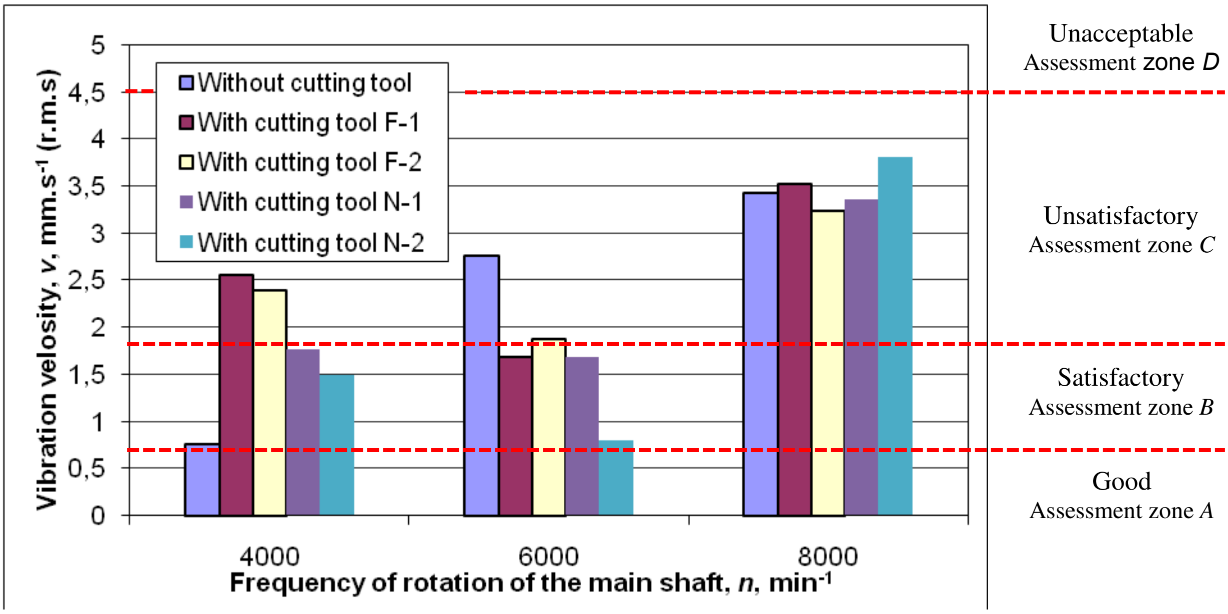

Figure 5. *Vibration severity in accordance to the cutting tool, measured at different rotation frequences of the main working shaft of the machine*

Changes in the vibration magnitudes, assessed at idling mode of the machine without cutting tool proved that the intensity of the vibrations increased with an increase in the rotation frequency of the working shaft. At rotation frequencies 6000 min^{-1} and 8000 min^{-1} the vibration intensity value falls in assessment zone *C* and the performance of the machine in relation to its dynamic behavior is determined as „Unsatisfactory”. By decreasing the rotation frequency to 4000 min^{-1} the vibration intensity falls in assessment zone *A* and the dynamic behavior of the machine is determines as “Good”. Mounting of a cutting tool significantly influenced the vibration severity. From the values presented on Fig. 5 is visible that mounting of one cutting tool (e.g. *F*-1, *F*-2 or *N*-2) could result in an increase or a decrease of the vibration severity at rotation frequencies 4000 and 6000 min^{-1}. When the cutting tools *F*-1 and *F*-2 are mounted, the severity of the vibrations at rotation frequency of 4000 min^{-1} significantly increased and the mean root square value of the vibration velocity *v* (r.m.s.) surpassed the limit value of 1,8 $mm.s^{-1}$ (the upper limit of assessment zone *B*). Therefore, the dynamic behavior of the machine is determined as „Unsatisfactory” (assessment zone *C).* When the cutting tools *N*-1 and *N*-2 are mounted, the dynamic behavior of the machine is defined as “Satisfactory” (assessment zone B), at the same rotation frequency of 4000 min^{-1}. When the machine works with the cutting tools *F*-1 and *F*-2, a significant decrease in the severity of the vibrations is observed when the rotation frequency of the working shaft increased from 4000 min^{-1} to 6000 min^{-1}. Under these conditions the dynamic behavior of the machine is assessed as “Satisfactory” (assessment zone *B*). This is most likely due to the fact that at rotation frequency of the working shaft n = 6000 min^{-1}, the balance of the total mass of the working shaft and the mounted cutting tools *F*-1 and *F*-2, which are with higher weight when compared to cutting tools *N*-1 and *N*-2 has been achieved.

At rotation frequency of the working shaft n = 8000 min^{-1} the vibration severity values fall into the assessment zone *C*. As a result of this, the dynamic behavior of the machine is assessed as “Unsatisfactory”. It has to be noted that at rotation frequency n = 8000 min^{-1}, the highest vibration severity has been achieved with a cutting tool *N*-2 which has also the lowest vibration severity when compared to the other cutting tools at rotation frequencies 4000 min^{-1} and 6000 min^{-1} of the working shaft.

4. CONCLUSION

Under the conditions of this study we found that for woodworking spindle moulder machines the higher vibration values have been observed at the upper bearing of the working shaft of the machine as with as well as without cutting tool. Our results proved the influence of the rotation frequency of the working shaft on the intensity of the vibrations during idling mode of the machine. Depending on the rotation frequency the dynamic behavior of the tested machine is assessed as "Good" (assessment zone *A*), at rotation frequency n = 4000 min^{-1} and assesses as "Unsatisfactory" (assessment zone *C*) at rotation frequency 6000 min^{-1} and 8000 min^{-1}.

Mounting of the cutting tool resulted in significant change in the vibration severity, generated by the tested machine, as at idling mode with the mounted cutting tool a significant influence had both the rotation frequency and the mass of the tool. For example, when the cutting tool *F-1* is mounted and the rotation frequency is n = 4000 min^{-1}, the vibration severity is v = 2,56 $mm.s^{-1}$ (r.m.s). However, it is interesting that using the same cutting tool and the rotation frequency is increased to 6000 min^{-1}, the vibration intensity decreased and v = 1,68 $mm.s^{-1}$ (r.m.s). This is equal to 34% decrease of the vibration severity at this working mode of the machine.

Regarding the dynamic behavior of the tested machine which was assessed in comparison to the vibration severity, the rotation frequency of the working shaft n = 6000 min^{-1} was recommended as optimal.

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A JUSTIFICATION OF THE USE OF SPECIALIZED CIRCULAR SAWS FOR WOOD

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ABSTRACT

The aim of the research presented in this paper was to establish a justification of the use of the specialized circular saws for wood cross cutting. This estimation is made on the base of machinability investigation of beech solid wood panel. The criteria for the assessment of the machinability of wood were cutting power and the roughness of the machined surface. The basic hypothesis was that different technological parameters of processing result in different quantities of energy needed for cutting, as well as different surface qualities in the case where the same cutting speed and feed rate were applied. The investigations were carried out for a variety of circular saw types (with different teeth number and tool geometries).

Key words: circular saws, machinability, cutting power, surface quality

1. INTRODUCTION

Circular saws are commonly used tools in mechanical processing of wood and wood based materials, including all production phases from the saw milling all the way to finall processing stages. Circular saws are also used for cutting other materials such as: plastic, metal, ceramics, different types of construction materials etc. Taking into the consideration ever present demand for increased productivity, simultaneously taking into account demanded product quality, the construction and design of circular saws are in perpetual changing process. Acording to Fragassa et al, 2015, there are two main factor groups with decisive role in defining characteristics of circular saws:

- factors attached to the cutting process itself (Material being machined, Cutting Thickness, Cutting Speed, Spindle Speed, Feed Rate, Noise Level, Surface Quality),
- factors attached to the tool features (Core Material, Diameter, Core Thickness, Teeth Thickness, number of teeth, Tip Thickness, Tip Granulometry, Lifetime and Tool Cost).

From the perspective of production process optimization, identification of above mentioned factors is necessary, since the small changes in their values can influence machined surface quality, energy consumption, production process efficiency, tool life cycle, level of noise etc.

The quality of machined wood surfaces is a primary and important characteristic of any wood product and it may be influenced by an array of physical, mechanical and aesthetical properties (Csanády et al, 2015). The surface roughness, among the physical properties, formed as a result of the repetition of the cutting tool tip moving along the workpiece at the desired feed rate plays a very important role. Due to its capillary-porous nature, wood has two major roughness components one is related to machining and the other one is caused by the anatomical structure of wood (Magoss 2008, 2013). Structural roughness coused by wood anatomy could not bee eliminated during machining process, whilst those influenced by process kinematics could and should be affected by controlling corresponding factors. A large number of studies about surface profile and roughness of machined products show that cutting conditions, tool wear, tool vibration, the material properties of tool and workpiece, as well as cutting parameters (including cutting speed, depth of cut, feed rate, tool geometry) significantly influence the surface quality of machined parts (Kilic et al, 2006, Lu, 2007, Csanády et al, 2015).

Another important aspect of machining process is energy consumption. More factors influence the energy consumption, such as choice of a suitable material for the cutting tool, its geometry and optimal cutting conditions (cutting speed v_c, feed rate v_f, feed per one tooth). Efficient use of energy impacts not only manufacturing costs but also other areas of industry such as customer service and environmental aspects (Quesada-Pineda et al, 2015). Energy consumption could be estimated indirectly by measuring of the power as presented in this research.

Circular saws for solid wood are specifically designed for making rip-cuts (circular saws for longitudinal cutting - ripping), cross-cuts (circular saws for transversal cutting - crosscutting), or a combination of both (universal circular saws). They differ in the number and profile of teeth and in the way of sharpening. The tooth profile and the way of sharpening must correspond to the required performance of a circular saw and to the requested quality of machined surface. They must be defined according to the type of workpiece (soft, hard wood and other wood-based materials) and the material of cutting edge (Kováč and Mikleš, 2010).

Solid wood panels were chosen as the objects of presented research, considering their increasing use. Solid wood remains the most valuable material in woodworking and joinery, but regarding its high price, not easily available. Satisfying solution that reconciles affordable price with the most important properties of solid wood was found in solid wood panels, and not surprising upward trend in their use. In ideal scenario formatting the panel could be done with single tool (saw) leading to processing without tool change, less production time and increased productivity. Justification of use of different circular saw types cross-cutting, ripping and universal saws) for perpendicular cutting of solid beach wood panels. Criteria for machinability evaluation of different saw types were: quality of machined surface (determined by average roughess *Ra* and mean peak-to-valley height *Rz*) and average cutting power *P*.

2. MATERIAL AND METHODS

The examination was conducted on solid wood panels with dimensions of 600 x 1000 x 30 mm made of longitudinal and transversely assembled beach wood lamells.

Previous to machinability examinations, researches of beach solid wood panel physical properties took place at Wood Properties Laboratory, Faculty of Forestry Belgrade University. Physical properties were tested in accordance with standard for determination of density (EN 323: 1993) and standard for determination of moisture content of wood-based panels (EN 322: 1993). Panel density and moisture content were tested on 56 samples with dimension of 50 x 50 x 30 mm. The samples have been conditioned before testing in laboratory environment conditions: relative humidity of 45±5% and room temperature of 20±3°C. These conditions brought the samples to an equilibrium moisture content of 8±1%, which is standard recommendation for values of moisture content for furniture in Serbian climates conditions. Mean values for samples' measured physical properties are presented in tab. 1

Table 1. *Average values of measured samples physical properties*

	Valid N	Mean	Minimum	Maximum	Variance	Std.Dev.	Coef.Var.
Density ρ_v (g/cm³)	56	0,733	0,660	0,817	0,001	0,038	5,182
Ovendry density ρ_0 (g/cm³)	56	0,711	0,637	0,796	0,001	0,039	5,419
Moisture Content v_a (%)	56	8,007	7,246	8,926	0,089	0,299	3,734

According to experimental data for investigated physical properties it was noticed that there is no considerable difference in the density and moisture content of observed panels and consequently absence of significant influence of these two properties upon investigated machinability criteria.
Further research refered to cutting power and surface roughness measurements as machinability criteria, based on which was evaluated justification of use of different types of circular saws for cross cutting of solid beach wood panels.

Cutting power measurements were conducted on universal machine Mini-Max at Centre for Machines and Wood Processing, Faculty of Forestry, Belgrade University. Variable feed rate was accomplished by Maggi Engineering, Vario Feed device, with feed rate ranging from 3 to 24 m/min. Three circular saw types manufactured by Freud (LU1C, LU2C, LU2B) were used for this research. These saws differed in the number of teeth and cutting edge geometry (Fig. 1). All tested saws were new, meaning that blunt radius of cutting egde was as recommended from manufacturer, not influencing obtained results. Other technical characteristics were same for all saws: diameter D=250 mm, core thickness b=2,2 mm and teeth thickness B= 3,2 mm. During the experiment feed rate was at constant value u=5 m/min, constant peripheral tool speed v=51,55 m/s, respectively constant rpm of the tool n=3940 min^{-1} and in transversal cutting direction.

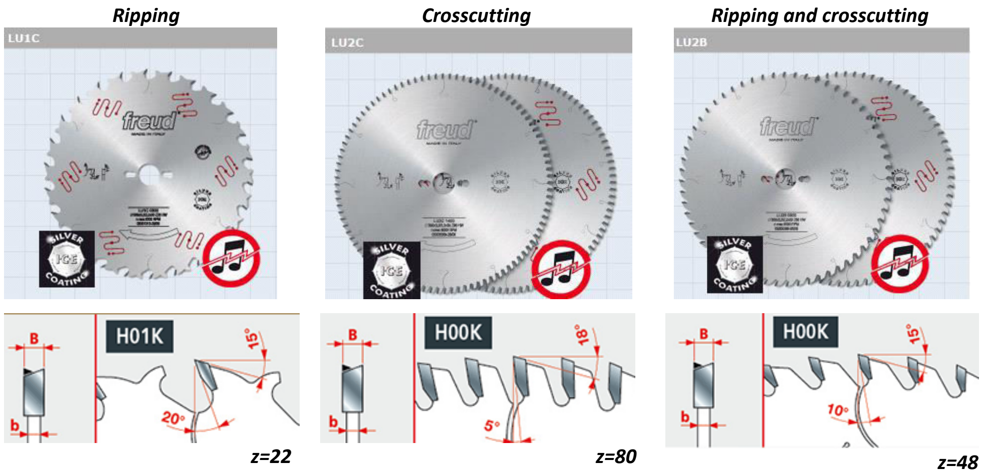

Figure 1. *Technical characteristics for choosen types of circular saws*

Cutting powers were determined indirectly by measuring engaged power of drive electromotor using the measurement-acquisition device SRD1 manufactured by UNO-NS, Belgrade, Serbia. The device was developed and applied in the Laboratory for Machines and Apparatus in order to measure, monitor process and analyze the power consumption in the cutting with different types of the utilized tools. The device has CW-TAN (Circutor) active power transducer for the unbalanced three-phase systems with these characteristics: Altering current 5 A, altering voltage 230 V, frequency 50 Hz, accuracy 0.5 % and analog voltage output 0-10 V. The possible measuring ranges are 1, 2, 5, and 10 kW. The operator is choosing expected range for better resolution of the results. The whole system is based upon Power Expert software platform. Measuring device is portable and can be connected to different machine types taking into account the maximum allowed power (up to 10 KW).

Power measurement installation is presented in next figure, where are denoted as follows: a) 1 – tool; 2 – oak sample; 3 – measurement acquisition device SRD1; and 4 – personal computer; b) data acquisition interface.

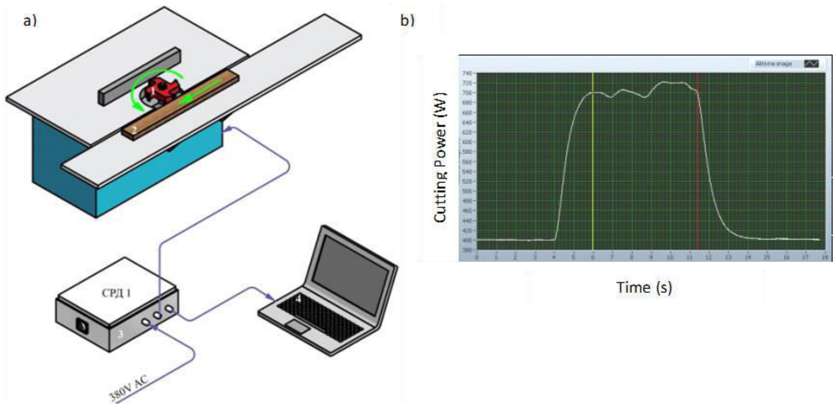

Figure 2. *Power measuring installation and data acquisition interface*

Machined surface roughness was determined by means of the contact-mechanical measuring device MarSurf PS10 (fig. 3a), at Faculty of Mechanical Engineering, University of Belgrade.

a) b)

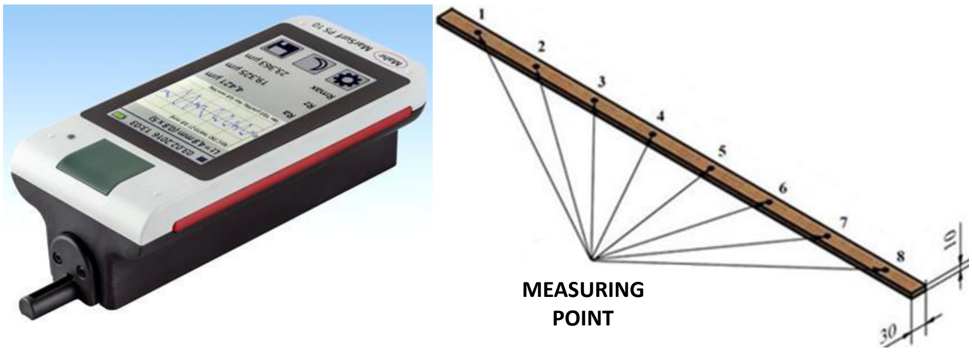

Figure 3. *a) Surface rougness measuring device MarSurf PS10, b) Surface measuring sample*

The trajectory length of contact spike was set according to ISO 4288: 1996, standard recommendations. Due to the expected values of arithmetic mean surface profile deviation (**2** < R_a ≤ **10** μm), the referent trajectory length was set to 2,5 mm, resulting in total observation lenght of 12,5 mm for surface roughness testing. Eight cuts per different circular saw type were performed and corresponding cutting powers were recorded, making the total of 24 cuts/measurements and providing 24 samples for surface rougness testing. Additionaly, there were 8 measuring points on each surface roughnes testing sample, resulting in total number of 192 measurements for suface roughess.

3. RESULTS AND DISCUSSION

As previously mentioned, the validation of different circular saw utilization based upon machinability criteria, included the cutting power and surface roughness measurements when cutting accros the grain. Experimental results for cutting power and 2 surface roughness parameters (average roughness Ra and mean peak-to-valley height Rz) for beach wood panels are presented in Table 2.

Table 2. *Cutting power and machined surface roughness parameters Ra and Rz*

No	Circular saw for ripping			Circular saw for crosscutting			Universal saw		
	LU1C			LU2C			LU2B		
	P (W)	Ra (μm)	Rz (μm)	P (W)	Ra (μm)	Rz (μm)	P (W)	Ra (μm)	Rz (μm)
1	378,310	5,908	48,530	839,340	2,745	27,139	676,140	6,659	47,053
2	389,080	5,765	48,827	847,620	2,839	26,441	676,000	6,462	46,119
3	392,230	6,585	50,569	848,400	2,728	27,993	680,200	6,686	47,590
4	394,300	6,362	47,688	853,570	2,805	25,471	684,500	6,569	44,389
5	386,350	6,885	52,957	857,480	2,971	26,104	679,560	6,377	44,339
6	383,200	6,962	55,577	857,720	2,765	27,028	681,980	6,307	44,054
7	374,500	6,890	61,753	848,950	3,047	27,443	675,450	6,413	45,964
8	380,990	6,854	57,814	855,430	2,935	28,247	687,210	6,202	41,992
Mean	384,870	6,526	52,966	851,064	2,855	26,983	680,130	6,460	45,186
Minimum	374,500	5,770	47,690	839,340	2,730	25,470	675,450	6,200	41,990
Maximum	394,300	6,962	61,753	857,720	3,050	28,250	687,210	6,690	47,590
Variance	47,346	0,220	25,413	38,813	0,014	0,888	18,265	0,029	3,368
Std.Dev.	6,881	0,469	5,041	6,230	0,118	0,943	4,274	0,171	1,835
Coef.Var.	1,788	7,180	9,518	0,732	4,132	3,493	0,628	2,643	4,062

It is obvious that the lowest average cutting power value (384,870 W) was recorded in the case of ripping circular saw (LU1C) by as much as 55% less regarding to 851,064 W when crosscutting circular saw (LU2C) and about 44% less then 680,13 W which was obtained with universal circular saw (LU2B). These results are not surprising taking into the consideреation discrepancy between selected saw types, such as rake angle γ and number of teeth z (LU1C: γ=20°, z=22; LU2C: γ=5°, z=80; LU2B: γ=10°, z=48). Along with other cutting conditions the cutting angle is decisive for the performance of tools, machines and economics of all machining types, machined surface quality and dimensional exactness of a workpiece (Kováč and Mikleš, 2010).

The cutting angle δ magnitude directly influences the value of cutting force for every form of cutting. The lower the value of cutting angle, the easier for cutting edge to penetrate the wood resulting in less cutting power value, and vice versa. Increasing the rake angle causes decreasing of cutting angle, cutting edge easier penetrates the woods, and the specific cutting resistance is lesser.
It is also known that the increase of number of incidence teeth increases the cutting power. In the case of LU1C the incidence teeth number was Z_{Z1} = 1,47, for LU2C it was z_{z2}=5,35 and for LU2B, z_{z3}=3,21. Measured values of cutting power for all 3 saws prove above statement.
Machined surface roughness parameters Ra i Rz for different circular saw types are presented in Fig.4.

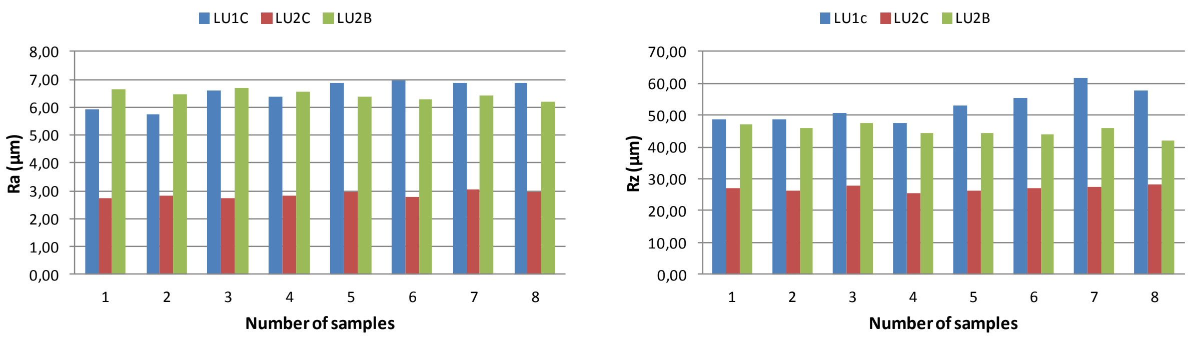

Figure 4. *Vales of machined surface roughess parameters Ra i Rz for different circular saw types*

The average roughness (Ra) and mean peak-to-valley height (Rz) act differently depending on the saw type. The lowest average roughess and peak-to-peak values (Ra=2,855 µm and Rz=26,983 µm), consequently the best surface quality were obtained in the case of crosscutting circular saw LU2C.
The ripping circular saw (LU1C) and universal circular saw (LU2B) showed similar behavior with no significant diference in the value of Ra (average Ra=6,526 µm for LU1C and Ra=6,460 µm for LU2B). However, the value of Rz is 14 % higher in the case of LU1C (Rz=52,966 µm) comparing to the Rz value for LU2B (Rz=45,186 µm).

4. CONCLUSIONS

In accordance with previously said it is possible to conclude that:

- from the perspective of cutting power and consequently power consumption, the best performance is shawn by ripping saw blade (P = 384,870 W), followed by universal and crosscutting circular saw (P = 680,130 W and P = 851,064 W, respectively);
- concerning the cutting power, with increase of incidence teeth the cutting power was getting higher;
- far best machined surface quality expressed through surface roughness parameters Ra and Rz is provided by deployment of crosscutting circular saw, what could be explained by largest number of teeth and specific tooth shape adjusted specialy for transversal wood cutting;
- other two saw types performed in similar manner, more teeth the better surface quality;
- the surface quality and cutting power stand in reverse ratio for all types of investigated circular saws;

Generally it is possible to conclude that, in this research, predominant factor affecting both the cutting power and surface guality was the number of teeth at specific circular saw. Since the influence of other factors such as feed rate, cutting speed and tool override were not examined there is room for futher researches.

Acknowledgments

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THE INFLUENCE OF WOOD DENSITY UPON MASS LOSS DURING ABRASIVE WATER JET CUTTING

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ABSTRACT

Obvious advantages of Abrasive Water Jet Cutting (AWJC) lead to inevitable process analysis by means of multifactor experiment layout. Input variables of the AWJC chosen for this research were: jet pressure (*p*), feed rate (*u*) and nozzle distance (*h*), while the observed output variable was mass loss (Δm), all in respect to observed oak wood density. However some other process characteristics such as deposed mass of abrasive particles, kerf width and visual surface appearance were also taken into consideration. Comparing results obtained from previous researches with those regarding the influence of wood density differences were found, but not enough significant to improve prior mathematical models in the terms of parameter significance for chosen values.

Key words: abrasive water jet cutting, particleboard, oak wood, mass loss, orthogonal plan matrix, electronic microscopy, abrasive particles, mathematical model

1. INTRODUCTION

For the means of better quantitative and qualitative use of the wood and wood based materials special attention could be paid on the trim waste reduction during mechanical processing, especially different forms of cutting. Comparing the AJWC with conventional cutting processes it is possible to notice some advantages of AWJC such as: 1) contour cutting; 2) very precise cutting with better cutting surface quality; 3) lesser frying and chipping and 4) reduction of environmental pollution with wooden particles.

According to previous researches by other authors it was possible to conclude which AWJC parameters could significantly affect the total amount of eroded wood, expressed as mass loss. This latter is especially important in sawmilling. The main previous conclusions important for conducted research are that the prediction model could be given in the respect of depth of penetration, feed rate and wood density affect the quality of on cutting surface roughness, and that the jet geometry significantly influences the amount of eroded material.

However, there were no clues of the mass of deposed abrasive particles and its influence upon the total mass loss, so as the influence of wood density and wood hardness on the wasted mass of trimmed material.

In previous researches (Svrzić et.al. 2015; 2016) it was found out that the chosen exponential model is adequate but there was no parameter significance, so the aim of this study was to see if the there is any change in model or model parameter significance, when sample densities are taken into the consideration.

2. MATERIAL AND METHOD

Material used for this research were oak (*Quercus robur* L.) slats, with dimension of 40 x 90 x 21 mm. Slats were all picked from the radial direction of the trunk in order to diminish anatomic influences upon wood properties. All samples were divided into 9 different groups for the purpose of cutting with the AWJ, and for each group additional 10 samples with dimensions of 50 x 50 mm were made for moisture content determination.

Moisture content of oak wood was carried out according to EN-322, using laboratory oven and electronic scale at Department of Chemical & Mechanical Wood Processing, Faculty of Forestry, Belgrade University. The electronic scale was also used for density determination and mass loss measurements.

The sample densities were determined after reaching equilibrium MC after conditioning phase, for each sample individually.

All samples were conditioned at the controlled temperature of 20±2 °C, in the exicator, above saturated NH_4 NO_3 solution where absolute humidity was at 65±5 %.

The amount of deposed abrasive particles was estimated according to images taken from Scan Electronic Microscopy (SEM) laboratory, Faculty of Mining and Geology, Belgrade University.

The areas with the desist population of abrasive particles were investigated. The dimension of each spotted particle was measured and referring to previously known density of abrasive material it was possible to calculate the total abrasive mass on investigated area, resulting in the highest possible deposed mass.

Prepared samples were subjected to AJWC on Numerically Controlled NC 3015E machine, produced by WJS Water-jet, Sweden. The performed cuts on the samples were orthogonal with the grain direction. The values of input parameters for conducted experiment are shown in Table 1.

Table 1. *AWJC input parameters*

Jet pressure p (Mpa)		Nozzle distance h (mm)		Feed rate u (mm / min)	
p_1	200	h_1	2,5	u_1	500
p_2	230	h_2	5	u_2	600
p_3	250	h_3	10	u_3	700

After processed by AWJC the samples were conditioned once again, in order to regain the moisture content before cutting. Than is possible to re-measure the mass of each specimen.

The difference between mass of the entire slat before AWJC and two remaining and conditioned pieces of the same after AWJC was used for calculating total mass loss per meter Δm (as in eq.1),

$$\Delta m = \frac{m_0 - m}{l} \cdot 1000 \; [\text{g/m}] \tag{1}$$

where: m_0 stands for initial sample mass before AWJC, m is the sum of pieces after AWJC and conditioning phase and l presents the cutting length of each sample (sample width).

The conditioning phase obtained equal MC for proper mass loss measurements.

The results analysis was carried out by the means of multifactor experiment layout (Box-Wilson plan matrix) providing efficient method for mathematical model determination.

The coding values (-1, 0, 1) presents minimum, zero and maximum magnitude levels, respectively, for each observed input parameter (x_1, x_2, x_3), as presented in Table 2.

In order to eliminate the influence of the wood density upon the mass loss, the charts of mass loss to density were determined. According to established relations expressed as linear equation, and introducing the mean density value it was possible to recalculate the mean mass loss value for each group of specimens independent from density variation.

It was presumed that mathematical model equation would have exponential form:

$$R = C \cdot f_1^{p_1} \cdot f_2^{p_2} \cdot f_3^{p_3} \tag{2}$$

Comparison of calculated and tabular values for model adequacy and parameter significance according to Fischer criterion, gives answer if proper model was selected and if there was enough influence for varying values of selected input parameters.

Additionally the kerf width and cutting surface were photographed with SUPER EYE digital USB microscope.

3. RESULTS AND DISCUSSION

According to conducted research the following results are presented.

The value of the MC for control samples were at about 10,1 %. After AWJC average MC slightly increased to approximately 10,31 % . The third measurement after cutting and conditioning showed the value of the MC reached its initial value (not exceeding more than 0,2 % of relative change).

The microscopic examinations for proving the presence of abrasive material on cutting surface were conducted by means of Scanning Electron Microscope (SEM). Detailed examination of presence of abrasive particles, originated from garnet mineral and its alterations, did not show significant amount of mass deposed on cutting surfaces and it was evaluated at about $4{,}15\cdot 10^{-4}$ g/cm^2.

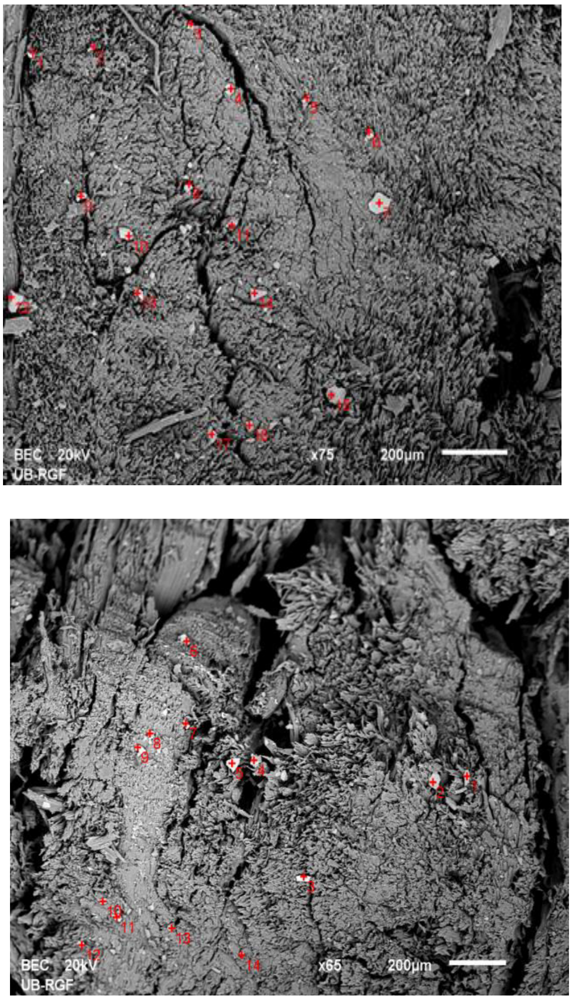

Figure 1. *Deposed garnet particles on the cutting surfaces*

Calculation showed slightly altered change in the mass, not enough to be considered as influential factor for final results.

The mass difference of the same samples before and after AWJC was denoted as $\Delta m^1 = m_0 - m$, and was used in order to determine density to mass loss correlation for each regime code.

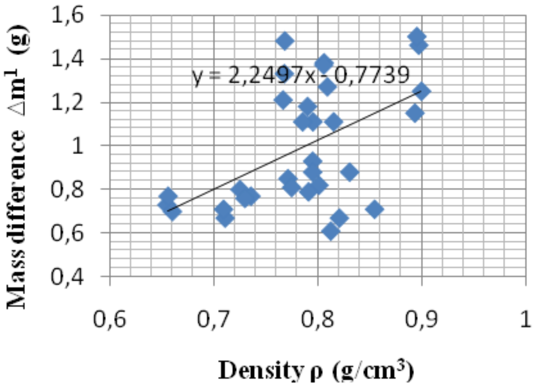

Chart 1. *Mass difference to density dependence for cutting regime coded as 000*

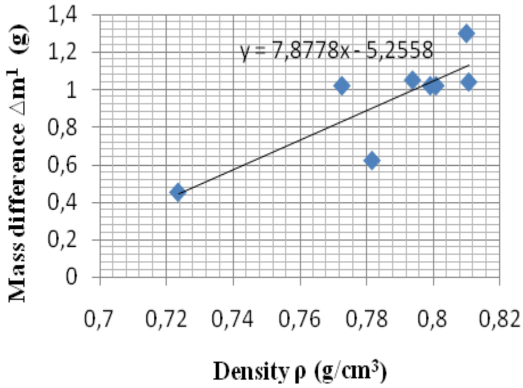

Chart 2. *Mass difference to density dependence for cutting regime coded as 111*

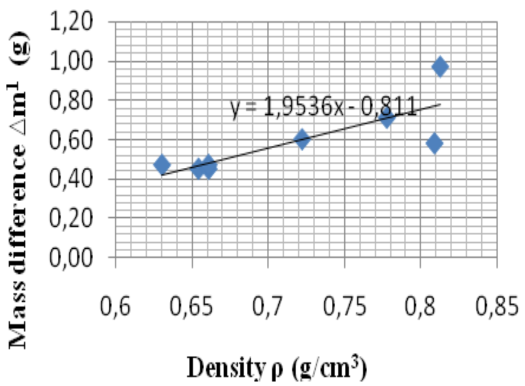

Chart 3. *Mass difference to density dependence for cutting regime coded as 1-11*

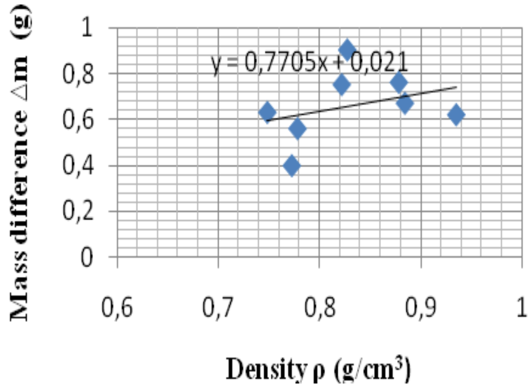

Chart 4. *Mass difference to density dependence for cutting regime coded as -111*

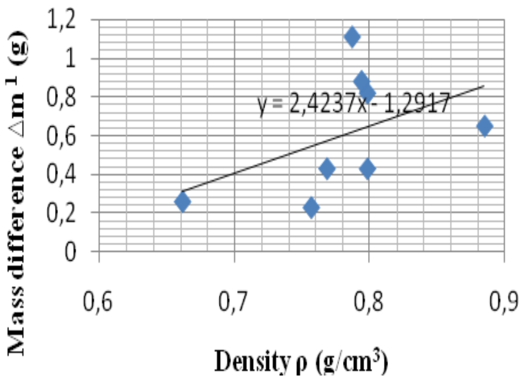

Chart 5. *Mass difference to density dependence for cutting regime coded as -1-1-1*

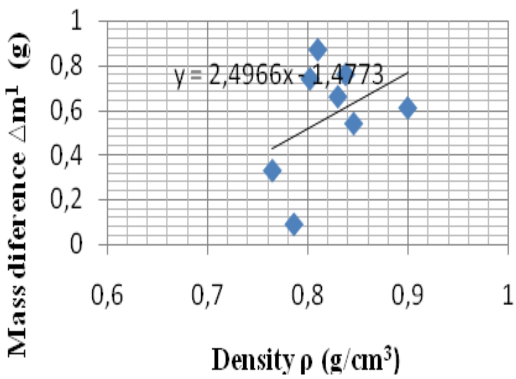

Chart 6. *Mass difference to density dependence for cutting regime coded as -11-1*

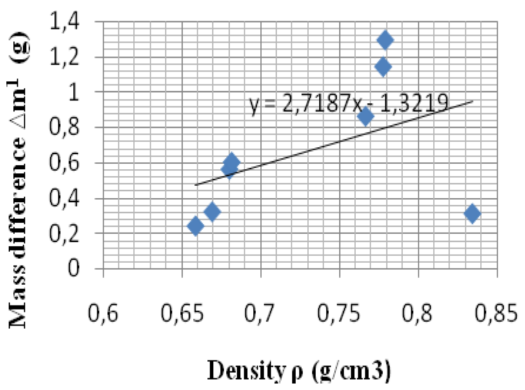

Chart 7. *Mass difference to density dependence for cutting regime coded as 11-1*

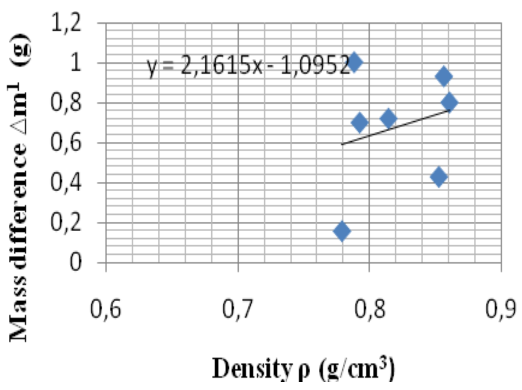

Chart 8. *Mass difference to density dependence for cutting regime coded as -1-11*

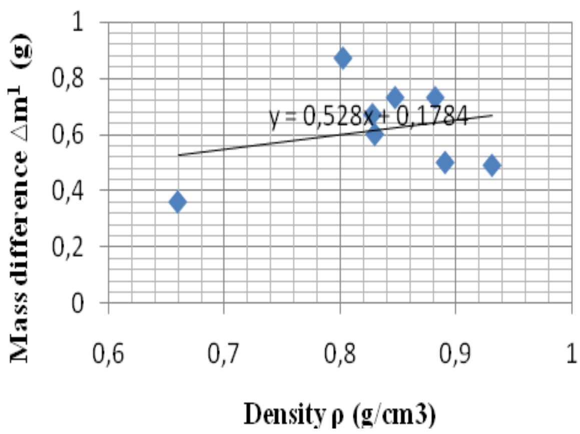

Chart 9. *Mass difference to density dependence for cutting regime coded as 1-1-1*

On the basis of mass difference to density correlations and mean values of density for each AWJC regime it was possible to calculate the average mass loss per meter Δm, as shown in Table 3.

Table 3. *Average sample group densities and mass losses*

No.	Regime code	Average density (g/m^3)	Mass loss (g/m)
1.	0 0 0	0,785	24,82
2.	1 1 1	0,786	23,5
3.	1-1 1	0,716	14,69
4.	-1 1 1	0,83	16,53
5.	-1-1-1	0,781	15,03
6.	-1 1-1	0,822	14,37
7.	1 1-1	0,73	16,62
8.	-1-1 1	0,82	16,93
9.	1-1-1	0,834	15,47

Obtained results and analysis gave following mathematical models for AWJC of oak wood in equation 3.

$$\Delta m = 0{,}11648 \cdot p^{0{,}43023} \cdot h^{0{,}0854} \cdot u^{0{,}41088} \tag{3}$$

According to the *F* test criterion mathematical model was proven to be adequate, since the calculated value of F_r was 0.538137 that is less than tabular value for level of significance of α=0,05 and f=5 deegres of freedom, which is F_t = 9.01.

However, none of cutting parameters showed significance in proposed exponential model equation (Eq.3). The mathematical model acted as in previous researches (Svrzic et al 2016) even after density variations were taken into the consideration.

4. CONCLUSIONS

Based on all been said so far it is possible to conclude that:
- proposed mathematical model proved to be adequate;
- neither of process parameters (pressure, nozzle distance and feed rate) acted significantly in the respect to AWJC mass loss, according to *F* test criterion;
- the pressure factor is not significant from obvious reason: threshold level have been exceeded (all samples had clear and completed cut) and further increase in pressure intense would not affect the amount of eroded material;
- the mass loss is higher with increased sample density, but not effecting process parameter significance;
- the kerf geometry showed that kerf average width was at about 1 mm, proving the superiority of AWJC for wood cutting, especially when quantitative yield is taken into the consideration;
- there was no noticeable effect of disposed abrasive particles upon sample mass change;
- it would be practical to widen the value span of observed parameters, especially nozzle distance and feed rate, in future research.

Acknowledgment

This paper was realized as a part of the project "Studying climate change and its influence on the environment: impacts, adaptationand mitigation" (43007) financed by the Ministry of Education and Science of the Republic of Serbia within the framework of integrated and interdisciplinary research for the period 2011- 2017.

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STREET FURNITURE IN CROATIA – PARK USERS REQUIREMENTS FOR (WOOD) URBAN EQUIPMENT

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ABSTRACT

Urban equipment, in generally, with an accent to street (wood) furniture creates the settings for resting, sitting and eating, but also for socializing, playing, and talking. Such settings may be of great importance to the elderly people, those with limited mobility, adults who have small children, but also to a joung people (students and/or schoolars) and on the other hand, also to business people. In the context of urban equipment, wood is a very usuasl choice of materials for street furniture, because it is a netural friendly material, it has lots of visual, functional, and design advantanges.

The aim of the paper was to find out the opinions of urban equipment users with an accent to park wood furniture. The street (wood) furniture analized in this paper was related to tables, banches, and dust bins.

Key words: wood furniture, urban equipment, street furniture, Croatia

1. INTRODUCTION

Urban equipment, in generally, with an accent to street (wood) furniture creates the settings for resting, sitting and eating, but also for socializing, playing, and talking. Such settings may be of great importance to the elderly people, those with limited mobility, adults who have small children, but also to a joung people (students and/or schoolars) and on the other hand, also to business people. In the context of urban equipment, wood is a very usuasl choice of materials for street furniture, because it is a netural friendly material, it has lots of visual, functional, and design advantanges. According to Wan (2008) street furniture refers to objects and facilities located in urban public spaces that provide various services and functions to the public and it is one of the essential elements of the urban environment that contributes to humans and their activities. Even more, street furniture plays a significant role in determining the quality of an urban environment and in representing the image of a city. Of all the urban landscape elements, street furniture has the closest contact and interaction with humans. The role of street furniture has been emphasised in developed parts of the world (e.g., the United States, Europe, and Japan) Under the influence of rapid urbanisation and globalisation, global warming, and a growing emphasis on humanism, urban landscape design (including street furniture) is facing unparalleled challenges and requirements in the 21st century. However, comprehensive studies on street furniture are rare.

In order to give some contribute to the research activities regarding a street furniture and also maybe to provocate stakeholders involved to these activities thet he aim of the paper was to find out the opinions of urban equipment users with an accent to park wood furniture. The street (wood) furniture analized in this paper was related to tables, banches, and dust bins.

Street (WOOD) furniture chatacterisitics

Street furniture create the settings for resting, sitting and eating, and social encounters with others which accoriding to Deakin *et al.* (2007) may be of great importance to the elderly, those with limited mobility, and adults who have small children; but in addition to their functional aspect, items of urban furniture such as benches and tables in parks and squares can also be socially significant. However, Main and Greet (2010) noted that an appropriately selected and placed furniture can draw people to outdoor spaces with the aim of making them feel welcome, relaxed, and involved. If street furniture is properly integrated in the design of a public space, it creates an identity and develops a sense of place around it (Transport & Regional Affairs Department of the Environment 2000). When desidig about furniture items for outdoor spaces Yücel (2013) noted that the items must be constructed of safe materials and designed to prevent injury, without sharp edges or exposed fasteners. More precisely, they should be attached to the ground with anchor bolts (for example, using surface mounting, i.e. attaching a bench to a concrete slab), or embedded in the ground. Also, according to Yücel (2013) furniture selection and design should take into account weather effects such as sunlight, expansion and contraction, wind stress, moisture, and in some cases, salt spray, frost, or ice. When taking into consideration which material to use for street/urban furniture Yücel (2013) moted that the most popular materials used are steel and wood, while other possibilities are stone, concrete, recycled plastic and various other materials. He also noted that the choice of materials depends on the context and limitations of the design; for example, whether the furniture should be resistant to vandalism, whether ventilation is needed for drying it during wet weather spells, what the weather conditions may be, how frequently the furniture is likely to be used and by whom, what the initial costs are, including mounting, the costs and ease of maintenance, and whether there is a possibility of using eco-friendly materials. In that context, wood is popular choice of material for street funriture, because it is a natural material that feels warmer in cold weather and cooler in hot weather, unlike metals. Wood may be inexpensive, but the type of wood selected should depend on the location and frequency use of the furniture. Paint or other finishing materials of furniture should be non-toxic and non-staining (Lovejoy 1997). In addition, the use of recycled materials in street furniture enables manufacturers to conserve natural resources and reduce their carbon footprints; it also educate the users of the furniture and the public, on the importance and mental and physical benefits of recycling (Yücel 2013). The location of the furnishings should be based on their functions (Crankshaw 2008) and coherent with the patterns and designs of the hard surfaces at the site (Yücel 2013).

2. MATERIAL AND METHODS

The sample frames were random samples of 200 persons visiting some of urban parks placed in the capital yity of Croatia, Zagreb. A personal, 'face-to-face' interview based on survey questions was the method used for surveying respondents for this study. Based on research objectives, a questionnaire was developed, pre-tested, and finalized based on pre-tested inputs. Straightforward questions and Yes/no, items were used. Furthermore, multi choice item measure was used because according to Thorndike (1967) cited by Lewis-Beck et al. (2004) it can be a superior to a single, straightforward question. At the beginning of personal interviewing the introducing statement by a researcher, justifying the research study, legitimize him, explaining the recipient's (respondent's) role and convincing that his participation in research is essential (Dillman et al., 1976) was presented to respondent.

The questionnaire consisted of 16 questions and data collection was carried out during March, April, and May 2017.

Data were analyzed in MS Excel.

3. RESULTS AND DISCUSSION

Profile of 'park users' in the Zagreb City

As seen in Table1, respondents were asked to indicate their age, education level and gander. Age was classified into five categories, while education was classified into three categories. As shown in

Table 1, according to 200 respondents, 43% of respondents were male and 57% of total number of respondents were female. More than half, 61% are people between 19 and 35 years old. In addition, 9% of respondents were teenagers, between 14 and 18 years old. According to respondents, 60.5% of total respondent number are high school graduate people, followed by respondents who have university education level (29.5% of total number of respondents). Only, 10% of respondents have a primary school level of education

Table 1. *Respondent profile of park users in Zagreb City*

Gender of respondents (%) (n=200)		Education level of respondents (%) (n=200)		Age groups of respondents (%) (n=200)	
Male	43	Primary school	10	14 – 18 years old	9
				19 - 25 years old	32
		High school	60.5	26 – 35 years old	29
				36 – 50 years old	12
Female	57	University	29.5	51 – 60 years old	13
				Older than 60	3

Respondents were asked to note with whom they mostly spend time in some of parks in the Zagreb City. Sixty four percent of 200 respondents noted that the time they spend in parks mostly with their friends, while 1/3 of the respondents noted that they spend it alone (34.5%) or with their pets (37.5%). Further more, 22.7% noted that they often come to a park (big City parks or local neighborhood park) to spend with their children. In addition, respondent were asked to indicate the purpose of spending time in the city and/or the neighborhood parks. As seen in figure 1, 21.5% of the respondents noted that they are coming to parks to play with their children, 20.5% of respondents visit parks to do some kind of physical activity *e.g.* body exercising or training, followed by spending a time in a picnic (18.5%). On the other hand, majority of respondents (80%) noted that they are coming to parks to have some relaxing or resting time.

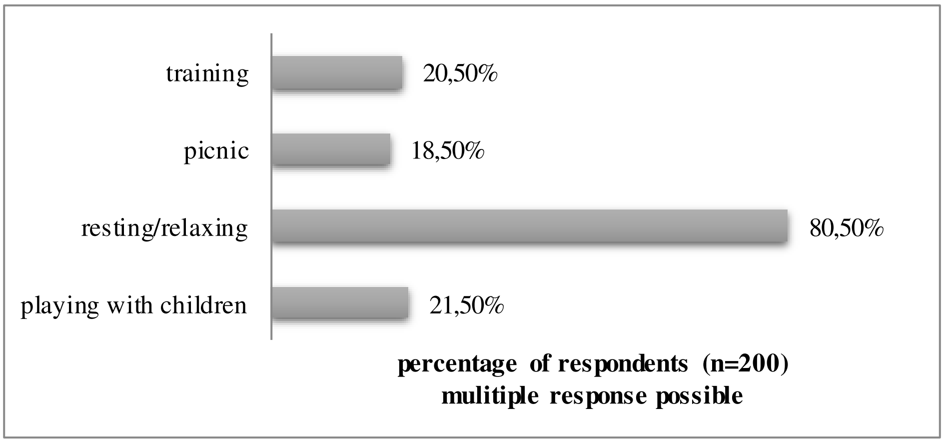

Figure 1. *The purpose of spending time in the Zagreby City parks (n=200)*

Such a large difference in percentages for the use of parks can be attributed to the lack of urban park equipment itself, which can be read from the standpoint of urban park equipment itself.

Evaluation of parks which they attend often was the next question that was presented to 'park users' in the Zagreb city. As seen in figure 2, twenty nine percent of the respondents noted that they are satisfied (evaluation mark 3), while 33.5% noted that they mostly satisfied (evaluation mark 4) with their city parks. Furthermore, 14.5% of respondents noted that they are very satisfied with the city park when looking for park facilities, while on the other hand only 3% of responded were totally unsatisfied with their city parks in general. On average, the level of respondent's satisfaction with the city parks in general was 3.9.

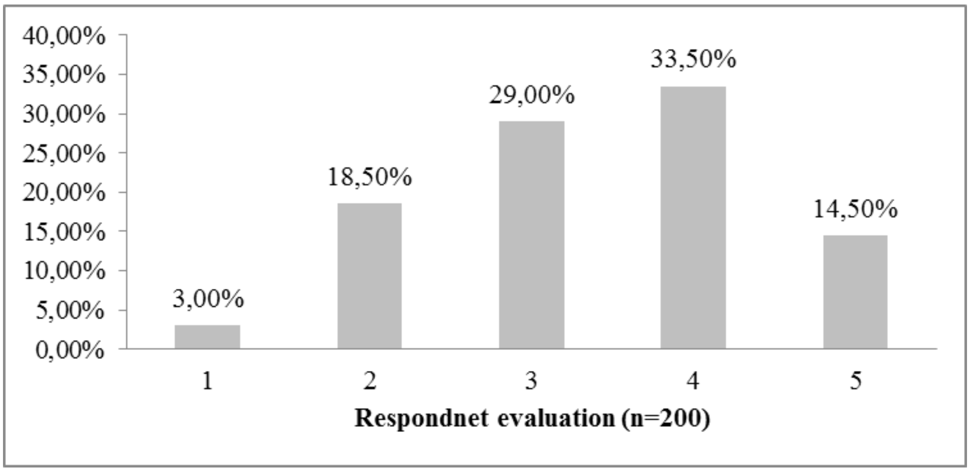

Figure 2. *Respondents evaluation on Zagreb City parks in general (n=200)*

Perception of wood furniture in the Zagreb City parks

In order to get more information about wood furniture equipment placed in the parks, like benches, tables, and waste bins the 'park users' were asked to note their level of satisfaction with wood furniture equipment in general. According to results shown in figure 3, more than 1/3 of the respondents (35% of 200 respondents) were satisfied with urban furniture in the parks, 25% noted that they are very satisfied, while 9.5% of them noted that they are extremely satisfied with the urban furniture in their city parks. Only 7% of respondents noted that they are not satisfied with the urban furniture pleased in their parks. In general, the 'park users' are satisfied with the furniture paces placed in their city parks (a mean of responses was 3.07).

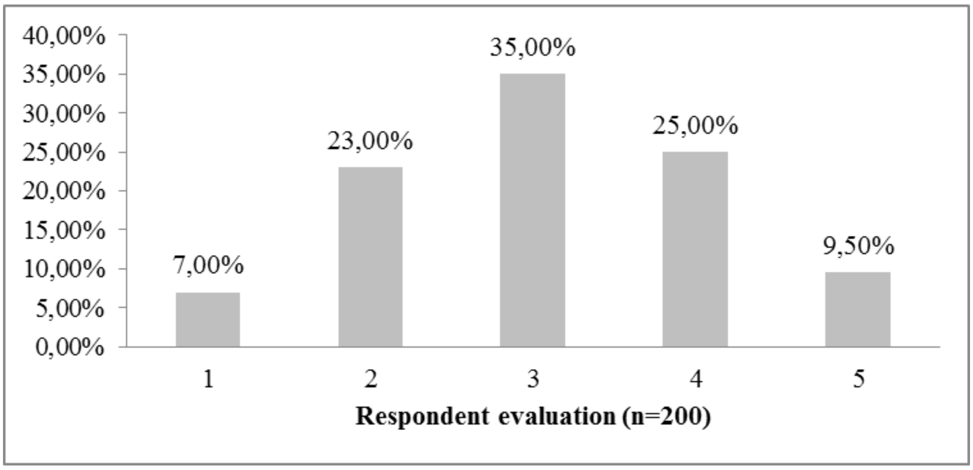

Figure 3. *Respondents evaluation of wood furniture in the Zagreb City parks (n=200)*

In addition, to get a 'better picture' about the level of 'park users' satisfaction regarding a wood furniture in parks, respondents were asked to note the level of their satisfaction about certain furniture attributes, like design, functionality, commodity, and material which furniture was made of.

When deciding about attributes regarding benches, mean response: about design was 3.36, about functionality was 3.42, about commodity was 2.94, and about martial used was 3.41, respectively. On the average, the mean response of all bench attributes was 3.21.

For tables, mean responses for all attributes were as follows, design was 3.08; functionality was 3.26, and material used was 3.10. On the average, the mean response of all attributes was 3.14.

Waste bin was the third wood 'street furniture' that was analyzed in this study. Accoridng to the analyzed attributes, the highest mean response was noted for 'functionality' attribute (3.45), followed by 'material selection' attribute (3.12), and design' attribute (3.07).The mean response of all waste bin attributes on average was 3.21.

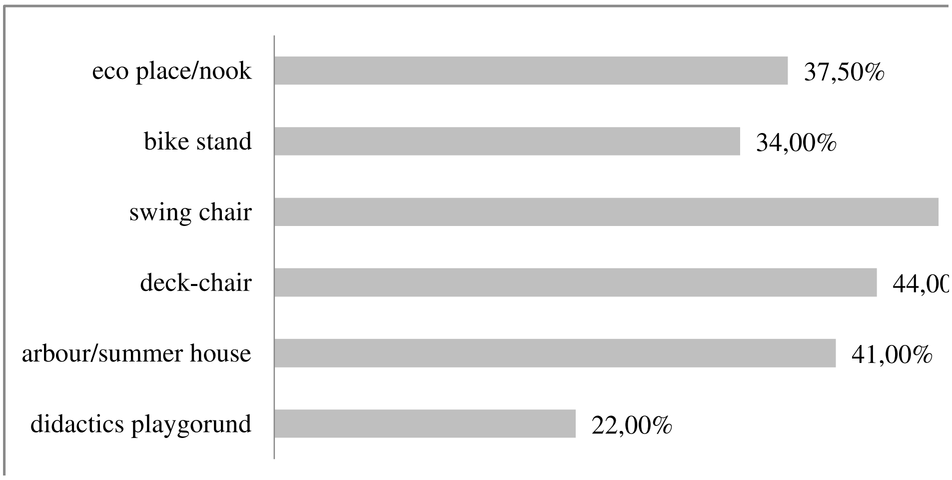

Figure 4. *Wishes and need of 'park users' in the Zagreb City (n=200; multiple response)*

At the end of personal interviews 'park users' were offered to multiple choice options to choose an additional wood equipment accessories which they would prefer to use in the park, but which was not available at that time, like bike stands, deck-chairs, swing chairs, didactic playgrounds or eco nooks. As shown in figure 4, about 45% of respondents noted the lack of resting facilities - they would prefer swing-chairs (48.5%), deck-chairs (44%), and some kind of arbors/small summer houses (41%). Also, eco place/nook was one of faculties that was found to be missing in the parks and 'parks users' would prefer to use it in the park. Bike stands (34%) and didactics playgrounds (22%) was also one interesting park facility that would be very interesting to use between respondents.

4. CONCLUSIONS

For example, some parks serve people more for the purpose of short and occasional vacations while others are visiting for longer stays. This research sowed that parks in Zagreb do not have wood urban equipment for relaxation and relaxation, even though people use it. The existing urban (mostly) wood furniture is often a combination of wood and metal, which means that it should be maintained during the years of standing on external weather conditions. Given the size of parks and their position in the city, the parks have a fair amount of basic urban equipment, with thoughts on desks and waste bins. In the summer months when parks are visited more frequently, the lack of primarily seating and relaxation elements was noticed. Every 2 to3 km city ride encourages people to use the bicycle as a means of transport, but the City of Zagreb does not provide the equipment for that purpose in sufficient quantity. In general, the 'park users' are satisfied with the furniture paces placed in their city parks, but ther is always a possibility to make it better!

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INFLUENCE OF THE DOWEL WITHOUT ADHESIVE ON STRENGHT OF INSERT FITINGS

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ABSTRACT

Tests were carried out in order to determine influence of the number of dowels without adhesive on strength of insert fittings of cabinet furniture. Minifix fitting, produced by Hafele, was used for joining. Testing was conducted on seven groups of samples. Within all groups position and number of insert fitting remained unchanged but number of dry dowels was varied. The effects of number of dowels, their position in joint, and its distance were investigated. The results indicated that moment capacity increased as number of dry dowels increased. The results also indicated that position of dry dowel has no impact on bending moment capacity.

Key words: cabinet furniture, ready to assemble construction, eccentric insert fitting, dowel without adhesive, strength, durability

1. INTRODUCTION

The idea for this paper came during inspection of the results of box type furniture within the Faculty of Forestry - Institute for Furniture Quality Control. Comparison of the tests results of strength and durability of box type furniture (according to EN 16122: 2012) and constructive solutions, showed large variations among the way how knock-down fittings were used. This analysis included only products made by medium and large factories (companies), which are forced that, to due to lower transport and storage costs of furniture, design their products as disassembly.

The strength given by knock-down fittings has been analyzed many times (Efe and Kasal, 2000; Smardzewski and Prekrat, 2002; Kasal et al., 2006; Malkoçoğlu, Yerlikaya, and Çakiroğlu 2013; Malkoçoğlu 2014; N. Çetin and Aktas 2012; Yuksel et al. 2015; Yuksel et al. 2014). On the basis of previous studies it can be clearly seen that the joints represents the critical zones of the construction, and that the rigidity and durability of the box type furniture are in direct correlation with the type of the applied fittings. However, despite the large number of results presented in those papers, the engineer who works on the elaboration of product construction has little useful information about safe choice of the optimal knock-down fitting.

If we try to compare the most widely used connecting fittings for box type furniture: a chip bolts, screws and knock-down fittings, lowest values of the bending strength are shown by knock-down fittings (Yuskel et al 2015). However, compared to other assembly-disassembly fittings, knock-down fittings allows unlimited number of assembly and disassembly. In addition to all this above mentioned another advantage of knock-down fittings is invisibility of a fitting on the outer side of the product.

Except the type of connection element, strength and durability of box type furniture are also affected by the type of material (Tankut and Tankut 2010; Yuksel et al., 2015). Yuksel et al (2014) examined strength of angle joints within box type furniture. Significantly lower values of bending strength were obtained when particle board was used in relation to the chipboard and fiberboard. This can be explained with more porous structure of the particle board, and therefore less "mass" that provides resistance to distortion (Tankut and Tankut 2010). Influence of types of the wood based boards on bending strength of corner joints within box type furniture was also examined by Malkoçoğlu (2013 и 2014). In this research joining was done by knock-down fittings.

One of the construction solutions to increase the strength of corner joints with in box-type furniture when the sides are made of chipboard is to use a higher-density board (Yuksel et al. 2014). This solution will increase costs of materials, and therefore production costs. Since the furniture made of chipboard belongs to the group of lower price products, the goal is to find a way to achieve better strength of joints without increassing production costs. If we bear in mind advantages of the knock-down fittings from the one side, and the insufficient strength of the joints as compared to some other types of fittings, it is necessary to find the optimal parameters of a knock-down fittings which will produce the maximum strength.

Based on the results obtained in previous studies (Yhang and Eckelman, 1993; Yerlikaya 2014) it can be concluded that bending strength of knock-down fittings whithin the box type furniture made of particle boards is influenced by the number of “dry” dowels. Distance of “dry” dowels from the edge of board have influence on strength of the box type furniture (SIMEK et al. 2008; Malkoçoğlu 2014).With the increasing of the number of the dry dowels strength of the joint with knock-down fittings will also rise. But the bending moment is in direct correlation wit spacing between the dowel wherein the longer distance provides a greater stiffness of the compounds of the chipboard panel (up to 160 mm, after which the strength decreases with further increase in the distance to 192 mm) (Malkoçoğlu et al. 2013).

Kořený, and A. Simek, M. (2011) came with the similar conclusions. During their researches they analyzed the impact of the distances of the dry dowels from the knock down fittings. Axial spacing of the dry dowels from the knock down fittings was 40, 80, 120 and 155mm. On the basis of conducted test they came with the recommendation the highest strength is obtained when the distances between dry dowels from the knock down fittings are 80 and 120 mm. From the standpoint of joints strength theories this information has great value. But from the standpoint of practical application these recommendations leads the constructors to dilemma. If we analyze wardrobe closet, with a depth of 560mm, number of required knock down fittings is three. According to recommendation given by Kořený and Simek is not clear how much dry dowels should be inserted, as well as what their positions.

Within the very extensive research carried out by Malkoçoglu with his associates (Malkoçoğlu et al. 2013; Malkoçoğlu 2014), the influence of the number and type of fittings on the strength of the joints, as well as the number and positon of dry dowels was analyzed. In this research, the type of fit of dry dowels was not taken into consideration. In the work presented at the international conference Dzincic I., Nestorovic, B. (2015) analyzed the influence of the shape of the fit in the dry dowels, and confirmed the preliminary hypothesis that the type of fit of a dry dowel, has influence on the strength of the angle joints, as well as the rigidity of the box-type furniture.

Although it is clear that the joints represent weak points in construction, it is not clear enough whether it is possible to predict the stability or stiffness of the furniture during the exploitation only on the basis of strength of the joints .

Based on the literature reviewed, it can be concluded that, in this field of work, there are a large number of papers that provides valuable information to the scientific and professional public. The use of the presented data in practice requires additional engagement from engineers with a constant critical review of the applied solution. The aim of this paper is to examine the influence of the number and position of dry dowels on the strength of the assembly disassembly joint in the box-type furniture with a special owerviev on the approach of the scientific experiment to the real requirements of practical application.

2. MATERIAL AND METHODS

For the purposes of this paper, seven groups of samples were formed. The groups are numbered from 1 to 7, Table 1. Within each group, 30 samples were made for testing the bending strength of the corner joints, while for testing the strength and rigidity of the box type furniture, three samples were made per group. Within all groups, the type of joints was the same, while the number and position of the dry dowels were varied.

Table 1. *Groups of samples*

Group	Type of joint	No.of dry dowels	Joint position
I	Häfele Minifix	0	1
II		2	1+2+6+7
III		2	2+3+5+6
IV		3	1+2+4+6+7
V		3	2+3+4+5+6
VI		4	1+2+3+4+5+7
VII		5	1+2+3+4+5+6+7

Figure 1 shows the joints setup on a sample with a combination of the position of the joining elements.

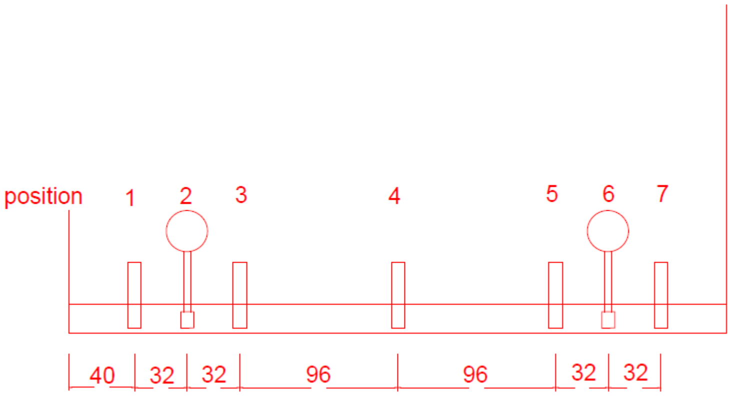

Figure 1. *Combination of the position of the joining elements (dry dowels are on positions 1, 3, 4, 5 and 7, while knock-down fittings are on the positions 2 and 6)*

All samples (corner joints and box samples) are made of three-layer chipboard, 18mm in thickness with melamine foil. The properties of the chip board was not controlled. Based on the manufacturer's data, the average density of the chipboard was 710m^3, while the average value of the modulus of the elasticity was 1950 N / mm^2. The knock-down fitting produced by Näfele, the "Minifix" model, was used to join the samples. This type of fitting is the most commonly used for knock-down furniture, which is constructed of chipboards. Dry dowels, dimension 8 • 32mm, was made of beech wood. All samples were made on a numerical machine. Before joining of the samples, the machine accuracy was controlled. Dry dowels was selected so as to achieve an overlap type of fit with the overlap of 0.1 mm.

The samples for testing the bending strength of the corner joints had dimensions 400 x 150 x 132 mm, fig. 2. The dimensions of the box type samples for the rigidity and durability tests were 400 x 600 x 1600 mm (width · depth·height). Backboard was set in the slot. In order to avoid additional stiffness and to obtain results that depend only of strength of corner joints, the box type samples did not have a sock.

Prior to testing, all samples were conditioned in accordance with EN16122: 2012, section 4.1.

The method for testing the bending strength of the corner joints has not been standardized, so the method is based on methods used by other researchers (Zhang and Eckelman, 1992; Tankut and Tankut, 2002; Koreny et all, 2013) Figure 2. The test was carried out on the AMSLER universal test machine. The feed rate of the samples when testing the bending strength of the angular joints was 10mm / min. Bending strength is calculated according to the form M = F • r, where M is the bending moment (Nm), F is the bending force (N), while r is the force arm (m), and it is r = 0.099m.

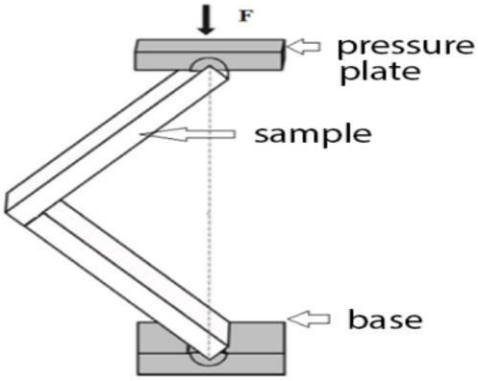

Figure 2. *Loading of the samples*

Control of the rigidity of the box type furniture was carried out according to EN 16122: 2012, chapter 6.4. Figure 3 shows the force directions.

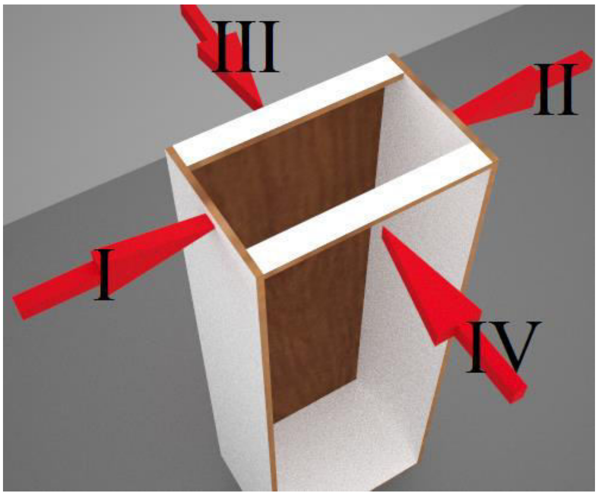

Figure 3. *Force directions*

The results of the test for the bending strength of the corner joints and the rigidity of the box samples are shown in the form of mean values and standard deviations by groups of samples. In order to determine whether there is a statistically significant difference between the results of the testing of individual groups, a one-way ANOVA analysis was conducted for the significance level α = 0.05 using the SPSS IBM Statistics 20. The equivalence of the variance was tested using the Levine's test . When the equivalence of the variance is established and if the ANOVE results show that there is a statistically significant difference in the results between groups, the Tukey HSD post-hoc test has determined which groups of samples are statistically different from the results. In case of inequality of variation, the test results were transformed through the Welch test, and for the determination of a group of samples that statistically differed according to the results of the test, the Games-Hovell post-hoc test was used.

3. RESULTS

The average values of the bending strength, expressed at the bending moment at the standard deviation values, are shown in Table 2.

Table 2. *Bending strength results*

Group	I	II	III	IV	V	VI	VII
Average value of bending moment (Nm)	9.11	11.43	11.26	15.38	15.50	21.86	25.01
Standard deviation (Nm)	0.10	0.48	0.44	0.16	0.26	0.16	0.11
	A	B	B	C	C	D	E

Calculation showed that there is no equivalence of the variance (Levine's test F (6.189) = 7.7 for p <0.001), which is a prerequisite for conducting the analysis, the Welch modification test was used (F (6; 79.25) = 62565.3 for p <0.001) there is a statistically significant difference in the results of individual groups. To determine between which group of samples is a statistically significant difference, the Games-Hovell post-hoc test was used. In order to show result in most transparent way, in the last row of Table 2, groups of samples that do not statistically differ from the test results are marked with the same letters (A to E).

The mean values values of the deflection ofthe box type samples, expressed over the size of the deflection (given as standard deviation), are shown in Table 3. Since the equivalence of the variance (Levine's test F (6,28) = 0,660 for p = 0,682) was established, the precondition for analyzing the variance showed that there is a statistically significant difference in the stiffness results of individual groups of samples (F (6.28) = 5.265 for p = 0.001). Using the Tukey HSD post-hoc test, it was found that the stiffness of the samples of the I, II, II and IV groups is statistically significantly higher (letter A) than the stiffness of samples of group VII (letter B). The results of the stiffness of the samples of the V and VI groups did not show a statistically significant difference in relation to the results of the stiffness of the samples of the other groups.

Table 3. *Stiffness results*

Group	I	II	III	IV	V	VI	VII
Deflection (average) (mm)	14.60	13.20	13.40	14.00	12.60	11.60	9.20
Standard deviation (mm)	1.949	1.304	2.074	1.581	1.817	2.074	1.304
	А	А	А	А	АБ	АБ	Б

4. DUSCUSSION

Observing the values of standard deviations of the bending moment of, large variations of these values was detected. The deviations were probably influenced by the properties of the chipboard. Since the properties of the panels have not been examined, it can only be assumed that the variation in the results was due to the uneven quality of the base material.

Comparing the results of the bending moment, it can be seen that samples of the first group showed lowest values of the strength. This result was expected due to fact that they were connected only by use of knock down fittings, without the use of a dry dowels. If we compare the values of the bending moment of groups with different number of dry dowels (group I in relation to II and III group, respectively IV and V), it can be seen that there is a significant difference between them. This can be explained by the presence of a dry dowel whose presence leads to an increase in the value of the bending moment. This conclusion is a confirmation of the results of the study by other authors where, with the increase in the number of dry dowels along the length of the joint, strength of the angle joints increases independently of the type of plate (Yhang and Eckelman 1993; Malkoçoğlu 2014; Yerlikaya 2014).

If we compare the results of the strength of joints between groups of samples with the same number of dry dowels (II and III groups, respectively IV and V groups), it can be concluded that the position of dry dowels in relation to the knock-down fittings does not affect the strength of the joints. Based on the visual examination of the samples of the four groups of samples, it was concluded that in the samples with where the dry dowel was from the inside (III and V group), the joining line were less open than in the groups of samples in which the dowel was from the outside. Based on this, it can be recommended that the knock-down fittings should be placed on the outside of the corner joint. With this positioning of the knock-down fittings, it is prevented from opening the joint during load, without damaging the joint strength.

If we compare the values of the joints strength obtained in this paper with those obtained by other investigators (Malkoçoğlu et al. 2013; Malkoçoğlu 2014), it can be seen that these values are greater by about 10%. Such deviations can be explained by a lower quality of the chip board, since the compressive stress of the joint strength is conditioned by the tensile strength (layering) of the plate (Hajdarević and Martinović 2016). In addition to this, observations on the position and the fracture are also observed when testing the strength of the corrugated board joints, where it has been established that the size of the cracks caused by the fracture depends on the size of the chipboard in the layer where the fitting is placed (Šimek et al., 2008). As the quality of the base material is not examined, this claim can only be declared as a presumption, without disrupting the strength of the joint.

The results of this study showed that the higher strength of the corpus joints leads to a smaller incline, or more stiffness of the corpus, in the force effect in the horizontal direction. This result is a confirmation of the conclusions of previous studies on the effect of joint strength on the rigidity and durability of the corpus (Cai and Fenghu 1993; N. Çetin and Aktas 2012).

The highest value of the deformation of samples of group I (14.6 mm average) compared to other groups of samples is explained by the absence of dry dowels in the joint. A higher value of the strength of the joints reduced the size of the deformation to a statistically significant level only when higher number of dry dowels (5 of them) was used. However, the main disadvantage of the applied test method is the lack of information on the required load, that is, the size of the force acting on the box side. According to the recommendation of standard EN 16122, the force was 150 N. On the other hand, in the literature, data from the load of 350N for the same test (Smardzewski 2015) can be found. What is missing is the data on the real load value that can act on the corpus furniture pages during exploitation.

In order to make recommendations for the practical application of the test results, it is proposed that for each thickness of the plate material, as well as the depth of the box, a layout of dry dowels be determined to achieve the required strength of the joints. This proposal also covers different lengths of joints or depths of the boxes, as previous studies have shown that the length of the joint is an important factor of the correlation of the bending strength whithin joint (Malkoçoğlu 2014; Yerlikaya 2014).

The visual inspection of the joints after the breakage shows that the results of the strength test can not be the only factor in selecting the position of the dowels in the joint. Bearing in mind that the applied strength test method is not standardized, it is also necessary to develop methods for measuring the size of the "opening of the joint" and to include them in the evaluation of the strength of the joints.

5. CONCLUSION

The paper analyzes the influence of the number and position of dry dowels on the strength of the knock-down fittings in the box-type furniture. The knock-down fitting of the Näfele model, the "Minifix" model, was used to join the samples. According to the data of the Office for Quality Control of Furniture, this type of fittings is the most commonly used fittings for knock-down furniture, which is constructed of chipboard. The test was carried out on seven groups of specimens. The number of knock-down fittings in all groups was identical, while the number and position of the dry dowels was varied.

Based on the analysis of the experimental results, as well as on the basis of the comparison of the values with values obtained by other researchers, it can be concluded that the number of the dry dowels in the knock-down box-type furniture contributes to increasing the bending strength of the corner joints, and contributes to increasing the stiffness of the box-type furniture. Position of dry dowels in relation to the position of the knock-down fitting has no significant effect on the bending strength of corner joint. However, the samples in which the dry dowels were from the inside showed smaller gap between the horizontal and the vertical plates.

The missing data in the professional literature is the value of the load which affects corner joints during exploitation. Lack of this data puts the constructors in a position to determine the number of joints per depth of the box-type furniture based on their experience.

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NORMS FOR DESTRUCTIVE BENDING MOMENTS OF END CORNER OPEN MORTISE AND TENON JOINTS OF FRAME STRUCTURAL ELEMENTS MADE OF SOLID SPRUCE WOOD WITH A CROSS SECTION OF 50 x 30 mm

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ABSTRACT

In the presented research are established the normative values for the destructive bending moments of the end corner open mortise and tenon 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 68,6 % from the experimentally established values, and in the arm compression bending test – 68,7 %.

The established normative values for the destructive bending moments of the end corner open mortise and tenon 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

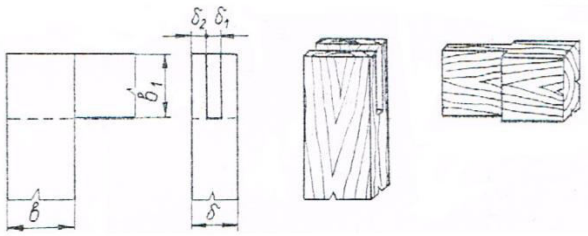
1. INTRODUCTION

Norms for the destructive bending moments of end corner open mortise and tenon 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 of structural elements with a cross section 50 x 30 mm (Kyuchukov G. et al, 2014). The samples for the test are manufactured from the same solid spruce wood (Picea abies Karst) as in the previous study (Kyuchukov G. et al, 2015b). The basic physical mechanical properties of wood 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 (Kyuchukov G. et al, 1990).

2. MATERIAL AND METHODS

The following types of end corner mortise and tenon joints are tested: open mortise and tenon joints (Figure 1), miter open mortise and tenon joints (Figure 2) and half blind mortise and tenon joints

(Figure 3). The parameters of the joints correspond to the Bulgarian State Standard 5527-73 and are given at figures 1 to 3.The corner joints of the frame structural elements were manufactured by gluing with the same polyvinyl acetate adhesive as in the study (Kyuchukov G. et al, 2015b; Kyuchukov G. et al, 2016). 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, G. 1995; Kyuchukov, G. 1988). 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), worked out at the Laboratory of Furniture Construction at the University of Forestry (Kyuchukov G., 1995; Kyuchukov G. and Jivkov V., 2015a). The distance between the inner edges of the arms of the joint is L= 200 mm.The experiment was carried out at an universal testing machine at equal 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.



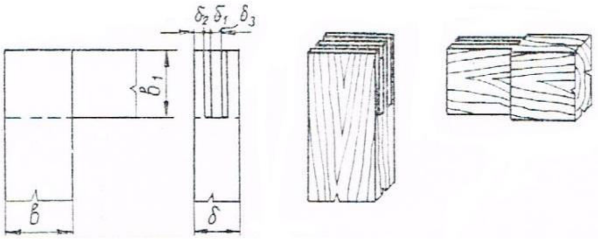
1

$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1 = 0{,}4\ \delta = 12$ mm

$\delta_2 = 0{,}3\ \delta = 9$ mm



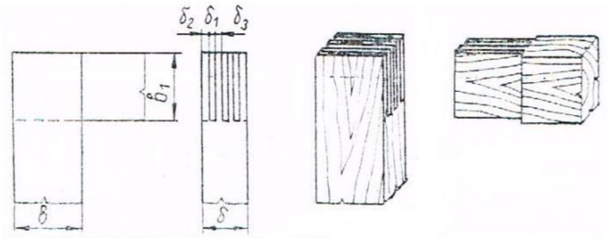
2

$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1 = \delta_3 = 0{,}22\ \delta \approx 7$ mm

$\delta_2 = 0{,}16\ \delta \approx 4{,}5$ mm



3

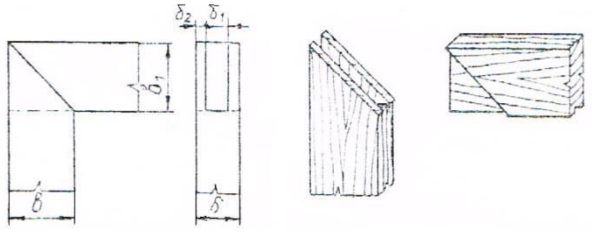
$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1 = \delta_3 = 0{,}16\ \delta \approx 5$ mm

$\delta_2 = 0{,}10\ \delta \approx 2{,}5$ mm`

Figure 1. *End corner open mortise and tenon joints: **1** – open trough mortise and tenon joint; **2** – twin open mortise and tenon joint; **3** – triple open mortise and tenon joint*



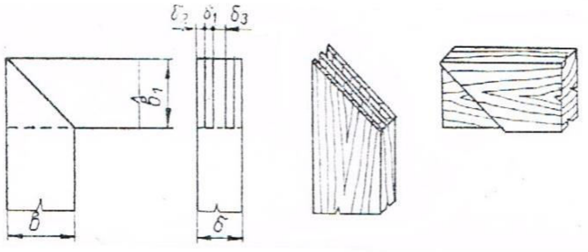
4

$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1 = 0{,}4\ \delta = 12$ mm

$\delta_2 = 0{,}3\ \delta = 9$ mm



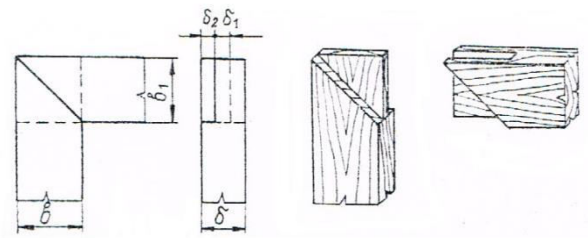
5

$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1 = \delta_3 = 0{,}22\ \delta \approx 7$ mm

$\delta_2 = 0{,}16\ \delta \approx 4{,}5$ mm



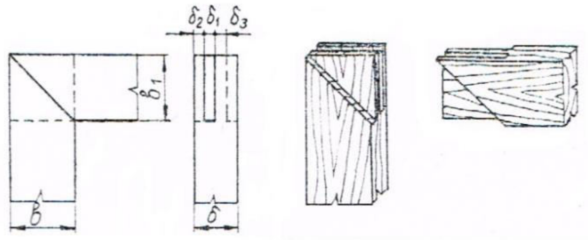
6

$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1 = 0{,}4\ \delta = 12$ mm

$\delta_2 = 0{,}3\ \delta = 9$ mm



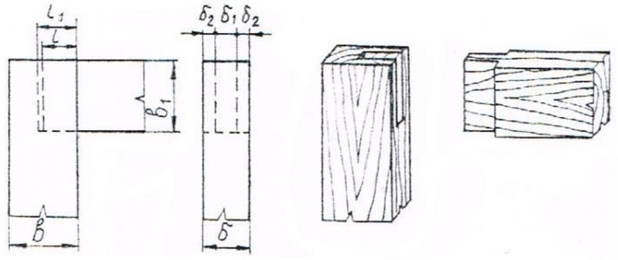
7

$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1=\delta_2=\delta_3=0{,}25\delta=7{,}5$ mm

Figure 2. *End corner miter tenon and mortise joints:* ***4*** *– miter open mortise and tenon joint;* ***5*** *– miter twin open mortise and tenon joint;* ***6*** *– open tenon and mortise joint with mitered face;* ***7*** *– twin open tenon and mortise joint with mitered face*



8

$b = b_1 = 50$ mm

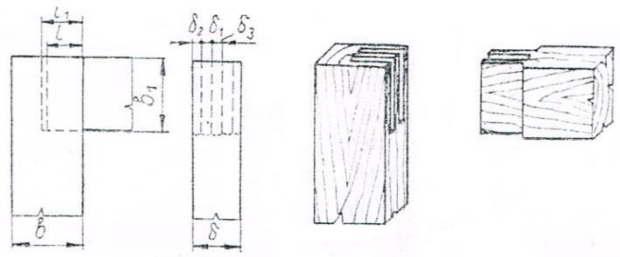
$\delta = 30$ mm

$\delta_1 = 0{,}4\ \delta = 12$ mm

$\delta_2 = 0{,}3\ \delta = 9$ mm

$L= (0{,}5\div0{,}8)\ b=30$ mm

$L_1=L+1\div2mm= 32$ mm



9

$b = b_1 = 50$ mm

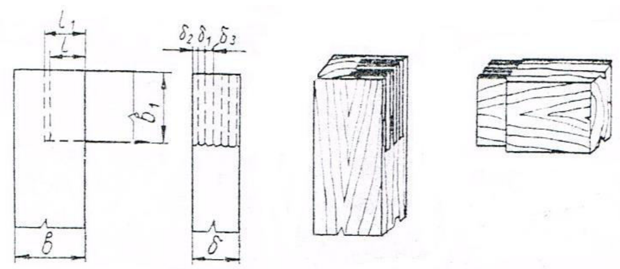
$\delta = 30$ mm

$\delta_1=\delta_3=0{,}22\delta \approx 7$ mm

$\delta_2 = 0{,}16\ \delta \approx 4{,}5$ mm

$L= (0{,}5\div0{,}8)\ b=30$ mm

$L_1=L+1\div2mm= 32$ mm



10

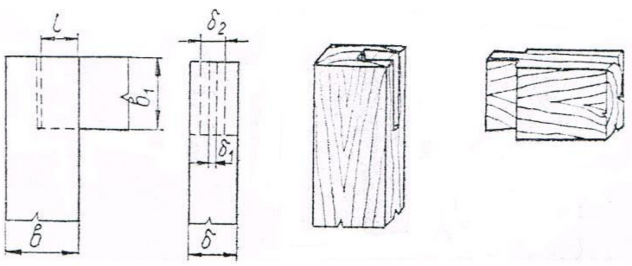
$b = b_1 = 50$ mm

$\delta = 30$ mm

$\delta_1=\delta_3=0{,}16\ \delta\approx 5$ mm

$\delta_2 =0{,}10\ \delta \approx 2{,}5$ mm

$L= (0{,}5\div0{,}8)\ b=30$ mm



11

$b = b_1 = 50$ mm

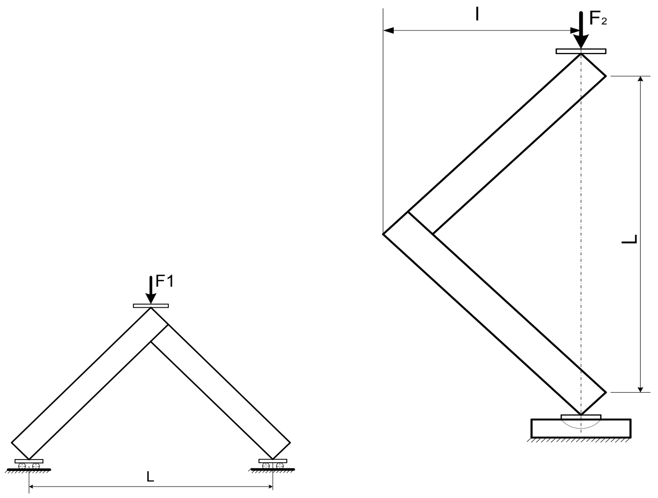
$\delta = 30$ mm

$\delta_1= 0{,}33\ \delta \approx 10$ mm

$\delta_2 = 0{,}6\ \delta = 18$ mm

$L= (0{,}3\div0{,}5)\ b =20$ mm

Figure 3. *End corner half blind mortise and tenon joints:* ***8*** *– half blind mortise and tenon joint;* ***9*** *– half blind twin mortise and tenon joint;* ***10*** *– half blind triple mortise and tenon joint;* ***11*** *– half blind dovetail mortise and tenon 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 destructive bending moments M_1 under arm opening bending test and M_2 under compression bending test have been calculated correspondingly by formulas (1) and (2).

$$M_1 = \frac{F_1 . L}{4} \tag{1}$$

$$M_2 = F_2 . l \tag{2}$$

where

F_1 – failure force in arm opening bending test in N

F_2 – failure force in compression bending test in N;

L – span distance of arm opening bending test in m

l – arm of bending in compression bending test in 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 G. et al, 2014), 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.

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 $\bar{x} \pm 3s$, and over 99 % of the data lie into the limits $\bar{x} \pm 2{,}5s$. 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.

The mean square deviation s is a function both of the data spread about the mean and the number of the tested samples. It is determined the average variational coefficient v_{av} to eliminate the influence of the accidental factors of particular samples of the given type of joint. In the arm opening bending test v_{av} = 12,6 %, and in the arm compression bending test v_{av} = 12,5 %. 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 open mortise and tenon joints in arm opening and arm compression bending load are determined by the formulas (7) and (8).

$$M_{1\,\text{norm}} = \overline{x_1} - 2{,}5.\,s_1 \tag{7}$$

$$M_{2\,\text{norm}} = \overline{x_2} - 2{,}5.\,s_2 \tag{8}$$

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 71 % 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, i.e. the area of the glue line.

At both schemes of testing – arm opening and arm compression bending load, the twin open mortise and tenon joint, triple open mortise and tenon joint and open trough mortise and tenon joint as well as the miter open mortise and tenon joint and the miter twin open mortise and tenon joint are destroyed at a considerably higher bending moment than the rest tested types of joints.

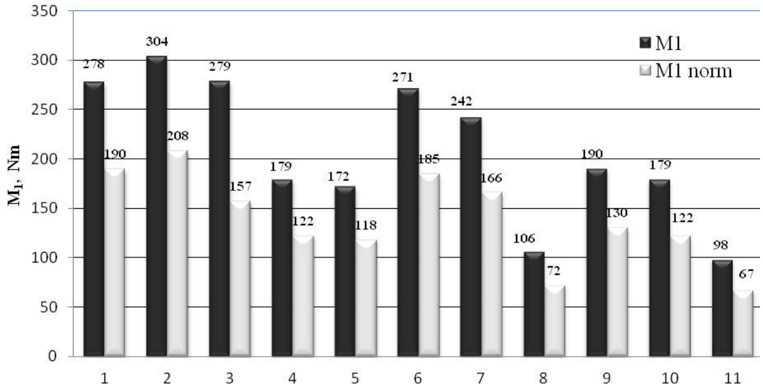


Figure 5. *Destructive bending moments and norms for end corner open mortise and tenon joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm in arm opening bending load:* ***1*** *– open trough mortise and tenon joint;* ***2*** *– twin open mortise and tenon joint;* ***3*** *– triple open mortise and tenon joint;* ***4*** *– miter open mortise and tenon joint;* ***5*** *– miter twin open mortise and tenon joint;* ***6*** *– open tenon and mortise joint with mitered face;* ***7*** *– twin open tenon and mortise joint with mitered face;* ***8*** *– half blind mortise and tenon joint;* ***9*** *– half blind twin mortise and tenon joint;* ***10*** *– half blind triple mortise and tenon joint;* ***11*** *– half blind dovetail mortise and tenon joint*

In both types of loading at considerably biggest bending moment is destroyed the twin open mortise and tenon joint, and at lowest bending moment – the half blind dovetail mortise and tenon joint. The proportions between them are respectively 3,1 and 5,3 times. The destruction of the samples of the joints which have bigger bending moment is on the element outside the glue line and in particular on the glue line. 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 68,6 % from the experimentally established values, and in the arm compression bending test – 68,7 %.

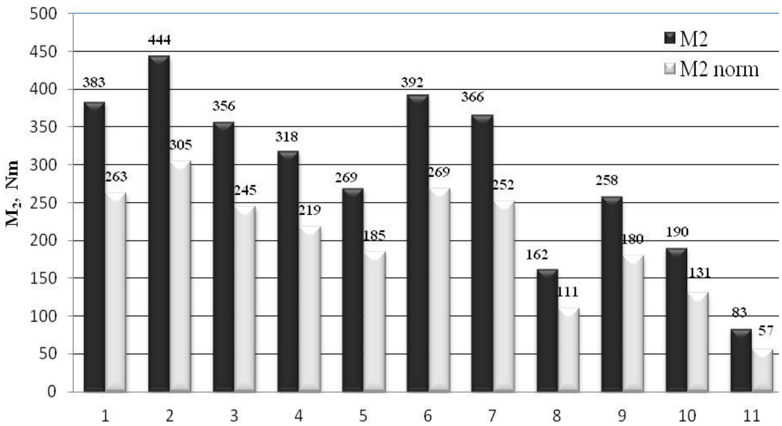


Figure 6. *Destructive bending moments and norms for end corner open mortise and tenon joints of frame structural elements made of solid spruce wood with a cross section of 50 x 30 mm in arm compression bending load:* ***1*** *– open trough mortise and tenon joint;* ***2*** *– twin open mortise and tenon joint;* ***3*** *– triple open mortise and tenon joint;* ***4*** *– miter open mortise and tenon joint;* ***5*** *– miter twin open mortise and tenon joint;* ***6*** *– open tenon and mortise joint with mitered face;* ***7*** *– twin open tenon and mortise joint with mitered face;* ***8*** *– half blind mortise and tenon joint;* ***9*** *– half blind twin mortise and tenon joint;* ***10*** *– half blind triple mortise and tenon joint;* ***11*** *– half blind dovetail mortise and tenon joint*

4. CONCLUSION

The established normative values for the destructive bending moments of the end corner open mortise and tenon 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 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 IMPACT OF TEMPERATURE OF COATING AND UV LAMP POSITION ON THE GLOSS OF UV ACRYLIC COATING ON WOOD

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ABSTRACT

This paper investigates the gloss of UV transparent coating applied on wood on the finishing line in the real industrial conditions. The samples of three-layer wood engineered flooring with upper (visible) layer made of oak (*Quercus robur L.*) were used. Five layers of UV acrylic transparent coating was applied by roller coaters and cured by ultraviolet (UV) lamps in a flow. The gloss of the coated samples was observed in terms of parameters of the top coating (temperature and viscosity) and the parameter of the curing process (distance of the last UV lamp from the substrate). Higher gloss of coated wood was achieved by lowering the position of the last UV lamp from the wood surface (from 250 to 210 cm), when the temperature of top coating was 24.8 ^{o}C. The increase of temperature of the top coating (from 23.1 to 24.8 ^{o}C) resulted in increase of the gloss of coated wood when the last UV lamp was in higher position (250 cm from wood surface). For lower position of the last UV lamp (210 cm from wood surface) the increase of temperature of top coating (from 24.8 to 25.3 ^{o}C) did not significantly affect gloss of coated samples. Results had shown that by adjusting the temperature of top coating and the distance of the last UV lamp from the substrate small variation of gloss of the coated surface can be achieved.

Key words: gloss of coating, temperature of coating, dry film thickness, UV lamp position, wood, UV acrylic coating

1. INTRODUCTION

There are a number of factors that affect the gloss of the coated wood surface: the properties of the substrate, the properties of the coating and the parameters of the working process (substrate preparation, application process and drying/curing of the coating).

Regarding the properties of the substrate, previous research had shown that the wood species does not affect the gloss of coated wood surface when conventional coatings and UV polyacrylic coatings with nanoparticles were used (Kaygin and Akgun, 2009). On the other hand, moisture content of wood can affect the gloss of coated wood (Sönmez, Budakçı, Pelit, 2011). The geometrical state of the surface can impact the gloss of the coated wood surface since the reflection of light varies depending on the smoothness of the surface (Franco and Graystone, 2009; Goldschmidt and Streitberger, 2007). In general, there is a reduction of gloss with increase of surface roughness of coated surface (expressed by the parameter R_a) (Fletcher, 2002). The influence of the surface roughness on the gloss of the coating on wood surface was confirmed in previous studies where the lower roughness of the coated surface (expressed by the parameter R_a) resulted in higher gloss values of the coating (measured by geometry 60)(Jaić and Palija, 2015; Palija et al, 2014; Pelit et al, 2015). In addition, the gloss of coated wood can be affected by it`s cross-section (Živković, 2004).

It was reported that the type of the coating has the primary effect on gloss of coating on different wood species (Kaygin and Akgun, 2009). Thus, in the research of the gloss of varnish applied on scots pine (*Pinus sylvestris* L.), it was found that the 1K water-based topcoat varnish fills the pores on the wood material surface more effectively, leading to lower roughness of the surface (expressed by the parameter R_a) and higher gloss (measured by geometry 60) compared to 2K water-based topcoat varnish (Pelit et al, 2015).

It was found that the method of the surface preparation of the eastern beech (*Fagus orientalis* L.), scots pine (*Pinus sylvestris* L.) and sessile oak (*Quercus petraea* L.) affects the roughness of the wood surface coated with polyurethane varnish, measured by the parameter R_a (Budakçı, et al, 2007). Also, beside surface preparation other processes like inter-coat sanding can have an effect on gloss of coated surfaces (Franco and Graystone, 2009).

In the research on the impact of the number of shellac layers on the gloss of coated surface of mango wood it was shown that increase in the number of layers of coating leads to the higher gloss of the coated surface, measured at an angle of 60°(Gupta, Sharma, Kumar, 2008). So, it can be assumed that the dry film thickness of the coating (*DFT*) affects the gloss of the coated surface (Živković, 2004). However, in addition to the *DFT*, the texture of the surface can also have impact on the gloss of the wood coated surface, regarding the method of application and/or irregularities that can occur during application and curing of the coating.

Comparing the methods of applying 100% UV-acrylic water-based coating to alder wood (*Alnus glutinosa* Gaertn L.), it has been found that higher gloss values (measured with a geometry of 60 °) were obtained when the coating was applied by roller coater, then when the coating was applied by manual spraying (Salca et al, 2016). The higher gloss values achieved with roller coater were explained by roller-controlled coating thickness in comparison to the spraying application. Also, the coating structure was more cured due to the influence of the UV energy when compared to water-based varnish type, which was related to the differences in gloss values.

Regarding the impact of other parameters of the wood finishing process, it was shown that the conveyor speed can have an effect on the gloss of UV coating applied on wood due to the variation of irradiation dose absorbed by coating at different conveyor speed (Darsono, 2015).

Having in mind a large number of factors that can affect the gloss of wood coated with transparent coating the goal is to achieve a uniformity of gloss of coated surface. Under the uniform gloss of the wood surface coated with transparent coating, in practice, a deviation of ± 3 units of gloss is allowed when the gloss of coated surface exceeds 25; ± 2 units of gloss when the gloss of coated surface is between 10 and 25 and ± 1 units of gloss when the gloss of coated surface is below 10 (measured with geometry of 60°)(Klumpp, n.d).

In the previous phase of this study, it was determined that wood properties affected by sanding impact the gloss of the wood surface coated with transparent coating during processing of the samples on the UV finishing line (Palija et al, 2014). In the second phase of this research, we examined how the parameters of the finishing process affect the gloss of the wood surface coated with transparent coating. It was expected that the increase of the temperature of the coating will cause viscosity to decrease, which will impact the gloss of the coated surface. Research was conducted in real production conditions on the UV finishing line with the working station for the determination of gloss of the warm samples at the very end of the line, for purpose of the control of the process. In the case where the values of the gloss were close to the critical, the last UV lamp was raised or lowered to adjust the dose of irradiation and thus the degree of gloss of coated samples. Accordingly, we investigated whether the distance of the last UV lamp from the surface of the samples affects the gloss of the coated wood surface at significant level.

2. MATERIAL AND METHODS

For the research three-layered samples of engineered flooring dimensions (l × b ×d): 2280×198×14 mm were used. The upper (visible) layer of samples was made from oak wood (*Quercus robur* L.) in form of lamellas. The lamellas were obtained from tangential and radial cuts and were arranged in upper layer in accordance to esthetic characteristics by manual sorting.

Sanding of samples, application and curing of UV-acrylic coating was done in real production conditions, on industrial finishing line that consists of sanding machine (for preparation of the samples); roller coaters (for the application of coating); UV lamps (for the curing of the coating after each layer of application) and sanding machine (for intermediate sanding of coating). Preparation of the samples by sanding was done on the wide-belt sanding machine (LSM 8, Heesemann, Germany) with fallowing grit sizes of abrasive belts: P60, P80, P100 and P120. Sanding speed was set to 20 m/s, conveyor speed was 16 m/min and the sanding pressure was 6 bar.

Four layers of base transparent coating (IS 485 OR 124 sealer, Akzonobel) and one layer of top transparent coating (IL 485 OR LACK CLASSIC B, Akzonobel) were applied on sanded surface of the samples. The application rate of coating was set from 11 to 18 g/m^2, according to layers (Table 1). The layers of coating were cured by passing of coated samples under the UV lamps of different type and input power (Table 1). The intermediate sanding of coating was performed after application of the first and the fourth layer of coating on the wide-belt sanding machine with the following grit sizes of abrasive belts: P180 and P240, respectively.

Table 1. *The application rate, the type and the input power of UV lamps according to the coating layer*

Number of coating layer	Average application rate (g/m^2)	Number, type and input power of UV lamp		
		1. position[1]	2. position[2]	3. position[3]
I	18	1x Hg UV lamp[4] (60 W/cm)	/	/
II	20	1x Ga UV lamp[5] (80 W/cm)	1x Hg UV lamp (100 W/cm)	1x Hg UV lamp (100 W/cm)
III	12	1x Ga UV lamp (100 W/cm)	1x Hg UV lamp (100 W/cm)	1x Hg UV lamp (110 W/cm)
IV	11	1x Hg UV lamp (80 W/cm)	/	/
V	11	1x Ga UV lamp (100 W/cm)	1x Hg UV lamp (110 W/cm)	1x Hg UV lamp (110 W/cm)

[1,2,3] In relation to the distance to respondent roller coater
[4] Hg UV lamp - Mercury UV lamp
[5] Ga UV lamp - Gallium UV lamp

Temperature of the top liquid coating was measured by the infrared thermometer (model MS6530, Sinometer Instruments Manufacturer, China), at the discharge plate of the roller coater machine. Discharge plate is used for drainage of the surplus of the material, which is not applied on the surface of the samples, to the reservoir of the coating. The temperature of top coating was recorded during the working time of the production order. Four groups of samples were formed base on the recorded temperatures of the top coating.

Kinematic viscosity of the liquid top coating was measured by efflux method by DIN dip cup with 4 mm orifice (manufacturer Byk-Gardner, Germany) according to DIN 53211:1987. The value of the viscosity was expressed as the mean value of two measurements of the efflux time of coating at recorded temperature.

Measurement of the *DFT* and the gloss of cured coating was done on the samples which were positioned at the middle of conveyor (in relation to its width) in order to reduce the variation of the application amount of the coating, which can appear along the width of the conveyer (Šućur, 2013). For each measured temperature of the top coating one sample was used for the measurements of *DFT* and gloss of the coated wood.

The DFT was measured by ultrasonic gauge (model PosiTector 200 Series, DeFelsko, USA) without destruction of the coating, in accordance with SRPS EN ISO 2808:2011. Dry film thickness of the coating for each group was expressed as average value of 9 measurements across the surface of the sample (3 × at the beginning of sample, 3 × at the middle of sample and 3 × at the end of the sample, in relation to it`s length).

The gloss of coated samples was measured by reflectometer (model Micro-TRI gloss, BYK Gardner, USA), in accordance with EN ISO 2813:2014. According to named standard for the semigloss surfaces (within a range from 10 to 70 gloss units) an angle of incidence of 60° should be used for the measurement of gloss. Based on results of the gloss of hot samples (immediately after curing of the top layer of the coating) the geometry of 60° was chosen for the gloss measurement of the samples in our research. Gloss of coated samples for each group was expressed as average value of 9 measurements. The measurement of gloss was conducted at same measuring position which was used for the measurement of *DFT*.

Having in mind that a real production order was analyzed in this research, the last UV lamp on the line was raising and lowering when the gloss values of the warm coated samples were close to critical (30 ± 3 gloss units). For this reason, the last UV lamp on the line was in two different position during measurement of gloss: at 210 and 250 mm from the surface of the sample on the conveyor.

Statistical analysis of the results was performed in the software IBM SPSS statistics 21 using descriptive statistics, independent samples T – tests and analysis of variance (one-way ANOVA). When ANOVA showed statistically significant difference between sample groups, a Tukey HSD post-hoc test was used for further analysis.

3. RESULTS AND DISCUSSION

Table 2 shows the results of the temperature and viscosity of the liquid top coating during the application process, as well as the distance of the last UV lamp from the wood surface according to the groups of samples.

Table 2. *The temperature of the liquid top coating and the distance of the last UV lamp from the samples surface according to groups of the samples*

	Group of the samples			
	I	II	III	IV
Temeperature of liquid top coating (°C)	23.1	24.8	24.8	25.3
Kinematic viscosity (s)	18.9	16.8	16.5	16.4
Distance of the UV lamp from the samples (cm)	250		210	

Figure 1 presents the viscosity of top coating, expressed by efflux times, at different temperatures of the coating.

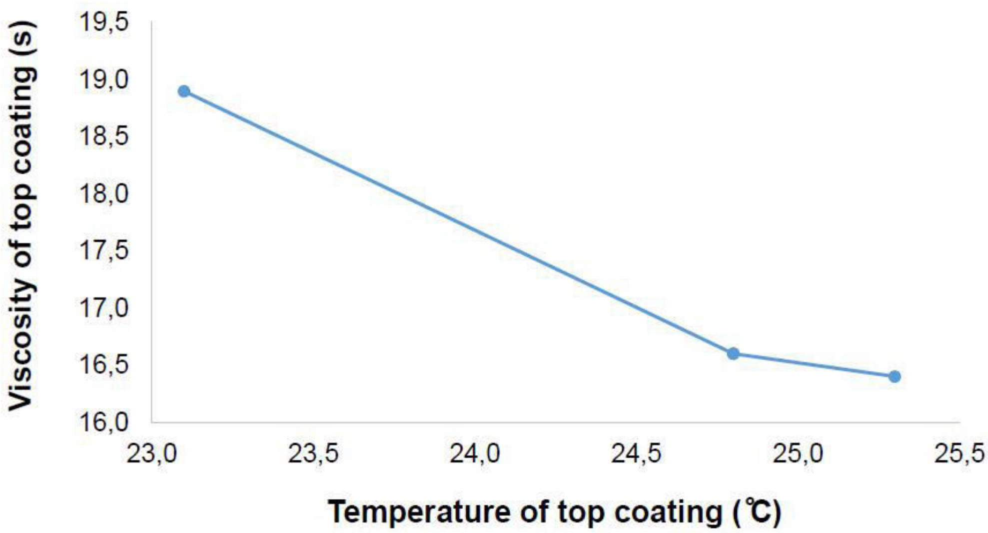

Figure 1. *Viscosity of top coating at different temperatures*

As expected, the increase of temperature led to the decrease of the kinematic viscosity of top coating, measured by the efflux method. In the case of samples of II and III group, the temperature of the coating was the same, but there was the difference (0.3 s) between efflux times of the coating, expressed by average value of two measurements. This difference can be related to measurement method where small deviations are expected due to subjective readings of the results. Since the measurements were carried out on the finishing line in the real production conditions, a method for determination of the kinematic viscosity was chosen as most suitable one. For this reason, the viscosity of coatings for II and III group of samples was expressed as mean value of four measurements (Figure 1).

Table 3 shows the descriptive statistics of dry film thickness of the coating according to groups of samples.

Table 3. *Dry film thickness of coating according to groups of samples*

Dry film thickness of the coating (µm)	Group of samples			
	I	II	III	IV
$\bar{x}$	**75.6**	**69.3**	**66.6**	**70.8**
Min	70	66	61	67
Max	88	73	77	75
Sd	5.6	2.6	4.9	2.9

($\bar{x}$ – mean; *Min* – minimum; *Max* – maximum; *Sd* – standard deviation)

The results of dry film thickness was normally distributed for each group, as assessed Shapiro-Wilk's test ($p > 0.05$) and homogeneity of variances was not violated, as assessed by Levene's Test of Homogeneity of Variance ($p = 0.344$). ANOVA showed that there was a statistically significant difference in *DFT* (F (3.36) = 7.140, p <0.05). According to Tukey HSD post-hoc test *DFT* of the sample of I group (75.6 ± 5.6) was significantly higher than the dry film thickness of the coating of the samples of II and III groups. The higher thickness of *DFT* of I group can be explained by lower temperature (23.1 °C) and higher viscosity (18.9 s) of the top coating. The differences in *DFT* between samples of II and III group, which had the same temperature of the top coating (24.1 °C), was not statistically significant, so it can be assumed that layers of the coatings were uniformly applied across the surface of the samples. Lower values of *DFT* of the samples of II and III groups in relation to the sample of I group can be explained by lower viscosity (16.6 s in comparison to 18.9, respectively) and thus a smaller application amount of the coating. With a further increase of temperature of top coating in the IV group (25.3 °C), further decrease in viscosity (16.4 s) was measured, but the values of *DFT* were higher compared to the samples of II and III groups. Although there was no statistically significant difference in *DFT* on the sample of the IV group in relation to the samples of groups I, II and III, it is possible that a lower application rate of the coating caused uneven texture of the film that could impact the roughness of the coated surface and measurement of the dry film thickness of the coating.

Table 4 shows the descriptive statistics of the gloss of coated wood according to groups of samples.

Table 4. *Gloss of coated wood according to groups of samples*

Gloss of coated samples	Group of samples			
	I	II	III	IV
$\bar{x}$	**30.7**	**26.3**	**31.9**	**30.9**
Min	29	23	30	29
Max	33	30	34	33
Sd	1.1	2.0	1.6	1.4

($\bar{x}$ – mean; *Min* – minimum; *Max* – maximum; *Sd* – standard deviation)

The results of gloss of coated wood surface was normally distributed for each group, as assessed Shapiro-Wilk's test ($p > 0.05$). Since the coating on the samples was cured under the action of the UV lamp at different positions from the surface of the samples, the effect of the lamp position on the gloss of the coated wood surface was considered first (Figure 2).

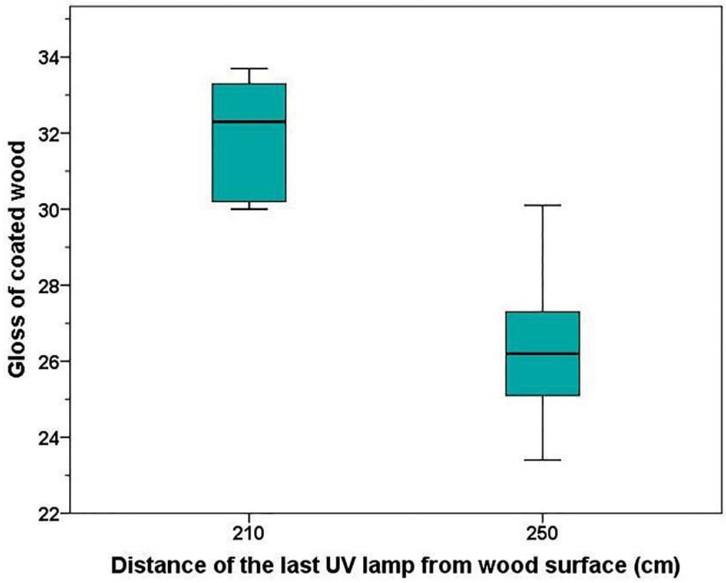

Figure 2. *Gloss of coated wood in relation to UV lamp position*

An independent samples t-test was run to determine if there was difference in gloss of coated samples with different position of the last UV lamp. For the temperature of top coating of 24.8 °C, the gloss of coated sample was significant higher (31.9 ±1.6) when the distance of the last UV lamp from the sample surface was lower (210 cm) compared to the gloss of coated sample (26.3±2.0) which was cured under the UV lamp at higher distance from wood surface (250 cm), ($t(16) = 6.549$, $p < 0.05$). The higher gloss values for the sample which passed under the last UV lamp at shorter distance from the surface were the result of higher irradiation of the coating, since radiant power of the lamp decreases with the square of the distance (Schwalm, 2006). The impact of the irradiation on the gloss of coated wood was confirmed in research on sengon wood (*Paraserianthes falcataria* L. Nielsen) where significantly decrease of the gloss of the coated surface was explained by decrease of the irradiation dose absorbed by UV coating (Darsono, 2015).

Next, the impact of the top coating temperature at different positions of the last UV lamp was analyzed. An independent samples t-test was run to determine if there was difference in gloss of coated samples with different temperature of top coating when samples were cured under UV lamp at distance of 250 cm from its surface (Figure 3). There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = 0.192$). The increase of temperature of top coating of 1.7 C resulted in significant decrease of gloss (4.4 gloss units), ($t(16) = 5.644$, $p < 0.05$). This result is in accordance with the practice guidelines according to which the higher temperature of the coating leads to a decrease in the viscosity of the coating, which can lower the applied amount of the material and reduce the gloss of the cured coating on the surface (Klumpp, n.d). This was confirmed by the results of II group of sample which had lower average dry film thickness of the coating (reduction of 8.3%) and lower average gloss value of coated wood (reduction of 14.3% units) at higher temperature of the top coating, in comparison to the I group of sample.

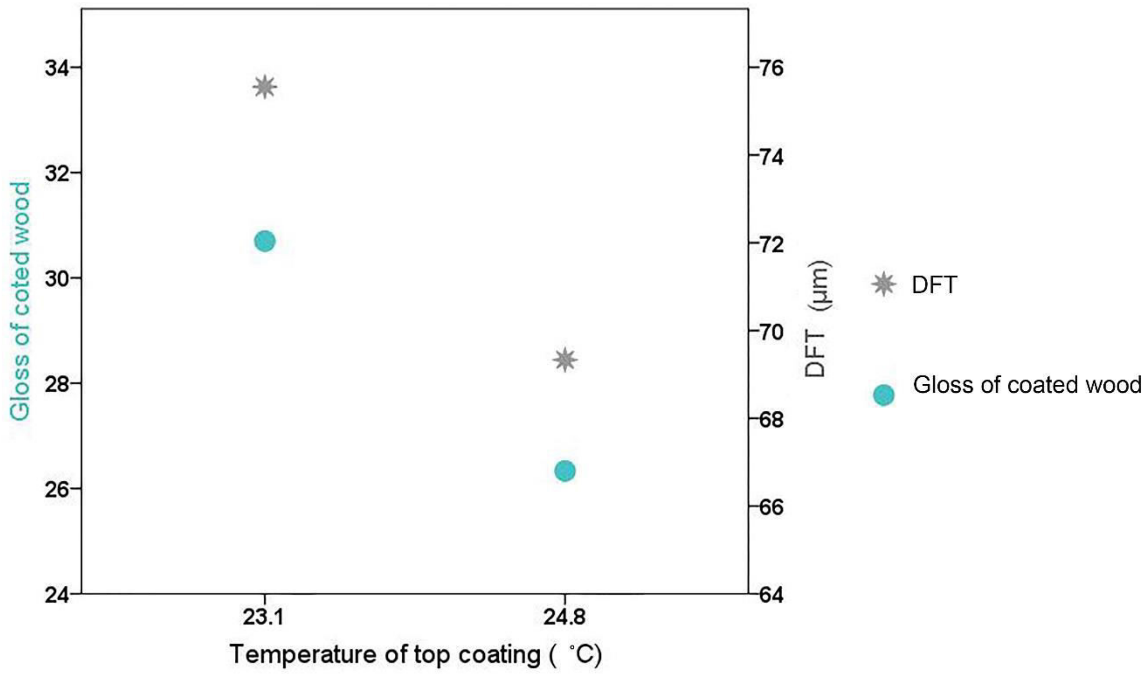

Figure 3. *Gloss and dry film thickness of coating at different temperatures of top coating (UV lamp position: 250 cm)*

Then, an independent samples t-test was run to determine if there was difference in gloss of coated samples for different temperature of top coating, when samples were cured under UV lamp at distance of 210 cm from its surface (Figure 4). There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = 0.415$). Between the samples of III and IV group there was not significant difference of gloss of coated wood (t (16) = 1.484, p = 0.157). This result can be explained by a slight difference in the top coating temperature of samples III and IV (0.5 ^{o}C) and the absence of a statistically significant difference in the dry film thickness of the coating.

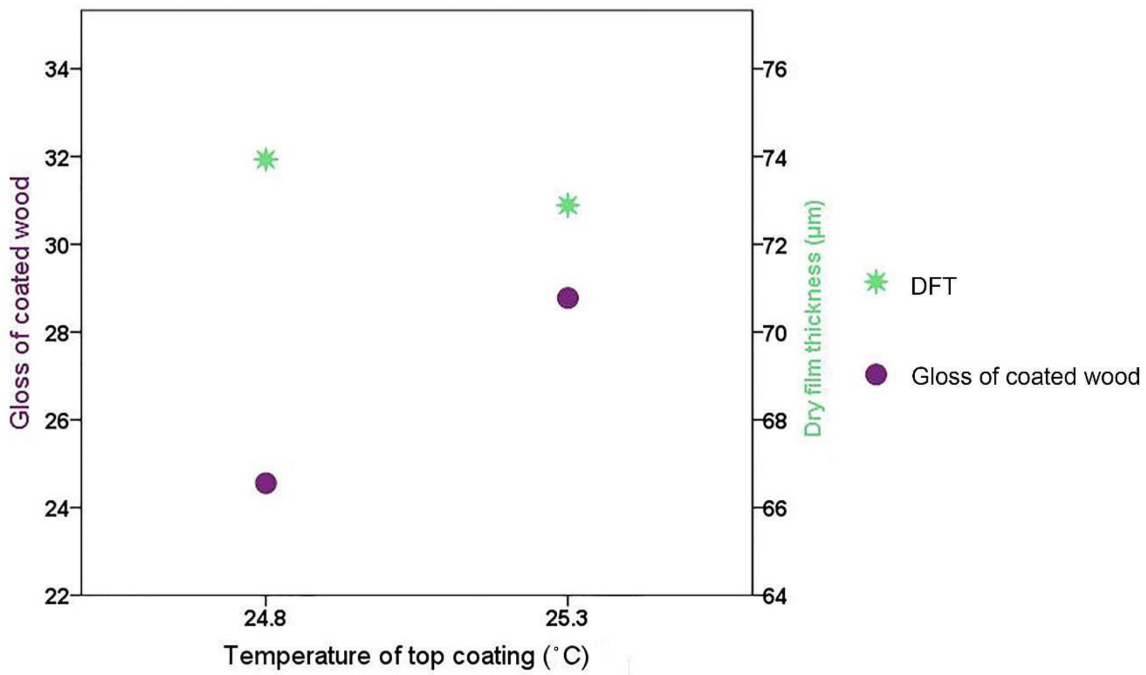

Figure 4. *Gloss and dry film thickness of coating at different temperatures of top coating (UV lamp position: 210 cm)*

Changes of the temperature of the coatings that were recorded during this research are inevitable during operation on the finishing line and can be minimized by adjusting the viscosity of the coating. One way of adjusting the viscosity of the coating is the addition of monomeric diluents (Schwalm, 2006). The other way is the installation of the heating/cooling equipment to ensure that the values of coating temperature will be within the specified range. In both cases, beside the additional costs, the viscosity adjustment requires more precise determination methods of temperature and viscosity of coating, which are not always possible to include in industrial environment. Another method of maintaining the gloss value of coated wood within the given limits implies adjusting the distance of the UV lamp from the surface of the sample, which is easier and more economical method, especially in industrial conditions.

It is known that the gloss of coated wood is affected by surface roughness (Jaić and Palija, 2015; Palija et al, 2014), but there are no literature findings related to the roughness caused by roller application method. For the future analysis, if the coating is applied by roller application, surface roughness should be included in the assessment of the properties of dry coating that can affect the gloss of coated wood.

4. CONLUSIONS

Based on the results of the research, the following can be concluded:

- As the temperature of the top coating increased (from 23.1 to 25.3 °C), the viscosity decreased (from 18.9 to 16.4 s).
- It is possible to increase the gloss of the coated wood surface for 5.6 gloss units at temperature of top coating of 24.8 °C by reducing the distance of the last UV lamp (from 250 to 210 cm) from the surface of the sample.
- The increase of temperature of the coating from 23.1 to 24.8 °C, when the last UV lamp was set at higher position from the surface of the sample (250 cm), led to decrease of gloss of the coated wood (from 30.7 to 26.3), which was related to reduction of the dry film thickness of the coating (from 75.6 to 69.3 μm). Smaller increase of temperature of top coating of 0.5 °C (from 24.8 to 25.3 °C) did not significantly change the gloss of coated wood samples, when the last UV lamp was set at lower position from the surface of the sample (210 cm), which was explained by absence of the statistically significant difference between dry film thickness of the coating.

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COMPARISON OF RESISTANCE OF SOME WATER BASED ACRYLIC RESIN BASED WOOD COATING SYSTEMS AGAINST OUTDOOR CONDITIONS

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ABSTRACT

In this study, panels of pine and beech sapwood coated with 12 different coating systems were exposed to artificial weathering using fluorescent UV-lamps and water during 2016 hours. In these coating systems, water in different proportions, boric acid, two different acrylic resins and three different UV absorbers supplied by BASF were used. The aim was to compare durability of different coating systems in artificial weathering in terms of the color change, surface roughness, and adhesion strength. These test methods were used to evaluate the appearance and physical properties of the coatings after artificial weathering test. The results lead to the selection of the best coatings formulation for the wood durability in outdoor condition usage. The appearance and physical values after 2016 hours of weathering test showed that boric acid increases adhesion of the varnish for usage in outdoor conditions. In addition to, the varnish formulation containing especially acrylic resin and Tinuvin 400 DW provided the highest resistance against outdoor conditions.

Key words: Acrylic resin, artificial weathering, boric acid, UV absorber, wood coating, wood durability

1. INTRODUCTION

Wooden versatility is a natural material that has long been known for its impressive engineering and structural properties. Wood is the only building material that harmonizes with human physiology. However, as with all other biological materials, destruction and degradation of wood materials in outdoor conditions is due to organic and inorganic factors. The changes in the chemical, physical and microscopic structure, surface color of wood occur in ourdoor condition after a certain period of time. The main factors in this disruption are UV and rain effect, which is called "weathering" in the literature. The weathering of wood in outdoor conditions is a rather complicated process. The reactions originating from UV radiation on the wood surface have consequences such as color change, loss of gloss and surface texture change. The degree of color change depends on the type of wood, the wavelength of the light and its intensity. The changes in the wood color during UV irradiation reflect chemical changes. The onset of photodegradation causes a considerable change in the physical, chemical and mechanical properties of all wood polymers (cellulose, lignin, and hemicellulose) that are capable of absorbing UV radiation (Teacă et al., 2013). UV radiation chemically degrades the structural components of wood (lignin and carbohydrates) with an efficient energy, causing surface changes. Stresses and cracks occur on the surface of the wood resulting from moisture increase or loss due to relative humidity, rain and dew (Hon, 2001; Williams, 2005).
In order to prevent erosion and color change on the surface of wood with the effect of outdoor conditions and to make the wood more durable against outdoor conditions, different methods are applied today.

The application of UV treatments (paint, varnishes, coating systems, water repellent materials, etc.) to cut the contact with the wood surface of UV rays and rain water is a method used to protect the wood surface against weathering. In order to protect the surface of wooden material against photodegradation, intensive researches are being carried out on sealants such as resin-based varnishes, UV absorber and Hindered Amine Light Stabilizer (HALS) used in the industrial sector. According to these studies, high protection is provided on the surface against photodegradation with organic or inorganic UV absorbers added to the acrylic resin (Aloui et al., 2007, Custódio and Eusébio, 2006, Deka et al., 2008; George et al., 2005). Compared to older generation surface treatments, resin based wood coating systems containing UV absorber (UVA) or HALS materials provide much longer protection against outdoor conditions. The acrylic resin containing UVA or HALS protects the applied wood surface from washing without lignification and thus provides color stabilization on the surface (Forsthuber and Grüll, 2010; Özgenç et al., 2012).

One of the most important effects of outdoor exposure is to remove the varnish layer from the wood surface. In the literature, there are many studies on adhesion strenght between varnish and wood surface. According to these studies, properties such as roughness, moisture content, fiber orientation, anatomical structure of the wood surface affect the varnish adhesion strength (Ozdemir and Mengeloglu 2008; Sonmez et al., 2009; Ozdemir et al. 2013). Wood coating systems exposured outdoor conditions also adversely affects adhesion strength. Hernández and Cool (2008) evaluated the effect of sandpaper, fiber orientation and perpendicular planing on the varnish layer on the birch wood surface.

In this study, the adhesion sterngth performance of 12 different coating systems applied to the scots pine and oriental beech wood surfaces was evaluated. The effect of varnish on adhesion to wood surface, dry film thickness, viscosity and outdoor exposure has been investigated. After exposure to the outdoor, it was also observed the changes on the coating layer in the wood surface.

2. MATERIALS AND METHODS

2.1. Wood Materials

As a raw material Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* L.) were selected and cut into pieces with dimensions of 120 mm in length by 60 mm wide by 10 mm thick from sapwood according to TS EN 927-6 standard. Wood samples were conditioned in a climate room at 23±2 ^{o}C and 65±5 relative humidity until constant weight was attained. One control and three test samples were cut for each variation. Cross sections of wood samples were coated with epoxy paint to increase resistance to weathering conditions.

2.2. Coating Systems

The commercial water-based impregnation product, having active ingredients of 1.20% propiconazol, and 0.30% iodopropynyl butylcarbamat, was used as a primer for the protection of the samples against biological deterioration, including soft rot and blue stain. The primer was applied to the samples at a spread of 120 g/m² using a brush. Tinuvin 400 DW as UV absorbers were used in this study. Commercially produced finishing, having acrylic resin, a copolymer dispersion of methylacrylate/methylmethacrylate/ butylacrylate, was used as a topcoat for the specimens. A small amount of defoamer and 2,2,4-trimethyl-1,3-pentandiolemonoisobutyrate, a coalescending agent was added in the topcoat formulation to reduce the effect of other additives on the photostabilization performance. These formulation products were supplied from BASF Company for the wood coatings (Table 2). Three layers of topcoats were also applied to each sample at a spread rate of 100 g/m² by brush. Later, the specimens were sanded with a 240 grit size of sandpaper and kept at room temperature for two days before applying the second layer of topcoat. The codes of wood coating materials in the study are given in Table 1.

***Table 1.** UV absorbers for wood coating systems*

Pruducts	Product Type	Physical form	Active content (%)
Tinuvin 477 DW	UV Absorber	liquid	20
Tinuvin 400 DW	UV Absorber	liquid	20
Tinuvin 5333 DW	UV Absorber	liquid	40

***Table 2.** Acrylic resin types for wood coating systems*

Acrylic resin code	Detailed information
Acrylic Resin 1	Superior weathering resistance, excellent blushing resistance, tack-free films, also for colored aggregates.
Acrylic Resin 2	Exceptional outdoor durability and film elasticity together with outstanding water barrier properties, blocking resistance and wet adhesion.

***Table 3.** The formulations of wood coating systems*

Formulation products	Content (%)	A	B	C	D	E	F	G	H	K	L	P	T
Acrylic Resin 1	73.7	x	x	x	-	-	-	x	x	x	-	-	-
Acrylic Resin 2	73.7	-	-	-	x	x	x	-	-	-	x	x	x
Tinuvin 477 DW	6.0	x	-	-	x	-	-	x	-	-	x	-	-
Tinuvin 5333 DW	6.0	-	x	-	-	x	-	-	x	-	-	x	-
Tinuvin 400 DW	6.0	-	-	x	-	-	x	-	-	x	-	-	x
Film-forming agents	0.67	x	x	x	x	x	x	x	x	x	x	x	x
Defoamers	1.0	x	x	x	x	x	x	x	x	x	x	x	x
Dispersing agent	0.6	x	x	x	x	x	x	x	x	x	x	x	x
Rheology modifier	1.3	x	x	x	x	x	x	x	x	x	x	x	x
Distiled water	16.73	x	x	x	x	x	x	-	-	-	-	-	-
Distiled water with 1% Boric acid	16.73	-	-	-	-	-	-	x	x	x	x	x	x

2.3 Artificial Weathering Test (QUV)

Artificial weathering was performed in a QUV/spray accelerated weathering tester (Q-Panel Lab Products, Cleveland, USA), equipped with UVA 340 lamps. The temperature in the chamber was approximately 60 ^{0}C. The weathering experiment was conducted by cycles of UV-light irradiation for 2.5 hours followed by a water spray for 30 minutes followed by 24 hours of condensation at approximately 45 ^{0}C in an accelerated weathering test cycle chamber for 2016 hours (TS EN 927-6).

2.4. Dry film thickness measurements

The viscosity of the eight different coatings applied in this study was determined by using DIN cup/4mm/20 0C (ASTM D 1438, 1971). After applying the coating, dry coating thickness was determined by using a dry film thickness apparatus (ASTM D 4541, 1978) (Erichsen P.I.G. 455).

2.5. Pull-off test

Pull-off methods were used to evaluate adhesion strength between the wood surface and the coating (Bulian and Graystone, 2009). Two random measurements with a contact area of 20 mm circles were taken from the side of three samples for each of the coating formulations. Erichsen Adhesion-525MC with a head glued to the surface of the samples was employed for the tests. The equipment ran at a constant speed of 10 cm/min and applied tension forces to the surface layer by pulling the coating from the surface. The adhesion strength value of the coating was the limiting value of the tension force applied, which was registered on the display screen of the equipment in N/mm2.

2.6. Surface macroscopic evaluation

General images for surface erosions of control and test wood samples subjected to the natural weathering test were evaluated in accordance with the ASTM D 662-93 standard. Test and control samples were examined after the weathering test and a point scale of 10 (flawless surface with no erosion) to 0 (surface with high level of erosion) was used. According to the scale, a wood sample with no erosion on its surface after the weathering test was evaluated as a 10. However, a cracked wood surface was evaluated as a 0.

3. RESULTS AND DISCUSSOINS

3.1. Dry film thickness and adhesion strength

In this study, the effect of wood species (beech and pine) and coating viscosity on the adhesion strength were investigated. Summary of the results was presented in Table 4 and 5. As seen in Table 4, the viscosities of the surface formulations (A, D, G and L) used for the Tinuvin 477 DW (UV absorber) are higher than other formulations. As the viscosity value increases, the dry film thickness on the wood material of the varnish also increases. The pH of all varnish formulations are close values. Ozdemir et sl. (2013) investigated the relationship between varnish viscosity and adhesion strenght in their study. They found that the reduction of the varnish viscosity improved coating adhesion strenght.

Table 4. *The dry film thickness of coating applied to wood surfaces and the coating viscosity formulations*

Formulations	Beech Dry Film Thickness (µm)	Pine Dry Film Thickness (µm)	Application Viscosity (s)	PH
A	74±1.1	68±1.0	100	8.8
B	70±1.0	65±1.1	90	8.5
C	68±1.3	58±1.7	75	8.0
D	64±1.2	62±1.4	95	8.5
E	68±1.3	65±1.0	85	8.4
F	60±1.5	55±1.8	70	8.8
G	67±1.0	62±1.1	90	8.7
H	63±1.4	60±1.7	80	8.0
K	55±1.5	50±1.4	60	8.0
L	65±1.4	60±1.2	90	8.8
P	65±1.5	58±1.1	80	8.5
T	62±1.2	55±1.0	60	8.1

The effect of outdoor conditions on adhesion strength of 12 different coating formulations applied to beech and pine woods is given in table 5. The pull-off test results before the artificial weathering test showed that the adhesion strength of boric acid-free coating formulations was higher. In addition, 12 coating formulations have higher adhesion strength values in beech wood.

The artificial weathering test has adversely affected the adhesion strength of both types of wood for all coating formulations. However, the lowest adhesion strength loss for beech wood; A, G, H and P coating formulations, A, C, D and K coating formulations for pine wood.

Table 5. *Adhesion strength of unweathered and weathered woood samples*

Sample Code	**Beech**					**Sample Code**	**Pine**				
	After weathering		**Before weathering**				**After weathering**		**Before weathering**		
	Pull-off Test	*St.Ss	Pull-off Test	*St.Sp	*Lost in adhesion (%)		Pull-off Test	*St.Sp	Pull-off Test	*St.Sp	*Lost in adhesion (%)
A	1.55	0.17	1.72	0.34	0.09	A	1.16	0.39	1.29	0.21	0.11
B	1.06	0.35	2.38	0.35	0.55	B	0.46	0.07	2.38	0.31	0.81
C	1.05	0.55	2.39	0.41	0.56	C	1.23	0.25	1.74	0.15	0.29
D	1.11	0.39	2.03	0.28	0.45	D	0.64	0.29	0.91	0.43	0.30
E	1.12	0.27	2.79	0.46	0.60	E	0.355	0.17	1.05	0.41	0.66
F	1.02	0.44	2.77	0.71	0.63	F	0.24	0.06	0.91	0.46	0.74
G	1.50	0.75	1.72	0.79	0.13	G	0.75	0.44	1.22	0.51	0.39
H	1.66	0.38	1.90	0.38	0.13	H	0.33	0.17	1.5	0.32	0.78
K	1.54	0.23	2.51	0.47	0.39	K	1.18	0.71	1.41	0.08	0.16
L	0.84	0.31	2.21	0.03	0.62	L	0.65	0.44	2.3	0.51	0.72
P	1.65	0.41	2.24	0.74	0.26	P	0.35	0.21	1.72	0.38	0.80
T	0.37	0.24	1.69	0.26	0.78	T	0.51	0.26	0.95	0.35	0.46

3.2. Macroscopic evaluation

The faces of the wood samples were assessed visually, with the aim of verifying the eventual appearance of defects. The system defined in ISO 4628 was used to classify the degrees of the degradation (Custódio and Eusébio, 2006).

An all alteration of the surface of the coating was observed in all formulations, which consisted of an increase in the irregularity of the surface of the films due to weathering in Fig. 1 and 2. These observations are summarized in Table 6. According to the results of visual evaluation; C, F, K and T coating formulations that best protect surface quality after artificial weathering test. Grüll et al. (2014) determined that as increasing dry film thickness there was a tendency towards higher durability during artificial weathering.

Table 6. *Macroscopic evaluation of coated wood samples after artificial weathering test*

Sample Code	Beech	Pine
A	3	2
B	4	3
C	7	6
D	4	3
E	4	3
F	8	7
G	3	2
H	5	4

K	8	7
L	7	6
P	5	4
T	8	7

Note: A point scale of 10 (flawless surface with no erosion) to 0 (surface with high level of erosion) according to ASTM D 662-93 standard.

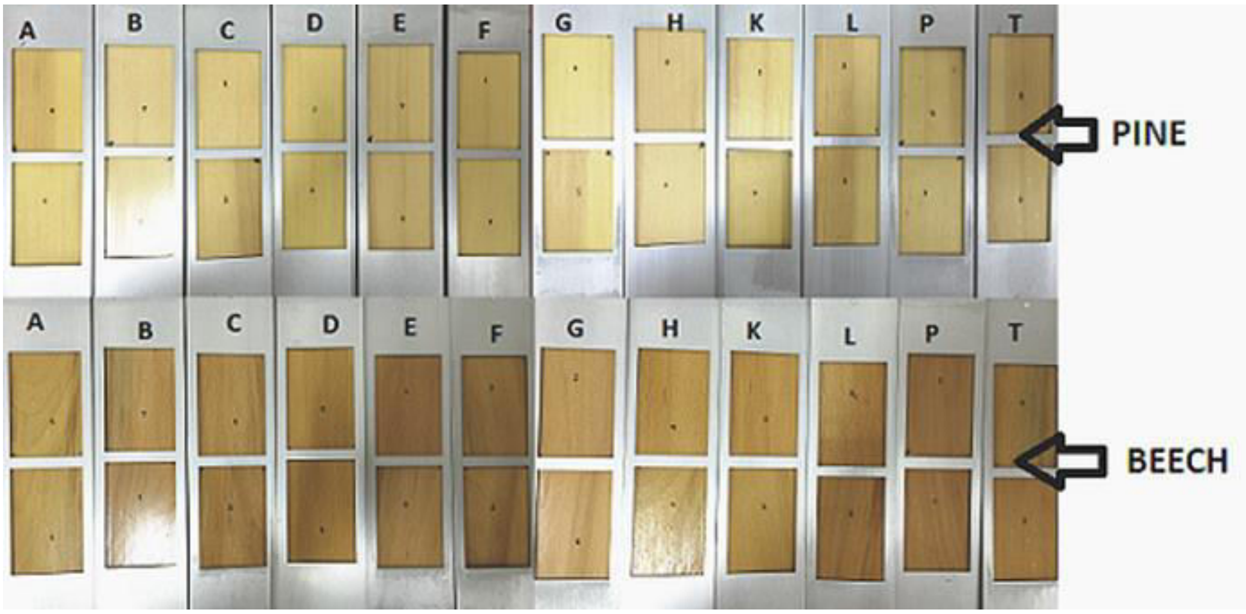

Figure 1. *Beech and pine samples applied 12 different coating systems before weathering test*

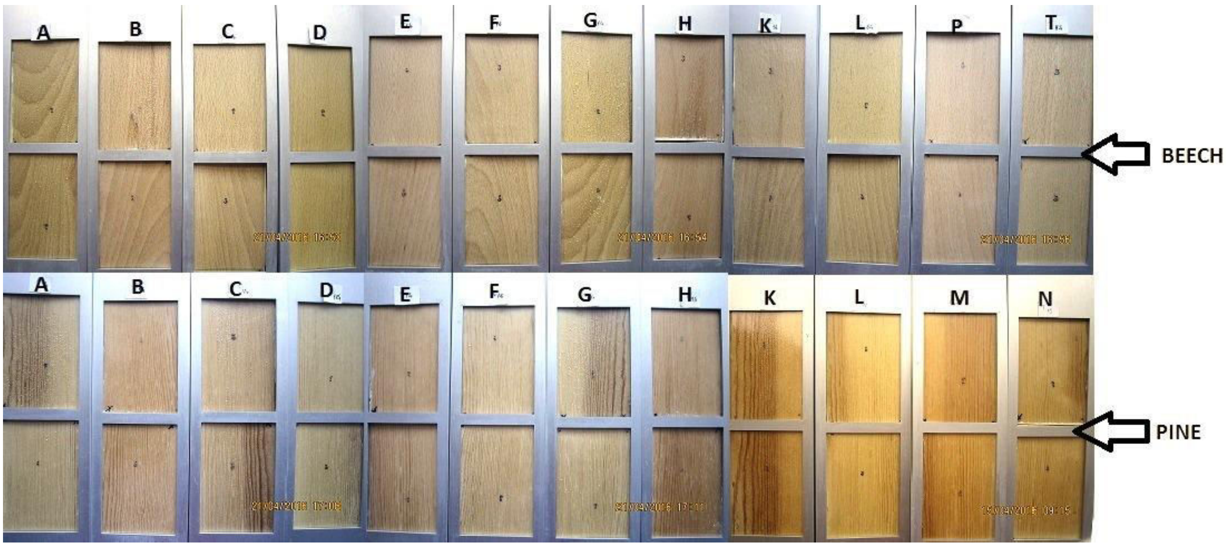

Figure 2. *Beech and pine samples applied 12 different coating systems after weathering tes*

4. CONCLUSIONS

Comparison of the durability of coating systems in artificial weathering using UV-lamps and water proved that there is a reasonable conformity between 12 different coating systems. It was confirmed that the weathering method described in EN 927-6 is suitable to test the performance of coatings on scots pine and beech wood. The weathering performances of coating systems applied on wood samples were examined by adhesion test and macroscopic observation. The results of this study demonstrated that careful selection of the analysis techniques and exhaustive interpretation of results is necessary to evaluate the durability of coatings for exterior applications.

Based on the results, a comprasion of the performance of the several formulations studied can be established:

- After the weathering test, the lowest loss of adhesion strength was determined in the scots pine and beech samples applied to coating formulation A. However, macroscopic evaluation of coating formulation A after weathering testing is not good. The degradation was observed in the coating film layer on the sample surfaces.
- With the exception of formulation A, the lowest loss of adhesion strength due to the weathering was observed in the formulations K, C, D and G for scots pine; formulations G, H, P and K for beech wood.
- After the weathering test, the best formulations with the smoothest surface and the macroscopic evaluation were found as formulations C, F, K and T.
- When all the results are evaluated; for both two species of formulation K, the loss of adhesion strength was lowest and visual evaluation was best in outdoor conditions.

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DETERMINATION OF LEACH RESISTANT AND LIMITED OXYGEN INDEX LEVELS OF DIFFERENT WATER BASED ACRYLIC WOOD-CLEAR COATING SYSTEMS

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ABSTRACT

In this study, the limited oxygen index levels (ASTM D 2863-76) were investigated to obtain an indication of the relative flammability of fire retardant and leaching resistant for wood-clear coating systems containing different water based acrylic with UV absorber. Six different wood-clear coating were used, two of which were synthesized in laboratories and others were commercial. These wood clear-coating systems were applied on the scots pine and oriental beech woods samples. The amount of clear-coat in the leaching water was determined by UV spectrophotometer at the intervals of 2, 4 and 8 hours during the leaching test. The results show that the limited oxygen index (LOI) of the wood-clear coating systems synthesized in the laboratory and commercial coatings were close values. However, as compared to uncoated and clear-coated beech samples; the (LOI) values of the uncoated and clear-coated scots pine were found to be low. While smoke formation was not observed in beech samples, it was observed in pine specimens. The leaching rates of all coating systmes were obtained to be quite high.

Key words: Acrylic resin, beech, clear-coat, fire retardancy, leach retardancy, oxygen index, scots pine

1. INTRODUCTION

Wood is mostly found material in the nature and also biodegradable, biorenewable, and biorecycle which are recognized as favorable for environment (Rowell, 2012). Besides this, it is the most preferred engineering material due to its high mechanical and aesthetic properties compared to many structural materials. It has also a complex structure composed of cellulose, hemicellulose, and lignin, which gain itself a strong character (Sjöström, 1993).

It is well-known that wood can be easily degraded by biological threats, such as fungi, insects, molds, etc. to be obtained CO_2, H_2O and energy under the appropriate conditions (Schmidt, 2006). Wood can be also changed at the outdoor conditions. Solar radiation, water, chemicals, humidity, UV rays, temperature, and oxygen are factors that cause to change the wood chemical and physical structure (Derbyshire and Miller, 1981, Feist and Hon, 1984; Schmidt, 2006; Sell and Feist, 1986).

Fire is another factor that damages the wood. When wood is warmed up, thermal degradation starts that causes to consist of some chemical reactions, which are breaking of chemical bonds, dehydration, formation of CO_2, and CO gases, carbonyl and hydroperoxide groups (Rowell, 2012). The preservatives and toxic chemical are used to increase wood durability and biological resistance. Ammonium phosphate, ammonium phosphate with ammonium chloride, boron compounds are some of the fire retardants used for wood (Richardson, 2002). It is important to determine thermal properties of wood. One of the used methods to determine the fire performance of wood is limited oxygen index test (LOI) because of rapid, requiring small sample sizes, and an easy sample preparation (Dizman Tomak and Donmez Cavdar, 2013; Donmez Cavdar, 2014).

The main objective of this study was to examine physical properties of wood-clear coating systems. For this purpose, scots pine and beech wood samples were treated with different coatings. The leaching resistance of coatings was determined by UV spectrophotometer. The thermal properties of wood treated with coatings also evaluated with limited oxygen index test.

2. MATERIALS AND METHODS

2.1 Wood Materials

As a raw material Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* L.) were used in this study. Sapwood blocks were prepared for leaching test by the dimensions of 20 mm (R) x 20 mm (T) x 20 mm (L) and 10 mm (R) x 3 mm (T) x 150 mm (L) for the oxygen index (O.I.) test. Wood samples were conditioned in a climate room at 23±2 ^{o}C and 65±5 relative humidity until constant weight was attained.

2.2 Coating System

The commercial water-based impregnation product, having active ingredients of 1.20% propiconazol, and 0.30% iodopropynyl butylcarbamat, was used as a primer for the protection of the samples against biological deterioration, including soft rot and blue stain. The primer was applied to the samples at a spread of 120 g/m² using a brush. Tinuvin 400 DW as UV absorbers were used in this study. Commercially produced finishing, having acrylic resin, a copolymer dispersion of methylacrylate/methylmethacrylate/ butylacrylate, was used as a topcoat for the specimens. A small amount of defoamer and 2,2,4-trimethyl-1,3-pentandiolemonoisobutyrate, a coalescending agent was added in the topcoat formulation to reduce the effect of other additives on the photostabilization performance. These formulation products were supplied from BASF Company for the wood coatings (Table 2). Three layers of topcoats were also applied to each sample at a spread rate of 100 g/m² by brush. Later, the specimens were sanded with a 240 grit size of sandpaper and kept at room temperature for two days before applying the second layer of topcoat. The codes of wood coating materials in the study are given in Table 1.

Table 1. *The codes of wood coating materials in the study*

Formulation Code	Pruducts
A	Water-based acrylic resin coating containing UV absorber.
F	Water-based acrylic resin coating containing UV absorber and 1% boric acid.
B	Commercial product
C	Commercial product
D	Commercial product
G	Commercial product

Table 2. *The formulations of A and F wood coating systems*

Formulation products	Content (%)	A	F
Acrylic resin	73.7	x	x
Tinuvin 400 DW	3.0	x	x
Film-forming agents	0.67	x	x
Defoamers	1.0	x	x
Dispersing agent	0.6	x	x
Rheology modifier	1.3	x	x
Distiled water	19.73	x	x
Distiled water with 1% Boric acid	19.73	-	x

2.3. Leaching Test Procedure

The color intensity of this wavelength was determined with the maximum wavelength of varnishes using Libra / Biochrom brand UV spectrophotometer. Then, varnished wood samples were taken at constant temperature water bath (JSR/JSSP-30 T brand) and washing experiments were carried out. Here, a certain number of varnished wood samples were placed in a beaker with 250 ml of distiled water. These samples were taken at constant temperature in an agitated water bath and rinsed at 120 rpm for 120 minutes (Figure 1). During this process, the color changes in the water which has been agitated after 5, 15, 30, 60, 75, 90, 120 minutes have been investigated. In this step, 5 ml of rinsing water was centrifuged each time, and color changes were determined by UV spectrophotometer at a wavelength range of 190-1100 nm. (Figure 1).

Figure 1. *UV spectrophotometer and water bath*

2.4. Flame retardant (FR) properties measurement

The FR properties of all samples were determineted by the Limited oxygen index (LOI) test. The high value of LOI indicates that the fire resistance is high. LOI test is performed according ASTM D2863 standard and used Dynisco Limiting Oxygen Index Chamber tester. Scots and beech wood samples were placed vertically in the center of the glass column using a sample holder and then were burnewd in a precisely controlled atmosphere of nitrogen and oxygen. LOI was defined as the lowest oxygen consentration in the carrier gas flow at which combasting the samples in 3 min or 5 cm (Mamatha et al., 2017). Five samples from each groups were tested.

Figure 2. *LOI test chamber*

3. RESULTS AND DISCUSSIONS

3.1. Leaching Test

The adhesion performance of the coating systems on the wood surface was evaluated in this study. Many factors affect the adhesion of coating systems such as the ability of bond of coatings with wood, bulk volume, density, and wood species. The color intensity of wavelength was determined with the maximum wavelength of varnishes, as seen in Table 3. The leaching values of wood coating systems and samples was also seen in Table 4 and Fig. 3.

Table 3. *The wavelengths of wood coating systems*

Coating groups	Max. wavelengths (nm)
A	322
B	279
C	302
D	254
G	364
F	297

According to obtained results, the leaching rate of coating systems increased with increasing time from 150% to 600% from 5 min to 120 min for scots pine samples. Leacing rate of group B, C, and D was higher than the other groups. On the other hand, it was very low for group A, D, and F in the first 30 min. Morever, leaching was almost all constant for group G, and F. The highest leacing was obtained from group D (600%), while the lowest one was group F (150%). Meanwhile the leaching resistance of wood-clear coatings synthesized in laboratories was less than the commercial products for pine samples.

Table 4. *Leaching test values of wood coating systems*

Wood species	Leaching time (min.)	A	B	C	D	G	F
Scots pine	5	0.002	0.008	0.025	0.002	0.002	0.002
	15	0.002	0.014	0.068	0.008	0.002	0.003
	30	0.003	0.018	0.085	0.012	0.003	0.003
	60	0.005	0.035	0.116	0.012	0.005	0.003
	90	0.006	0.044	0.130	0.012	0.005	0.004
	120	0.011	0.048	0.150	0.015	0.006	0.005
Oriental beech	5	0.001	0.005	0.022	0.004	0.001	0.001
	15	0.001	0.012	0.062	0.007	0.002	0.001
	30	0.002	0.018	0.085	0.010	0.003	0.003
	60	0.003	0.027	0.112	0.011	0.004	0.003
	90	0.003	0.033	0.130	0.012	0.004	0.004
	120	0.005	0.038	0.141	0.013	0.005	0.004

The leaching rate was obtained to be high in the beech samples than pine samples, as seen in the Table 4. Similarly it increased from 225% to 660% from 5 min to 120 min for beech samples. Leaching rate was constant for group A and F in 15 min. Moreover, it was very low for group A, D, G, and F. The highest leaching was obtained from group B (660%) while the lowest one was group D (225%). Likewise, scots pine samples, the leaching rate of wood-clear coatings synthesized in laboratories was higher than the commercial products for beech samples.

Figure 3. *Leaching test samples*

3.2. Flame retardant (FR) properties

The LOI values of wood coating systems are given in Table 5 and Fig. 5 and test samples can be also seen in Fig. 4. All coating groups, excluding B (for beech wood), showed low LOI values than control groups. The addition of coatin systems on the wood samples decreased the LOI values, which are an indication of decreased flame resistance. Uysal at al. 2011 demonstrated that the varnishes have the triggering and enhancing effect on combustion during the burning process.

Table 5. *LOI values of wood coating systems*

Sample Groups	LOI (%)	
	Beech	Pine
Control	24.38	21.34
A	22.70	20.65
B	24.42	20.50
C	22.55	20.66
D	22.57	20.68
E	23.46	20.72
F	23.50	20.50

According to the results, the tree species significantly affect the fire resistance (Bari et al., 2015; Mederski et al., 2015). It was determined that pine wood samples had higher flammability properties than beech. In the present studies, beech and pine wood density values were found that 0.750 and 0.455 g/cm^3, respectively. Palacio at al. (2012) was found that fire performance is related to wood density. The increase in density results in increasing of duration of ignition and temperature. Furthermore, the high air void ratio and oxygen content in the material facilitates the combustion properties. The increase in density reduces the amount of space in the material. In addition, the high amount of extractives may have had the effect of reducing the burning strength in pine wood (Poletto et al., 2012).

Figure 4. *LOI test samples*

According to the results, the coating systems used in the this work did not create a resistance against burning in wood samples. But, there is no effect that increases the flammability properties of wood samples due to coating systems (Fig. 5).

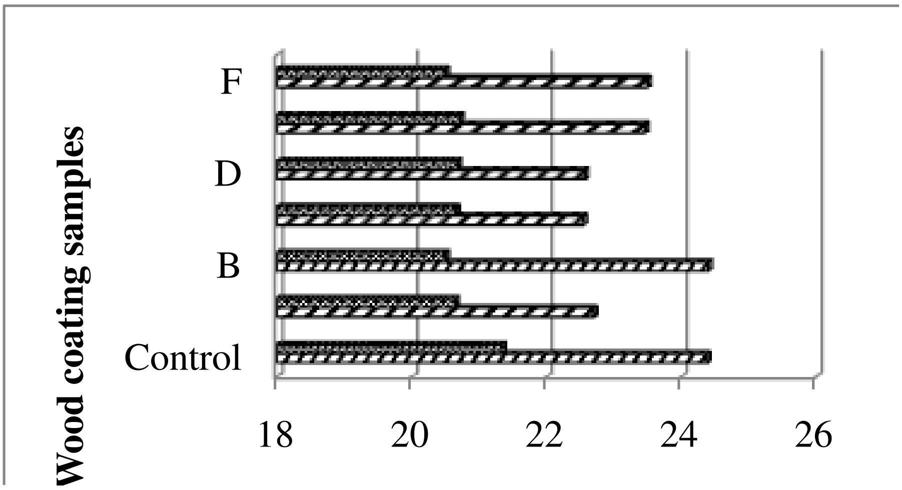

Figure 5. *LOI values of control and test wood samples*

4. CONCLUSIONS

Wood can be easly degraded by organic and inorganic factors under the appropriate conditions. The diversity of wood chemicals and methods have been used to improve wood durability. Coating systems are one of the preservation methods. However, leachability and fire performans of chemicals used as a preservative are important to evaluate their performance. In this study, we investigated six different coating systems' fire performance and leachability. Leaching rate increased with increasing time for all of coating systems. It was found to be low for commercial coatings than the laboratory-synthesized coatings. There were also differences between pine and beech wood samples leachability.

Wood species, density, bulk volume, bonding capacity also affect leaching. It is known that wood-coating systems decreased the wood fire performance. However, there were no significant differences between control and coating applied samples. The decrease in the fire performance for pine samples was lower than the beech samples. The adhesion and leachablity performance was found to be better than beech samples, which could affect the fire performance.

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ADHESION OF GLUING AND FINISHING FILMS TO CHESTNUT SOLID WOOD

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ABSTRACT

This report refers to the experimental examination of the adhesion of gluing and finishing films. The gluing films are formed by reactive acid-curing urea-formaldehyde resin: Prefere 4114 and acetate polymer adhesive: Jowacoll 124. The Strength of adhesion of gluing films is determined under regulations BDS EN 302 and BDS EN 205 (ASTM D 905). Protective-decorative films was formed with acrylic water-deluted varnish and Deva D3 reactive acid-curing varnish (butanolysis melamine-urea- formaldehyde resin). For this aim are used test samples from of chestnut *(Castanea sativa L.)* solid wood. The purpose of research is to study the influence of surface roughness on the adhesion. The Strength of adhesion of finishing films was determined by methods of pull out of glued metallic-stem under regulation BDS EN ISO 4624(BDS 13088). The obtained results indicate, that the surface roughness influence on the strength of adhesion of gluing and finishing films on chestnut solid wood. The coarser grind surface generally had the best adhesion. The highest adhesion strength of gluing was obtained with 40-grit sandpaper (6.34 N/mm^2 for PVA glue and 8.88 N/mm^2 for MUFR glue). For varnishes, the maximum adhesion strength was obtained for Deva D3 varnish (4.49 N/mm^2), followed by acrylic (2.64 N/mm^2) and water-based (1.87 N/mm^2).

Key words: chestnut; adhesion; reactive glues; acrylic varnish; reactive acid-curing lacquer

1. INTRODUCTION

The wood is an unusual material because it is formed in the living tree. It is renewable material. Solid wood is use for manufacturing furniture, windows, doors, and another building structures. For these purpose timber is glued. The wood bonding process involves a great number of factors that determine how successfully an adhesive bond will perform during its service life. Therefore, the application of bonding technologies requires dealing with some basic topics in order to establish the theoretical bases for a proper use in practice. A lot of information is available, though it is widely spread, and therefore, difficult for an evaluation on a comprehensive level. The wood has many defect: uptake water and reduce dimensions; decay; destroying from insects. This is the reason to du protection of the wood surface.

There are two main types of wood species in commercial use: softwoods and hardwoods. Examples of softwoods include pines, larch, firs, hemlocks. Examples of hardwoods include such species as the oaks, chestnut, beech, elm, maples, poplar, mahogany. Hardwoods are often separated into two classes: "diffuse-porous" and "ring-porous". Beech, maples and poplar are examples of the "diffuse-porous", whereas oaks, chestnut and elm are ring-porous. Adhesion is a physical-chemical phenomenon involving adsorption of the adhesive on the wood surface, rather than some form of mechanical interlocking to the porous structure itself. Some bonding processes involve heating at high temperatures to cure the adhesive film. The gluing of wood is probably one of the earliest applications of adhesives. The early woodworking adhesives were of natural origin (animal, blood-glues, casein, soybean). The greatest advances in wood bonding have come since the mid-1930s with the introduction of various synthetic-resin adhesive systems [6]. Most of these are based on the thermosetting resins such as phenol-formaldehyde, resorcinol-formaldehyde, urea-formaldehyde, melamine-formaldehyde, epoxy resins. They may cured with suitable catalyst and curing agents for room- temperature curing in cold presses (acid-catalysts; amine, amide and isocyanate curing agents). They may also be formulate for hot pressing. Urea-formaldehyde resin glues can also be formulated for curing under radio-frequency-heating techniques. Phenol-resin glues are commonly used as alkaline dispersions in water with addition of fillers. They require hot pressing at temperatures of 150ºC or higher but are capable of producing very durable glue lines (films) that are resistant to long exposure to weather, moisture, heat, and microorganism attack. Resorcinol-formaldehyde have been used since World War II to provide very durable glue films of curing at normal room temperature. Their principal use has been in laminating heavy structural timbers for exterior exposures [6]. The epoxy-resin have been investigated for wood bonding, but they are useful for bonding metals to wood for special uses [6].

Thermoplastics polymeric glues (rubber-base; polyurethanes) have found considerable application for nonstructural applications. These adhesives are normally applied to both mating surfaces, and then allowed to dry to a tack-free state before assembly. The work well in thin glue films, and bond under essentially contact pressure or roller-press operation at normal room temperatures. They develop only a moderate level of strength on curing as the solvent escapes. A typical rubber-base contact glue is a dispersion of neoprene elastomer in organic solvents. Some rubber-base glues in aqueous-emulsion form have been introduced for wood bonding, but they have not found any extensive use. One of the most important adhesive systems for wood bonding is that based on aqueous emulsions of polyvinyl acetate or its various copolymers [6]. These adhesives are ready to use when received and they are used in production of furniture. Paper overlays of various types are often bonded to the surface of lumber or plywood. In this case special paper sheets, previously impregnated with various amounts of phenol-formaldehyde and melamine-formaldehyde resin, are used [6].

Difference kind of film-forming materials are used to finishing of wood surfaces (reactive and un-reactive). During much of the laminating operation described, the adhesive-coated wood surfaces may be partially exposed to the air, so-called "open assembly", during which time the solvents can escape from the adhesive, with resultant thickening and after that any pressure applied by high temperature (120-130 ºC) to obtaining hard film. Since the adhesive will thicken both from evaporation and from chemical reaction as a function of rising temperature, these assembly condition are usually cited for two or three different shop temperature [6].Testing wood adhesives include determinate of working properties such as viscosity of the mixed glues, pH, pot life, rate of development of strength in joints, amount of filers and nonvolatile (solids) content of resins. Procedures for determining shear or tensile strength made in the prescribed laboratory conditions [1;3;4;5]. The most commonly used strength tests are the block shear and plywood shear tests . For these purpose are used wood with higher density such maple, beech or birch [1; 5; 6]. This is to provide as strong wood as possible, in order to reduce the premature failure in the wood. As a further criterion of joint quality, estimations are made of the percentage of wood failure in broken specimens

2. MATERIALS AND METHODS

The main aim of this research was to test comparatively the adhesion of glued and finishing films applied to Sweet chestnut wood. For this aim test samples from Sweet chestnut wood are used because ***(Castanea sativa Mill.)*** is an important wood resource in Bulgaria and is being used for the fabrication of interior furniture and other interior structures (e.g. staircases). Timber is with medium density (550-600-650 kg/m^3), hardness, strength and easily machine processing and glued. The heartwood contains a very proportion of tannin, therefore it is fairly resistant to destroying from fungus. It is very durable under water. Sweet chestnut wood is used as construction element shipbuilding, railway sleepers, staves, barrels, turned wood and carving wood, in furniture building, especially for the chairs and table legs, and for the parquet staves. Lately, these have been made most out of solid wood panels resulting from longitudinal finger-joint and lateral gluing of wooden strips.

Primarily, test samples were obtained from chestnut wood at 18x60x600 mm dimensions such that they had regular fiber structure without knots and cracks, they were cut so that the annual rings were perpendicular to the wood surface. The following machines were used in the processing of chestnut wood and preparation of bonding and finishing surfaces: band saw machine; circular saw machine; plane machine; thickness machine; calibrating sanding machine (with P40; P60; P80 and P100 grit sandpaper). The timber (with equilibrium moisture content of 12 %) was cut to dimensions of 15x50x300 mm with radial surfaces. Surface roughness measurements of chestnut wood samples were carried out in radial surface using contact electrical surface profile-meters PCE-RT1200 (figure 1) instrument with sensitivity of 0.005 µm according to DIN4768 standard. The average roughness (Ra) was measured to evaluate the surface roughness of chestnut wood samples. According to the surface processing types, the roughness measurements were carried out in a perpendicular direction to the fibers. Measurements were made at five different positions of the each sample. The measurements were recorded at the same points on the radial surface of each sample [2].

Figure 1. *Contact electrical surface roughness instrument PCE-RT1200*

For the making laboratory researching were used two glues: PVAc (polyvinyl acetate): Jowacoll 124.00 and UF (urea-formaldehyde): Prefere 4114.These adhesive are the most widely used adhesive types in the wood working industry. The next signature for gluing film were used: UFR for urea-formaldehyde resin PREFERE 4114; PVA for polyvinyl acetate glue Jowacoll 124.00.These adhesive were used to bond sample pairs to determine their shear strength. Adhesives were applied to both surfaces of each shear pair at a spread rate of 200-250 g/m^2. The pairs (specimen blocks) were then pressed (cold or hot) using an approximate pressure of 0.5 N/mm^2 (5 kg/cm^2) for 60 min. The adhesive were applied in the recommendations of the producing companies (Jowat – Germany; Dynea- Hungary). The glue PREFERE 4114 is reactive and low toxicity. It has (60-70%) dry content; with free formaldehyde content ≤0.4%; with specific gravity 130 g/ml and pH = 8.5. The hardener (curing agent) is Prefere 5272.

The glues mixture is received by arithmetic relation 5:1 (resin: hardener). For pressing the specimens according to their cutting dimensions, a hydraulic laboratory press with table dimensions of 300x300 mm, whose temperature and pressure can be adjusted, was employed. During pressing, the recommendations of the producer company were followed: the pressing temperature was 50^{0}C for specimens with PVAc and 125^{0}C for specimens with UF glues. The Strength of adhesion of dry gluing films was determined under the regulation BDS EN 205 and BDS EN 302-1 and, which is similar to ASTM D905: 2008- Standard test method for strength properties of adhesive bonds in shear by compression loading [1]. The pressed specimen blocks were sized 15x15x150 mm and were formed at in line with BDS EN 302-1 to form test specimens (fig.2).

For every variant was prepared 25 specimens. The prepared specimens were then placed in an environmental test chamber with a temperature of 20±2ºC and relative moisture content of 65±3 % to homogenize them and bring air dryness to moisture content value and left there until their weight reached a fixed state (12 % moisture content value). The specimens for the test (fig.2) were tied to the machine in line with the standard. During the test the machine´s loading speed was adjusted to 12.7 mm/min. The force at the moment the pieces broke away from each other was read from the scale and recorded. The achieved were used in the equation below to determine the shear strength of each piece (1):

$$\sigma_a = \frac{Pmax}{S}, N/mm^2 \quad (1)$$

Where: $\boldsymbol{\sigma_a}$ is the shear strength (*N/mm*^{2}), $\boldsymbol{P_{max}}$ is the maximum force at the moment of rupture in (*N*) and $\boldsymbol{S}$ is the bonding surface area in (*mm*^{2}).

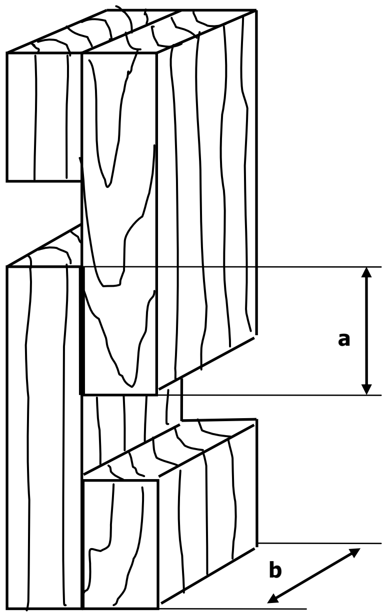

Figure 2. *Shear test specimens- Bonding of the specimens by being matched with their radial-radial surfaces (BDS EN 302-1)*

$$\sigma_a = \frac{Pmax}{S}, N/mm$$
$$S = a.b, mm^2$$

This report experimentally examined adhesion of finishing protective-decorative films formed with reactive acid-curing varnishes (QUI Deva D3) producing from QUI DEVA Ltd -Spain; and acrylic water-diluted varnish AQUIS Natural Colors, producing from Orgachim AG-Russe- Bulgaria. The next signature for protective decorative finishing film were used: UMF- urea-melamine formaldehyde acid-curing varnish, ACWD- acrylic water-diluted emulsion varnish. For these aim are used ***6*** test sample from chestnut wood, which was cut to dimensions of 15x50x300 mm with radial surfaces with 5 different surface roughness. They were produced with helping circular saw machine; plane machine; thickness machine; calibrating sanding machine (with P40; P60; P80 and P100 grit sandpaper). The films were prepared with spray-gun in special Equipment. The coats are cover up three times for received with enough thickness after hardening. After drying of all layers is done sand with P320 grit sand paper.

The thickness of dry film is determined with micrometer with precisely 0,01mm (10μm) with equation (2):

$$\delta_{dc} = \delta_f - \delta_s, [\mu m] \tag{2}$$

Where: δ_{dc} is the thickness of dry film, μm; δ_f is the thickness of the sample with hardening film, μm; δ_s is the thickness of the sample without coat, μm.

The Strength of adhesion of finishing films was determined by methods of pull off of glued metallic-stem (figure 3) under the regulation BDS 13088 (BDS EN ISO 4624). For every variant were prepared ***6*** specimens with 6 testing, or for every variant were received 36 test results. The steel dolly (metallic-cylinder stem) is glued with ethyl-cyan-acrylic glue ”Loctide Super Glue Liquid Professional”, producer of Henkel AG- Germany.
The adhesion strength of film to each piece is calculation by equation (3):

$$\sigma = \frac{P_{\max}}{S} = \frac{P_{\max}}{\pi.R^2} = 0.032.P_{\max}, N/mm^2 \tag{3}$$

Where: $P_{\max}$ is the breaking force, kg; ***S*** is the area of the steel dolly, cm^2 (3.14 cm^2); R=1 cm.

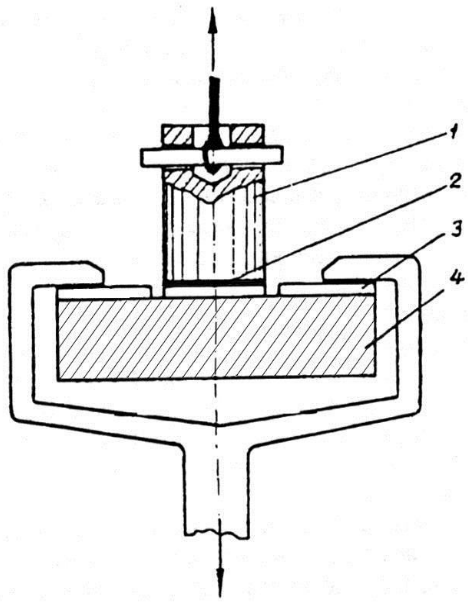

Figure 3. *Test assembly for rigid substrates according BDS 13088 (BDS EN ISO 4624:2016)*

1-Steel cylinder stem (dolly);
2- cyan-acrylates layer adhesive;
3- paint (varnish) coating (film);
4- rigid substrates (wood);

$\sigma_a = \frac{Pmax}{S}, N/mm^2$; $S = \pi R^2$

Data obtained by the testing of specimens for gluing films and for finishing films in accordance with different variables were subjected to statistical analysis. To determine whether the surface processing type (surface roughness), cutting direction, glue and varnish type an effect on the shear strength (bonding) of beech wood, statistical analysis was carried out. If the value resulting from this analysis was smaller than ±5 %, the variable was considered to be effective on the shear strength (bonding strength of the glue) or put-out strength of the finish films (adhesion of the hard film to wood surface). Statistical software package was used for the statistical evaluation of the test results (MSTAT-C). The parameters were calculated by equations (4; 5; 6; 7; 8; 9; 10):

$$(4) \rightarrow Aver = \frac{\sum x_i}{n} \quad (5) \rightarrow D = \pm\frac{\sum(X_i - Aver)^2}{n-1} \quad (6) \rightarrow StD = \pm\sqrt{\frac{\sum(X_i - Aver)^2}{\mathrm{n}-1}}$$

$$(7) \rightarrow Error = \frac{StD}{\sqrt{n}} \quad (8) \rightarrow V = \frac{StD}{Aver}.100,\% \quad (9) \rightarrow p = \frac{Error}{Aver}.100,\%$$

Comparisons were made using Student test and the least significant difference (LSD) test. For determine (establish) the reliable of the differences between variances volume of Student coefficient are calculated with next equation (10):

$$m_d = \frac{Aver_1 - Aver_2}{\sqrt{Er_1^2 + Er_2^2}} \quad (10)$$

The differences are reliable when $m_d \geq 3$.

3. RESULTS AND DISCUSSION

The outside vision of some wood finishing test species before testing and after testing are given in Fig. 4.

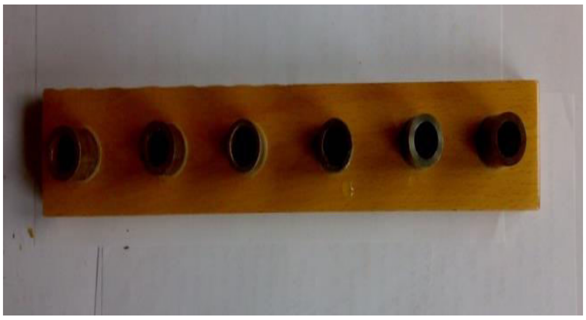

Figure 4a: *Sample before testing*

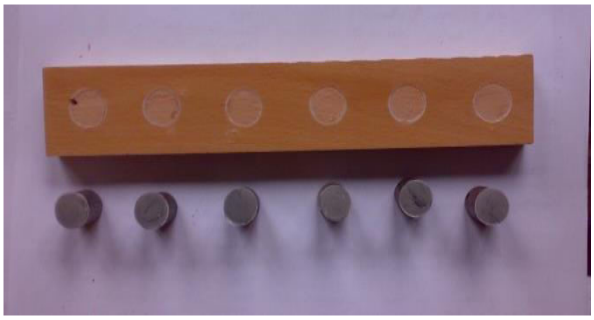

Figure 4b: *Sample after testing*

Data and statistical analyses summarizing the effects of the wood species, cutting direction, sandpaper grit (surface roughness), glue and varnish type on adhesion strength are presented in Table 1 and Table 2. In table 1 are presented the average value of adhesion strength of investigated glue films to radial surfaces of Sweet chestnut wood prepared with urea- formaldehyde and PVA glue. From these results is outlook, that with increasing the surface roughness become increases the value of the adhesion strength of glue films. These tendency is watch over by two used glue (fig.5). By compare analysis is establish, that the highest adhesion have the glue films forming with urea-formaldehyde resin (6.17-8.88 N/mm^2), which is in good accordance with results of another researches for oak wood [7; 8; 9;11].

Table 1. *Adhesion Strength of Urea-formaldehyde and PVA Glue Films to radial Chestnut Wood*

Index of Variant	**Sand-paper type (ST)**	**Average surface roughness (Ra-μm)**	Statistical data for Adhesion Strength , (**N/mm^2**)						
			Aver. [N/mm^2]	StD ±[N/mm^2]	Error ±[N/mm^2]	V %	p %	Rupture , % in wood	Rupture , % in film
CS-PVA	PLM	9.50	7.98	0.87	0.17	10.9	2.2	20	80
	40 grit	8.20	6.28	0.80	0.16	12.7	2.5	10	90
	60 grit	7.70	6.75	0.92	0.18	13.6	2.7	10	90
	80grit	6.20	5.95	0.72	0.14	12.1	2.4	10	90
	100 grit	5.20	5.15	0.91	0.18	17.7	3.5	15	85
CS-UFR	PLM	9.50	8.88	0.83	0.17	9.3	1.6	40	60
	40 grit	8.20	7.25	0.78	0.15	10.7	2.2	30	70
	60 grit	7.70	7.48	0.84	0.17	11.2	2.2	20	80
	80grit	6.20	6.87	0.90	0.18	13.1	2.6	10	90
	100 grit	5.20	6.17	0.95	0.19	15.4	3.1	10	90

Description: ***CS-PVA: chestnut wood+ PVA Glue; FS-UFR: chestnut wood+ UFR Glue; Ra-surface roughness (mean deviation between valleys and peaks); PLM- planed on plane machine;***

Some l differences between variances are reliable, because of the volume of Student coefficient are bigger from 3 (m_d > 3). For example by compare differences between PLM and 100 grit in variants CS-PVA Student coefficient value is 17.5; between PLM and 40 grit is 7.39; between PLM and 60 grit is 5.0; between PLM and 80 grit is 9.22; between 40 grit and 100 grit is 4.70; between 40 grit and 80 grit is 1.57 , but these difference is not statistically significant; between 40 grit and 60 grit is 1.96 or these difference is not statistically significant too.

In table 2 are presented the average value of adhesion strength of investigated finishing films to radial surfaces of chestnut wood prepared with used varnishes: urea-melamine-formaldehyde Qui Deva D3: CS-UMFR; ACWD acrylic water-diluted varnish AQUIS Natural Colors: CS-ACWD. From these results is visible, that with increasing the surface roughness become enlarge the value of the adhesion strength.These results were in good accordance with the cotter working theory, e. c. the film is clamp up in wood pore. These tendency is watch over by two used varnishes. But these tendency is limited (Table 2; fig.6). By compare analysis is establish, that the highest adhesion have the finishing films forming with urea-melamine formaldehyde varnishes (3.62-4.89 N/mm^2). The adhesion strength of the finishing films forming with acrylic water-diluted varnish AQUIS Natural Colors: (CS-ACWD) is smaller and it is in limit: (2.87-4.25 N/mm^2), which is in good accordance with results of another researches [7; 8; 9;12]. Looking at interactions among wood species, cutting direction, and sandpaper grit, the highest adhesion strength was observed using 40-grit sandpaper (4.89 N/mm^2 and 4.05 N/mm^2) on chestnut wood in radial direction, while the lowest adhesion strength was observed using 100-grit sandpaper (3.62 N/mm^2 and 2.87 N/mm^2) on chestnut wood in radial direction (Fig. 6). Combining the species and looking at sandpaper grit size alone, the highest adhesion (4.89 N/mm^2) was observed with the 40-grit for variant: CS-UMFR (finishing films forming with urea-melamine formaldehyde varnishes), while the lowest (2.87 N/mm^2) was obtained for 100-grit sandpaper for variant: CS-ACWD (finishing films forming with acrylic water-diluted varnish AQUIS Natural Colors). Table 2 and fig.6 show that in variant CS-UMFR by roughness 8.20 μm average adhesion is **4.89±0.13 N/mm^2** , but by roughness **9.50 μm** average adhesion **is 4.25 ± 0.14 N/mm^2**). The reason for decrease of adhesion strength with higher roughness is not fully clear. On the one side the anatomical structure of sweet chestnut 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. The results showed, that with increasing the surface roughness the adhesion strength also rises, but this depends on chemical composition of the varnishes and glues. With increase of the surface roughness at very high levels the adhesion strength decreases probably because of breaking of the film and decrease of connection between film and wooden surfaces. These tendency is watch over by two used varnishes. Table 2 and fig. 6 show that in variant CS-ACWD by roughness **8.20 μm** average adhesion is **4.05±0.13 N/mm^2** , but by roughness **9.50 μm** average adhesion **is 3.54 ± 0.13 N/mm^2**).

Some differences between variances are reliable, because volume of Student coefficient are bigger from 3 ($m_d > 3$). For example by compare differences between PLM and 100 grit in variants CS-UMFR Student coefficient value is 4.84; between PLM and 40 grit is 3.36; between PLM and 60 grit is 3.08; between PLM and 80 grit is 0.61 or these difference is not statistically significant; between 40 grit and 100 grit is 6.68; between 40 grit and 80 grit is 5.22; between 40 grit and 60 grit is 1.33 or these difference is not statistically significant too.

***Table 2.** Adhesion Strength of Varnish Finishing Films to radial Chestnut Wood*

Index of Variant	**Sand paper type (ST)** grit	**Average surface roughness (Ra), μm**	**Thick-ness of dried film μm**	Statistical data for Adhesion Strength , (**N/mm^2**)						
				Aver. N/mm^2	StD $\pm N/mm^2$	Error $\pm N/mm^2$	V %	p %	Type Failure , %	
									in wood	in film
CS-UMFR	PLM	9.50	230	4.25	0.78	0.13	18.3	3.1	40	60
	P40	8.20	230	4.89	0.82	0.14	16.8	2.8	50	50
	P60	7.70	220	4.65	0.80	0.13	17.2	2.8	40	60
	P80	6.20	210	3.95	0.72	0.12	18.2	3.0	40	60
	P100	5.20	190	3.62	0.78	0.13	21.5	3.6	30	70
CS-ACWD	PLM	9.50	210	3.54	0.78	0.13	22.0	3.7	30	70
	P40	8.20	220	4.05	0.76	0.13	18.8	3.2	40	60
	P60	7.70	200	3.62	0.70	0.12	19.3	3.3	20	80
	P80	6.20	190	3.16	0.62	0.10	19.6	3.2	20	80
	P100	5.20	200	2.87	0.62	0.10	21.6	3.5	20	80

Description: ***CS-UMFR: chestnut wood+ UMFR finishing film; CS-ACWD: chestnut+ ACWD finishing film;***

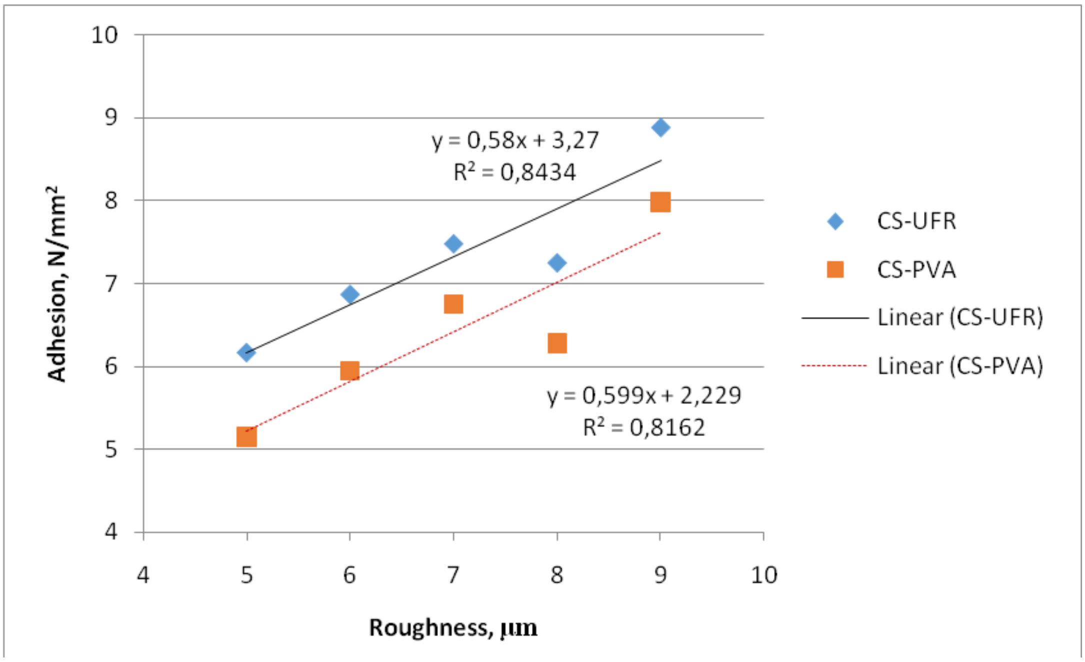

Figure 5. *Influence of Surface Roughness on Adhesion Strength of glue films*

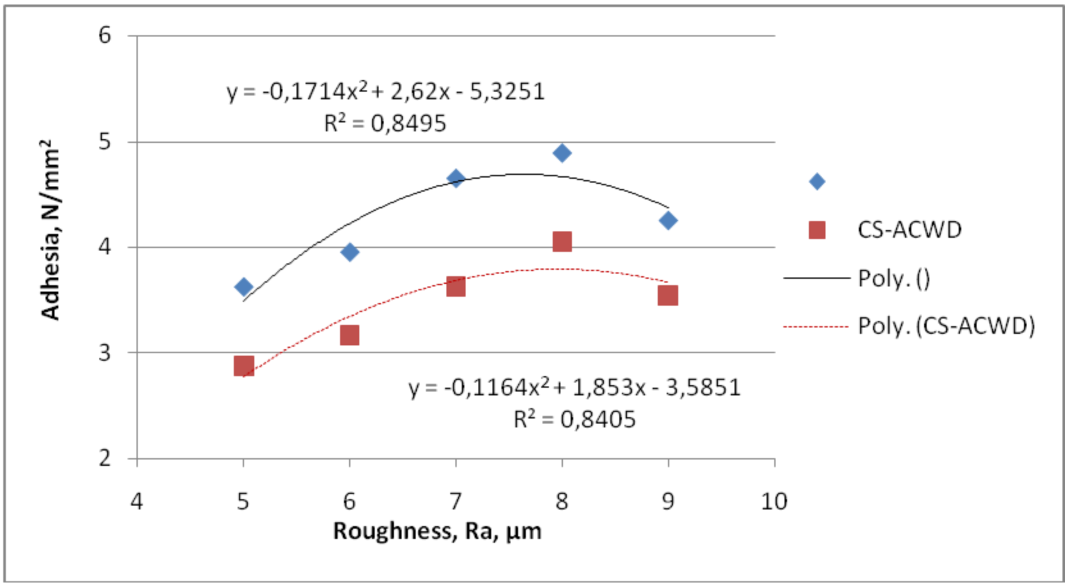

Figure 6. *Influence of Surface Roughness on Adhesion Strength of finishing films*

4. CONCLUSION

The results of this study showed, that with increasing the surface roughness the adhesion strength of gluing films also rises, but this depends on chemical composition of the varnishes and glues. The highest adhesion have the glue films forming with urea-formaldehyde resin (6.17-8.88 N/mm^2), From these results is outlook, that with increasing the surface roughness become increases the value of the adhesion strength of finishing films. These tendency is watch over by two used varnishes. With increase of the surface roughness at very high levels the adhesion strength decreases in varnishes probably because of breaking of the film and decrease of connection between wood surfaces and films.

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THE FOREST FIRES IMPACT ON BARK CHEMICAL COMPOSITION OF THE ALEPPO PINE (*Pinus halepensis* Mill.)

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ABSTRACT

Forest fires occur with uncontrolled fire in the forests. They are causing great damage, which depends on the age of the forest, the tree species, the vegetation and the type of fire and its intensity, which are less common with natural causes and most often by human activity. In the Republic of Croatia fires occur most commonly in Dalmatia, the islands and the Dalmatian Zagora. Since in the mentioned areas after the fire, significant quantities of fire burned trees have been left behind, the question arises as to what degree they are chemically degraded or whether they still possess all the properties for further application in mechanical or chemical processing.

The aim of this paper was to research the group chemical composition and CHNS/O of the Aleppo pine (*Pinus halepensis* Mill.) bark before and after the impact of low ground fire and high fire of the treetops at the height of the trees of 0, 2 and 4 m. The obtained results showed significant differences in the group chemical composition, as well as in CHNS/O of the bark between nonburned and burned wood resulting from the direct contact of the mentioned fire with the bark.

Key words: Aleppo pine (*Pinus halepensis* Mill.), bark group chemical composition, forest fires, nonburned wood, burned wood

1. INTRODUCTION

In recent decades, open-air fires or forest fires become a key factor in reducing the forest surface areas in the Mediterranean. In addition to causing extremely large material and economic damage, in a large number of cases they negatively affect on biological and landscape diversity. Forest fires, are one of the major factors of devastation and degradation of forests and forest land and their ecosystems in the Mediterranean, mainly at coastal karst. Forest fires occur when all of the necessary elements of a fire triangle come together in a susceptible area: an ignition source is brought into contact with a combustible material such as vegetation, that is subjected to sufficient heat and has an adequate supply of oxygen from the ambient air. A high moisture content usually prevents ignition and slows propagation, because higher temperatures are required to evaporate any water within the material and heat the material to its fire point. Dense forests usually provide more shade, resulting in lower ambient temperatures and greater humidity, and are therefore less susceptible to forest fires. Less dense material such as grasses and leaves are easier to ignite because they contain less water than denser material such as branches and trunks. Plants continuously lose water by evapotranspiration, but water loss is usually balanced by water absorbed from the soil, humidity, or rain. When this balance is not maintained, plants dry out and are therefore more flammable, often a consequence of droughts (Prgin, 2005). In the period from 1995 to 2014, there were 5377 fires in the Republic of Croatia in forest and other areas, and a total of 259,003.17 ha were burned. The annual average for this period is 283 fires, and the annual burnt (fired) area is 13.631,74 ha. In Croatia, the area of the Mediterranean karst is particularly vulnerable to fires. The average burned area per one karst area is 55.67 ha (Bakšić, Vučetić and Španjol, 2015). Furthermore, Table 1 shows an estimate of damage to wood biomass and general forest functions in the period from 2008 to 2014 (Source: Croatian Forests Ltd.). According to some research, about 95% of the fire causes man to act (negligent or malicious), and only 5% because of atmospheric disasters, usually because of thunder. The causes of fire, as a result of certain human activities, are manifold and numerous. It is therefore necessary to organize good preventive protection in order to minimize the possibility of their occurrence (Prgin, 2005).

Table 1. *Estimation of damage to wood mass and general forest functions in € (from 2008 to 2014)*

	Karst area	Continental area	Total
Wood mass	51.509.299,00	8.225.329,00	59.764.628,00
General forest functions	151.411.740,00	5.046.515,00	156.458.255,00
Total	202.921.039,00	13.301.844,00	216.222.883,00

It's not excessively to say that wood is one of the most important products of nature. Wood is a multicomponent, hygroscopic, anisotropic, fibrous, porous, biodegradable and renewable raw material, and all its properties are in good balance, which is one of the reasons that wood is so close to human. It is generally clear that wood has unique structural and chemical characteristics that show a wide spectrum of end-use possibilities. For these reasons, it can be assumed that basic knowledge of the structure and chemical composition of wood is of essential importance, considering the choice optimization of certain wood species for different applications. Every wood species are unique in their chemical composition and varies from species to species, as well as their chemical, physical, and mechanical properties. Wood is composed primarily of cellulose, hemicellulose, and lignin, as well as a small amount of pectin, protein, accessory materials (extractives) and ash. From the chemical point of view, wood consists 40–45% cellulose, 25–35% hemicelluloses, 15–30% lignin and up to 10% other compounds. All the main wood components are high-weight-molecular polymers and form an interwoven network in the wood cell wall; consequently we can say that the wood is a natural polymer (Antonović, 2010).

As well as wood tissues (sapwood and heartwood), the chemical composition of bark is equally complex, and varies between and within species, and also between the inner and outher bark. Proximate chemical analysis of bark from different species indicate that the chemical constituents of bark can be classified into four major groups: polysaccharides (cellulose, hemicellulose, and pectic materials), lignin and polyphenols, hidroxy acid complexes (suberin), and accessory materials (fats, oils, phytosterols, resin acids, waxes, tannins, terpens, phlobaphenes, and flavonoids). If we compare the chemical composition of tissues and bark, we can conclude that the bark contains a higher content of ash, accessory materials (extractives) and lignin, and a lower content of polysaccharides cellulose and polyoses (hemicellulose) (Antonović et al., 2010).

When trees is exposed to forest fires elevated temperatures, changes can occur in its chemical composition that affect its performance. The extent of the changes depends on the temperature level and the length of time under exposure conditions. Combustion of wood, cellulose, and lignin is preceded by thermal degradation where gaseous and liquid products are formed as well as a solid residue of charcoal. Some of the gases and liquids, when mixed with air, burn with a flame, whereas the charcoal burns in air by glowing without flame. Wood burn "indirectly" in the sense that the wood do not actually burn, but combustion takes place as a reaction between oxygen and the gases released from a wood (high molecular weight components). Under the influence of heat, wood produces easily substances that react eagerly with oxygen, leading to the high propensity of wood to ignite and burn. Ignition and combustion of wood is mainly based on the thermal decomposition of cellulose and the reactions of thermal degradation products with each other and with gases in the air, mainly oxygen. When temperature increases, cellulose starts to degrated. The decomposition products either remain inside the material or are released as gases. Gaseous substances react with each other and oxygen, releasing a large amount of heat that further induces degaradation and combustion reactions (Thomas and McAlpine, 2010).

On the all above basis, after the forest fires, significant quantities of burned Aleppo pine trees are left behind, and the question is araises as to what degree they are chemically degraded or whether they still possess all the properties for further application in mechanical or chemical processing. Furthermore, the main aim of this research was to contribute to a better understanding of the possibility of using burned or fired wood species, as a very large raw material base in the Republic of Croatia, in the further development of production, production technologies and wood products. Therefore, the impact of forest fires on the allepo pine bark group chemical composition, as well as the total content of carbon, sulfur, hydrogen, nitrogen and oxygen was researched. The research was carried out by determining the group chemical composition (accesory materials, mineral substances, cellulose, wood polyoses and lignin), and the total content of carbon (C), sulfur (S), hydrogen (H), nitrogen (N) and oxygen on allepo pine burned wood bark and nonburned wood bark, for comparison with the burned, by sampling the rings at the height of the trees 0 m, 2 m 4 m (also reffer as forest fire heights). Based on the chemical analysis results of the burned Allepo pine wood bark, the impact of forest fires on the chemical composition changes was determined by comparison with the nonburned Aleppo pine wood bark, and its possibility for further and wider application (ecological-productive potential).

2. MATERIALS AND METHODS

Wood specie – Allepo pine (*Pinus halepensis* Mill.)

For the research of forest fires impact on the wood bark chemical composition, Allepo pine wood (*Pinus halepensis* Mill.) was chosen, as wood specie which most often represents coastal karst, especially in Dalmatia, the islands and the Dalmatian zagora of the Republic of Croatia.

Aleppo pine wood (*Pinus halepensis* Mill.) occupies more and more larger areas thanks not only to new afforestation but also to its biological properties of natural expansion and regeneration on fired surfaces. Monoculture of Aleppo pine favors faster spread of fires than mixed forests of Mediterranean hardwoods. The use of aleppo pine wood in Mediterranean countries has wide application. It is especially appreciated as quality wood in pulp production, and some countries are based on the Aleppo pine raw materials for their wood industry. Furthermore, it is used for heating, small technical wood in agriculture, mining wood, in construction for internal joinery, sawmill boards and others. Aleppo pine forests favor the development of economic activities, employment of the population, raising the quality of life of people and creating local culture identity of the people. With realisation of the potential opportunities offered by Aleppo pine forests, as well as other forests areas, it will be opened opportunities for development of forestry and wood processing, and hence to the employment of the local population, and thus a clear conception of forestry development on areas until now passive karst (Meštrović, 1977; Matić, 1986).

Wood bark sampling locations and forest fires characteristics

Sampling of nonburned and burned Allepo pine wood was carried out under the ingeration of the company "Croatian Forests Ltd.", in the Forest Administration Split – Forest department Šibenik unit Jelinjak, (Location 1), and Forest department Biograd unit Jamina and Konjička draga (Location 2) (Table 2).

According to the occurence method, fires are grouped into (1) natural (uncontrollable, wild, sifted) and (2) artificial (controlled, planned) (Dimitrov, 1987; Španjol, 1996). According to the fuel material type we distinguish (1) underground fire or soil fire (roots and peat), (2) ground or low fire, (3) fire in the tops or high fire and (4) fire of lonely trees and shrubs (Španjol, 1996). Underground fire or soil fire (roots and peat) is affected by humus and peat layers beneath forestry mats. It is advancing very slowly but constantly. Peat fires may last (smolder) for several months and are constantly threatened to emerge from the surface and become a dangerous groundwater fire. Damage is great because of the damage of the roots of trees that are then dried. Such a fire is very difficult to detect and it is difficult to extinguish. Ground fire or low fire occurs when the upper layer of forest mats, booming shrubs and young stands are ignite. This is the most common type of fire that occurs in all types of forests.

Strong ground fire in forests where the trees are with thin bark damages the tree roots, and caused cambium dying and trees drying, and places and whole stands. For destroying the cambium, the 54 °C temperature is sufficient. Fire in the tops or high fire is the kind of fire that surely destroys the entire forest ecosystem, which is most occur in coniferous forests. At the so-called flying fires, fire spread from one tops to another. With the help of the wind, this fire can destroy large forest complexes. The fire of lonely trees and shrubs is mainly caused by the lightning strike and the tree then burns. It is most often connected to large forest areas. Although the cause of the occurence may be the burning of fire along the trees (Španjol, 1996).

Table 2. *Wood bark sampling locations and forest fires characteristics*

	Location 1	Location 2
Fire type	Ground fire (law) Treetops fire (high)	Ground fire (law) Treetops fire (high)
Burned surface size (ha)	19,25	16,71
Forest breeding	high (Allepo pine forest culture) - 3,15 ha (16,36%) low (garrigue) – 14,9 ha (77,40%) agriculture land (perennial crops) – 1,20 ha (6,23%)	high (Allepo pine forest culture) - 8,40 ha (50,27%) overgrown forest land – 8,31 ha (49,73%)
Forest description	Old Allepo pine forest culture (*Pinus halepensis* Mill.) 53 years old. The bushy layer and plants groundfloor layer is very rare, rocky ground very expressed, 10º incline, 50m altitude.	Middleage Allepo pine forest culture (*Pinus halepensis* Mill.) 40 years old. There is no bushy layer, and plants groundfloor layer is very rare, rocky ground very expressed, 15º incline, 221m altitude.
Sample mark	1a – nonburned tree 1b – burned tree	2b – burned tree

Forest fires front is the portion sustaining continuous flaming combustion, where unburned material meets active flames, or the smoldering transition between nonburned and burned material. As the front approaches, the fire heats both the surrounding air and woody material through convection and thermal radiation. First, wood is dried as water is vaporized at a temperature of 100 °C. Next, the pyrolysis of wood at 230 °C releases flammable gases. Finally, wood can smoulder at 380 °C or, when heated sufficiently, ignite at 590 °C. Even before the flames of a forest fires arrive at a particular location, heat transfer from the forest fires front warms the air from 800 to 900 °C, which pre-heats and dries flammable materials, causing materials to ignite faster and allowing the fire to spread faster (Bakšić et al., 2015).

Sampling, grinding and sieving of wood bark samples

To chemical composition determinations of the wood bark, three trees of Aleppo pine were sampled, at Location 1 one nonburned (1a) and one burned (1b) wood, and at Location 2 one burned wood (2b). For the purpose of researching the influence of different types of forest fires (ground fire - low and treetops fire - high) on the chemical composition of burned (b), as well as nonburned (a) wood bark of Allepo pine for comparison with burned, ring sampless of 10-30 cm thickness were taken at three different tree heights (fires heights) according to next: (1) first ring sample at a height of 0 m (the first ring from the cut felling point, next to the stump), (2) second ring sample at a height of 2 m, and (3) the third ring sample at a height of 4 m. Rings were taken immediately after cutting trees according to the standard TAPPI T257 cm-02 - Sampling and preparation of wood for analysis. Subsequently, the wood bark were mechanically separated from the mentioned ring samples.

Furthermore, wood bark samples were prepared according to previous studies (Antonović et al., 2007; Antonović et al., 2008) and laboratory analytical procedure Preparation of samples for compositional analysis (Hames et al., 2008). Air-dried bark samples were milled using a knife-mill Fritsch – Pulverisette 19 on different particles size. After milling, bark samples were sieved through standardized sieves. The milled bark particles which passed the screen of sieve 0.71 mm and stay on sieve 0,50 mm were used in further chemical analysis, due to their ideal particle size for all isolation methods of group chemical composition, and which is recomended in previous studies. For screening, laboratory electromagnetic sieves shaker Cisa RP.08 (shaking time $\tau = 15 \pm 1$ min) was used.

After wood bark grinding and sieving, three smaller samples were taken of each criterion, on which all the chemical analysis of main wood components isolation, as well as the CHNSO analysis were performed, and the results were presented as the average values of these three samples.

Wood bark main chemical components isolation

Isolation methods for determining the content of bark group chemical composition, namely ash, accessory materials (extractives), cellulose, hemicellulose (polyoses) and lignin were conducted in compliance with previous study (Antonović et al., 2007; Antonović et al., 2008; Sluiter et al., 2005a; Sluiter et al., 2005b; Sluiter et al., 2008). Bark compositional analysis consisted of a series of isolation methods of the main components, which can be schematically presented as shown in Figure 1. A small portion of the prepared bark sample was first used to determine the ash content, and the other major part for prior bark sample extraction (treatment with a solvent mixture of methanol, CH_3OH and benzene, C6H6 in the volume ratio 1: 1) to remove the accessory materials from sample which could interfere during further chemical analysis. Thus, additional residual solid content was determined as a content of accessory materials or extractives). Furthermore, from the extracted sample was isolated sulfonic acid lignin or Klason's lignin (treatment with 72% sulfuric acid, H_2SO_4) and the polysaccharides cellulose (by treatment with a solvent mixture of nitric acid, HNO_3 and ethanol, C_2H_5OH in a volume ratio of 1: 4). The content of hemicellulose (polyose) in bark sample was not separately determined and analyzed, but is determined by calculation according to share of other mentioned components in the sample. The hemicellulose content was calculated according to next expression: WP = 100 - (% A +% AM +% C +% L) in %. All used chemicals were high purity (p.a.) and were obtained from commercial sources.

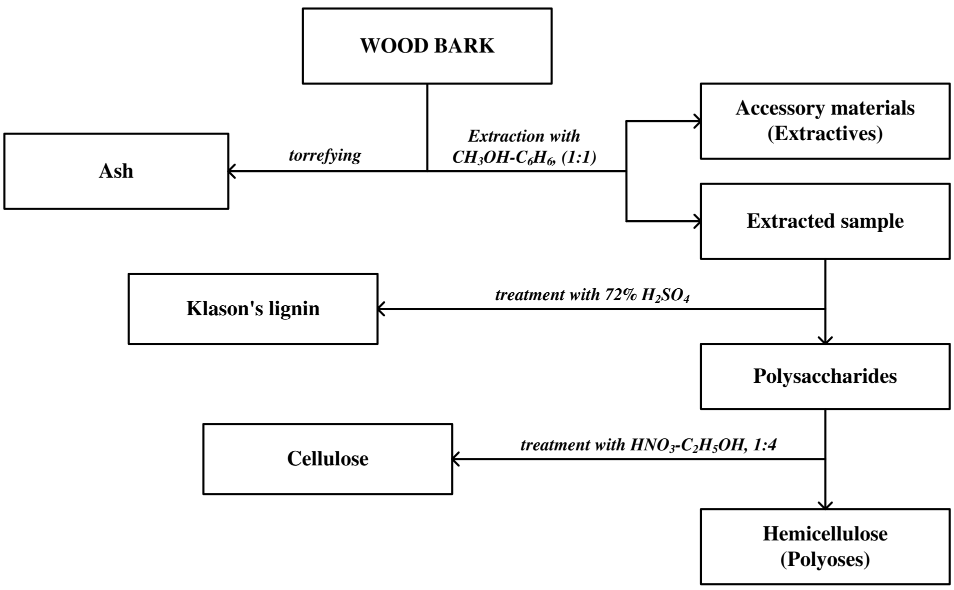

Figure 1. *Shematic view of bark main chemical components isolation methods*

Total content determination of wood bark carbon (C), sulphur (S), hydrogen (H), nitrogen (N) and oxygen (O)

Total content determination of wood bark carbon (C), sulphur (S), hydrogen (H), nitrogen (N) and oxygen (O) is carried out according to HRN EN 15104: 2011 for the carbon (C), hydrogen (H), nitrogen (N) and oxygen (O) and HRN EN 15289: 2011 for sulphur (S) by dry combustion method on Vario Macro CHNS analyzer (Elementar Analysensysteme GmbH, Germany). The procedure is based on the incineration of the sample in the oxygen stream at 1150 °C in the presence of wolfram (VI) oxide as a catalyst. During incineration, NOx, CO_2, SO_3 and H_2O gases were release. In the reduction column, heated to 850 °C, with the help of copper as a reducing agent, the NOx gases are reduced to N_2 and the SO_3 gases to SO_2. The resulting N2 gas helium (gas carrier) carries directly to the TCD (Thermo-Conductive Detector), while the remaining gases of CO_2, H_2O, SO_2 before entering the detector pass through adsorption columns for CO_2, H_2O and SO_2. Oxygen content is calculated according to next: Oxygen (%) = 100 - C (%) - H (%) - N (%) - S (%).

3. RESEARCH RESULTS WITH DISCUSSION

Forest fires in vegatative fuels emit a complex mixture of particles and gases into the atmosphere. The diversity in composition of combustion products results from wide ranges in fuel types, fuel chemistry, and fire behaviour. The chemical characteristics of the vegetation affect the rate of combustion and influence the overall forest fire behaviour. At temperatures above 100ºC, chemical bonds begin to break. The rate at which the bonds are broken increases as the temperature increases. Between 100 °C and 200 ºC, noncombustible products, such as carbon dioxide, traces of organic compounds and water vapor, are produced. Above 200ºC the cellulose break down, producing tars and flammable volatiles that can diffuse into the surrounding environment. If the volatile compounds are mixed with air and heated to the ignition temperature, combustion reactions occur.The energy from these exothermic reactions radiates to the solid material, thereby propagating the combustion reactions. If the burning mixture accumulates enough energy to emit radiation in the visible spectrum, the phenomenon is known as flaming combustion. Above 450ºC all volatile material is gone. The residue that remains is an activated char that can be oxidized to carbon dioxide, carbon monoxide and water vapor. Oxidation of the char is referred to as afterglow (Basin, 2011).

Depending on environmental conditions of wood thermal degradation caused by forest fires can proceed mainly in two pathways. The tar forming pathway, taking place in a temperature of approximately 300 °C, is related to the "normal" burning of wood. In this case, degaradation produces a lot of tar including levoglucosan that decomposes easily into burning gases under the influence of heat. Thermal degaradation can take place also through char forming pathway. In this process, cellulose is first transformed to unstable, "active" cellulose that further decomposes so that reaction products are mainly carbon dioxide and water, and the "backbone" of cellulose containing a lot of carbon. The pyrolysis of wood is dependent on external factors, such as the way of heating, warming-up rate of the material, etc. Therefore, wood products do not have an explicit ignition temperature, but ignition takes place on a certain temperature range where the probability of ignition becomes large enough. The temperature for the piloted ignition of wood is typically about 350 °C, whereas the spontaneous ignition requires a temperature of approximately 600 °C (Alexander, 1982).

Wood bark group chemical composition

The thermal degradation of wood caused by forest fires can be represented as the sum of the thermal degradation reactions of the individual wood chemical components (group chemical composition), namely ash, accessory materials, cellulose, lignin and polyoses (hemicellulose). However, the thermal degradation reactions of wood itself can vary from the sum of the individual component reactions. Therefore, this discussion on thermal degradation includes analysis of the individual components and wood itself (Antonović et al., 2016; Krička et al., 2016).

The influence of the individual chemical components on the thermal degradation reactions of bark depends on the species and its moisture content, and forest fires exposure period as a function of temperature for the components and for wood itself. The chemical components of wood are thermally degraded at different speeds, and the degradation takes place in the following order: hemicellulose → cellulose → lignin. The degradation of holocellulose, which consists of the alpha-cellulose plus the hemicelluloses, most closely follows that of wood. Lignin generally degrated at a slower rate than cellulose and holocellulose, although the degradation period begins somewhat earlier than for the holocellulose. Alpha-cellulose and wood appear to degrade at similar rates, although wood begins to degrade at slightly lower temperatures than alpha-cellulose but higher temperatures than holocellulose. This lower degradation temperature of wood is primarily due to the hemicelluloses in the wood and holocellulose. The wood degradation resembles more closely the degradation pattern of the alpha-cellulose and holocellulose than the degradation pattern of the lignin. This is reasonable because cellulose and holocellulose account for approximately 50% and 75% of the wood, respectively (Antonović et al., 2017; Jurišić et al, 2017; Krička et al., 2017).

Table 3. *Bark group chemical composition average values of nonburned and burned Aleppo pine wood*

Sample		Wood chemical component				
		A	AM	C	L	WP
		(%)	(%)	(%)	(%)	(%)
1a	**0**	3,63	8,61	24,12	49,45	14,18
	2	3,42	9,58	24,15	49,55	13,30
	4	5,89	8,37	24,79	49,94	11,01
1b	**0**	2,72	12,47	18,44	46,71	19,67
	2	2,53	13,17	20,50	47,18	16,61
	4	3,10	13,17	19,20	47,13	17,40
2b	**0**	2,79	8,57	19,94	47,88	20,82
	2	2,35	10,74	18,26	47,81	20,83
	4	3,93	8,93	16,64	46,41	24,08

A – ash; AM – accessory materials; C – cellulose; L – lignin; WP – polyoses (hemicellulose); 1 – location 1; 2 – location 2; a – nonburned wood; b – burned wood; 0 – height 0m; 2 – height 2m; 4 – height 4m

Table 3 and Figure 2 shows the nonburned and burned wood bark chemical components contents of the Allepo pine depending on the sampling heights or forest fires heights. If we compare the results of the Allepo pine nonburned bark with the results of previous researches of different wood species (Antonović et al., 2007), we can conclude that the distribution of chemical components is similar. In comparasion with chemical composition results of sapwood and heartwood the distribution is also similar, which means that the bark contains a significantly higher content of ash, accessory materials (extractives) and lignins, and a significantly lower content of polysaccharides cellulose and polyoses (hemicellulose) than sapwood and heartwood. Furthermore, the figure shows a significant difference in reduced ash, cellulose and lignin content, and in the increased accessory materials and wood polyoses (hemicellulose) content between the nonburned and burned wood bark. It should also be noted that the content of individual chemical components at different forest fires heights of 0, 2 and 4m for each sample 1a, 1b and 2b does not differ significantly, except for ash, which can be explained by phytocenological criteria of different sampling locations.

Decreased content of ash, cellulose and lignin and increased content of accessory materials (extractives) and wood polyoses (hemicellulose) in nonburned and burned wood bark can be explained according to next. The inorganic content of wood species usually refered to as its ash content, which is an approximate measure of its mineral salts and other inorganic matters content. The ash decreased content of burned wood bark in comaparasion to nonburned is probably due the rapid water evaporation where mineral salts were dissolved at high temperatures caused by fires. Further, during the burning in the presence of oxygen and the appearance of the flame, a part of the inorganic substances is evaporated and thus the loss of mass of inorganic substances is assumed.

Cellulose is principally responsible for the production of flammable volatiles. The cellulose decreased content is caused according to the thermal degradation occurs through dehydration, hydrolysis, oxidation, decarboxylation and transglycosylation, and can be represented by two pathways, one occurring at high temperatures (>300 ºC), the other at lower temperatures. These two competing reactions occur simultaneously. By the low-temperature pathway, the cellulose shows a large decrease in its degree of polymerization. As the temperature increases, the degree of polymerization of cellulose decreases further, free radicals appear and carbonyl, carboxyl and hydroperoxide groups are formed. Thermal degradation rates increase as heating continues. Next, the primary reaction of the high-temperature pathway is depolymerization. This takes place when the cellulose structure has absorbed enough energy to activate the cleavage of the glycosidic linkage to produce glucose, which is then dehydrated to levoglucosan (1, 6-anhydro-ß-D-glucopyranose) and oligosaccharides. During thermal degradation, water and acids are produced from both the hemicellulose and the cellulose. The degradation reaction of cellulose is an exothermic reaction, and begin at 240-350 °C, and thus decomposed on anhydrocellulose and levoglucosan.

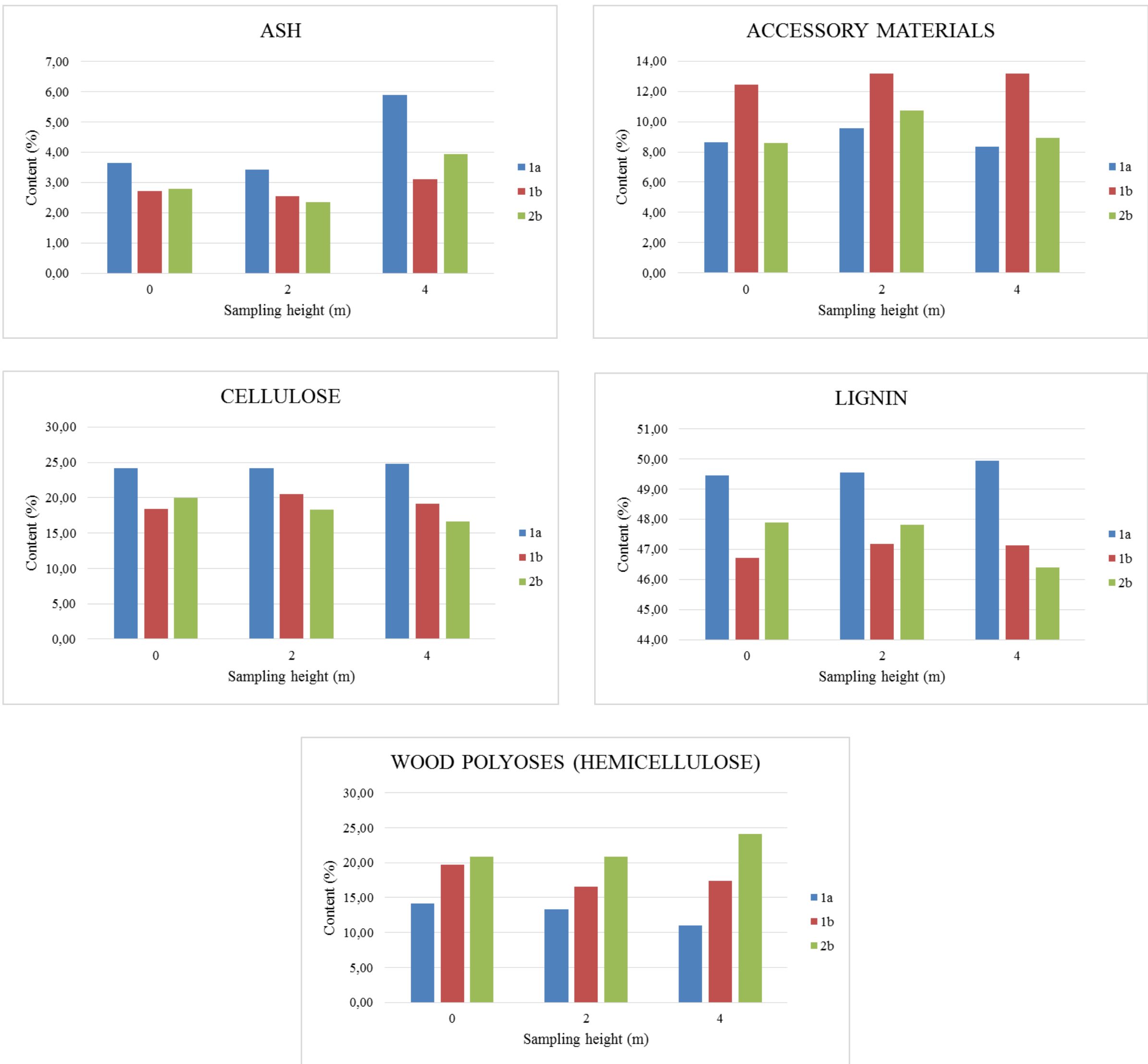

Figure 2. *Bark group chemical components content of nonburned and burned Aleppo pine wood in dependence on sampling height (forest fire height)*

Thermal degradation of lignin yields phenols from cleavage of ether and carbon–carbon linkages and produces more residual char than does thermal degradation of cellulose. Dehydration reactions around 200°C are primarily responsible for thermal degradation of lignin and one part of decreased content. Second part of lignin decreased content part occurs between 150 °C and 300 °C and cleavage of a- and ß–aryl-alkyl-ether linkages, around 300°C, aliphatic side chains start splitting off from the aromatic ring, and finally, the carbon-carbon linkage between lignin structural units is cleaved at 370–400 °C. The degradation reaction of lignin is also an exothermic reaction, with peaks occurring between 225 °C and 450 °C.

The accessory materials (extractives) include various aliphatic or acyclic compounds such as terpenes and terpenoids with resin acids and steroids, fatty acid esters (fats and waxes), fatty acids and alcohols, and some alkanes, further various phenolic compounds such as simple phenolic, lignans, isoflavones and isoflavonides, flavanoides, tannins, and other compounds such as various simple sugars (monosaccharides), cyclotols, tropolones, amino acids, alkaloids, coumarins and quinones (Antonović, 2010). Previous researches, as well as research in this paper, showed that the chemical components of the wood cell wall (cellulose, hemicellulose, and lignin) are thermally degraded under the influence of high temperatures caused by forest fires, i.e. the high polymeric compounds are degraded in compounds with low molecular weight. It is assumed that many new low molecular weight compounds, due to their chemical character similar to the different groups of accessory materials mentioned above, during Soxhlet extraction were extracted together with the original accessory materials and thus joined to their total content. Furthermore, in previous studies (Antonović - recessed wood - reconditioning) has been shown that at high temperatures after the thermal decomposition of wood high polymer chemical components, different compounds with low molecular weight and with their different chemical properties occur. It has also been shown that due to the action intensity of the same or higher temperature, recondensation (repolymerization) or reaction of these same law molecular weight compounds formed by thermal decomposition occurs, in new compounds with higher molecular weights but with similar chemical properties as accesory materials. Of course, recondensation occurred under the influence of a forest fires and its elevated temperature. Therefore, it is to be assumed that the increased content of the accessory materials in burned wood bark compared to the nonburned was effects of repeated polymerization, and these same compounds were extracted during analysis along with the original accessory materials and thus joined to their total content, which was the case and with low molecular weight compounds.

Although belonging to the same group of polysaccharides, wood polyoses (hemicellulose) differs from cellulose by the composition of different sugar units, by a much shorter molecular chain and by molecule chain branching. Units of sugars (anhydrous sugars) which form polyoses, can be divided into groups such as pentoses, hexoses, hexouronic acids and deoxyhexoses. Based on the sugar units, for example which of them make up the main chain, polylyses are divided into xylan, mannose, glucans, galactanes and pectins. Hemicelluloses are less stable thermally than cellulose and evolve more noncombustible gases and less tar. Most hemicelluloses do not yield significant amounts of levoglucosan. Much of the acetic acid liberated from wood by forest fires is attributed to deacetylation of the hemicellulose. Softwood hemicelluloses contain a small amount of xylan and are rich in galactoglucomannan. Of the hemicelluloses, xylan is the least thermally stable, because pentosans are most susceptible to hydrolysis and dehydration reactions. The hemicelluloses degrade first at temperatures from 200 °C to around 260 °C since their branched structure facilitates a faster degradation compared to the other components present in wood. Previous researches have shown that significant reductions in hemicelluloses occur at thermal treatment at mentioned temperatures, so it should be assumed that the same content is even lower due to forest fire effects and temperatures up to 900 °C depending on the type of fire. As the obtained results show increased hemicellulose content in the burned wood bark compared with nonburned, and with the comprehension that hemicellulose was mathematically calculated, it should be assumed that increased hemicellulose content is caused by thermal decomposition of other chemical components of the wood bark group chemical composition (cellulose and lignin) in to low molecular weight compounds that are joined to the sum of the hemicelulose total content. Naturally, there should be assumed and the recondensation of the low molecular weight compounds by thermal degradation caused by forest fires. It should be noted that these compounds were obtained as explained within accessory materials, but different chemical properties than accessory materials that were not extracted together with them in Soxhlet apparatus.

Therefore, in next researches it is necessary to further isolate the hemicellulose in order to determine the exact content, and thus the rest content of other novel low molecular weight compounds.

Furthermore, the simple aproach to predicting thermal degradation of wood in forest fires would be to take the length of exposure above certain temperatures. An average forest fires on the forest floor have flames reaching 1 metre in height and can reach temperatures of 800°C or more. Under extreme conditions a fire can give off 10,000 kilowatts or more per metre of fire front. This would mean flame heights of 50 metres or more and flame temperatures exceeding 1200 °C. The flash point, or the temperature at which wood will burst into flame, is 300 °C. Accordingly, we can conclude that with increasing the fire height results in an increase in temperature and a greater impact of the fire on the bark chemical composition. However, in these studies, the effect of the fire height of 0, 2 and 4m did not have a significant difference in the change of the bark chemical composition, assuming that the temperature of the fire and its intensity were approximately the same at all the above mentioned heights.

Wood bark total content of carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and oxygen (O)

Table 4. *Bark total contents of chemical elements values of nonburned and burned Aleppo pine wood*

Sample		Wood chemical elements				
		C	H	N	S	O
		(%)	(%)	(%)	(%)	(%)
1a	**2**	48,770	5,877	0,238	0,170	44.745
		48,750	5,866	0,233	0,187	44,764
	ẋ	**48,760**	**5,872**	**0,236**	**0,179**	**44,755**
1b	**2**	50,700	5,839	0,278	0,193	42,990
		50,710	5,789	0,287	0,188	43,026
	ẋ	**50,705**	**5,814**	**0,283**	**0,191**	**43,008**
2b	**2**	52,650	5,828	0,222	0,243	41,057
		52,680	5,942	0,191	0,372	41,015
	ẋ	**52,665**	**5,885**	**0,207**	**0,308**	**41,036**

Table 4 shows the obtained results of nonburned and burned Allepo pine wood bark total content of carbon (C), hydrogen (H), nitrogen (N), sulfur (S) and oxygen (O) at a 2m fire height. From the results we can see an increased carbon content and reduced oxygen of burned wood bark compared to nonburned. This research has shown that the chemical components of the wood cell wall (cellulose, hemicellulose and lignin) thermally degraded under the influence of elevated temperatures caused by forest fires. The high polymeric compounds are broken down into low molecular weight compounds, and therefore significant changes can be found in this finding. Furthermore, it is assumed that increased carbon content is caused by the carbonation of highpolymer compounds, by the formation of non-condensing gases such as carbon monoxide, carbon dioxide and methane, and tar and coal respectively. Reduced total hydrogen content can be assumed to be caused by evaporation of water at an increased forest fire temperature. For the other analyzed elements, we can conclude that there are no significant differences in the total content of oxygen, nitrogen and sulfur depending on the nonburned wood bark compared to the burned. In further researches it is necessary to analyze the impact of fire height and at 0 and 4 m and compare with these studies.

4. CONCLUSION

The main aim of this paper was to research the group chemical composition and CHNS/O of the Aleppo pine (*Pinus halepensis* Mill.) bark before and after the impact of low ground fire and high fire of the treetops at the height of the trees of 0, 2 and 4 m.

Obtained results show that the distribution of main chemical components of Allepo pine nonburned wood bark is similar in comparasion with the results of previous studies of bark for different wood species. The distribution is also similar, when we bark compare with chemical composition of sapwood and heartwood for different wood species. That means that the bark contains a significantly higher content of ash, accessory materials (extractives) and lignins, and a significantly lower content of polysaccharides cellulose and polyoses (hemicellulose) than sapwood and heartwood.

Furthermore, the results shows a significant difference in reduced ash, cellulose and lignin content, and in the increased accessory materials and wood polyoses (hemicellulose) content between nonburned and burned wood bark. It should also be noted that the content of individual chemical components at different forest fires heights of 0, 2 and 4m for each sample 1a, 1b and 2b does not differ significantly, except for ash, which can be explained by phytocenological criteria of different sampling locations.

The obtained results of elements total content of nonburned and burned Allepo pine wood bark at a 2m fire height shows an increased carbon and reduced oxygen content of burned wood bark compared to nonburned. For the other analyzed elements, we can conclude that there are no significant differences in the total content of oxygen, nitrogen and sulfur depending on the nonburned wood bark compared to the burned. In further researches it is necessary to analyze the impact of fire height and at 0 and 4 m and compare with these studies.

This research has confirmed previous studies that the chemical components of the wood cell wall (cellulose, hemicellulose and lignin) thermally degraded under the influence of elevated temperatures caused by forest fires. These high polymeric compounds are broken down into low molecular weight compounds, and therefore significant changes can be found in this finding. It is assumed that many new low molecular weight compounds, due to their chemical character similar to some original wood components, during analysis were obtained together with the original compounds and thus joined to their total content. Furthermore, It has also been shown that due to the forest fires action intensity of the same or higher temperature, recondensation (repolymerization) or mutual reaction occur between these same law molecular weight compounds, and therefore emerge new compounds with higher molecular weights but with similar chemical properties as some original compounds.

In further researches on the same wood samples, it is necessary to analyze the impact of forest fires on sapwood and heartwood at different tree heights (fire heights) to see if the fire had effect on their chemical composition changes, and to compare with these studies.

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SCREW WITHDRAWAL RESISTANCE OF BEECH WOOD

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ABSTRACT

In this paper, screw withdrawal resistance of beech wood (*Fagus moesiaca C.*) was investigated. The results were obtained by testing of withdrawal resistance of two-threaded "Hanger" screws M8 x 90 mm. Screw withdrawal resistance was carried out in two anatomical directions, radial and tangential. Specimens were divided in two groups. The first group was conditioned to moisture content of 8.5% (temperature: 23 ± 2 °C; relative humidity: 46 ± 3%) and specimens of the other group were oven-dried. Wood properties, such as moisture content, shrinking, density, hardness and compression strength parallel to the grain were also examined. According to the test results, it was found that there were significant statistical differences of screw withdrawal resistance between specimens in radial and tangential anatomical directions, with both moisture contents. On the other hand, there were no significant statistical differences of screw withdrawal resistance between specimens at moisture content of 8.5% and oven-dried specimens, observed in both anatomical directions.

Key words: withdrawal resistance, beech, two-threaded screw, density, hardness, compression strength parallel to the grain

1. INTRODUCTION

When designing wood furniture, the two-threaded screws are often used for joining the components. The quality of the screw connection depends on the technological properties of the wood based on the screw withdrawal resistance of wood (Šoskić and Popović, 2002). Based on the value of screw withdrawal resistance of wood, the strength of the joint can be calculated, and thus the number and arrangement of the screws in the joint can be determined. Two-threaded „Hanger" screws are very often used in the design of dining tables. For the research conducted in this paper, a two-threaded M8 × 90 mm screw was used.

The main objective of this study was to determine the value of screw withdrawal resistance of the beech wood. In addition to the main objective, moisture content, density, shrinking, hardness of wood and compression strength parallel to the grain were examined. Based on the obtained results of the experiment, we examined a simple linear correlation between the screw withdrawal resistance of wood and other tested properties.

2. MATERIAL AND WORK METHOD

In this study, the specimens of the Moesian beech (*Fagus moesiaca* C .) were obtained from beech trees originating from the mountain Goč, from the forest in the Teaching-scientific base at the Faculty of Forestry, University of Belgrade. Out of three radially cut beech boards, 50 mm nominal thickness, 45 × 45 × 100 mm specimens were made. After the inspection, specimens with wood defects, such as knots and cracks, were discarded. The conditioning of the remaining specimens was carried out at temperature of t = 23 ± 2 ° and relative air humidity φ = 46 ± 3%, for a period of 30 days. After conditioning, by random selection, 20 specimens were tested for moisture content, density and shrinking of wood. To test the screw withdrawal resistance of wood, the hardness of the wood and the compression strength parallel to the grain, 60 specimens were separated from the remaining specimens, and then divided into two groups of 30 specimens. Half of the specimens had moisture content achieved by conditioning, while the other half of the specimens were oven-dried. The testing of the mentioned mechanical properties was carried out on the testing machine "AMSLER" with a capacity of 40.000N.

2.1. The examination of basic physical properties of wood

Preliminary moisture content of wood testing was carried out on 10 out of 20 specimens, using an electric resistance moisture meter. Direct moisture content of wood testing was performed using the gravimetric method according to the standard SRPS EN 13183-1: 2005. From each of the twenty specimens measuring 45 × 45 × 100 mm, one small specimen measuring 45 × 45 × 20 mm was cut. The mass of the conditioned and oven-dried specimens were measured on an electronic digital scale with an accuracy of 0.01 g, and the dimensions in the axial, radial and tangential anatomical direction were measured with an electronic digital caliper with an accuracy of 0.01 mm.

Calculation of the absolute moisture content of the wood was carried out according to the equation:

$$v_a = \frac{m_v - m_0}{m_0} \cdot 100[\%]$$

Where: v_a – is absolute moisture content in %; m_v – is mass of wet specimen in grams; m_0 – is mass of the oven-dried specimen measured in grams.

The density of the wood was calculated according to the equation:

$$\rho = \frac{m}{V} = \frac{m \cdot 1000}{T \cdot R \cdot A}[g/cm^3]$$

where: ρ – is wood density in g/cm^3; m – is specimen mass in grams; V– is specimen volume in cm^3; T – is specimen dimension in the tangential anatomical direction in mm; R – is dimension of the specimen in the radial anatomical direction in mm; A – is the dimension of the specimen in the axial anatomical direction in mm.

Linear and volumetric shrinkage of wood was examined on the specimens. Linear shrinkages were determined for linear dimensional changes, in the tangential, radial and axial anatomical direction according to the equations:

$$U_t = \frac{T - t}{T} \cdot 100[\%];\ U_r = \frac{R - r}{R} \cdot 100[\%];\ U_a = \frac{A - a}{A} \cdot 100[\%];$$

where: U_t, U_r, U_a – is linear shrinkage in the tangential, radial and axial anatomical direction in %; T,t; R,r; A,a; – is dimensions of the specimen in a given anatomical direction before and after shrinkage in mm.

Volumetric shrinkage was determined according to the formula:

$$U_z = \frac{V - v}{V} \cdot 100[\%]$$

where: U_z – is volumetric shrinkage in %; V,v – is volume of the specimen before and after shrinkage in cm^3.

Comparable to the determination of the values of linear shrinking, the coefficients of the shrinking were determined for each of the anatomical directions, according to the equation:

$$k_u = \frac{U_x}{v_a}$$

where: k_u – is coefficient of shrinkage for a certain anatomical direction ; U_x – is the value of linear shrinkage in a given anatomical direction, or volumetric; v_a – is moisture content in % which caused the shrinkage.

2.2. Determination of the screw withdrawal resistance of wood

The testing of the screw withdrawal resistance (SWR) of wood was carried out according to the international standard ISO 9087 (1998). The dimensions of the specimens used for the study in this paper were d × b × l = 45 × 45 × 100 mm (Figure 1).

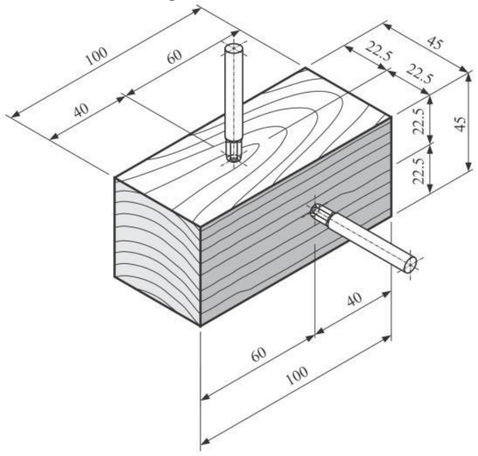

Figure 1. *Schematic diagram of the specimen with the screw positions (measures in mm)*

In order to fit the screw into solid wood, it is necessary to drill a hole first. Based on the diameter of the root of the selected screw, which was 5.5 mm (Figure 2), the drilling diameter for beech wood was determined according to the literature recommendation: $d = 0.9 \cdot 5.5 = 4.95 \approx 5\,\text{mm}$

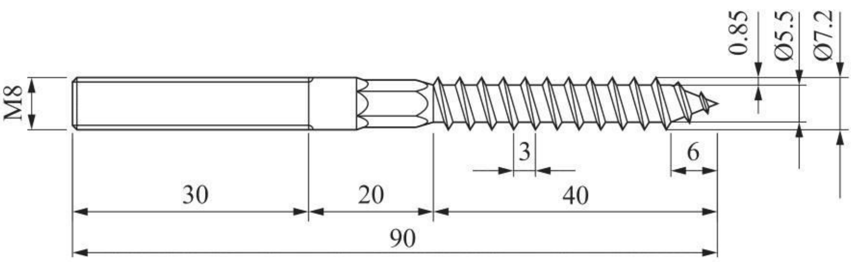

Figure 2. *Basic technical characteristics of the "Hanger" screw (measures in mm)*

The screws were placed in the specimens manually at a depth of l=40 mm, which was the length of the part of the screw with the thread for the wood. The "Hanger" screw does not have a head, so the round head M8 nuts (Figure 3) were used for easier insertion into the wood. Two screws were inserted into each specimen, i.e. one in radial and one in tangential anatomical direction. Screw withdrawal resistance of wood was tested using the testing machine (Figure 4) and the maximum load required to pull out the screw was measured.

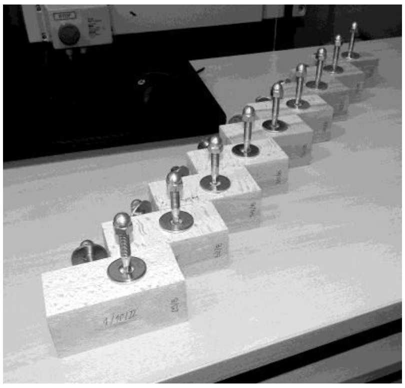

Figure 3. *Specimens prepared for the testing*

Figure 4. *The testing of SWR of wood on the specimen in the testing machine*

During the screw pulling out, according to the ISO 9087: 1998 standard, we ensured that the time of each pull-out of the screw ranges from 60 to 120 seconds. According to the above standard, the screw withdrawal resistance of the wood was calculated using the equation:

$$\sigma_W = \frac{F_{max}}{l} \left[\frac{N}{mm}\right]$$

Where: F- is maximum load in N; l- is the depth of screw insertion in mm.

2.3. Hardness of wood and compression strength parallel to the grain

Hardness was tested by the Brinell method according to SRPS EN 1534:2012 standard. For the test, a 1000 N injection force was selected. The dimensions of the specimens were 20 × 20 × 40 mm and were cut from the specimens previously tested for screw withdrawal resistence of wood (Figure 5). Prior to testing, the specimens of both moisture groups were accurately measured using the electronic digital caliper, as well as the masses on the digital scale. The dimensions of the specimens were needed in order for us to calculate the cross-sectional area as the input data for calculating the compression strength parallel to the grain, while the weights and dimensions of the specimens were required in order for us to determine the density of each specimen and to allow a correlation analysis between the density and screw withdrawal resistance of the wood.

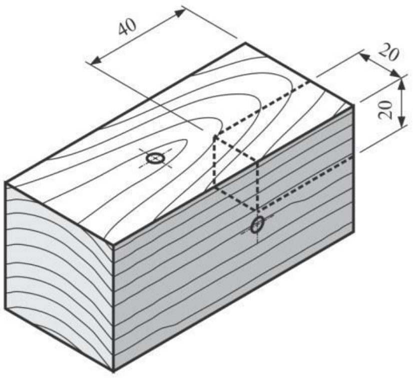

Figure 5. *Schematic presentation of the cutting of the specimen for testing the hardness of wood and compression strength parallel to the grain (measures in mm)*

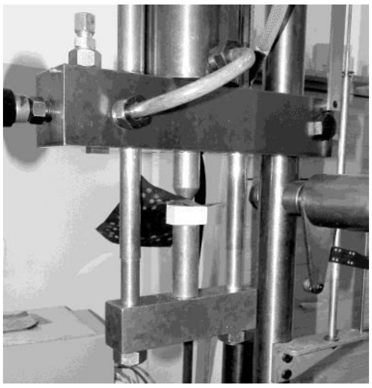

Figure 6. *Testing the hardness of wood on the testing machine*

The ball was pressed in radial and tangential anatomical direction (Figure 6). After the ball was pressed onto the wood, the diameters of the dent the ball left on the test sample were precisely cross-measured, using a magnifying glass with a measuring scale. Hardness was determined according to the equation:

$$H = \frac{2 \cdot F}{\pi \cdot D(D - \sqrt{D^2 - d^2})} \; [\mathrm{MPa}]$$

where: F- is force of the ball impact -1000 N; D – is diameter of the ball -10 mm; d – is diameter of the dent in mm on the lateral sides taken as an average of two cross-sections: $d=(d_1+d_2)/2$.

After testing the hardness, the maximum compression strength parallel to the grain was tested on the same specimens according to the standard SRPS EN 408:2014. The specimens were loaded with forces that cause fracture when pressed in the testing machine (Figure 7). The compression strength parallel to the grain was determined according to the formula:

$$\sigma_p = \frac{F}{A} \left[\frac{N}{mm^2}; \mathrm{MPa} \right]$$

where: F – is maximum load in (N); A- is the cross-sectional area to which the pressure force is applied in mm^2

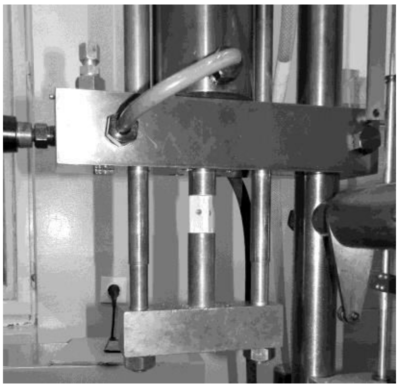

Figure 7. *The testing of compression strength parallel to the grain*

According to Šoškić and Popović (2002), the influence of hygroscopic humidity on the compression strength is extremely high. Accordingly, if the compression strength parallel to the grain is evaluated at moisture content that is different from the prescribed standard of 12%, due to the mutual comparison of values, it is necessary to perform correction by means of the following equation:

$$\sigma_{p12} = \sigma_v \cdot [1 + 0{,}04 \cdot (v_a - 12)] \text{ [MPa]}$$

where: σ_{p12} – is compression strength parallel to the grain; v_a- is moisture content of the wood at which the compression strength was determined in %; σ_v - the compression strength determined at some moisture content in the interval of 6-25%.

3. PROCESSING THE RESEARCH RESULTS

Statistical processing of experimental results was carried out in the program "IBM SPSS Statistics 21" and it included descriptive statistics, T-test, correlation and regression analysis. Within the descriptive statistics, the basic statistical indicators are given: number of specimens, maximum, minimum, arithmetic mean, standard error of arithmetic mean, standard deviation and coefficient of variation.

4. RESEARCH RESULTS AND DISCUSSION

4.1. Basic physical properties of wood

The average moisture content of beech wood obtained by using the electric resistance moisture meter was 7.02%. Compared to the average wood moisture content value of 8.5% obtained by the gravimetric method (Table 1), the moisture content measured by the electric resistance moisture meter had a lower value. Taking into account that electric resistance moisture meters show accuracy in the measurement of ± 1%, the 8.5% moisture content of specimens was comfirmed.

Table 1. *Statistical indicators for the moisture content of beech wood*

Wood property	n	Min (%)	Max (%)	$\bar{x}$ (%)	$\sigma_{\bar{x}}$ (%)	σ (%)	ν (%)
v_a	20	7.74	9.06	8.53	0.08	0.36	4.17

The symbols shown in the table have the following meanings:
n – the number of specimens; Min – minimum value; Max – maximum value; $\bar{x}$ – arithmetic mean; $\sigma_{\bar{x}}$ – standard error of arithmetic mean; σ – standard deviation; ν – coefficient of variation

According to Table 2, the average value of beech wood density when oven-dried ($\rho_{0\%}$), was 0.641 g/cm^3. According to the literature data, the oven-dried beech wood density ranges from 0.49 to 0.88

g/cm^3 (Šoškić and Popović, 2002). In humid condition specimens, an average density of 0.665 g/cm^3 was obtained.

Table 2. *Statistical indicators for the density of beech wood*

Wood property	n	Min. (g/cm^3)	Max. (g/cm^3)	$\overline{x}$ (g/cm^3)	$\sigma_{\overline{x}}$ (g/cm^3)	σ (g/cm^3)	ν (%)
$\rho_{0\%}$	20	0.627	0.667	0.641	0.003	0.011	1.79

The average values of linear shrinking in the axial, radial and tangential anatomical direction were 0.175%, 1.613%, 2.64% respectively (Table 3). The mean value of volumetric shrinking was 4,378%. According to literature data, the values of linear shrinking are usually in relation to Ua: Ur: Ut = 1:10:20. When the average values from Table 3 are put into the ratio, 0.175:1.613:2.640=1: 9.217:15.085 is obtained.

Table 3. *Statistical indicators for linear and volumetric shrinking of beech wood*

Wood property	n	Min (%)	Max. (%)	$\overline{x}$ (%)	$\sigma_{\overline{x}}$ (%)	σ (%)	ν (%)
Ua	20	0.051	0.276	0.175	0.013	0.059	33.83
Ur	20	1.386	1.879	1.613	0.031	0.140	8.71
Ut	20	2.356	2.944	2.640	0.034	0.153	5.78
Uz	20	3.857	4.818	4.378	0.059	0.263	6.00

The symbols shown in the table have the following meanings:
Ua-Linear wood shrinking in the axial anatomical direction;
Ur-Linear wood shrinking in the radial anatomical direction;
Ut-Linear wood shrinking in the tangential anatomical direction;
Uz-Volumetric shrinking of the wood;

Based on the average moisture content of the specimens determined by the gravimetric method (v_a=8.5%), and the average values of the linear and volume shrinking, the average coefficients of shrinking were calculated: K_a=0.02, K_r=0.19, K_t=0.31 and K_z=0.51.

4.3. Hardness of wood and compression strength parallel to the grain

The hardness of the beech wood is determined in radial and tangential anatomical direction for specimens with both moisture contents. Based on the results given in Table 4, it can be seen that in the oven-dried conditions the average value of the hardness of the wood in the radial anatomical direction was 32.34 N/mm^2, while in the tangential anatomical direction it was 29.37 N/mm^2.

The average value of wood hardness in radial anatomical direction in specimens at moisture content of 8.5% was 27.19 MPa, while the average value in the tangential anatomical direction was 28.49 MPa. According to the data obtained by Popović and Todorović (2005), the average value of the hardness of the beech wood with an average moisture content of 8.4%, in the radial anatomical direction, was 28.74 N/mm^2, while in the tangential anatomical direction it was 32.74 N/mm^2.

Table 4. *Statistical indicators for the hardness of the wood and compression strength parallel to the grain for the oven-dried specimens*

Wood property	n	Min (MPa)	Max (MPa)	$\overline{x}$ (MPa)	$\sigma_{\overline{x}}$ (MPa)	σ (MPa)	ν (%)
H 0%R	30	24.71	42.76	32.34	0.81	4.44	13.74
H 0%T	30	23.05	41.88	29.37	0.79	4.31	14.69
σ_p 0%II	30	56.95	89.53	75.99	1.43	7.82	10.29

The symbols shown in the table have the following meanings:

H 0% R- Hardness of oven-dried specimens in radial anatomical direction
H 0% T- Hardness of oven-dried specimens t in tangential anatomical direction
σ_p 0%II – Compression strength of oven-dried specimens

The average value of the compression strength parallel to the grain in the oven-dried specimens was 75.99 MPa, while for the specimens at moisture content of 8.5% it was 57.33 MPa. In Figure 8 it can be seen that the specimens in the oven-dried condition had a distinctly vertical fracture, as opposed to the specimens with moisture content of 8.5%, which mainly broke at angles.

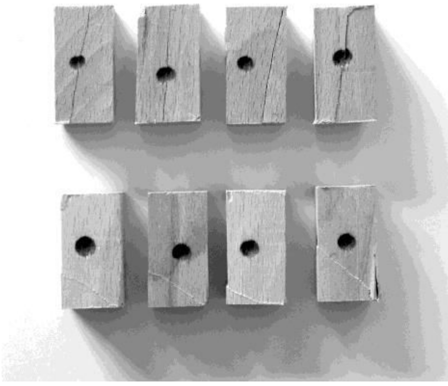

Figure 8. *Compression strength parallel to the grain: oven-dried specimens (upper row) and specimens at moisture content of 8.5% (lower row) with characteristic fracture appearance*

If the average value of the compression strength parallel to the grain of 57.33 MPa at moisture content of 8.5% obtained in this paper, is corrected to the standard prescribed moisture content, it yields σ_{p12}=49.37 MPa. In the literature, boundary values are given: 41.0 and 99.0 MPa (Šoškić and Popović, 2002) so that the obtained mean value of the compression strength parallel to the grain of 57.33 MPa at moisture content of 8.5% can be considered acceptable.

4.2. Screw withdrawal resistance

In Figure 9, cracks can be seen in the wood, between the channels in which the threads were. This means that the value of the force required to pull out the screw exceeded the value of the tensile strength perpendicular to the grain.

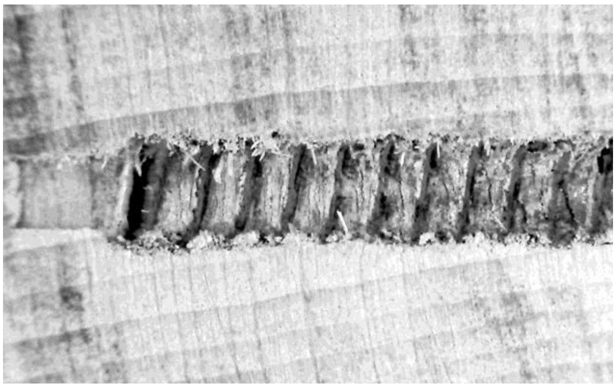

Figure 9. *Characteristic cross section of the specimen after the pull-out of the "Hangar" screw*

It could also be noticed that the screw "does not hold" to the wood at full depth, because its 6 mm long conical ending does not participate in this "holding" (Figure 9). The effective depth at which the screw was set was l = 40 – 6 = 34 mm. Accordingly, this is the equation for calculating SWR of wood:

$$\sigma_W = \frac{F_{max}}{34} \left(\frac{N}{mm}\right)$$

-where:
F_{max}- is maximum load in N;

Table 5. *Statistical indicators for screw withdrawal resistance of beech wood*

Wood property	n	Min (N/mm)	Max (N/mm)	$\overline{x}$ (N/mm)	$\sigma_{\overline{x}}$ (N/mm)	σ (N/mm)	ν (%)
SWR 0%R	30	298.88	418.41	337.32	5.67	31.07	9.21
SWR 0%T	30	234.53	355.71	283.14	5.03	27.53	9.72
SWR 8.5%R	30	311.29	386.12	334.08	3.01	16.47	4.93
SWR 8.5%T	30	267.26	356.91	295.63	3.71	20.29	6.86

The symbols shown in the table have the following meanings:

SWR 0%R- Screw withdrawal resistance of oven-dried specimens in the radial anatomical direction
SWR 0%T- Screw withdrawal resistance of oven-dried specimens in the tangential anatomical direction
SWR 8.5%R- Screw withdrawal resistance of specimens at moisture content of 8.5% in the radial anatomical direction
SWR 8.5%T- Screw withdrawal resistance of specimens at moisture content of 8.5% in the tangential anatomical direction

By conducting the analysis using the T-test for screw withdrawal resistance of wood, at a confidence level of 95%, the following was concluded:

- With oven-dried specimens, the difference in the mean values of the SWR of wood, observed in different anatomical directions, was statistically significant ($t=16.708$, $df= 29$, $p <0.0005$). For specimens at moisture content of 8.5%, a significant statistical difference was also determined ($t=18.246$, $df = 29$, $p <0.0005$). Thus, in oven-dried specimens, the SWR of wood in the radial anatomical direction had a 16.06% higher value compared to the SWR of wood in the tangential anatomical direction. In specimens at moisture content of 8.5%, this difference was 11.51%.
- The oven-dried specimens gave higher average SWR of wood values in the radial anatomical direction, compared to specimens at moisture content of 8.5%. Statistical analysis showed that the difference in average values was not statistically significant ($t=0.506$, $df=44.103$, $p> 0.05$). Observed in the tangential anatomical direction, specimens at moisture content of 8.5% gave higher average values of the SWR of wood in the tangential anatomical direction, compared to the oven-dried specimens; This difference in average values is not statistically significant ($t = -2.001$, $df=58$, $p>0.05$).

According to the above, it can be argued that the anatomical direction significantly influences the value of SWR of wood. It can also be argued that in this case, the change in the moisture content of specimens from 8.5% to the oven-dried condition does not significantly affect the value of SWR of wood.

Table 6. *Correlation within the value of screw withdrawal resistance of wood*

Correlation between		r	p-value
SWR 0%R	SWR 0%T	0.8229	p<0.0005
SWR 8.5%R	SWR 8.5%T	0.8226	p<0.0005
SWR 0%R	SWR 8.5%R	0.814	p<0.0005
SWR 0%T	SWR 8.5%T	0.766	p<0.0005

Based on the results shown in Table 6, the following could be noted:

- Between the SWR values of the oven-dried specimens, with different anatomical directions, a strong positive relationship with the coefficient of correlation r=0.8229 was calculated. The linear regression model had a form of $y = 0.729 \cdot x + 37.24$ with a coefficient of determination t r^2=0.6772;
- Between the SWR values of specimens at moisture content of 8.5%, with different anatomical directions, a strong positive relationship with the coefficient of correlation r=0.8226 was calculated. The linear regression model had a form of $y = 1.013 \cdot x - 42.95$ with a coefficient of determination $r^2 = 0.6767$;
- Between the SWR values of the specimens in the radial anatomical direction at different moisture contents, a strong positive relationship with the coefficient of correlation r= 0.814 was calculated. The linear regression model had a form of $y = 0.432 \cdot x + 188.51$ with a coefficient of determination $r^2 = 0.663$;
- Between the SWR values of the specimens in the tangential anatomical direction at different moisture contents, a strong positive relationship with the coefficient of correlation r=0.766 was calculated. The linear regression model had a form of $y = 0.564 \cdot x + 135.81$ with a coefficient of determination $r^2 = 0.586$.

Table 7. *Correlation between wood hardness and screw withdrawal resistance of the wood*

Correlation between		r	p-value
H 0%R	SWR 0%R	0.701	p<0.0005

With oven-dried specimens and radial anatomical direction, between the value of hardness and value of the SWR of wood, a positive relationship with the coefficient of correlation r=0.701 (Table 7) was calculated. The linear regression model had a form of $y = 4.90 \cdot x + 178.83$ with a determination coefficient $r^2 = 0.491$. Hardness tested by the Brinell method can be characterized as "surface hardness". Therefore, a weak linear correlation between hardness and SWR of wood was expected.

Table 8. *Correlation between wood density and screw withdrawal resistance of the wood*

Correlation between		r	p-value
ρ 0%	SWR 0%R	0.625	p<0.0005
ρ 0%	SWR 0%T	0.514	p<0.01

According to the Table 8, for oven-dried specimens, it was found that between the wood density and value of the SWR of wood in the radial anatomical direction, occurs a strong positive relationship with the coefficient of correlation r = 0.625. The linear regression model had a form of $y = 878.96 \cdot x - 216.09$ with a coefficient of determination $r^2 = 0.3908$. Between the density of wood and value of SWR of wood in the tangential anatomical direction, there is a strong positive bond, with a coefficient of correlation r=0.514. The linear regression model had a form of $y = 639.87 \cdot x - 119.74$ with a coefficient of determination r^2=0.2639.

5. CONCLUSION

Based on the results of the research on screw withdrawal resistance (SWR) of the beech wood, the following could be concluded:

- The average SWR values of beech wood in oven-dried specimens were in the radial and tangential anatomical direction 337.32 N/mm and 283.14 N/mm respectively. In specimens at moisture content of 8.5%, the average SWR values of the beech wood were in the radial and tangential anatomical direction 334.08 N/mm and 295.63 N/mm respectively. Based on previous research, these values can be estimated as fairly high and they depend on the properties of beech wood and the dimensions of the screw.
- Variability of the SWR of wood was greater in the oven-dried specimens in both anatomical directions (ν_R = 9.21%, ν_T = 9.72%), compared to the specimens at moisture content of 8.5% (ν_R = 4.93%, ν_T = 6.86%). This phenomenon was also noticed in all other investigated properties. Accordingly, it can be concluded that in the oven-dried specimens, there was a greater dispersion in the values of the tested wood properties.
- The difference between the average values of SWR of wood in different anatomical directions is statistically significant at a confidence level of 95% observed in specimens of both moisture contents. On the basis of this, it can be argued that the specimens in the radial anatomical direction showed a higher SWR value than the tangential anatomical direction. The anatomical direction significantly influences the value of screw withdrawal resistance of wood, so for practical purposes it is recommended to mount the screws in the radial anatomical direction.
- The difference between the average values of SWR of wood in specimens of different moisture contents, observed in the same anatomical directions, is not statistically significant at a confidence level of 95%. Accordingly, it can not be claimed that the oven-dried specimens showed a higher value of the screw withdrawal resistance of the wood compared to the specimens at moisture content of 8.5%. In this case, the decrease in moisture content of wood from 8.5% to 0% does not significantly affect the value of SWR of wood.
- The average values of other studied physical and mechanical properties of the beechwood are found in the frames provided by the reviewed references. Based on the correlation between the values of the SWR of wood and other properties tested in this paper, linear regression models are made, which can help us predict the values of the SWR of wood depending on the particular tested property.

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EFFECT OF DRILLING DIAMETER ON SCREW WITHDRAWAL RESISTANCE OF WOOD

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ABSTRACT

This study investigates the effect of three different drilling diameters on screw withdrawal resistance of beech wood. Specimens were devided into three groups with the following different drilling diameters: 5.0 mm, 5.55 mm and 6.0 mm. Two-threaded "Hanger" screws M8 x 90 mm were used in the experiment. Screw withdrawal resistance was carried out in tangential direction on specimens which were conditioned on moisture content of 7.2%. Density of specimens was also examined. A one-way repeated measures ANOVA were conducted to compare experimental results of the screw withdrawal resistance between the three groups of specimens. According to the test results, it was found that there were statistically significant differences among the three sets of scores.

Key words: screw withdrawal resistance, beech wood, drilling diameter, two-threaded screw, density

1. INTRODUCTION

Dining tables designed for the requirements of domestic production, are usually made of solid beech wood, and joints of the legs with belt of rails were achieved over a metal or a wooden corner block, via two-threaded "Hangar" screws. To put a screw into the table leg, it is necessary to drill holes of appropriate diameter first. For manufacturers of dining tables, it is important to have information on the diameter of the hole drilled on table legs, which in combination with the selected "Hanger" screw give optimum joint strength in service.

A review of the literature (Popović, 2005; Tankut, 2011) revealed that authors indicate the relationship between drilling diameter and root diameter of the screw, as an important precondition for achieving appropriate strength of the joint with screw. In domestic literature, (Potrebić, 1994; Šoskić and Popović, 2002), as recommendation for a hole diameter drilled in hardwood the authors gave d = 0.9 D, where the size of the "D" was not clearly brought in relation with a particular parameter of the screw, or with its root diameter.

Quality of the joint with screws, depends on the technological properties of the wood, based on resistance which wood provides during the pull-out of the screw (Šoškić and Popović, 2002). Therefore, the aim of this study was to investigate the effect of drilling diameter on screw withdrawal resistance (SWR) of beech wood, by using two-threaded "Hanger" screws. In experiment, drilling diameter was varied, which caused formation of the three groups of specimens with a drilling diameter of 5.0 mm, 5.55 mm and 6.0 mm, respectively.

2. MATERIAL AND METHODS

Due to its physical and mechanical properties, beech wood is a species of great importance for industrial processing in our country, and for making furniture and other products of wood. In Serbia, the most common two types of beech are: Moesian beech (*Fagus moesiaca C .*) and European beech (*Fagus sylvatica*). For research purposes in this study, beech wood tangential plunks, with nominal thickness of 38 mm were selected. Two-threaded "Hanger" screws are often used in the construction of the dining tables made of solid wood. Domestic manufacturers of dining tables commonly use two-threaded "Hanger" screws with dimensions M8 x 80 or M8 x 90 mm. For the research purposes in this study, two-threaded "Hanger" screws with dimensions M8 x 90 mm were selected (Figure 1).

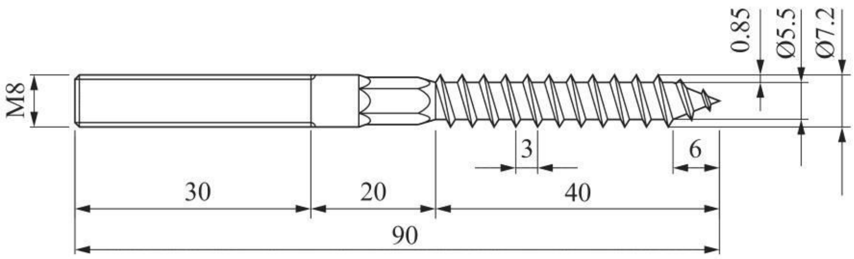

Figure 1. *Two-threaded „Hanger" screw*

2.1. Preparation of samples

Samples with dimensions d × b × l = 33 × 50 × 95 mm were cut from tangential beech planks. Conditioning of the samples was carried out in a closed room at a temperature T = 22 ± 2 °C and a relative humidity φ = 40 ± 3%, for a period of 30 days. While marking and sorting of the samples was carried out according to the drilling diameter, the care was taken to ensure that samples with different drilling diameter have been cut from the same plank, observing longitudinally (Figure 2). This was very important to make the mutual comparison of research results possible. Three groups with 76 samples in each were formed, and every group was drilled by drill bits of the following different diameters: Dd=5.0 mm, Dd=5.55 mm and Dd=6.0 mm. According to this methodology for testing of SWR of wood, 228 samples in total were prepared.

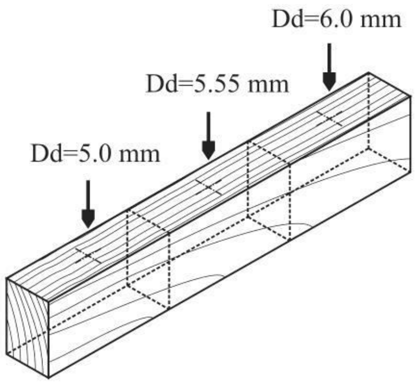

Figure 2. *Positions of samples in plank depending on the drilling diameter*

Recomendation from the literature was that the drilling diameter should be smaller than the diameter of the screw. Nominal diameter of "Hanger" screw that is used in this study was 7 mm, while the average actual diameter measured at the group of the 10 screws was 7.2 mm. Root diameter of the selected screw was 5.5 mm. Drilling was performed by a combined machine for wood processing (Figure 3). Based on part of the the screw length that should be placed in the wood, drilling depth of 40 mm was determined. "Hanger" screws were placed into the samples by using the machine shown in Figure 4.

Figure 3. *Drilling holes on samples*

Figure 4. *Inserting of „Hanger" screws in samples*

The scheme in Figure 5 represents the ratio of a diameter of the screw and the diameter of drilled holes for all three cases. The areas colored black represent the gaps between the diameter of drilled holes and the root diameter of the screw. Bearing in mind that the root diameter of the screw was 5.5 mm (Figure 1) in the first case, for drilling diameter of 5.0 mm there was no gap around the screw root (Figure 5a), and threads penetrate the wood with its full depth of 0.85 mm. For a drilling diameter of 5.55 mm, there is a clearance present and threads penetrate the wood with a depth of 0,825 mm (Figure 5b). In the third case, the gap is also present, because the drilling diameter of 6,0 mm was greater than the root diameter of the of screw by 0.5 mm, so that the threads were inserted into the wood to the depth of 0.6 mm (Figure 5c).

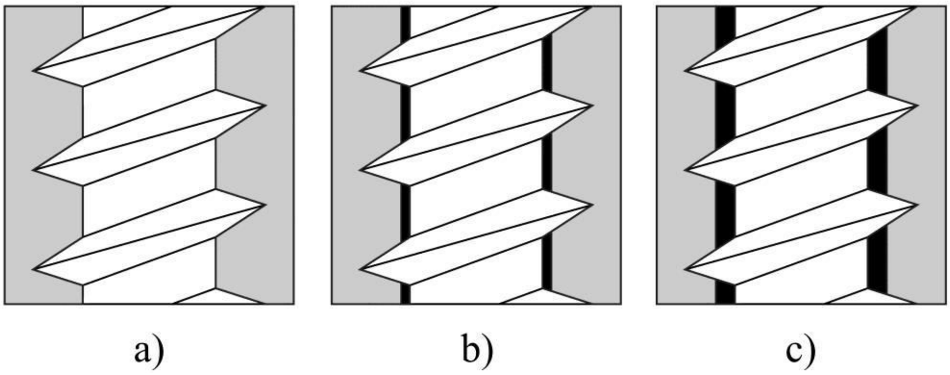

Figure 5. *Schematic representation of ratio between diameter of the screw and the diameter of drilled hole: a) Dd = 5.0 mm; b) Dd = 5.55 mm; c) Dd = 6.0 mm;*

2.2. Screw withdrawal resistance of wood

Investigation of Screw withdrawal resistance of wood was carried out based on the international standard ISO 9087 (1998). The dimensions of the samples which were used for research in this work were d × b × l = 33 × 50 × 95 mm. In each of the samples one "Hanger" screw was placed in the tangential anatomical direction (Figure 6). SWR of wood was tested on the three groups with 76 samples in each, i.e. 228 samples in total.

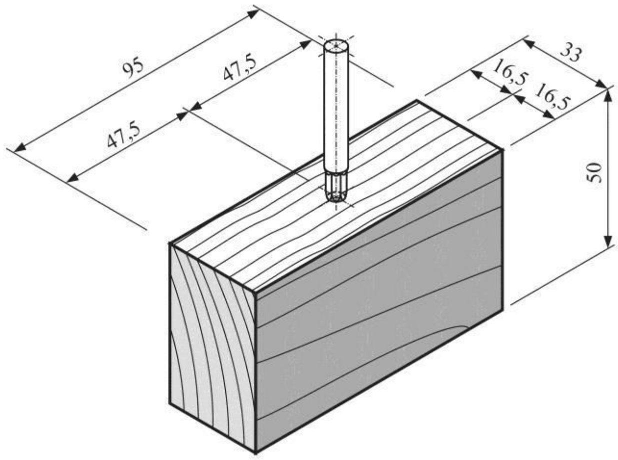

Figure 6. *Schematic representation of test sample with the position of the screw*

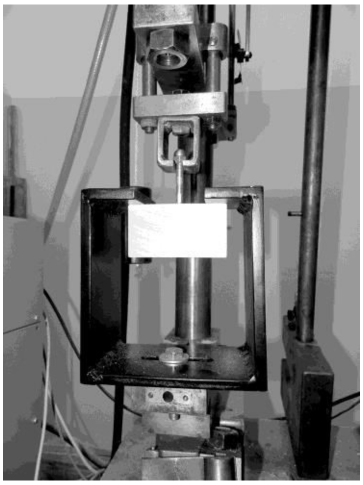

Figure 7. *Investigation of SWR on a universal testing machine*

The "Hanger" screw has no head, so conection of screw and the extracting tool was realized via impenetrable nut M8. Measurement of the maximum force required to pull-out the screws was conducted using a universal testing machine produced by "AMSLER", with capacity of 40,000 N (Figure 7). During the extraction of the screw, according to the standard ISO 9087: 1998, care was taken that the time per one SWR was in the range from 60 to 120 seconds. According to the above standard, the specific SWR is calculated using the following expression:

$$\sigma_W = \frac{F_{\max}}{l}\left[\frac{N}{mm}\right] \qquad (1)$$

-where Fis a maximum load in N; l is theinsertion depth of the screw in mm.

Conical end i.e. tip of the "Hanger" screw had a length of 6 mm and it was smaller in diameter than the outer diameter of the screw. Drilled hole has a cylindrical shape, so that the tapered end is not participating in the "holding" of the screw during its extraction. Accordingly, the effective depth to which the screw is placed was $l = 40 - 6[\text{mm}] \Rightarrow l = 34\,\text{mm}$.

2.3. Moisture content of the wood

Testing of moisture content was performed by gravimetric method according to standard SRPS EN 13183-1: 2005, on the test samples which were cut from the samples on which the previously SWR was examined. From each of the 76 samples in the first group (drilling diameter Dd = 5.0 mm) of dimensions 33 × 50 × 95 mm, a small test samples of dimensions 33 × 50 × 20 mm (Figure 8) was cut out.

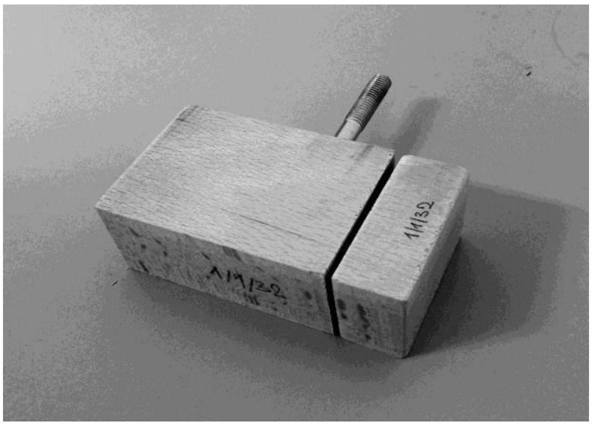

Figure 8. *Cut out test specimen for testing of moisture content by gravimetric method*

Figure 9. *Drying of the test samples in the laboratory oven*

After the cutting, the masses of the test samples were measured by an electronic scale with 0,01 g accuracy. Dimensions of test samples in the axial, radial and tangential directions were measured by digital caliper with 0.01 mm accuracy. In this way, data for the mass and dimensions of test samples with current moisture content were obtained. Drying of test samples to oven dry condition was performed at a temperature of 103 ± 2 ° C, in a laboratory oven (Figure 9). After drying, oven-dried test specimens were measured in size and weight as described previously. Determine moisture content was performed by the following formula:

$$v_a = \frac{m_v - m_0}{m_0} \cdot 100[\%] \qquad (2)$$

where: Va – is the absolute moisture content in%; m_v – is the mass of the test samples with current moisture content in grams; m_0 – is the mass of oven-dried test samples in grams.

In this way, moisture content was calculated for each of 76 test samples, and the average value was taken as a current moisture content of samples made of beech wood.

2.4. Density of wood

Based on measurement results of weight and dimensions of test samples, density of wood in the current moisture content and oven-dried condition were determined. The wood density was calculated by the expression:

$$\rho = \frac{m}{V} = \frac{m \cdot 1000}{T \cdot R \cdot A} [g/cm^3] \qquad (3)$$

where: ρ – is the density of wood in g/cm^3; m is the mass of test samples in grams; V is the volume of the test samples in cm^3; T, R, A – are dimensions of test samples in tangential, radial and axial anatomical directions in mm.

3. RESULTS AND DISCUSSION

Previous studies were intended to show the importance of the relationship between the diameter of the "pilot" hole and the root diameter of the screw. Due to different nature of the material that is used in them (particle boards), comparison of the results obtained in this study with the results of the previous researches, was not possible.

3.1. Screw withdrawal resistance of wood

Based on the results of statistical analisys of the data in Table 1, the highest average value of SWR of 313, 79 N / mm was provided by samples with drilling diameter Dd = 5.0 mm. This was expected, because in that case the largest area of contact between the screw and wood was achieved.

If the type of fit in the joint is observed , between the diameter of drilled hole and root diameter of the screw, in the samples of the first group with drilling diameter of 5.0 mm, there was a considerable overlap. According to the above-mentioned, during the extraction of the screws, in these samples there was a considerable friction between the surface of the screw root and the tissue of the wood, which gave a positive effect on the SWR of wood. On the other hand, in samples with a drilling diameters of 5.55 mm and 6.0 mm, there was a gap between the diameter of drilled holes and root diameter of the screw.

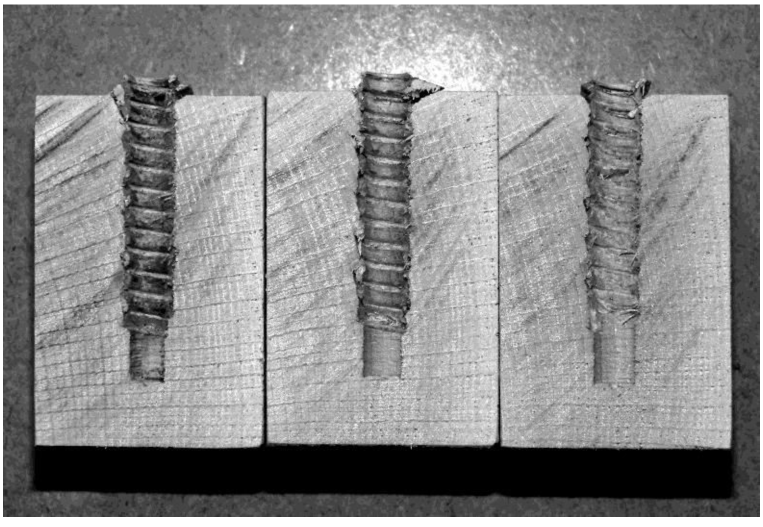

Figure 10. *Cross-sections of three reference samples belonging to the same plank after the screw extraction: From left to the right: Dd=5.0 mm, Dd=5.55 mm and Dd=6.0 mm*

Samples with the drilling diameter Dd = 5.55 mm resulted in a smaller average value of SWR of wood 306.02 N / mm, and the lowest average value of 300.62 N / mm was achieved by samples with drilling diameter of Dd = 6.0 mm. By observing the coefficient of variation as a measure of variability in Table 1, it could be noticed that with the increase of drilling diameter, values of SWR of wood in the groups of samples were more scattered.

Table 1. *Descriptive statistics for the specific SWR of wood with different drilling diameters*

Drilling diameter (mm)	n	Min. (N/mm)	Max. (N/mm)	$\bar{x}$ (N/mm)	$\sigma_{\bar{x}}$ (N/mm)	σ (N/mm)	ν (%)
5.0	76	251.50	418.68	313.79	3.81	33.21	10.58
5.55	76	249.32	389.94	306.02	3.79	33.03	10.79
6.0	76	239.74	417.50	300.62	3.92	34.14	11.36

Markings in the Table have the following meaning:
n – number of samples; Min. – the minimum value; Max. – the maximum value; $\bar{x}$– mean; $\sigma_{\bar{x}}$– standard error of the mean; σ – standard deviation; ν – the coefficient of variation.

Values of SWR of wood with drilling diameters of 5.0 mm, 5.55 mm and 6.0 mm are compered by a one-way repeated measures ANOVA. In Table 2 means and standard deviations of SWR of wood are given. A significant effect of drilling diameter was found (Wilks' Lambda = 0.682, F (2, 74) = 17.283, p <0.0005), with the effect magnitude of $\varepsilon^2 = 0.318$, based on which it may be concluded that approximately 32% of SWR of wood is contributed to the drilling diameter. Based on the results of post-hoc test of least significant difference shown in Table 2, it was found that there is a statistically significant difference in SWR of wood for all three drilling diameters used.

Table 2. *Comparison of pairs with associated probabilities*

(I) Drilling diameter	(J) Drilling diameter	Difference of means (I-J)	Standard erorr	p-value
5.0 mm	5.55 mm	7.766*	1.709	0.000
	6.0 mm	13.171*	2.327	0.000
5.55 mm	5.0 mm	-7.766*	1.709	0.000
	6.0 mm	5.405*	1.998	0.008
6.0 mm	5.0 mm	-13.171*	2.327	0.000
	5.55 mm	-5.405*	1.998	0.008

There were significant differences between average values of screw withdrawal resistance of wood, depending on the drilling diameter. By comparing these values among groups of samples, according to the difference of 7.766 N / mm, it could be concluded that the samples with a drilling diameter of 5.0 mm gave a greater value of screw withdrawal resistance (on average 2.5%) compared with a drilling diameter of 5.55 mm. Based on the difference of 13.171 N / mm, it could be concluded that the samples with a drilling diameter of 5.0 mm gave a higher value resistance to screw extraction on average by 4.4% compared to samples with a drilling diameter of 6.0 mm. Further, based on the difference of 5.405 N / mm, it could be concluded that the samples with a drilling diameter of 5.55 mm provided greater value of screw withdraval resistance (on average by 1.8%) compared to samples with a drilling diameter of 6.0 mm.

Based on the experiment results and their statistical analysis, it could be concluded that with the increase in drilling diameter, the value of screw withdrawal resistance of wood decreases.

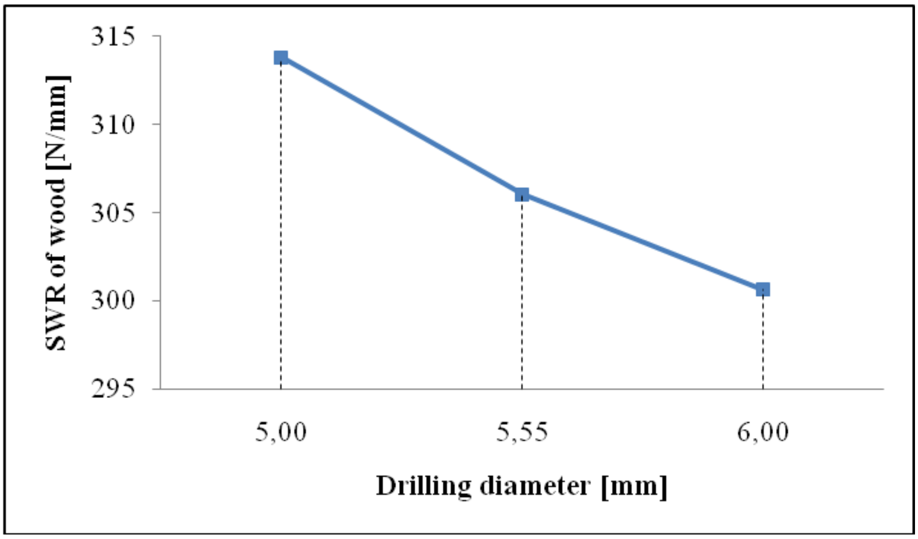

Figure 11. *Effect of drilling diameter on screw withdrawal resistance of wood*

In chart (Figure 11), decreasing tendency of the average values of screw withdrawal resistance with increasing drilling diameter can be clearly observed. By increasing the diameter of drilled holes, and for unchanged screw diameter, the contact area between the screw and wood was reduced.

3.2. Moisture content and density of wood

The results obtained for moisture content by gravimetric method, are given in Table 3. The mean value of moisture content of samples was 7.21%, with the variability expressed by coefficient of variation of 3.22%.

Table 3. *Descriptive statistics for moisture content of beech wood*

Moisture content	n	Min. (%)	Max. (%)	$\bar{x}$ (%)	$\sigma_{\bar{x}}$ (%)	σ (%)	ν (%)
v_a (%)	76	6.68	7.71	7.21	0.03	0.23	3.22

The average density value of oven-dried beech wood was 0.658 g / cm^3 (Table 4). According to the literature data, density of oven-dried beech wood ranges from 0.49 to 0.88 g / cm^3, with mean value specified as 0.69g /cm^3 (Šoskić and Popović, 2002).

Table 4. *Descriptive statistics for density of beech wood*

Density	n	Min. (g/cm^3)	Max. (g/cm^3)	$\bar{x}$ (g/cm^3)	$\sigma_{\bar{x}}$ (g/cm^3)	σ (g/cm^3)	ν (%)
$\rho_{7.2\%}$	76	0.616	0.784	0.679	0.004	0.039	5.705
$\rho_{0\%}$	76	0.595	0.761	0.658	0.004	0.039	5.877

Average density value of 0.679 g / cm^3 was obtained in the samples with moisture content of 7.2%. Based on the coefficient of variation, it could be concluded that the density had approximately equal variability, observed in both moisture contens.

3.3. Relationship between density of wood and screw withdrawal resistance of wood

Relation between density of wood and SWR has been tested using Pearson's linear correlation coefficient. Depending on the drilling diameter between above mentioned two variables, a positive correlation was calculated, where increasing values of the wood density were followed by increasing values of the SWR (Table 5).

Table 5. *Correlation between wood density and SWR of wood*

Drilling diameter Dd (mm)	Pearson's correlation coefficient r	Nomber of samples n	p-value
5.0	0.873	76	p<0.0005
5.55	0.859	76	p<0.0005
6.0	0.829	76	p<0.0005

Based on Pearson's correlation coefficient which was observed for all three groups of samples, it could be concluded that with the increase in drilling diameter this coefficient decreases, i.e. the degree of linear fit between values of wood density and the values of SWR decreases.

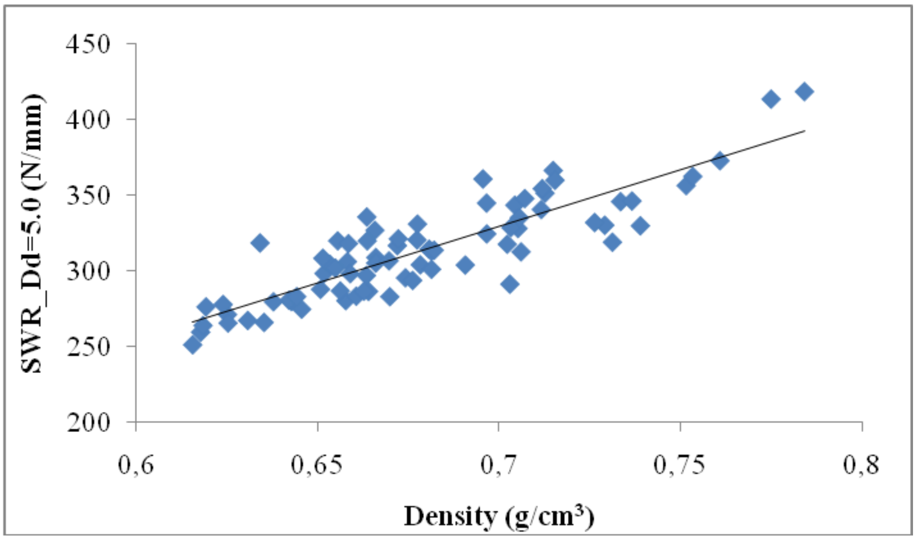

Figure 12. *Linear relationship between density of wood and screw withdrawal resistance of wood with drilling diameter of 5.0 mm*

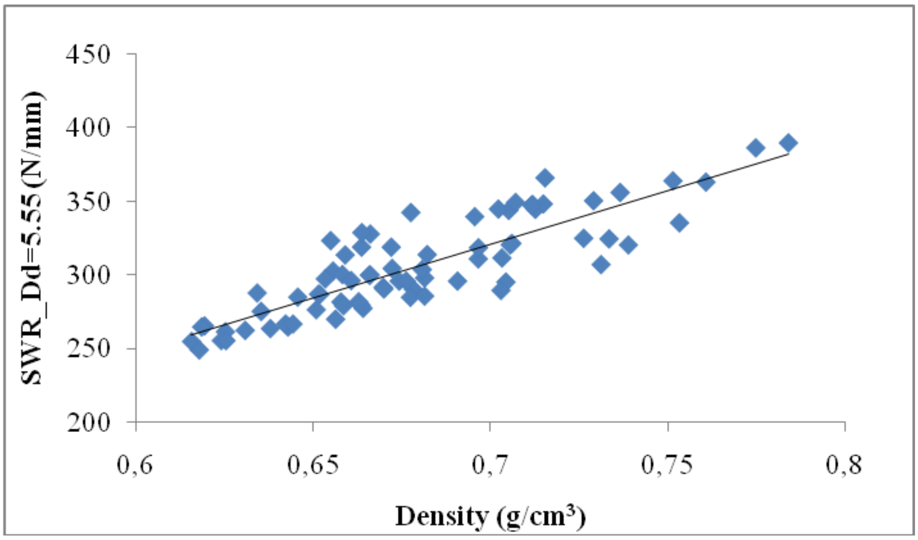

Figure 13. *Linear relationship between density of wood and screw withdrawal resistance of wood with drilling diameter of 5.55 mm*

In each of Figures 12, 13 and 14, diagrams of dispersion and the regression lines are given, which are estimated based on experiment data obtained for 76 samples per group. Regression line increases, which corresponds to a positive linear correlation. In the regression model, density of samples with moisture content of 7.2% is taken as an independent variable, while SWR with the appropriate drilling diameter was set as an dependent variable.

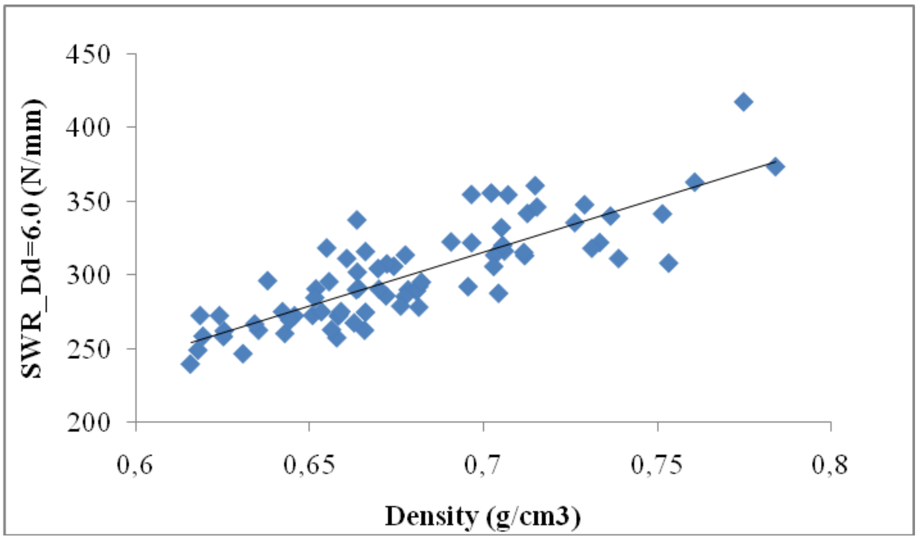

Figure 14. *Linear relationship between density of wood and screw withdrawal resistance of wood with drilling diameter of 6.0 mm*

Based on the results of the regression analysis, the effect of wood density on wood screw withdrawal resistance can be expressed by the expression:

$$\sigma_W = a \cdot \rho_{7,2\%} - b \tag{4}$$

-where the parameters are: σ_w-screw withdrawal resistance of wood in N/mm; $\rho_{7,2\%}$-density of wood with 7,2% of moisture content in g/cm^3.

Simple linear regression models, depending on the diameter of drilled holes, had the following form:

-for drilling diameter Dd=5,0 mm:

$$\sigma_W = 748{,}1 \cdot \rho_{7,2\%} - 194{,}52 \ [\mathrm{N/mm}] \tag{5}$$

-for drilling diameter Dd =5,55 mm:

$$\sigma_W = 732{,}1 \cdot \rho_{7,2\%} - 191{,}42 \ [\mathrm{N/mm}] \tag{6}$$

-for drilling diameter Dd=6,0 mm:

$$\sigma_W = 729{,}76 \cdot \rho_{7,2\%} - 195{,}23 \ [\mathrm{N/mm}]. \tag{7}$$

In the first case, the coefficient of determination was r^2 = 0.763, in the second case r^2 = 0.738, while the third case had r^2 = 0.687, respectively. Regression models are highly statistically significant and can be used for prediction.

The highest correlation coefficient of r = 0.873, and thus the coefficient of determination of r^2 = 0.763, were calculated for samples with drilling diameter Dd = 5.0 mm. If considering regression model, where value of SWR with drilling diameter of 0.5 mm can be predicted using the value of the wood density, it is interpreted as follows: For every increase in value of density of beech wood by 0.01 g/ cm3, the value of SWR will increase by an average of 7.48 N / mm.

Drilling diameter of 5.0 mm is approximately 90% of root diameter of the "Hanger" screw, so for the selected screw, wood type, moisture content and anatomical direction, the following form may be taken as a reference:

$$D_d=0{,}9\cdot d_r \text{ [mm]} \qquad (8)$$

where parameters are: D_d- drilling diameter in mm, d_r - root diameter of the „Hanger" screw.

4. CONCLUSION

In this paper, the effect of drilling diameter on screw withdrawal resistance of beech wood, using two-threaded „Hanger" screws, was analized. In the experimentthe drilling diameter was varied, which caused formation of three groups of specimens with drilling diameters of 5.0 mm, 5.55 mm and 6.0 mm, respectively. Based on the results obtained by testing of withdrawal resistance of wood, on a total of 228 samples divided into three groups of 76 samples, the following conclusions were made:

- Using One way repeated measurements ANOVA, the average values of the screw withdrawal resistance of wood were compared in all three groups of samples. Statistical analysis showed that the drilling diameter had significant influence on the withdrawal resistance of wood, i.e. with the increase in drilling diameter, the value of the withdrawal resistance decreases.
- Drilling a hole of a smaller diameter than root diameter of the „Hanger" screw (Dd=5,0 mm<d_r=5,5 mm), yielded the highest average value of the withdrawal resistance of wood, compared to the other two groups of samples. This could have been expected, because in this way the largest area of contact between the screw and wood was achieved. When placing the screw hole in this way, threads along its depth (h = 0.85 mm) are immersed into the wood tissue, in contrast to the other two sets of samples for which this was not the case.
- The relationship between wood density and withdrawal resistance of wood was investigated using the Pearson linear correlation coefficient. In each of the three groups of samples, a strong positive correlation was calculated between the two mentioned variables. Observed for the three groups of samples, Pearson's coefficient decreases with an increase od drilling diameter.

- The linear regression model to predict the value of the screw withdrawal resistance was expressed, depending on the value of the density, for samples with a 5.0 mm diameter of drilled holes, as $\sigma_W = 748{,}1 \cdot \rho_{7{,}2\%} - 194{,}52\ [\text{N/mm}]$.
- According to the results, the following expression for calculating the drilling diameter can be taken as a recommendation: Dd = 0.9·d_r [mm], where "d_r" is root diameter of the "Hanger" screw.

This research paper showed that the drilling diameter can be regarded as an important parameter when joints with the screw are considered. Controlling the relationship between the drilling diameter and root diameter of the screw can significantly affect the joint strength.

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THE INDUSTRY LOBBYING IN BRUSSELS

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ABSTRACT

This work introduces the lobbying procedure related to the most powerful industrial associations' players in the EU capital, Brussels, home to one of the highest concentrations of political power in the world. This work also explains the EU lobbying process, the multiple ways – some controversial - in which the lobbyists work to steer decisions to their advantage, and the often-serious impacts this has on people across Europe and in the rest of the world. As the power of the EU institutions has grown, Brussels has become a magnet for lobbyists, with the latest estimates ranging between 15,000 and 30,000 professionals representing companies, industry sectors, farmers, civil society groups, unions and others, along with those representing big business. Some areas of industrial activity are very well represented, such as environmental protection, agriculture and forestry, the energy and automotive industries.

Key words: lobbying, EU Transparency Register, forestry, wood Processing, RES

1. INTRODUCTION

1.1. Industrial lobbying in Brussels

Why lobbying? International trade is more and more important and new emerging-market nations take a significant position, including in the EU. Why do the main global firms expand across Europe and what is the current phase of globalization in the EU market[1]?

It is now commonplace for large numbers of firms, national associations, regions, and political, economic and legal consultants to have Brussels offices – and many more entities are frequent commuters to and from Brussels. European, national, and regional political processes are now closely intertwined. In response, interest groups and social movements have come to participate more or less regularly in EU the making and implementation of EU policy.

1.2. Lobbying: Definition

Lobbying is influencing legislation, typically by reducing regulation and compliance costs in highly regulated sectors like finance, engineering or utilities, usually in return for payment. Corporate lobbying in Brussels has long passed the one billion euro mark in annual turnover, which makes the city the world's second biggest center of corporate lobbying power, after Washington DC, world lobbying center with 3.21 billion USD spent in 2013.

Lobbying is also the "strategic communication of specialized information" (M. Nilsson, L. Nilsson, Ericsson 2009: 4455). Several terms are used in the research literature to describe the

[1] Growing demand in emerging markets makes them magnets for European business, but dynamic growth in these economies is creating important and significant local companies and big players with global aspiration. They usually want to export their own business and products in Europe.

activities of interest groups, like "lobbying" (e.g. Mazey and Richardson 1993; Coen 1998), "representation" (e.g. Greenwood 1997; Grant 2000) and "mobilization" (Marks 1992). However, both terms, "lobbying" and "mobilization", are very controversial and suggest too much. The word "lobbying" has acquired negative connotations (Charrad 2011) and usually for the general public means some negative or problematic actions, related with corruption or dealing with public authorities. The terms "interest representation" is more sophisticated and has no problematic connotations.

1.3. The Importance of Industrial Associations

A professional association is usually a non-profit organization seeking to further a particular profession, the interests of the individuals engaged in that profession, and the public interest. It is a body that acts "to safeguard the public interest". An industrial or trade association, also known as an industry trade group, business association or sector association, is an organization founded and funded by the businesses that operate in a specific industry.

Associations may offer other services, such as producing conferences, networking or charitable events or offering classes or educational materials. Many associations are non-profit organizations governed by law and directed by officers, representatives of members.

One of the primary purposes of a trade group is to attempt to influence public policy in a direction favorable to the group's members. Industrial and trade associations represent the largest lobbying subcategory in Brussels, and they began registering much earlier than companies, which comprise the second largest lobbying group. "Interest representatives" in the EU Register are all parties except individual persons that are engaged to interest representation activities.

Empirical data confirm that today's firms prefer direct political action where possible (Coen 1997). Generally speaking, it is possible to establish the relative importance of the Brussels institutions against the other national channels.

1.4. Description / Lobbying History and Structure

Lobbying in Brussels was born in the late 1970s. The fragmented nature of the EU's institutional structure provides multiple channels through which organized interests may seek to influence policymaking. Lobbying takes place at the European level itself and within the existing national states. The most important institutional targets are the Commission, the Council and the European Parliament. The Commission has a monopoly on initiatives in Community decision-making. Since it has the power to draft initiatives, it makes it ideally suited as an arena for interest representation.

Many large companies, NGOs and trade associations, either have dedicated public affairs people, or outsource lobbying to consultancies active in Brussels and member states. After the 2004 accessions, the industry exploded as more businesses and their stakeholders came under the auspices of EU law, resulting in over 2600 special interest groups now active. Their distribution was roughly as follows: European trade and industry federations (32 per cent), consultants (20 per cent), companies (13 per cent), NGOs (11 per cent), national associations (10 per cent), regional representations (6 per cent), international organizations (5 per cent) and think tanks (1 per cent) (Lehmann, 2003).

The Brussels lobby scene is populated by a bewildering variety of different organizations and individuals engaged in lobbying. Most are "in-house" lobbyists, employed by corporations and industrial associations to represent their employers' interests directly to policy and decision makers. Five hundred large corporations have their own lobbying offices in Brussels, including BASF, Siemens, BP, Vodafone, Rolls Royce, E.ON and many others, often in high profile locations. Almost every industry imaginable has its own trade lobby group in Brussels.

1.5. Problem Description / Lobbying Scandals

The public opinion in Belgium, and especially in Brussels, can be said to have a negative approach to lobbying due to the concentration of international pressure groups and as a result, there is a high level of awareness concerning this domain. In the last 10 years, politicians, academics, the business elite and the European public have become worried that lobbying in the European Union exacerbates issues of unequal access to the political institutions. Considering general theories of lobbying there are a number of reasons for concern.

In March 2011 came one of the biggest lobbying scandals in EU history, with three MEPs who had agreed to table amendments to change the EU law in return for promised payments being exposed. The scandal sent shockwaves through the European Parliament and started a debate about corruption and the Parliament's weak rules around financial interests and relations with lobbyists.

2. EU LOBBYING IN EXISTING LITERATURE AND ACADEMIC CONTEXTS

2.1. Overview And Types Of Available Literature

EU interest representation and lobbying have been studied extensively in recent years (Andersen and Eliassen 1993, 1995; Greenwood 1997; Greenwood and Aspinwall 1998; Mazey and Richardson 1993; Panebianco 2000; Pedler and Van Schendelen 1994). According to several researchers, there is now a greater variety of cleavages in EU policy-making and groups that mobilize opinion around ideas and norms have increased in importance.

Many authors also discuss the relation between lobbying and protest. The reason for the absence of environmental protest in Brussels might have to do with the possibility that lobbying EU institutions is by far more adequate and effective than the kind of unconventional protest action that is so common at national and subnational levels' (Rucht 2001).

EU institutions seek information, and interest groups seek influence. If they want to take influence, they have to provide information (Pappi and Henning 1999; Bouwen 2002; Michalowitz 2002). Some authors emphasize on other aspects of 'European route' like the complexity and informality of EU decision-making (Peterson 1995) and describe the activities of actors as a "hustle" (Warleigh 2000).

2.2. Academic Contexts

Critical political economy theories suggest that European integration promotes transnational neo-liberalism and spurs a new transnational dynamics of European capital. From a different perspective, centered on the EU decision-making processes, it is not clear who wields the influence: it is contested whether European integration enhances the influence on public policy of state institutions or that of interest organizations.

Sometimes the views of major European institutions in charge of European integration are opposed and incompatible. Until the early 2000s, the Commission was against the accreditation of pressure groups, as in their opinion, this would cause a problem for open access to EU policy-makers hampering their much needed information and expertise (McLaughlin and Greenwood, 1995).

Bender and Reulecke summarize the kinds of lobbying relating to policy process. They differentiate between 3 kinds of lobbying: "lobbying as prevention", "lobbying as reaction" and "lobbying as action" (Bender and Reulecke 2003). According to the authors, the most difficult one is preventive lobbying which aims to prevent or to postpone particular legislation before the call for legislative action exists. Lobbying as reaction means that the legislative proposal already exists and lobbying reacts to the legislative process.

3. EU LOBBYING - RESULT OF PERSONAL RESEARCH

3.1. Data Collection

In order to get into the subject and obtain relevant information about the situation in the lobbying sector, I had interviews with important people in the field of lobbying in Brussels. I selected in Brussels the following target interlocutors:

- two journalists from the field of energy and environmental protection
- one representative from the NGO sector, with the functions of advisor for the EU institutions
- one officer from DG Enterprise and Industry

- one member of the European parliament

Meetings were held during the special terms, which are set aside for interviews, or during some other public events that daily bring many officials and lobbyists together. On this occasion, I was engaged in writing notes, and my interlocutors often suggested to me some literature or media releases that helped me better understand the process of lobbying in Brussels.

Secondary data collection involved conducting an in-depth literature review in one of several specified areas of lobbying. Also used were all the available EU lobbying databases and statistical techniques for analyzing data and interpreting results and identifying the relevant conclusion.

3.2. Descriptions of Results

Results from interviews are very much as expected, because the selected professional five experts come from renewable energy sectors. Their answers confirm the intensive lobbying activity in the European energy area in last decade, and especially in RE. There is a strong lobby presence in Brussels called The Green 10, including among others, Greenpeace and Friends of Earth, large environmental groups with some inherent weaknesses due to their size.

NGO lobby can also be very influential, especially when it comes to open issues of disclosure of corruption or disclosure of some unfavorable details in the new legislation. If carbon emissions are limited below a certain percentage and before a certain year, catastrophic climatic changes will be averted. This topics means there is a very large audience for this lobbying group, because climatic changes area global political and socio-economical problem. A strong RE lobby should reframe the central carbon frame because presently it aligns too well with conventional energy systems. Analyzing different lobbying situations we can ask a simple question: do NGO lobbyists do enough or is their work sometimes insufficient to produce some common social benefit?

3.3. Main Industrial Lobbying Area

Industrial interests, especially connected with strong industrial players from the energy, chemical, IT or pharmaceutical sectors dominate throughout industrial lobby activity in the EU and this inhibits the development of a more progressive industrial policy. Capital investment in new technologies and innovation is a crucial EU orientation for future industrial development, in contrast with the high operating costs of conventional industries like the shipbuilding industry.

LOBBYING FOR RENEWABLE ENERGY

Energy is one of main economic tools for EU economy. At the same time, the environmental non-governmental (ENGO) RE lobby in the EU is very strong and visible. Conventional energy systems burn fossil fuels for energy (coal, oil, natural gas; and uranium), releasing green-house-gases (GHGs) into the atmosphere as a byproduct; other related problems are securing fossil and uranium energy and building massive infrastructure projects to support fossil fuel pipelines. There are environmental problems associated with conventional energy systems. The ENGO lobby disadvantages lobbying for RE because it remains entrenched in the carbon framework, its size limits its power, and its focus remains on the environmental frames.

LOBBYING IN THE INDUSTRY (AUTOMOTIVE, WOOD PROCESSING AND FORESTRY SECTOR)

Among the many sectors of corporate lobbying operating within the European Commission, the automotive industry is particularly emphasized. It is one of the most globalized sectors in the world. There are also other important industrial sectors; wood industry with following important professional organizations operating in the forest based sector:

- CEI BOIS (the European Confederation of Woodworking Industries) – It is the main body representing and defending the interests of the European woodworking and furniture industries towards the European Union.

- EOS (the European Organisation of the Sawmill Industry) – It is the main body representing and defending the interests of the European sawmill industry towards the European Union.
- EPF (the European Panel Federation) – It is the main body representing the particleboard, fibreboard and OSB industries with the supra-national authorities.
- EUSTFOR (the European State Forest Association) – Represents commercially oriented, state-owned forest companies, enterprises and agencies towards the European Union.
- CEPF (the Confederation of European Forest Owners) – It is the umbrella organisation of national forest owner organisations in the European Union. Their main goal is representation of the interests of forest owners in Europe.

3.4. Register of Interest Representatives

In order to bring some more transparency in the lobbying processes, the European Commission has set up a Register of interest representatives (Commission's policy paper of 21st March 2007). At the moment the Register is still voluntary but there are many initiatives to make it mandatory. This was the main opinion of the Secretary General of one influential Brussels NGO[2] in our interview. He recommended that the Commission staff use the Register as a reference point and encourage non-registered entities to register because this is considered an important contribution in raising the level of transparency in the lobbying processes.

As the European quarter is an area of high concentration of political power, it has attracted a thousand lobby consultancies, law firms and PR agencies and has become a heart of lobbycracy, making Brussels a corporate lobbying paradise. Lobbyists are employed by corporations and trade associations directly to represent their employer's interests to policy and decision makers. Two thirds of lobbyists work on behalf of business interests. Around one fifth of the lobbying in Brussels is done on behalf of states, regions and cities. It is estimated that five hundred large corporations have their own lobbying offices in Brussels. There are more than 1,500 industry lobby groups and several hundred 'public affairs' consultancies and law firms that advise and lobby for corporate clients.

The Brussels lobbyists' prime target is the EC – the source of almost all legislation and policy in the EU. But as the powers of the EP have grown, MEPs have also become an important target – with some 4,000 lobbyists registered to hold access badges for the Parliament.

3.5. Personal Lobbying Experience in European Parliament

During my professional work, I had the opportunity to participate in the activities of the EP. In the past few years I have been present at many meetings of the committees or inter groups in the EP and also in Commission. Based on my professional experience I was in January 2014 nominated as speaker in the debate about a new European forestry strategy, which the Commission proposed in 2013.

It was a rewarding experience through which I gained an insight into the important work of lobbying power, and I profited through a series of contacts that I made during the said meeting. A large number of different people, with very influential positions showed interest in meeting and holding additional discussions with me. Everyone wanted to get more information about the situation in the SEE countries and the development of Balkan countries' economies, especially regarding the use of wood biomass and renewable energy.

Small countries, or their professional associations are unable to pay the cost of a permanent presence in Brussels, and for this reason, various interest groups have shown interest in more information about the field of investment or strategic partnership.

My presentation in EP was for me a great professional achievement, as well as a tremendous experience that was useful, for my research work on the topic of European industry lobbying. After processing the collected data, I think it is necessary to clarify the main mechanisms and tools of lobbying process, with some recommendations that are also derived from the viewpoints expressed by the people I interviewed.

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[2] NGO operate in Green-Economy sector

4. CONCLUSIONS

4.1. Work Summaries

Existing processes of lobbying has the support of most stakeholders. Of course, the non-governmental sector is not satisfied with the results, so it is trying a lot to improve the situation. The decision making process seeks the cooperation of all parties, including lobbyists and political decision-makers. Policymakers need specialized information and lobbyists supply this in the exchange for political influence. One way that lobbyists can articulate this information is through framing policy language. In terms of lobbying, framing refers to the specific language employed to gain the desired policy results.

There is no doubt that by lobbying some good things can be achieved. Lobbying efforts and constant lobbying by various industrial associations and NGOs in Brussels have helped the EU to become the world leader in the economy, human rights, foreign aid and climate change. The Commission registry listed more than 3.900 groups with approximately 80 per cent stemming from business and 20 per cent representing diffuse or public interests.

4.2. Recommendation for Future Research

Lobbying is without any doubt a very important challenge for the EU future, especially in the policy making and legislative area. In same time, corruption is still a big problem. Lobbying is often mixed up with corruption and so people tend to forget that the lobbying processes serve also, for example, for the protection of the interests of minorities and for representing the range of the different positions of all stakeholders that are relevant in the process of European policy-making. So where is then the limit between corruption and lobbying and how could the system be improved? This is one possible challenge and topic for a future researcher.

4.3. Final Conclusions

Over time, the predominant lobbying organizational formats also changed. Initially, EU interest organizations were mainly sectorial or cross-sectorial peak associations of national interest groups. Today many are mixed membership groups that include combinations of national associations, multinational corporations, other interest organizations as well as cities and regions During my recent formal and informal education, especially during my last master education on Oxford University (Diploma in Global Business - Said Business School), I discussed with different EU officials and with representatives of Brussels' most powerful NGOs. Many of them also supported more transparency in lobbying activity and showed an interest in raising the level of rules, which would include some other stronger issues. The EU lobbying register should become mandatory as soon as possible, said my chosen interlocutors.

Today, interest groups are an important and highly institutionalized aspect of the EU decision-making process. Generally speaking, the lobbying process in EU is relatively fair, impartial and, most importantly, transparent.

As far as the forest based industry lobbying, it stands out, compared to other lobbying industries, with a strong and unified voice of its interest groups, which operate in a distinctive way by pooling together when it comes to representing and defending the interests of forest based industry, as well as its members, towards the European Union.

In the end, if we take into consideration all the research results, I can see some positive development in the lobbying process. The EU Lobbying Register is an important tool for democratic development in Europe and for future legislative processes. Industrial associations still play a crucial role in the European Quarter, but some NGOs have also became big lobbying players in Brussels, especially in the environment, industry and energy sector. This is also good challenge for future researcher.

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COMPRESSIVE STRENGTH OF PLYWOOD MADE FORM BEECH AND BLACK PINE VENEERS

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ABSTRACT

The research presented in this paper includes the study of compressive strength of plywood made from beech and black pine veneers. For this purpose, four experimental models of plywood were made. The models were made from peeled beech and black pine veneers. The modeling was made on the basis of changing the number and type of the veneers used for plywood manufacturing. Water-soluble phenol-formaldehyde resin was used as plywood binder. The in-plane compressive strength of the experimental plywood panels was tested in two directions, parallel and perpendicular to the face grain. According to the values of compressive strength plywood models can be used as structural panels in construction. Production of plywood with different number of veneers in panel structure, as well as plywood with the same number of the veneers but from different wood specie, gives opportunities for production of panels that can meet the different application requirements.

Key words: compressive strength, plywood, veneer, beech, black pine, phenol formaldehyde resin

1. INTRODUCTION

Plywood is one of the major types of wood composite materials for structural use for indoor and outdoor application. Structural plywood is used extensively in residential, commercial and industrial building components. Dimensional uniformity and reliable consistent structural properties makes plywood an attractive material choice from both a design and construction perspective.

Because of cross-laminated layup of veneers, plywood has excellent strength characteristics, stiffness and dimensional stability. It has high strength to weight ratios and it is very cost effective to use in structural applications such as flooring, siding, roofing, shear walls, formwork and engineered wood products (I-joists, box beams and stressed-skin panels). Basic structural plywood components include flooring of all types (domestic, commercial, industrial, sport floors and containers), bracing, combined wall cladding and bracing, and roof sheathing (EWPAA, 2009).

Because of its lightness, directional strength properties and inherent stiffness plywood is an excellent material to fix to timber beam elements to produce a composite construction. Such a structural system can have the plywood skins affixed to one or both sides of the stringers. Structurally, the function of the plywood skins is to develop the flexure stresses as in-plane tension and compressive stresses as a result of loading the panel perpendicular to its surface (EWPAA, 2009).

Plywood properties depend on the quality of the veneers, wood specie, combination of wood species in plywood structure, number and order of layers, as well as of the adhesive used for plywood bonding (Örs *et al.,* 2002; Hráskỳ and Král, 2005, 2006; Stark *et al,*. 2010; Jakimovska Popovska, 2011; Vasileiou *et al.,* 2011; Jakimovska Popovska and Iliev, 2013; Bal and Bektaş, 2014).

The performance of wood composite materials is characterized by wide range of engineering properties. Mechanical properties are mostly used to evaluate wood-based composites for structural and nonstructural applications. Elastic and strength properties are the primary criteria to select materials or to establish design or product specifications (Cai and Ross 2010).

The aim of the research presented in this paper is to determine the compressive strength of seven-layer and nine-layer plywood panels made from beech and black pine veneers.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For the realization of the research four experimental plywood models were made. Two of the models were made as seven-layer plywood, while the other two as nine-layer plywood. Peeled beech and black pine veneers with thickness of 1,5; 2,2 and 3,2 mm were used for plywood manufacturing. The seven-layer plywood models were made with two veneer sheets with thickness of 1,5 mm, two veneer sheets with thickness of 2,2 mm and three veneer sheets with thickness of 3,2 mm. The nine-layer plywood models were made with the same number of veneers with thickness of 1,5 and 3,2 mm and four veneer sheets with thickness of 2,2 mm.

The orientation of adjacent layers in plywood structure was at right angle, whereas in all models, the grain direction of the surface layers was parallel to the longitudinal axis of the panel. The central layer of each model represents a veneer sheet with thickness of 3,2 mm, oriented perpendicular to the face grain of the seven-layer plywood panel and parallel to the face grain of the nine-layer plywood panels. In all models the veneers with thickness of 1,5 mm build the surface layers of the panel. The compositions of the experimental plywood models are shown on Fig. 1.

Water-soluble phenol-formaldehyde resin with concentration of 48 % was used as plywood binder. 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 of the veneers with thickness of 3,2 mm in seven-layer models and on the both sides of the veneers with thickness of 2,2 mm in nine-layer models.

The plywood panels were made in a hot press under specific pressure of 15 kg/cm^2 at temperature of 155°C for time of 20 minutes for seven-layer models and 25 minutes for nine-layer models.

The panels were overlaid with phenol-formaldehyde resin impregnated paper that was bonded during the hot pressing process. Plywood overlaying with this paper is made in order to improve the water resistance of plywood, having in consideration the fact that these plywood panels are intended for application in construction where they can be exposed to high humidity conditions.

The plywood models were made with dimensions of 540×540 mm^2. The moisture content of the panels was 10 %.

According to this methodology four models of plywood were made:

– model B7: seven-layer plywood made with beech peeled veneers (panel thickness of 15 mm; density of 751,90 kg/m^3);
– model B9: nine-layer plywood made with beech veneers (panel thickness of 19 mm; density of 758,38 kg/m^3);
– model BP7: seven-layer plywood made with black pine veneers (panel thickness of 13 mm; density of 758,72 kg/m^3);
– model BP9: nine-layer plywood made with black pine veneers (panel thickness of 16 mm; density of 760,55 kg/m^3).

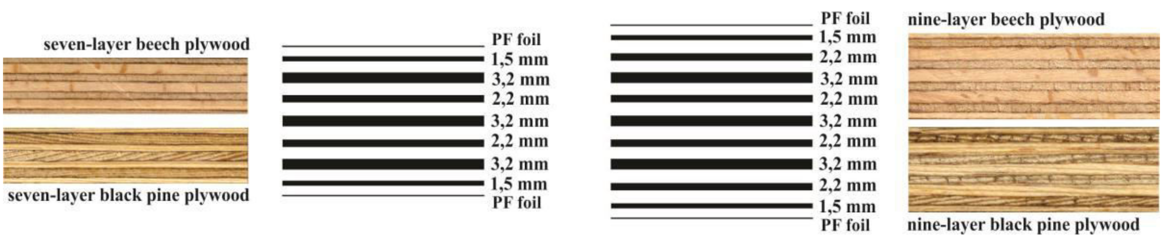

Figure 1. *Composition and cross section of the experimental seven-layer and nine-layer plywood models*

The in-plane compressive strength of the plywood panel was tested according to the national standard MKC D.A8.070/85. This property was tested in two directions, i.e. parallel and perpendicular to the face grain of the panel (Fig. 2).

The obtained data were statistically analyzed. One way ANOVA was used to determine the significance of the effect of type and number of the veneers in plywood composition on the compressive strength of the plywood 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 plywood models. Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

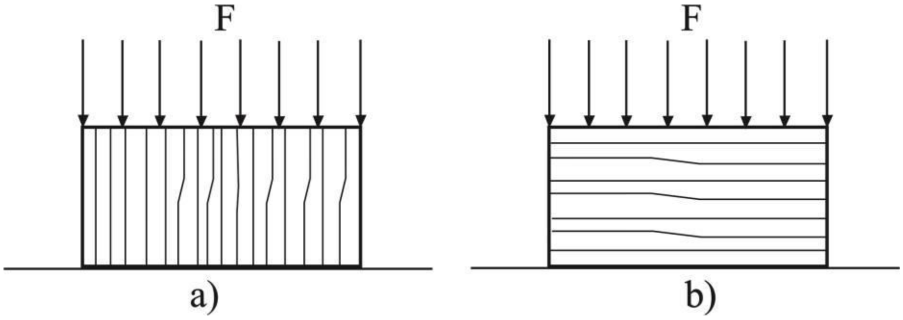

Figure 2. *Direction of compression force regarding the grain direction a-parallel to the face grain; b-perpendicular to the face grain*

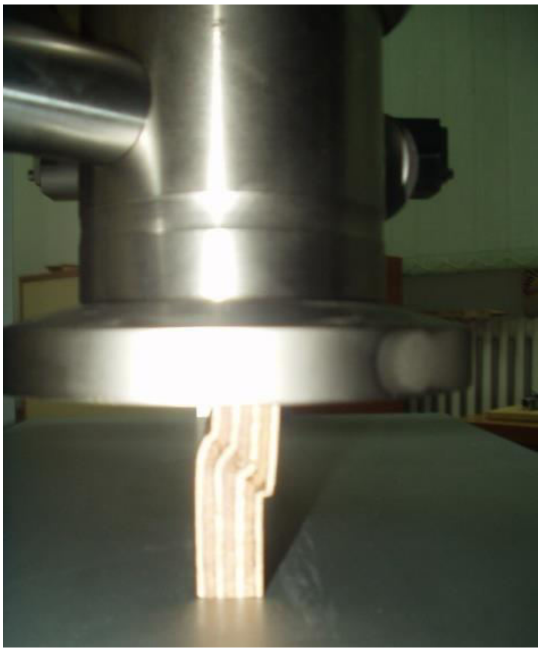

Figure 3. *Test specimen loaded in compression*

3. RESULTS AND DISCUSSION

The test results for the compressive strength parallel to the face grain of plywood panel are shown in tables 1 and 2.

Nine-layer plywood models made with beech and black pine veneers (B9 and BP9) have higher values compared to the seven-layer plywood models (B7 and BP7). The highest value of compressive strength parallel to the face grain of plywood is achieved in nine-layer model of plywood made with black pine veneers (model BP9). Compared to other plywood models, this model has higher mean value of this property up to 30,7 %.

***Table 1.** Statistical data for compressive strength parallel to the face grain of the experimental plywood*

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]***
B7	6	39,30[a]	38,47	40,15	38,63	39,97	0,64	0,26
B9	6	49,96[b]	49,55	50,78	49,49	50,43	0,45	0,18
BP7	6	40,43[a]	38,59	42,42	38,77	42,09	1,58	0,65
BP9	6	51,36[b]	50,05	52,45	50,19	52,53	1,12	0,46

The mean values with the same letters are not significantly different at 0,05 probability level

The analysis of variance of the obtained data for compressive strength parallel to the face grain of plywood (ANOVA: F (3; 20) = 216,815; 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 model B9 and BP9 compared to the models B7 and BP7. The differences in the values between model B7 and BP7, as well as between model B9 and BP9 are not statistically significant, which means that when plywood is made with the same number of veneers, the type of veneer (beech or black pine) used for plywood production does not cause significant differences in the value of compressive strength parallel to the face grain of plywood.

***Table 2.** Results for the ANOVA of the obtained data for compressive strength parallel to the face grain of the experimental plywood*

ANOVA					
Compressive strength parallel to the face grain					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	708,659	3	236,220	216,815	,000
Within Groups	21,790	20	1,089		
Total	730,449	23			

The higher values of nine-layer plywood models compared to the seven-layer models are attributed to the orientation of the veneers in plywood composition regarding the direction of compression force. In these two models (B9 and BP9) a bigger percentage of plywood thickness is occupied by the veneers oriented parallel to the direction of compression force which contribute in higher values of compressive strength, compared to the seven-layer models, where the bigger percentage of plywood thickness is occupied by the veneers oriented perpendicular to the direction of compression force. The compressive strength of wood is higher in the direction of the wood fibers compared to compressive strength in cross-direction of the wood fibers. By increasing the angle at which the compressive force loads the wood fibers the compressive strength decreases (Lukić-Simonović, 1983). Therefore, the compressive strength of plywood is higher in models that have a bigger percentage of wood fibers that are oriented parallel to the action of the compression force.

The test results for the compressive strength perpendicular to the face grain of plywood panel are shown in tables 3 and 4.

The highest value of compressive strength perpendicular to the face grain of plywood is achieved in seven-layer model of plywood made with black pine veneers (model BP7). Compared to other plywood models, this model has higher mean value of this property up to 42,4 %. Seven-layer plywood models (B7 and BP7) have higher values compared to the nine-layer plywood models (B9 and BP9).

The analysis of variance of the obtained data and post-hoc Tukey's test for compressive strength perpendicular to the face grain (ANOVA: $F(3;20) = 253,993$; $p=0,000$) showed that there are statistically significant differences in the mean values of this property between all plywood models.

Table 3. *Statistical data for compressive strength perpendicular to the face grain of the experimental plywood*

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]***
B7	6	45,91[a]	44,85	46,81	45,06	46,76	0,81	0,33
B9	6	34,95[b]	33,82	36,26	34,02	35,87	0,89	0,36
BP7	6	49,76[c]	47,35	51,42	48,24	51,29	1,45	0,59
BP9	6	40,12[d]	38,06	41,26	38,92	41,31	1,14	0,47

The mean values with the same letters are not significantly different at 0,05 probability level

The higher values of compressive strength perpendicular to the face grain of seven-layer plywood models compared to the nine-layer models are attributed to the orientation of the veneers in plywood composition regarding the direction of compression force. When compressive strength is tested in cross-grain direction, in these two models (B7 and BP7), a bigger percentage of plywood thickness is occupied by the veneers oriented parallel to the direction of compression force which contribute in higher values of compressive strength, compared to the nine-layer models, where the bigger percentage of plywood thickness is occupied by the veneers oriented perpendicular to direction of compression force.

Table 4. *Results for the ANOVA of the obtained data for compressive strength perpendicular to the face grain of the experimental plywood*

ANOVA					
Compressive strength perpendicular to the face grain					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	761,980	3	253,993	209,490	,000
Within Groups	24,249	20	1,212		
Total	786,228	23			

Seven-layer plywood models (B7 and BP7) have higher values of compressive strength perpendicular to the face grain compared to the values of this property in direction parallel to the face grain. Nine-layer plywood have significantly lower values of compressive strength perpendicular to the face grain compared to the values obtained when the panels are stressed parallel to the grain direction. The reason for this is the percentage of the panel thickness occupied by the veneers that run parallel to the direction of compression force. When plywood panels are stressed parallel to the face grain, 43,5 % of the nominal thickness of seven-layer plywood models is occupied by the veneers that run parallel to the direction of compression force, while when panels are stressed in cross-grain direction, 56,5 % of the seven-layer panel thickness is occupied by parallel veneers. In nine-layer plywood models, the differences in the percentage of plywood thickness that is occupied by the veneers that run parallel to the direction of compression force when panels are stressed parallel and in cross-grain direction is bigger than in seven-layer models. Nine-layer models have 58,9 % of the panel nominal thickness occupied by parallel veneers when the panels are stressed parallel to the face grain and 41,1 % of the panels thickness occupied by parallel veneers when plywood are stressed in cross-grain direction.

For plywood loaded parallel or perpendicular to the plywood face grain direction, the effective cross-sectional area in compression is the sum of the thicknesses of the plies with grain direction parallel to the force. These plies being loaded in their strong direction are effective at full compressive capacity (EWPAA, 2009).

The failure mode of the test specimens of experimental plywood models is shown on Fig 4.

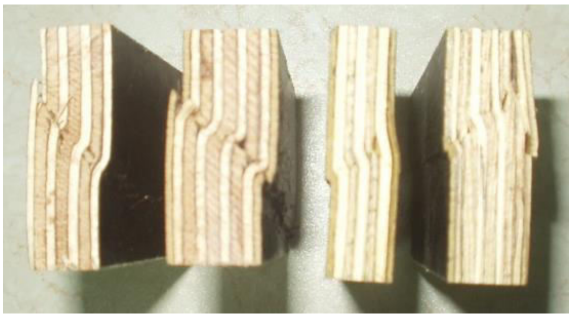

***Figure 4.** Failure mode of the test specimens of the experimental panels*

The force-strain diagram of plywood models is shown on figure 5.

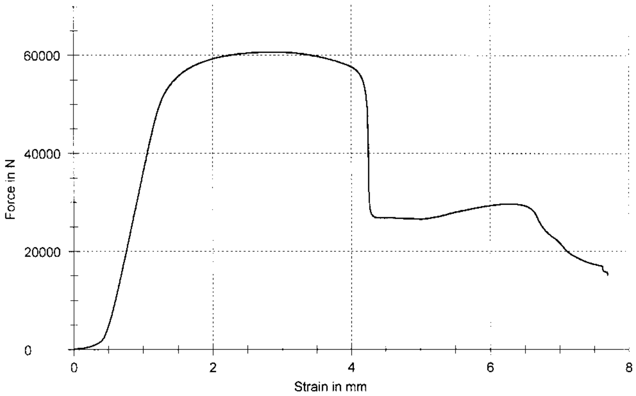

***Figure 5.** Example of force-strain diagram during testing the compressive strength of plywood models*

The obtained values of compressive strength of tested models are within the values for this property listed in available literature. Dimeski and Iliev (1997) gives values of 64,16 N/mm^2 and 55,64 N/mm^2 for compressive strength of seven-layered and nine-layered beech plywood respectively. Iliev (2000) gives a value of 64,08 N/mm^2 for seven-layered and 49,11 N/mm^2 for nine-layered beech plywood. Jakimovska Popovska and Iliev (2013) give the values in the range of 45,39 to 60,50 N/mm^2 for compressive strength parallel to the face grain of nine-layer beech plywood and values from 41,65 to 54,98 N/mm^2 for compressive strength perpendicular to the face grain.

All four plywood models meet the requirements of the national standard MKC D.C5.043 for structural plywood for use in construction, which prescribe a minimal value of 24 N/mm^2 for compressive strength parallel to the face grain of the panel and 12 N/mm^2 for compressive strength perpendicular to the face grain of the panel. The plywood models exceed the value of compressive strength parallel to the face grain of the panel for 1,6 to 2,1 times, while the value of compressive strength perpendicular to the face grain of the panel for 2,9 to 4,1 times.

4. CONCLUSIONS

On the basis of the conducted research it can be concluded that different number of the veneers and different veneer type used in plywood structure has significant impact on plywood in plane compressive strength.

The highest value of compressive strength parallel to the face grain is achieved in nine-layer black pine plywood. Nine-layer plywood models have higher values of compressive strength parallel to the face grain compared to the seven-layer models, which is a result of a bigger percentage of plywood thickness that is occupied by the veneers oriented parallel to the direction of compression force.

Type of veneer (beech or black pine) used for plywood production does not cause significant differences in the value of compressive strength parallel to the face grain of plywood, when plywood is made with the same number of veneers.

The orientation of the veneers regarding the direction of force of compression also is a reason for higher values of compressive strength perpendicular to the face grain of seven-layer plywood models compared to the nine-layer models.

Seven-layer models have higher values of compressive strength perpendicular to the face grain compared to the values of this property in direction parallel to the face grain, while the nine-layer models have lower values of compressive strength perpendicular to the face grain compared to the values obtained when the panels are stressed parallel to the grain direction. The reason for this is the percentage of the panel thickness occupied by the veneers that run parallel to the direction of compression force.

The production of plywood with different number of veneers in panel structure, as well as plywood with the same number of the veneers but from different wood specie, gives opportunities for production of panels that can meet the different application requirements. The choice of particular plywood configuration will depends on the application area, i.e., the type of loads on which the panel is exposed during the exploitation period.

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SCREW WITHDRAWAL RESISTANCE OF COMPOSITE WOOD-BASED PANELS MADE FROM PARTICLEBOARD CORE AND PEELED TWO-PLY CROSS-LAMINATED VENEERS

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ABSTRACT

The research presented in this paper includes the study of screw withdrawal resistance of composite wood-based panels for use in construction.

Three experimental wood composite panels were made by combining particleboards and peeled beech, black pine and poplar veneers with thickness of 1,5 and 3,2 mm. The core layer of the composite panels was made of single-layer particleboard with thickness of 16 mm, which was overlaid on both sides with two-ply cross-laminated 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 screw withdrawal resistance perpendicular to the plain of the composite panels.

According to the obtained values of the screw withdrawal resistance, composite panels can be used in construction.

Key words: composite wood-based panels, particleboard, veneer, beech, black pine, poplar, phenol formaldehyde resin, screw withdrawal resistance

1. INTRODUCTION

One type of wood-based panel for structural use in construction is composite wood-based panel, which represent a composition of particleboard and veneers (particleboard core overlaid with peeled veneers). These panels combine structural efficiency with favorable manufacturing cost (Biblis and Chiu, 1974).

Many authors have done researches on the properties of composite panels made from various core and face materials (Hse, 1976; Biblis and Mangalousis, 1983; Biblis 1985; Chow *et al.*, 1986; Dimeski *et al.*, 1996 and 1997; Miljković *et al.*, 1997; Mihajolva *et al.*, 2005; Iliev *et al.*, 1994, 2000, 2005, 2006, 2010; Buyuksari, 2012; Jakimovska Popovska, 2015). 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 studied by Iliev (2000) and Norvydas and Minelga (2006).

Beside other properties of composite wood-based panels that are important for panels use in construction, the screw withdrawal resistance is an important property that can shows the behavior of the assemblies of this kind of wood-based panels made with screws. The strength and stability of the structures made from particleboards depend very much on the fastening that holds the parts of the structure together (Miljković and Popović, 2004).

The screw holding performance of wood-based materials including particleboards, OSB, MDF and plywood had been studied by many authors (Eckelman, 1975 and 1988; Miljković *et al.*, 2007; Erdil *et al.*, 2002; Điporović-Momčilović *et al.*, 2006). This kind of studies can be used to develop estimates of face and edge screw holding strength that can be used in the product engineering of constructions made from wood-based materials.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For the realization of the research, three experimental composite wood-based panels were made by combining single-layered particleboard and peeled beech, black pine and poplar veneers. The core layer of composite panels represents a single-layer particleboard with thickness of 16 mm which was overlaid on both sides with two-ply cross-laminated beech/black pine/poplar veneers with thickness of 1,5 and 3,2 mm, where the veneers with thickness of 1,5 mm represent the surface layers of the panels (Fig. 1).

The single-layered particleboards were made from beech particles by mixing of equal weight ratios of particles for core and surface layer. Water solution of phenol-formaldehyde resin was used as an adhesive for particle bonding. The resin has a density of 1,22 g/cm^3 at 20°C; 50,43% dry matters content, 0,30% content of free phenol, viscosity of 195 s by Ford at 20°C, pH value – 11,0 and resin curing time of 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 particleboards were pressed under 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) at 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 two veneer sheets on each side of the panels. Beech, black pine and poplar veneers with thickness of 1,5 and 3,2 mm were used for overlay. The orientation of the adjacent veneers was at right angle, where the surface veneers with thickness of 1,5 mm were oriented parallel to the longitudinal axis of the particleboard. A water-soluble phenol-formaldehyde resin with the following characteristics was used for veneer bonding: 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 on the inner veneers with thickness of 3,2 mm 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 moisture content of 8,5 % and dimensions of 545×435 mm^2, with thickness range from 23,00 to 23,37 mm depending on the model.

According to this methodology three models of composite wood-based panels were made:

- model B: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated beech peeled veneers;
- model BP: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated black pine peeled veneers;
- model P: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated poplar peeled veneers.

The configuration of panels' structure is shown on figure 1.

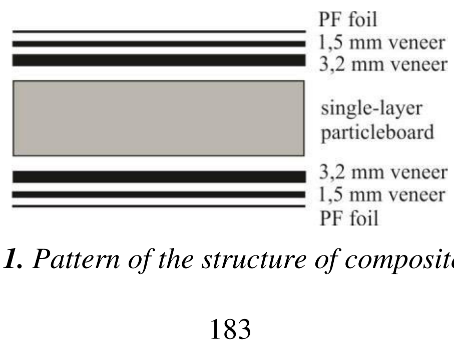

Figure 1. *Pattern of the structure of composite panels*

The screw withdrawal resistance of composite panels was tested according to MKS D.C8.112/82. This property was tested in two directions: perpendicular to the plane of the panel, i.e., when the screw was driven in the surface of the panel and in plain of the panel (the screw was driven in panel's edge).

Nine test specimens of each model were made with dimensions of 100×50×d mm. Slotted flat countersunk head wood screws according to the standard DIN 97 were used for these tests. The screws had the following technical parameters: thread diameter – 4 mm, length – 40 mm, threaded pitch – 1,8 mm, thread core diameter – 2,8 mm, diameter of unthreaded shank – 4 mm, head diameter – 7,5 mm, head height – 2,2 mm and width of the slot – 1 mm. The screw holes with diameter of 2,5 mm and depth of d_l-2 mm (where d_l is panel's thickness) were pre-drilled in the panels for screw driving into the surface of the panel. When the screws were driven in to the edge of the panel, the holes with diameter of 2 mm and the depth of 25 mm were pre-drilled. 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 screw was driven in to the surface of the test specimen and two screws in to the edge of the specimen.

The test specimens for determination of screw withdrawal resistance are shown on figure 2 and 3.

The tests were performed on universal testing machine, measuring the maximal force of withdrawal.

The specific screw withdrawal resistance perpendicular to the plane of the panel was calculated using the following equation:

$$Z_{\perp}=\frac{F}{d\times\pi\times(d_1-2)}\ [\mathrm{N/mm^2}],$$

where F is maximal force of screw withdrawal [N], d is diameter of the screw [mm] and d_l is the thickness of the panel.

The specific screw withdrawal resistance parallel to the plane of the panel was calculated using the following equation:

$$Z_{\parallel}=\frac{F}{d\times\pi\times l}\ [\mathrm{N/mm^2}],$$

where F is maximal force of screw withdrawal [N]; d is diameter of the screws [mm] and l is the depth of driving of the screw 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 screw 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 specie (different panel models).

Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

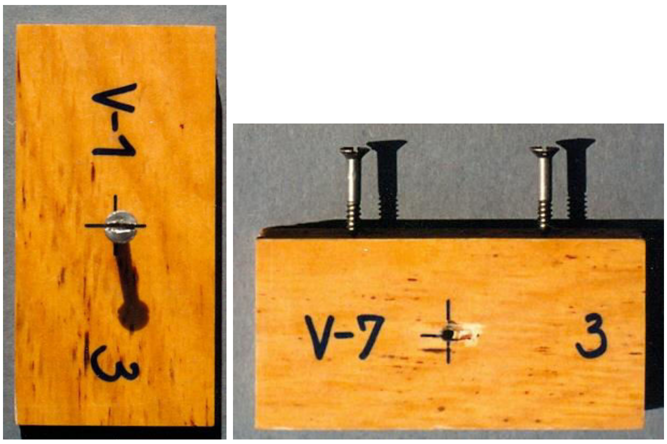

Figure 2. *Test specimens for determination of screw withdrawal resistance of composite panels*

3. RESULTS AND DISCUSSION

The values of the density of composite models are shown in table 1. The highest density of composite models is achieved in model B, i.e. in model overlaid with two-ply cross-laminated beech veneers. The ANOVA ($F(2,24)=8,647$; $p=0,001$) and Tukey's test for the density of the composite panels showed that there are statistical differences in the density of the composite model made with poplar veneers and other two models (model B and BP). The differences between the density of composite panel made with beech veneers and composite panel made with black pine veneers are not statistically significant.

The analysis of variance of the obtained data for the screw withdrawal resistance perpendicular to the plain of the panel (ANOVA: $F(2; 24)=5,623$; $p=0,010$) 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 composite model overlaid with two-ply cross-laminated beech veneers (model B) and other two models (model BP and P). 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, with the notation that the differences between the model made with black pine veneers (model BP) and that one made with poplar veneers (model P) are not statistically significant. These values correspond with the values of the density of the composite models (Tab. 1).

The analysis of variance of the obtained data for the screw withdrawal resistance parallel to the plain of the panel (ANOVA: $F(2; 24)=1,285$; $p=0,295$) 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 were made with the same core layer of single-layer particleboard, i.e., in all models the screw 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*
B	9	742,00^{a}	688,00	794,00	716,40	767,60	33,31	11,10
BP	9	725,89^{a}	658,00	758,00	702,79	748,99	30,06	10,02
P	9	676,22^{b}	609,00	721,00	644,93	707,52	40,71	13,57

The mean values with the same letters are not significantly different at 0,05 probability level

Table 2. *Statistical data for screw 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*
B	9	14,11^{a}	11,92	16,67	12,94	15,29	1,53	0,51
BP	9	12,13^{b}	9,40	14,51	11,02	13,25	1,45	0,48
P	9	11,92^{b}	9,78	14,51	10,68	13,15	1,61	0,54

The mean values with the same letters are not significantly different at 0,05 probability level

Table 3. *Statistical data for screw 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*
B	9	2,67	2,12	3,28	2,34	3,00	0,43	0,14
BP	9	3,00	2,09	3,90	2,55	3,45	0,58	0,19
P	9	2,65	1,95	3,54	2,23	3,07	0,54	0,18

There are no statistically significant differences between the mean values at 0,05 probability level

The obtained values of screw 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 9,69 to 12,95 N/mm^2 for screw withdrawal resistance perpendicular to the plain of the composite panels made with two-ply cross-laminated beech veneers. Miljković *et al.* (1997) give the value of 12,13 N/mm^2 for composite panel made with two-ply cross-laminated black pine veneers. For the screw withdrawal resistance parallel to the plain of the panel Iliev (2000) gives the values within the limits of 4,19 to 7,21 N/mm^2 for composite panels made with two-ply cross-laminated beech veneers.

According to Miljković (1991) the screw withdrawal resistance perpendicular to the plain of the particleboard panel is higher for 100 to 125 % compared to the screw withdrawal resistance parallel to the plain of the particleboard panel. The screw withdrawal resistance perpendicular to the plain of the particleboard increases proportionally with the increment of the particleboard density, while the edge withdrawal resistance depends on the quality of the bonds between particles (Miljković, 1991).

4. CONCLUSIONS

On the basis of the obtained results from the conducted research, it can be concluded that by combining the water resistant particleboard as core layer and peeled constructive veneers for particleboard overlay, composite wood-based panels for structural application in construction can be made.

The wood specie used for veneer production (beech, black pine or poplar) has significant impact on the values of screw 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 screw withdrawal resistance, the composite panels can be used in construction.

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UDK: 674.031.632.2.047.1

CHANGE IN MASS, VOLUME AND DENSITY OF EUROPEAN BEECH (*FAGUS SYLVATICA* L.) FIREWOOD DUE TO AIR DRYING

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ABSTRACT

In this research experimental and theoretical parameters of moisture, mass, volume and density of round and split firewood are explored, because of great importance to commercial trading with firewood. Firewood was made in specialized company using mechanised technology. The tools and machines which have been used were chainsaws, band saws and hydraulic log splitters. Each firewood piece was measured and marked with a purpose of measuring mass, dimensions and moisutre in green and dryish condition. Air drying was conducted on well-ventilated and sheltered company area from 20 March 2015 to 12 October 2015.

The average value of firewood moisture before drying was 66.02%. In dryish condition, average value of firewood moisture was between 15.74% and 32.72%. Considering green condition, loss in mass was between 25.89 and 29.47%. Given the green condition, reducing the volume amounted to an average between 9.54 and 13.6%. Considering green condition, density was reduced between 14.73 and 19.24 %.

Key words: European beech (*Fagus sylvatica* L.), firewood, mass, volume, moisture, wood density, air drying

1. INTRODUCTION

The last decade brought great changes on European firewood market. The obligations of EU member states defined by national action plans for renewable energy mobilize significant amounts of wood biomass for the production of new forms of solid biofuels mainly wood chips and wood pellets. The structure of the plan for the sale of the firewood and pulpwood from the state forests of the Republic of Croatia shows that about 80% of the total production volume is intended to be used as firewood for household and processing in short sawn wood and split wood, pellet production, use in co-generation plants and charcoal production.

Firewood in the traditional form of one-meter split wood and round wood, most commonly produced by self-production, is still the most important energy source for the production of heat energy in rural areas of the Republic of Croatia. In addition to the traditional way of production, sale and use of one-meter and longer than one-meter firewood, in recent years, an increasing number of companies started production of short sawn and split firewood, mainly for export, mostly in Italy, Slovenia, Hungary and Austria (Vusić at al., 2015).

When placing round wood on the market, it is possible to measure it by volume or mass. Measuring wood by mass is influenced by the current moisture content, and most commonly is used when dispatching firewood (Poršinsky at al., 2014). Firewood is used for heat production and it is not technically usable. It is made of all sorts of trees. Firewood is supplied and measured with in m^3 or in kg. We distinguish dry firewood and green firewood. Dry firewood is when it has been at least 6 months from the felling and green firewood is when it has been less than 4 months from the felling (Vusić at al., 2015).

The wood is porous, which means that its volume is not filled with wood, but with water in which mineral substances are dissolved. During the life of the tree through the pores, processes that are very important for the growth and development of trees are carried out, while after the felling of the tree production functions stop and water is excreted from it to a certain limit.

The higher the share of water in wood, the greater the mass of green wood is. There is free water and bound water in wood. The free water is most easily removed and is located in pores and cell lumen; while the bound water is in wood cell walls. Considering the water content of wood, we distinguish green wood or wood at the time of felling and immediately afterwards, semi-dry wood, dried wood and absolutely dry wood. In semi-dried wood, wood has lost all its free water and water content ranges from 22 to 40%. Dried wood has lost free water and part of the bound water, and is divided into shipping dry wood (18 to 22% water content) air dry wood (water content 12 to 18%) and room dry wood (water content 8 -12%). Absolutely dry wood is artificially dried to constant mass and its final water content is 0%. In the business the term dry firewood implies firewood that has been air dried for more than 6 months.

For wood drying, the fibre saturation point is of utmost importance, that is the border between free and bound water. Dryness of wood oscillates around hygroscopic saturation point, which also depends on adsorption and desorption of bound water. The adsorption and desorption processes change with respect to external conditions, and thus the wood density is variable value. Diffusion is responsible for the movement of water in wood, which is 10 to 15 times larger in the direction of wood fibres than in the direction perpendicular to the wood fibres. Reducing the water content makes the wood lighter, because in the wood pores instead of water, air enters with a low volume mass, which makes wood assortments easier for handling, loading, transport and it has lower consumption for the same volume.

Wood density is inversely proportional to wood porosity; that is higher wood density causes lower wood porosity. Density is influenced by tree species, tree age, habitat, chemistry, constitution of the wood etc. Reduction in density is also influenced by the length of firewood. According to Zelić and Međugorac (2001), a significant difference occurs only for sessile oak and birch, for lengths of 20 and 200 cm. The most likely cause of this is the impact of the thickness and colour of the bark of these wood species on the natural course of drying. In sessile oak bark acts as a thermal insulator, and in shorter forms faster drying takes place in the longitudinal direction rather than in the radial-tangential direction, while in the birch other than the longitudinal direction, there may be a significant influence of the white colour of the bark which slows down the thermal radiation or slows down the process of air drying.

As there are few months from felling and production to selling of firewood, there is a loss due to the shrinkage. The research results carried out by Zelić and Međugorac (2001) indicate that during air drying of firewood the outer conditions significantly slow down the course of air drying of wood. Wood density was conditioned by climate change, and wood mass was often higher than in previous weighing. According to their research results, the density of beech wood assortments of 20 cm in length ranged from 812.94 kg/m^3 in air dried condition to 1083.93 kg/m^3 in green condition. The density of beech wood assortments of 100 cm length ranged from 1048.18 kg/m^3 in green condition to 773.36 kg/m^3 in the air dried condition while at the length of 200 cm it ranged from 1079.67 kg/m^3 in green condition to 889.14 kg/m^3 in air dry condition. Loss in the density to the degree of dryness is different depending on the wood species and the length of the sample. The slowest loss of density is recorded in sessile oak, while the fastest in white poplar. For firewood longer than 200 cm the trend of loss of density is conditional in the same way as for wood assortments of 200 cm.

They concluded that one weighing of firewood is enough and a known period of time from felling to weighing, and with these parameters it is easy to determine the wood density for green or dry condition of firewood of a certain wood species.

2. AIM OF RESEARCH

The influence of moisture, mass, volume and density of firewood is of crucial importance to transport, quantity and price of firewood in commercial businesses.

The aim of the paper is to experimentally and theoretically explore the changes that occur in the course of air drying of firewood of common beech (*Fagus sylvatica* L.).

The results of this research should give the answers to how much have this firewood lost in mass, volume, moisture and density during air drying over a given period of time.

3. OBJECTS AND METHODS OF RESEARCH

For the purposes of research, the firewood was made in three forms (Figures 1 and 2):

- 1m - long round wood,
- 1m - long split wood and
- 33cm - short split wood.

For the purposes of measurement, 17 pieces of 1m long round wood, 13 pieces of 1m long split wood and 209 pieces of short split wood marked by numbers were selected, and their mass, dimensions and moisture in the green and air dried condition were measured. Air drying was carried out in sheltered and well-ventilated part of firewood yard.

Drying of 1m long round wood and split wood lasted for 207 days, from 20 March 2015 to 12 October 2015. Drying of 33 cm short split wood lasted 196 days, from 28 March 2015 to 3 October 2015.



Figure 1. *Stack of green round and split firewood samples*



Figure 2. *Stack of dry round and split firewood samples*

3.1. Production of firewood samples for measurement

After felling of wood assortments in the forest, raw material or long round firewood (longer than one metre) was transported by trucks to the log yard, at the company where the research was conducted. The raw material was unloaded and stored in previously planned place in log yard. Hereafter, a description of the production in stages up to short split firewood is given (Figure 3).

The production of firewood from the round wood longer than one metre started by cross-cutting it to one-meter length using a motor chainsaw. Then the splitting of such one-meter round wood with hydraulic log splitter followed. From each one-metre round wood, four split woods were split. Given that the commercial length of the split firewood is 25, 33 and 50 cm, the next stage of production was cross-cutting the one-metre split wood to one of these lengths. In our case, cross-cutting was done using band saw to 33 cm length. After that, short split woods are again cross-cut into smaller pieces depending on their final use and the type of combustion chamber where it will be burned. In the end produced firewood, depending on the shape, was arranged on 1 x 1 x 1.80 m pallets and using wheel loaders transported to the measuring site or to the later drying.

Figure 3*.Overview of the production process of firewood following the arrows: the stack of the round wood longer than 1 metre in log yard; cross-cutting of round wood longer than one metre and production of one-metre round wood by a motor chainsaw; splitting one-metre round wood; cross-cutting of one-metre split wood with a band saw to the final length and additional splitting; disposing on pallets and air drying*

3.2. Measuring mass, dimensions and moisture contents of samples
3.2.1. Firewood mass

The firewood mass was measured on the laboratory scale and the value was rounded to three decimal places. The firewood was weighed for the first time immediately after it was produced during the month of March, and the second time during the month of October after it was air dried on a well-ventilated log yard. The mass value is defined in kilograms.

The percentage of the firewood mass reduction due to air drying is calculated according to the expression 1.

$$\Delta(m)_{rel} = \frac{m_{green} - m_{dry}}{m_{green}} \cdot 100 \qquad (1)$$

$\Delta(m)_{rel}$ – relative change in sample mass, %,
m_{green} – sample mass in green condition, kg,
m_{dry} – sample mass in air dried condition, kg.

3.2.2. Firewood volume

Firewood volume is determined by volumetric method. For volume determination of 1m long round wood and split wood a bath with dimensions a = 1.205 m long and b = 0.50 m wide was used. For short split wood a volumetric cylinder with diameter of D_m = 15 cm was used. The measuring was performed in such way that first water level (h_{min}) was measured before immersing firewood in the bath or volumetric cylinder. Then the sample was immersed in the bath or the volumetric cylinder and the water level (h_{max}) with sample in it was measured. The difference between the water levels before and after the sample was immersed was calculated. The column of water level difference presents the volume of immersed sample and it is calculated according to expressions 2 and 3.

$$V = \left[(a \cdot b) \cdot (h_{\max} - h_{\min})\right] \qquad (2)$$

$$V = \frac{D_m^2 \cdot \pi}{4} \cdot \left(h_{\max} - h_{\min}\right) \qquad (3)$$

V – sample volume, m^3
D_m – volumetric cylinder diameter, m
h_{min} – measured level of water before immersing samples in the bath or volumetric cylinder, m
h_{max} – measured level of water after immersing samples in the bath or volumetric cylinder, m
a – bath length, m
b – bath width, m

The percentage of firewood volume reduction due to air drying is calculated in relative relation to expression 4.

$$\Delta(V)_{rel} = \frac{V_{green} - V_{dry}}{V_{green}} \cdot 100 \qquad (4)$$

$\Delta(V)_{rel}$ – relative change in the volume of the sample, %,
V_{green} – sample volume in green condition, m^3,
V_{dry} – sample volume in air dried condition, m^3.

3.2.3. Firewood moisture content

The moisture content of the firewood was measured by the gravimetric method, which is the method of measuring the amount of extracted water up to 0% of the final water content in wood (Pervan, 2000). This method was carried out using laboratory scale and drying oven. From firewood 25 mm thick samples were sawn for measuring moisture and immediately after production were weighed and then dried at a temperature of 102 to 103 ° C to a constant mass. The final value of the mass was measured when the sample mass value stopped changing. The same procedure was carried out after measuring air dried samples. After the drying of the samples in the drying oven and measuring the mass first of moist samples and then dried samples after several months of air drying, the moisture content of the firewood was calculated according to the expression 5.

$$u = \frac{m_1 - m_2}{m_2} \cdot 100 \tag{5}$$

u – sample moisture content, %
m_1 – initial mass of the sample, kg
m_2 – final mass of the sample, kg

3.2.4. Firewood density

Firewood density was calculated according to the definition that wood density is the ratio of mass and volume of the firewood. It was calculated according to expression 6:

$$\rho = \frac{m}{V} \tag{6}$$

ρ – firewood density, kg/m^3
m – firewood mass, kg
V – firewood volume, m^3

The percentage of firewood density changes due to air drying was calculated according to the expression 7:

$$\Delta(\rho)_{rel} = \frac{\rho_{green} - \rho_{dry}}{\rho_{green}} \cdot 100 \tag{7}$$

$\Delta(\rho)_{rel}$ – relative density change of the sample, %,
ρ_{green} – sample density in green condition, kg/m^3,
ρ_{dry} – sample density in air dried condition, kg/m^3.

3.3. Statistical data processing

For data processing, Microsoft Word and Excel programs and SigmaPlot v 10.0 were used. The research results are presented using descriptive statistics, graphically and tabularly.

4. RESULTS AND DISCUSSION

4.1. Descriptive statistics of measured values

Table 1 shows descriptive statistics of mass, volume, density and moisture content of green and dry split wood (L = 33 cm). The average value of the mass of all split wood in the green wood condition was 1.69 kg, and in the air dried condition this value was reduced to 1.19 kg. The percentage drop in mass regarding the green wood condition was 29.47%. In the green wood condition, the average value of the volume of all split wood was 0.00171 m^3, while in the air dried condition it was 0.00148 m^3. The percentage drop in volume regarding the green wood condition was 13.60%. In the green wood condition, the average value of density of all split wood was 988.71 kg/m^3, while in the air dried condition it was 806.76 kg/m^3. The percentage drop in density regarding the green wood condition was18.17%. During drying the split wood moisture content dropped from the initial 66.02% to 15.74% at the end of the study.

Table 1. *Descriptive statistics for the short split firewood (L = 33 cm)*

Firewood size	***Short split firewood (L = 33 cm)***						
	Size	**N**	**Min.**	**Median**	**Max.**	***Average***	**Std. dev.**
$\mathbf{m_{green}}$	kg	209	0.34	1.68	2.77	1.69	0.47
$\mathbf{m_{dry}}$	kg	209	0.27	1.17	2.04	1.19	0.33
$\mathbf{\Delta(m)_{rel}}$	%	209	18.32	29.53	39.43	29.47	3.37
$\mathbf{V_{green}}$	m^3	209	0.00041	0.00164	0.00300	0.00171	0.00047
$\mathbf{V_{dry}}$	m^3	209	0.00037	0.00148	0.00235	0.00148	0.00040
$\mathbf{\Delta(V)_{rel}}$	%	209	5.06	12.90	26.89	13.60	5.15
$\boldsymbol{\rho_{green}}$	kg/m^3	209	818.52	980.39	1144.78	988.71	67.96
$\boldsymbol{\rho_{dry}}$	kg/m^3	209	689.25	805.22	942.68	806.76	41.18
$\boldsymbol{\Delta(\rho)_{rel}}$	%	209	10.39	17.88	29.52	18.17	4.92
$\mathbf{u_{green}}$	%	10	56.16	64.08	82.32	66.02	7.95
$\mathbf{u_{dry}}$	%	19	14.62	15.50	17.85	15.74	0.85

Table 2 shows the descriptive statistics of mass, volume, density and moisture content of green and dry split wood (L = 100 cm). The average value of the mass of all split wood in the green wood condition was 14.72 kg, and in the air dried condition this value was reduced to 10.93 kg. The percentage drop in mass regarding the green wood condition was 25.89%. In the green wood condition, the average value of the volume of all split wood was 0.01427 m^3, while in the air dried condition it was 0.01256 m^3. The percentage drop in volume regarding the green wood condition was 12.66%. In the green wood condition, the average value of density of all split wood was 1022.68 kg/m^3, while in the air dried condition it was 870.62 kg/m^3. The percentage drop in density regarding the green wood condition was 14.73%. During drying the split wood moisture content dropped from the initial 66.02% to 21.07% at the end of the study.

Table 2. *Descriptive statistics for the 1 m split firewood (L = 100 cm)*

Firewood size	***1 m split firewood (L = 100 cm)***						
	Size	**N**	**Min.**	**Median**	**Max.**	***Average***	**Std. dev.**
$\mathbf{m_{green}}$	kg	13	8.50	14.30	22.8	14.72	4.73
$\mathbf{m_{dry}}$	kg	13	5.90	10.60	17.00	10.93	3.60
$\mathbf{\Delta(m)_{rel}}$	%	13	19.89	26.19	32.95	25.89	3.03
$\mathbf{V_{green}}$	m^3	13	0.00964	0.01326	0.02109	0.01427	0.00413
$\mathbf{V_{dry}}$	m^3	13	0.00723	0.01145	0.01988	0.01256	0.00409
$\mathbf{\Delta(V)_{rel}}$	%	13	4.55	10	25	12.66	7.04
$\boldsymbol{\rho_{green}}$	kg/m^3	13	881.74	1037.34	1130.21	1022.68	71.37
$\boldsymbol{\rho_{dry}}$	kg/m^3	13	735.03	855.02	977.41	870.62	72.03
$\boldsymbol{\Delta(\rho)_{rel}}$	%	13	4.43	15.75	22.68	14.73	6.35
$\mathbf{u_{green}}$	%	10	56.16	64.08	82.32	66.02	7.95
$\mathbf{u_{dry}}$	%	10	20.50	20.90	21.90	21.07	0.72

Table 3 shows the descriptive statistics of mass, volume, density and moisture content of green and dry round wood (L = 100 cm). The average value of the mass of all round wood in the green wood condition was 26.37 kg, and in the air dried condition this value was reduced to 19.21 kg. The percentage drop in mass regarding the green wood condition was 27.04%. In the green wood condition, the average value of the volume of all round wood was 0.02601 m^3, while in the air dried condition it was 0.02346 m^3. The percentage drop in volume regarding the green wood condition was 9.54%. In the green wood condition, the average value of density of all round wood was 1022.68 kg/m^3, while in the air dried condition it was 823.70 kg/m^3. The percentage drop in density regarding the green wood condition was 19.24%. During drying the round wood moisture content dropped from the initial 66.02% to 32.72% at the end of the study.

***Table 3**. Descriptive statistics for the 1 m round firewood (L = 100 cm)*

Firewood size	*1 m round firewood (L = 100 cm)*						
	Size	**N**	**Min.**	**Median**	**Max.**	***Average***	**Std. dev.**
$\mathbf{m_{green}}$	kg	17	9.40	25.20	37.50	26.37	6.85
$\mathbf{m_{dry}}$	kg	17	6.90	18.40	27.20	19.21	4.97
$\mathbf{\Delta(m)_{rel}}$	%	17	19.23	27.22	32.26	27.04	3.24
$\mathbf{V_{green}}$	m^3	17	0.00904	0.02651	0.03555	0.02601	0.00707
$\mathbf{V_{dry}}$	m^3	17	0.00844	0.02470	0.03133	0.02346	0.00627
$\mathbf{\Delta(V)_{rel}}$	%	17	3.70	8.70	19.23	9.54	4.08
$\boldsymbol{\rho_{green}}$	kg/m^3	17	795.43	1029.05	1224.53	1022.16	97.56
$\boldsymbol{\rho_{dry}}$	kg/m^3	17	688.11	809.96	941.81	823.70	70.55
$\boldsymbol{\Delta(\rho)_{rel}}$	%	17	11.15	19.67	26.45	19.24	4.06
$\mathbf{u_{green}}$	%	10	56.16	64.08	82.32	66.02	7.95
$\mathbf{u_{dry}}$	%	10	29.10	33.85	35.20	32.72	3.17

4.2. Relative change in mass, volume and density of firewood

Figure 4 shows a diagram of the relative change in mass of firewood after air drying. From the diagram it is apparent that the largest relative change in mass is evident in the short split wood (L = 33 cm), followed by 1m round wood (L=100 cm). A slightly unexpected result showed 1m split wood (L = 100 cm) as they had the smallest relative change in mass (L = 100 cm) although they reached a lower moisture content value after drying than round wood. Certainly, these results should be tested in the further research.

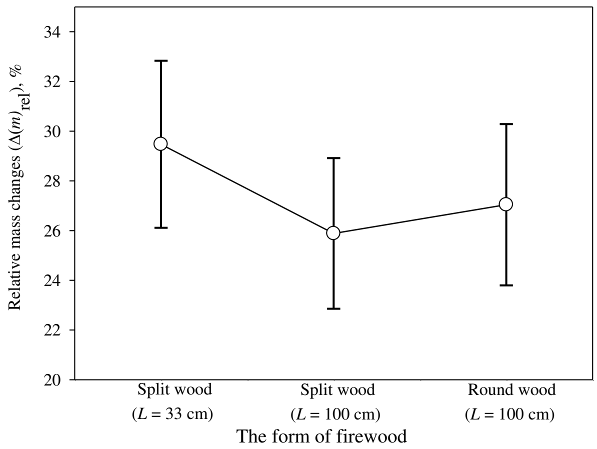

***Figure 4.** The relative change in the mass of firewood due to air drying*

Figure 5 shows a diagram of the relative change in volume of firewood after air drying. As can be seen, the largest relative change in volume occurred in the short split wood (L = 33 cm). The result was expected as these split wood were dried to the lowest moisture value below the fibre saturation point, which causes significant shrinkage. They are followed by 1m split wood (L=100 cm) which dried to a somewhat lower moisture than the fibre saturation point. Unlike split wood, the 1m round wood (L = 100 cm) were dried somewhere to the values around the fibre saturation point, which causes little shrinkage or change in volume.

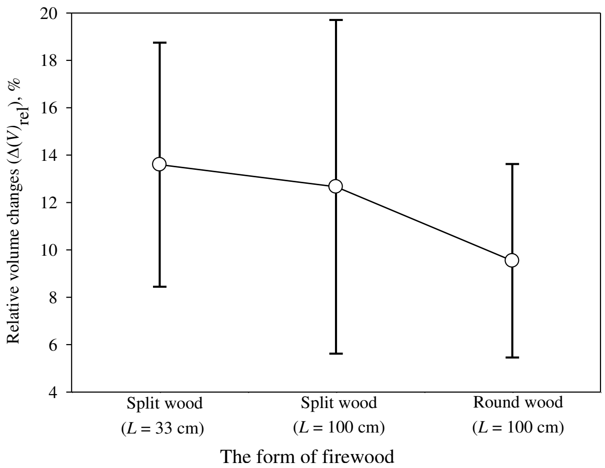

Figure 5. *The relative change in the volume of firewood due to air drying*

Figure 6 shows a diagram of the relative change in density of firewood after air drying. rom the diagram it is apparent that the largest relative change in density is evident in the 1m round wood (l=100 cm). They are followed by short split wood (L=33 cm) and in the end 1m split wood (L=100 cm).

Since the firewood is supplied by volume and by mass with the bark, it is possible that the bark factor has been of great influence on results given by round wood. Because of the higher water content, the density of raw bark is greater than the same volume of green wood (Krpan, 1986). By air drying of firewood, the water contained in the bark is lost to an average of 50% of the bark's density in green wood condition (Zelić and Međugorac, 2001).

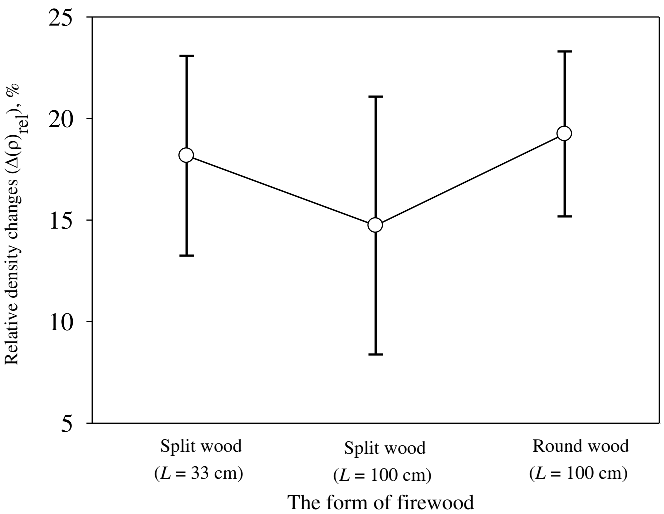

Figure 6. *The relative change in the density of firewood due to air drying*

5. CONCLUSION

Based on the results of this research it can be concluded:

- Air drying reduced mass, volume and density regardless of the shape of firewood,
- Relative change in the volume of firewood due to air drying was the largest for short split wood (L = 33 cm) and the smallest for 1m round wood (L = 100 cm),
- Relative change in mass of firewood due to air drying was the largest for short split wood (L = 33 cm) and the smallest for 1m split wood (L = 100 cm),

- The relative change of the density of the firewood due to air drying was the largest for the 1m round wood (L = 100 cm) and the smallest for 1m split wood (L = 100 cm).

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WOOD DRYING QUALITY OF PINEWOOD

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ABSTRACT

In order to develop optimized drying schedules, a series of experimental schedules of convective kiln drying of pinewood has been performed. Boards, 50,0 mm thick have been used as testing materials. The boards have been kiln dried from initial moisture content of 50,0 % to final moisture content of 10,0 % for a period of 15 days. In a drying schedule there were four stages: heating, active drying, equalizing and conditioning. The moisture content difference i.e. moisture content gradient between core and surface of the boards after drying is 2,4 %.

Key words: pinewood, convective drying, moisture content gradient, drying quality

1. INTRODUCTION

Drying is the key to adding value and we dry wood for many reasons: to make it lighter, to make it stronger, to make it stable, so that we can glue it, so that we can machine and process it, so that it can be finished, to make it less susceptible to fungal and insect attacks and so that we can treat it with preservatives. (Miller, 2000). As well as that, determining moisture content gradient across the thickness of the wood and end point after drying has always been a challenge for the kiln operator.

During the early decades, research concentrated on finding safe drying schedules for lumber, which were mostly characterized as drying relatively slowly and unevenly, and, in some cases, also being prone to check and warp. Recently, more emphasis has been put on optimized drying schedule which is used to reduce the total drying time and to improve the amount of adequate quality timber. (Pordage and Langrish, 2000)

By definition, drying schedule is the procedure of adjustment of the underlying factors such as temperature, humidity and speed of air that characterize the drying process. It can also be defined as guidelines in the form of tables where good results in terms of time, quality of drying and energy consumption are expected.

Development of optimized drying schedules is linked to their implementation and if the schedules are difficult to implement or their implementations results in wood defects, then kiln control needs to be improved.

Some of the different methods used by researchers to determine optimal drying schedules for kiln stacks of timber are Monte – Carlo simulations (Kayihan, 1993) and Markov chains (Cronin et al.1997). The aim of these methods is to account for the variability in the moisture content distribution across the kiln stack.

A much more important challenge is to explain the biological variability of the timber (Burdon, 1995) and its thickness when developing optimized drying schedules. Therefore the origin and dimensions of the timber needs to be considered most carefully in optimizing a drying schedule (Zlateski et al. 2013).

2. MATERIAL AND METHODS OF WORK

A total quantity of 50 m^3 pine boards with thickness of 50,0 mm, were dried in the convective kiln drier equipped with automatic system of drying control, manufactured by COPCAL – Italy. (Figure 1). The boards originated from Kožuv Mountain in the South of the Republic of Macedonia. The information on the temperature and equilibrium moisture content of the air as content of wood was obtained with the probes showed on Figure 2 and Figure 3. An assessment of moisture content differences (gradient) between core and surface of the boards was carried out by slicing test method (Figure 4). In order to define the drying schedule, the change in temperature and equal moisture content (EMC) of the air in the kiln chamber has to be registered, as well as the changing in the wood moisture content (MC) during all stages of the drying schedule: heating, active drying, equalizing and conditioning.

Figure 1.*Control unit of drying*

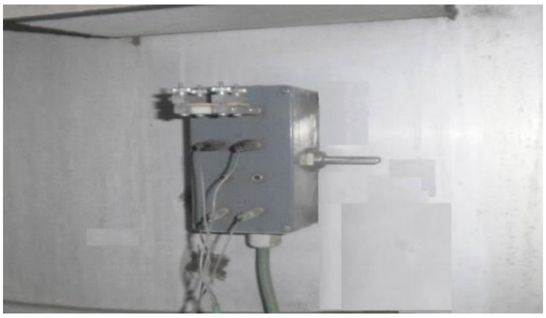


Figure 2. *Measuring of temperature of air and equilibrium moisture content (EMC)*

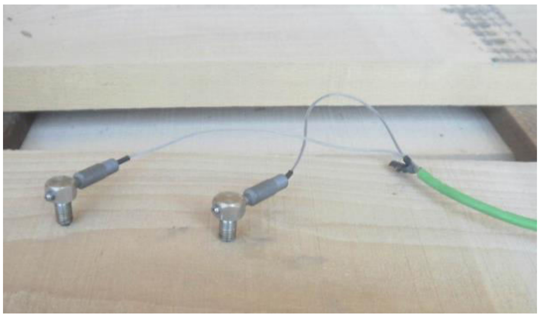


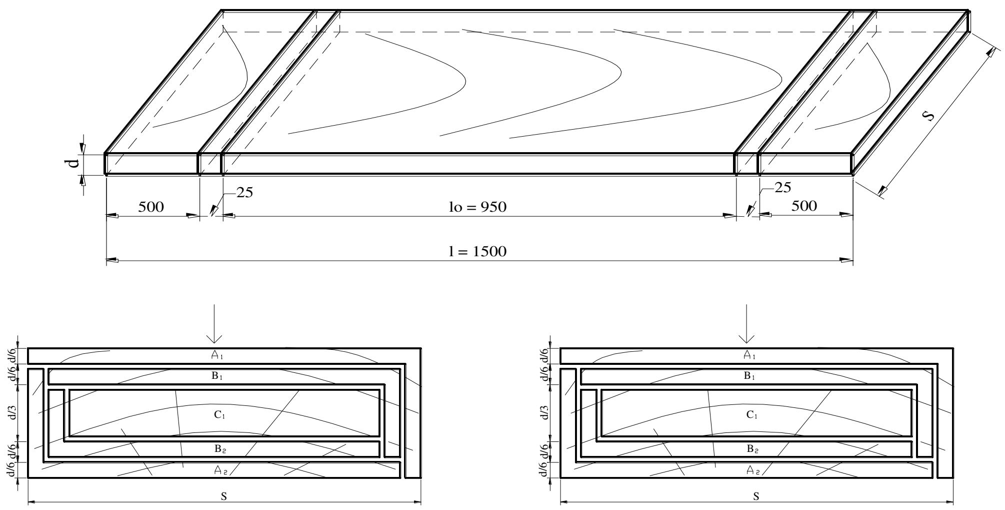
Figure 3. *Measuring of wood moisture content*

3. RESULTS AND DISCUSSION

Based on the values of temperature of the drying air, EMC and the values for the wood moisture content for 50,0 mm thick pine boards, the drying schedule shown in Table 1 and Figure 5 was defined. From the table it can be noticed that the drying schedule starts with air temperature of 42,0 ^{o}C, equilibrium moisture content [EMC) of 10,0 % and average moisture content in the wood of 50,0%. Further in the drying process, the air temperature increased to the value of 70,0 ^{o}C at the end of the drying phase of the schedule. This value keeps constant to the end of last phase of conditioning.

The EMC had a trend of decreasing from 10,0 % to 2,5 % until reaching the phases of equalization and conditioning when this EMC increased from 2,5 % to 12,0 %.

Average moisture content in the wood measured by six probes reached maximum value of 50,0% at the start and minimum value of 10,0 % at the end of the drying process. The drying duration of pine wood was 15 days.



A; B – specimens for surface MC determination
C – specimen for core MC determination

***Figure 4**. Slicing test (specimen production) for determining wood moisture gradient across the board's thickness*

4. RESULTS AND DISCUSSION

***Table 1.** Drying schedule of 50,0 mm thick pine boards*

Time of drying (day)	Drying schedule phase	Temperature of air in dry kiln	Equilibrium moisture content	Wood moisture content
(day)		**t (^{0} C)**	**EMC (%)**	**MC (%)**
I	Heating	42,0	10,0	50,0
II	Heating	44,0	10,0	46,0
III	Drying	46,0	10,5	40,0
IV	Drying	49,0	10,5	38,0
V	Drying	53,0	10,5	35,0
VI	Drying	56,0	8,5	31,0
VII	Drying	59,0	7,0	26,0
VIII	Drying	61,0	7,0	22,0
IX	Drying	63,0	5,5	18,0
X	Drying	65,0	4,0	15,0
XI	Drying	68,0	2,5	14,0
XII	Drying	69,0	2,5	13,0
XIII	Drying	70,0	2,5	12,0
XIV	Equalizing	70,0	8,0	11,0
XV	Conditioning	70,0	12,0	10,0

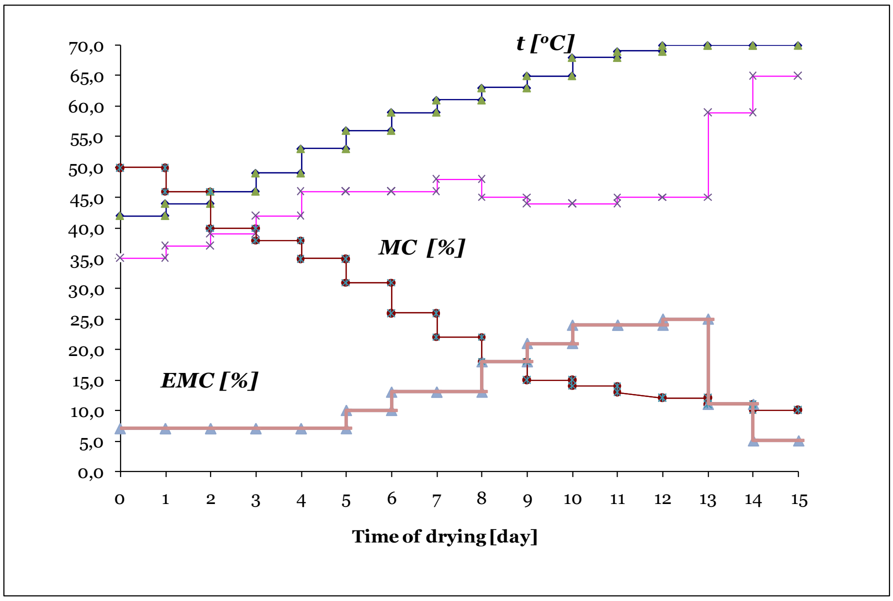


Figure 5. *Graphical view of drying schedule,50,0 mm thick pine boards*

The results of moisture content gradient are given in Table 2. Based on the data shown in Table 2, it can be concluded that the surface moisture content of the board is 9,30 % (layer A), 9,50 % (layer B) and 9,40 % (layer A+B).The core moisture content (layer C) of the boards is 11,80 %. The moisture content gradient, which is moisture content differences between the board's core moisture content (MC core) and the board's surface moisture content (MC surface), in absolute value is - 2,4% (Figure 5).

Table 2. *Data on surface and core moisture content of pine boards*

Thickness of the wood [mm]	Layer of the wood surface (mark)	Layer of the wood core (mark)	Average wood moisture content Xsr ± fxsr	Standard deviation S ± fs	Coefficient of variation V ± fv
50,0	A		9,30 ± 0,030	0,191 ± 0,021	2,049 ± 0,229
50,0	B		9,50 ± 0,036	0,230 ± 0,026	2,424 ± 0,271
50,0	A+B		9,40 ± 0,037	0,234 ± 0,026	2,488 ± 0,278
		C	11,80 ± 0,089	0,400 ± 0,063	3,386 ± 0,536

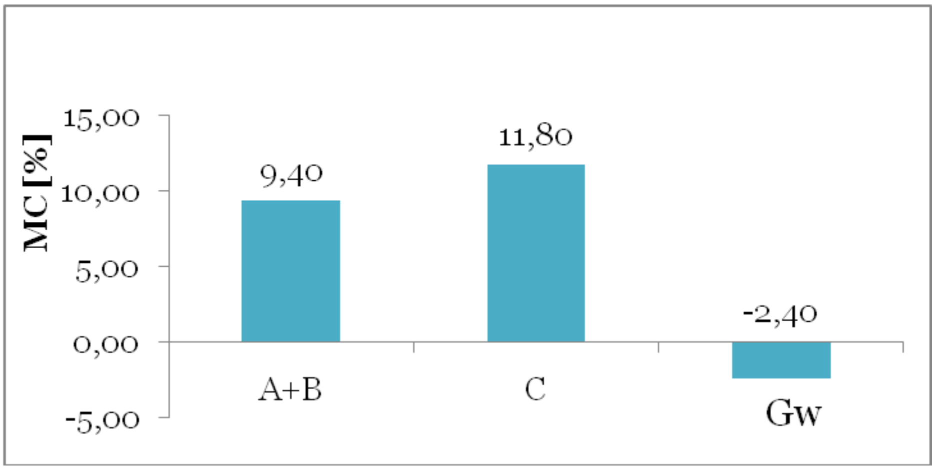


Figure 5. *Wood moisture content distribution (gradient) across the board*

5. CONCLUSION

According to the data presented and results obtained during the drying of pine boards with 50,0 mm in thickness the following can be concluded:

1. The schedule of drying pine boards was defined. There are four phases in the drying schedule: heating, drying, equalizing and conditioning. It was found that the boards were dried from their initial average moisture content of 50,0 % to their final average moisture content of 10,0 % for a period of 15 days.
2. Air temperature increases from 42,0 °C to 70 °C.
3. The EMC has a trend of decreasing from 10,0 % to 2,5 % at the start of drying until reaching the phase of equalization, and trend of increasing from 2,5 % to 12,0 % at the end of the drying.
4. The surface moisture content of the boards is 9,40 % (layer A+B)
5. The core moisture content of the boards is 11,80 % (layer C).
6. The moisture content distribution (moisture gradient) across thickness of pine boards during convective drying is - 2,40 %, which is quite suitable for production of products from solid wood.

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WOOD SHRINKAGE OF AUTOCHTHON AND ALLOCHTONE WOOD SPECIES IN THE REPUBLIC OF MACEDONIA

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ABSTRACT

Wood shrinkage of the following wood species was studied: *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 shrinkage of the tested autochthon and allochthon species are in the limits of the values for the species that have been systematized by Ugrenović (1950), Horvat (1980) and Enchev (1989).

Within the same deciduous specie, shrinkage of wood from the vegetative origin is higher than shrinking of the wood from generative origin.

Among coniferous species form artificial afforestation, within the same specie, wood shrinkage is increased by the aging of the tested stand from 26 to 58 years.

Key words: wood shrinkage, deciduous species, coniferous species, generative origin, vegetative origin, natural stands, afforested plantations

1. INTRODUCTION

By evaporation of moisture located in wood cell membrane, i.e. from crystallite cavities with diameter up to 1 nm, and when the bond with the cellulose is physic-chemical, the wood shrinks. It is developed in longitudinal, radial and tangential direction with expressive anisotropy which can result with deformations.

Knowledge of the wood dimensional changes and deformation related to them is of particular meaning in wood technology. This is important for finding technological methods for in time removing of the possible consequences of deformation. This is achieved by improving the wood drying regimes and giving adequate over measure, and nowadays for certain wood species by wood impregnation with materials that decrease the dimensional change, i.e. the anisotropy.

Wood shrinkage is one of the most investigated physical properties. In our research, we will comparatively use the limitation and mean values of wood shrinkage of the most important species that were systematized by Ugrenović (1950), Horvat (1980) and Enchev (1989) on the basis of published papers by Gayer-Fabriciu *et al*., and Kollman *et al*.

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 shrinkage.

In certain wood species the age and the origin of stands (generative or vegetative) carry the variations of wood shrinking.

2. MATERIAL AND METHOD OF THE EXPERIMENTAL WORK

Test specimens used for determination of wood density (Nacevski *et al.,* 2015) were also used for determination of wood shrinkage, which expedite the procedure and contribute in rational utilization of the material. The method of testing and calculation is prescribed by the standard for wood testing МКС D.A1.049.

Following properties were determined: total radial shrinkage, total tangential shrinkage and total volumetric shrinkage of wood.

3. RESULTS FROM THE RESEARCH

3.1 Radial shrinkage of wood

Total radial shrinkage of beech wood from generative origin (5,99 %) is lower for 17,83 % compared to the total radial shrinkage of beech wood from vegetative origin (7,29 %).

Total radial shrinkage of wood from Hungarian oak (6,64 %) is lower for 11,82 % compared to the total radial shrinkage of wood by Cornish oak (7,53 %).

Total radial shrinkage of wood from black locust raised on alluvial soil (5,19 %) is lower for 8,30 % compared to the total radial shrinkage of wood from black locust, raised on cinnamon soil (5,66 %).

Total radial shrinkage of wood from black pine artificial stands is lowest in the locality of Pochivalo in the region of Shtip (2,34 %), while highest in the locality of Ramnoborje in the region of Pehchevo (4,19 %). The mean values of the total radial shrinkage of wood from other ten localities are between these limits.

Total radial shrinkage of wood from white pine artificial stands (3,14 %) is lower for 25,06 % compared to the total radial shrinkage of wood from black pine artificial stand (4,19 %) at the same age and from the same locality.

Total radial wood shrinkage for fir and spruce from natural stands is 3,45 % and 4,90 %, respectively.

The artificial stands of Douglas fir have the highest radial wood shrinkage in the locality of Gorici (3,70 %), lower in the locality of Vitachevo (3,60 %) and lowest in the locality of Ramnoborje (3,50 %).

Total radial shrinkage of wood from cupressus aphid, giant redwood, mountain pine and European larch, all raised as artificial stands is 3,60 %, 2,20 %, 3,30 % and 4,00 %, respectively.

3.2 Tangential shrinkage of wood

Total tangential shrinkage of beech wood from generative origin (11,76 %) is lower for 13,72 % compared to the total tangential shrinkage of beech wood from vegetative origin (13,63 %).

Total tangential shrinkage of wood from Hungarian oak (9,78 %) is lower for 9,36 % compared to the total tangential shrinkage of wood from Cornish oak (10,79 %).

Total tangential shrinkage of wood from black locust raised on alluvial soil (8,31 %) is higher for 0,85 % compared to the total tangential shrinkage of wood from black locust, raised on cinnamon soil (8,24 %).

Total tangential shrinkage of wood from black pine artificial stands is lowest in the locality of Pochivalo in the region of Shtip (5,61%), while highest in the locality of Ramnoborje in the region of

Pehchevo (7,77 %). The mean values of the total tangential shrinkage of wood from other ten localities are between these limits.

Total tangential shrinkage of wood from white pine artificial stand (7,01 %) is lower for 9,78 % compared to the total tangential shrinkage of wood from black pine artificial stand (7,77 %) in the locality of Ramnoborje in the region of Pehchevo.

Total tangential wood shrinkage for fir and spruce from natural stands is 7,41 % and 6,00 %, respectively.

Total tangential shrinkage of wood from Douglas fir is highest from the artificial stands in the locality of Vitachevo (7,00 %), lower in the locality of Gorici (6,40 %) and lowest in the locality of Ramnoborje (6,30 %).

Total tangential shrinkage of wood from cupressus aphid, giant redwood, mountain pine and European larch, all raised as artificial stands is 7,20 %, 3,90 %, 6,30 % and 7,90 %, respectively.

3.3 Volumetric shrinkage of wood

On the basis of the obtained dimensions in longitudinal, radial and tangential direction of wood in saturated condition and standard dry condition, total volumetric shrinkage of wood was calculated. In order to calculate this shrinkage, data for the linear shrinkage of wood were used.

Total volumetric shrinkage of beech wood from generative origin (17,66 %) is lower for 14,35 % compared to the total volumetric shrinkage of beech wood from vegetative origin (20,62 %).

Total volumetric shrinkage of wood from Hungarian oak (15,89 %) is lower for 7,92 % compared to the total volumetric shrinkage of wood from Cornish oak (17,26 %).

Total volumetric shrinkage of wood from black locust raised on alluvial soil (14,30 %) is higher for 2,88 % compared to the total volumetric shrinkage of wood from black locust, raised on cinnamon soil (13,90 %).

Total volumetric shrinkage of wood from black pine artificial stands is lowest in the locality of Pochivalo in the region of Shtip (7,98 %), while highest in the locality of Ramnoborje in the region of Pehchevo (11,97 %). The mean values of the total volumetric shrinkage of wood from other ten localities are between these limits.

Total volumetric shrinkage of wood from white pine artificial stands (10,18 %) is lower for 14,95 % compared to the total volumetric shrinkage of wood from black pine artificial stands (11,97 %) in the locality of Ramnoborje in the region of Pehchevo.

Total volumetric wood shrinkage for fir and spruce from natural stands is 10,87 % and 10,90 %, respectively.

Total volumetric shrinkage of wood from Douglas fir is highest from the artificial stands in the locality of Vitachevo (10,70 %), lower in the locality of Gorici (10,20 %) and lowest in the locality of Ramnoborje (9,80 %).

Total volumetric shrinkage of wood from cupressus aphid, giant redwood, mountain pine and European larch, all raised as artificial stands is 10,90 %, 6,00 %, 9,60 % and 10,20 %, respectively.

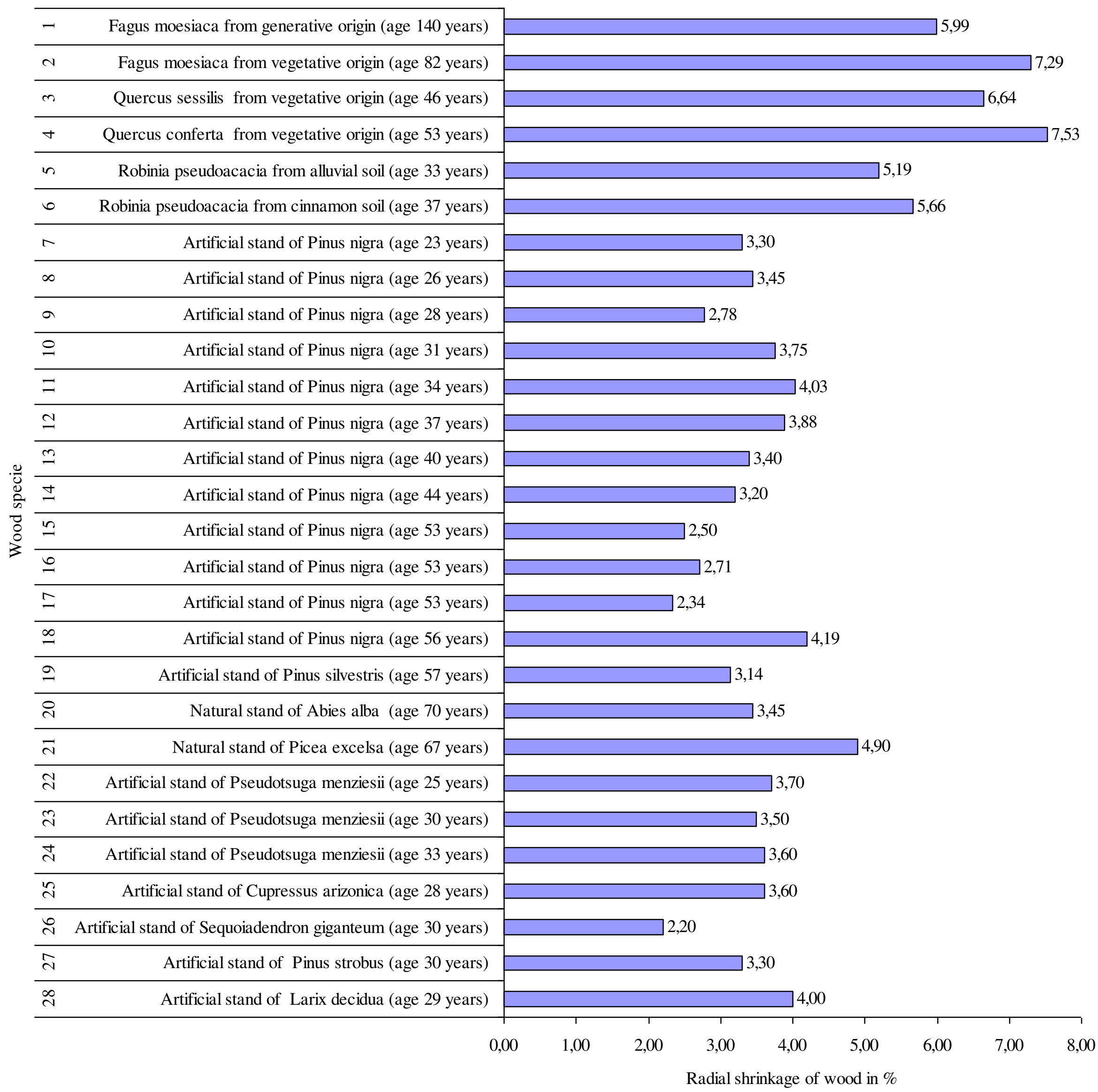

Figure 1. *Histogram for the radial shrinkage of wood*

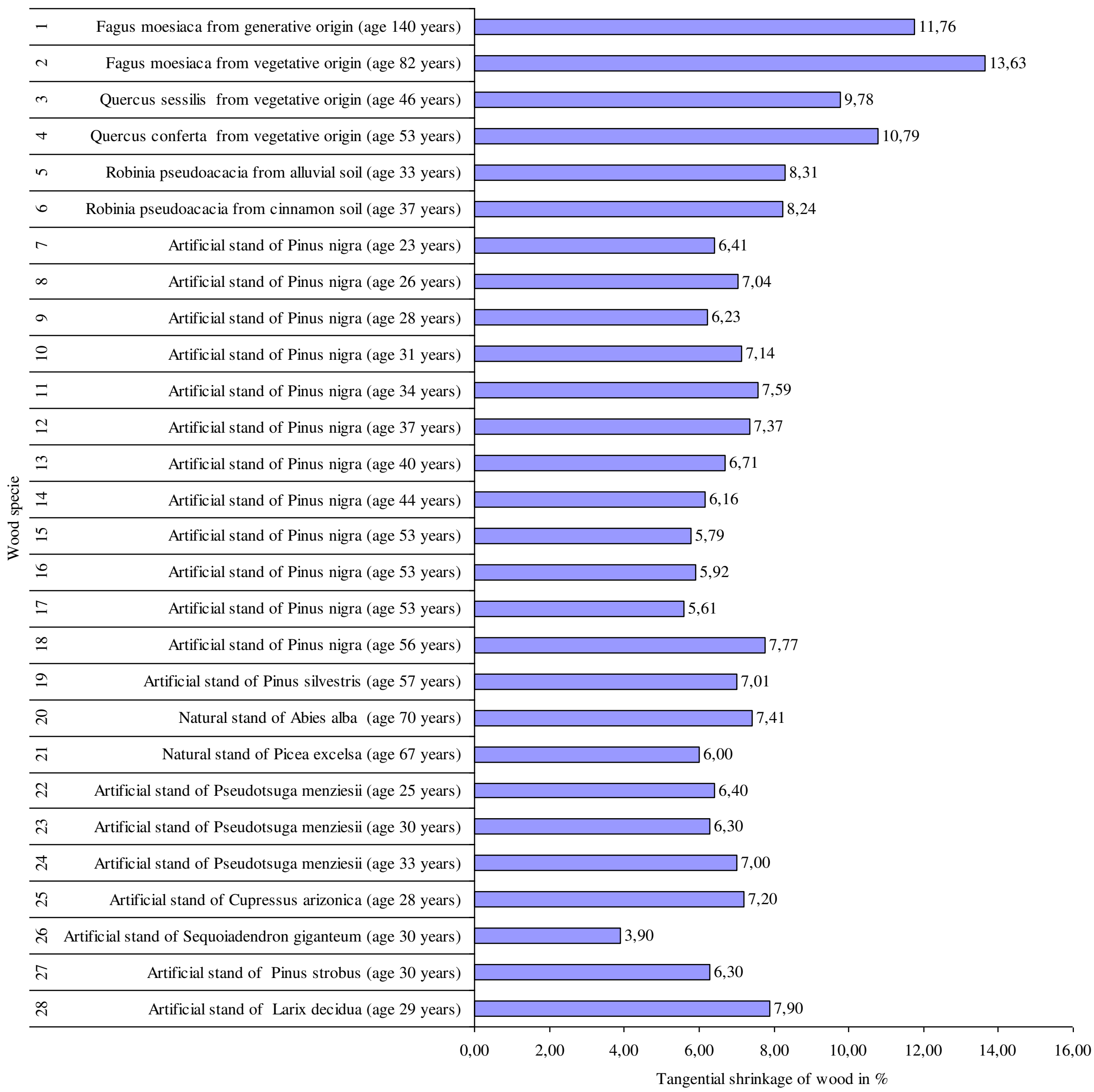

***Figure 2**. Histogram for the tangential shrinkage of wood*

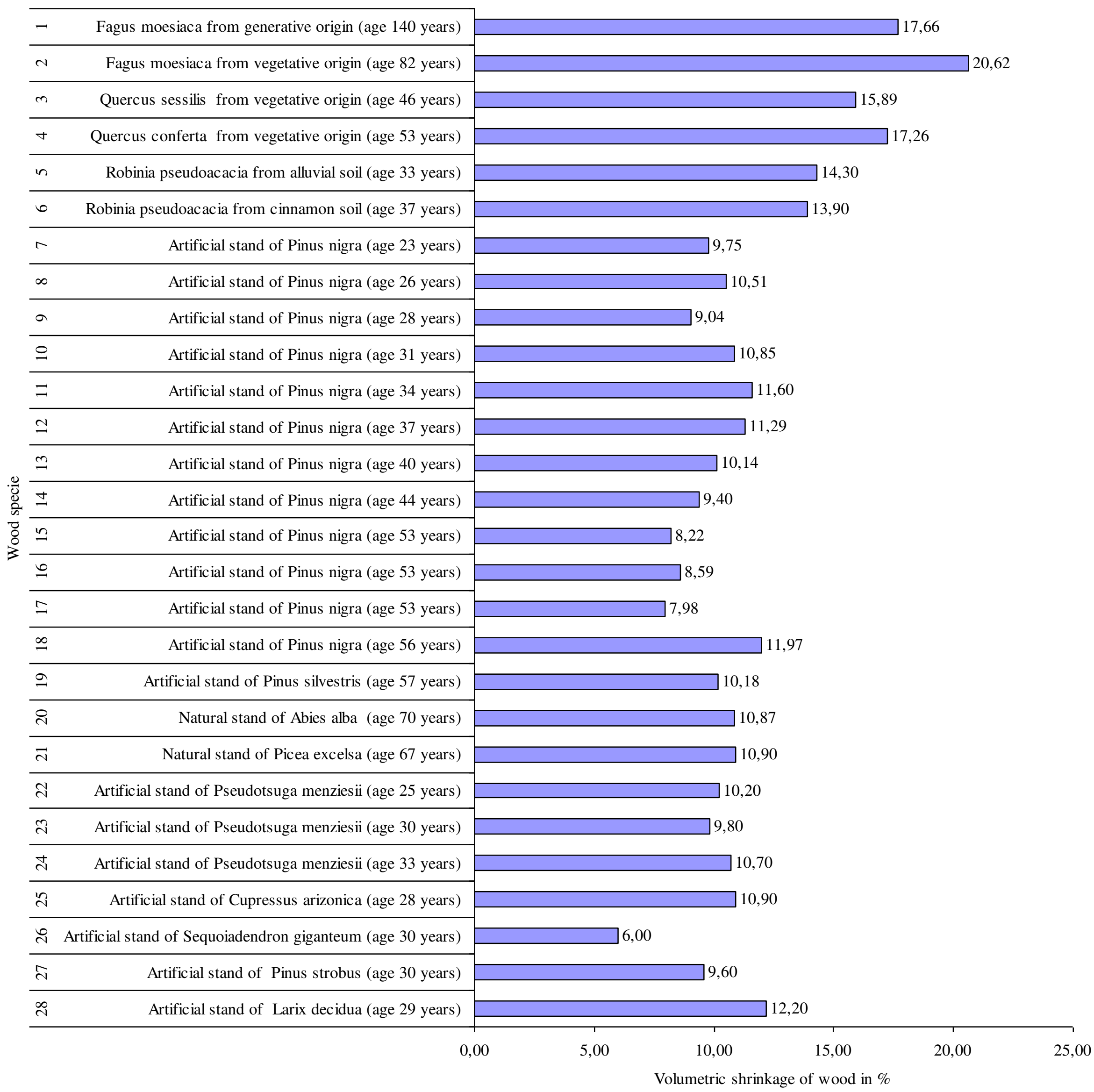

Figure 3. *Histogram for the volumetric shrinkage of wood*

4. CONCLUSIONS

On the basis of the research, following conclusions can be drawn:

- Among tested wood species, deciduous wood is characterized by higher shrinkage (radial, tangential and volumetric) compared to coniferous wood.
- Deciduous wood from vegetative origin shrinks more than the wood from generative origin within the same wood specie.
- The shrinkage of coniferous species that are raised with afforestation, with minor deviations increases by the wood aging from 23 to 58 years.
- Within the same wood species, the increment in density is followed by the increment in wood shrinkage which is a contribution to the previous conclusions.

Generally, the mean values of the wood shrinkage from tested autochthon and alochthon species in Republic of Macedonia are in the frame of the limitation values for the species systematized by Ugrenović, Horvat and Enchev. The stated quotations are confirmed by the research results presented on figures 1, 2 and 3 in the paper.

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COSTS OF OCCUPATIONAL ACCIDENTS IN THE BULGARIAN WOODWORKING AND FURNITURE INDUSTRY

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ABSTRACT

Despite the considerable improvements of working conditions in most of the European countries, the rate of occupational accidents has remained persistently high. These work-related injuries not only cause human suffering for workers and their families but also result in significant economic costs to individuals, businesses and society as a whole. Other potential negative effects include early retirements, loss of skilled personnel, increased productivity, medical, administrative and insurance costs. The net effect of occupational accidents represents a significant national economic loss. Depending on the country, the costs may vary from 1-4% of the gross domestic product. These enormous economic costs of occupational accidents inhibit the economic growth and affect the competitiveness of companies, particularly of micro, small and medium-sized enterprises.

An efficient way to convince both employers and decision-makers about the importance and profitability of improving the working conditions and the potential benefits of preventing work-related accidents is to determine their economic costs. In this respect, analysis and estimation of the costs of occupational accidents in the Bulgarian woodworking and furniture industry have been carried out on the basis of the officially published statistical data.

Key words: occupational accidents, health and safety at work, woodworking and furniture industry

1. INTRODUCTION

Despite the considerable improvements of working conditions in most of the European countries, the rate of occupational accidents has remained persistently high in the recent decades. According to the International Labour Organization (ILO), 2.34 million people lost their lives as a direct consequence of occupational accidents and/or illnesses. In addition, it was estimated that another 317 million people suffered from work-related injuries resulting in absence from work of four or more days. This represents an average of 850,000 injuries per day. The ILO has estimated that the direct and indirect costs of occupational accidents and diseases lead to about 4% loss of annual gross domestic product worldwide (ILO, 2011). At the European level, in 2014 there were approximately 3.2 million non-fatal accidents that resulted in at least four calendar days of absence from work and 3 739 fatal accidents in the EU countries (Eurostat, 2017). The number of occupational accidents is related to the respective economic sectors and the total number of persons employed. In terms of industries, there are several sectors, characterized by high levels of occupational risks, such as the construction, manufacturing, transportation and storage, forestry, woodworking and furniture industries, which account for more than two-thirds of all fatal accidents at work.

Small and medium-sized enterprises (SMEs) are particularly vulnerable to occupational risks as they have fewer resources to put complex systems for worker protection in place. On the other hand, the European woodworking and furniture industry is an economic sector, comprised mainly by SMEs and micro firms. This puts the workers and employees in these companies in a highly dangerous work environment.

The main health and safety risk factors include working with machinery and equipment (25% of all major accidents); fire and explosion; slips, trips and falls; exposure to wood dust and other hazardous substances; exposure to increased levels of noise and vibrations at work; manual handling operations, etc.

These work-related injuries not only cause human suffering for workers and their families but also result in significant economic costs to individuals, businesses and society as a whole. The improvement of work environment in woodworking and furniture enterprises is desirable not only from the perspective of workers, but also contributes significantly to labour productivity and promotes economic growth. The adoption of occupational safety and health practices increases the competitiveness and productivity of enterprises by reducing the costs resulting from occupational accidents and by enhancing workers' motivation. Moreover, a decrease in accidents and illness relieves pressure on public and private social protection and insurance systems.

An efficient way to convince both employers and decision-makers in the woodworking and furniture sector about the importance and profitability of improving the working conditions and the potential benefits of preventing work-related accidents is to determine their economic costs. In this respect, analysis and estimation of the costs of occupational accidents in the Bulgarian woodworking and furniture industry have been carried out on the basis of the officially published statistical data.

The main purpose of the present study is to estimate some of the indirect costs appeared due to accidents, respectively injuries at work in Bulgarian Furniture production and Production of wood products without furniture.

2. THEORETICAL FOUNDATIONS OF OCCUPATIONAL ACCIDENT COSTS AND THEIR MEASUREMENT

According to the official definition of the ILO, occupational accident is *"any unexpected and unplanned occurrence arising out of or in the course of work which results in one or more workers incurring a personal injury, disease or death"* (OECD, 2002). The so called commuting accidents, occurring on the direct way between the place of work and the worker's residence, the place where the worker usually takes his/her meals, or the place where the worker usually receives his/her remuneration, which result in death or personal injury involving loss of working time, are considered as occupational accidents.

According to the applicable Bulgarian legislation the term occupational accident includes any sudden health impairment occurring during and in relation with the course of work, as well as any work activity performed in the interest of the company which caused temporary incapacity for work, permanently reduced working capacity or death. When the injured person has intentionally harmed his/her health, it is not considered as an occupational accident. Pathological conditions due to diseases of any nature, such as epilepsy, chronic ischemic heart disease (all clinical forms, including myocardial infarction), stroke, diabetes mellitus, atherosclerosis, high blood pressure and mental illness are not considered as sudden health impairments and cannot be reported as occupational accidents.

The national methodology and guidance for studying and assessing the occupational traumatism is provided in the Statistical System Occupational Accidents, adopted in 2001, which includes all the aspects of determining and classifying the accidents at work. The national statistical system is developed on the basis of the European Statistics on Accidents at Work (ESAW) and ensures full compliance between the existing national legislation and the requirements for reporting work-related accidents in the EU countries. The ESAW was launched in 1990 in order to harmonize data on accidents at work for all accidents resulting in more than three days absence from work.

Occupational accident is defined in the ESAW methodology as *'a discrete occurrence during the course of work which leads to physical or mental harm"* (ESAW, 2001). The phrase 'in the course of work' means whilst engaged in an occupational activity or during the time spent at work. Fatal accidents at work are those that lead to the death of the victim within one year of the accident. Non-fatal accidents at work are those that imply at least four full calendar days of absence from work (also called 'serious accidents at work'). Non-fatal accidents at work often involve considerable harm for the workers and result in a considerable number of days of work being lost within the national economy.

As a minimum, three types of basic information are required to collect information about the accident:

- Information to identify where the accident occurred, who was injured and when - the economic activity of the employer; the victim's occupation, occupational status, sex, age and nationality; economic activity, location and size of the enterprise; time and date; working environment, respective workplace and the working process;
- Information to reveal how the accident occurred (the specific circumstances) - specific physical activity, deviation from normal working conditions, contact mode of injury, and their respective associated material agents;
- Information on the nature and seriousness of the injuries and the consequences of the accident - the body part injured, type of injury and number of days lost. Days lost means the number of calendar days during which the injured worker is unfit for work due to an occupational accident.

The economic costs of poor or inadequate health and safety at work are determined by the number of occupational accidents and the consequences associated with them. The costs of occupational accidents may be divided into two main categories (direct costs and indirect costs) and into the following five main types:

- Productivity costs: costs related to decreased production levels;
- Medical (healthcare) costs – the costs for providing medical care, hospitalization, rehabilitation, etc.;
- Administrative costs: costs of administration (e.g. reporting on a work-related accidents, applying for social security payments, etc.);
- Insurance costs: compensation and insurance payments;
- Quality of life losses: decreased life quality, such as physical pain and suffering

These types of costs are distributed among the following types of stakeholders: injured workers - the affected persons and their families who are impacted by the consequences of the work-related accidents (e.g. loss of income, direct and indirect medical costs, physical pain, etc.; employers - the respective company or organization for which the affected individual works (e.g. sick payments, production losses, damaged machinery and equipment, etc.; state authorities - the relevant public authorities (e.g. security payments, early retirement, temporary or constant disability, etc.); society - the overall impact of occupational accidents represented as output losses.

An important element in the distribution of costs among the different stakeholders is the classification of the employer costs. According to the ILO the direct and indirect costs follow exactly in this group (ILO, 2012). They claim that despite the disputable nature of direct costs and especially their concept these costs represent real payments. Some of them are mentioned above. The wages during the time of absence can also be classified as employer costs. In Bulgaria these costs affect employers in the first three days of absence from work and amount to 70% of the daily payments on an average basis. Other types of costs can be classified as costs of society (ILO, 2012; Lebeau, 2013) because their payments are responsibility to the National Social Security Institute. Payments to the health insurance fund and social securities during the time of absence from work also represent indirect costs to the Bulgarian employers.

The present study is focused exactly on some of indirect costs in employers like: costs for wages – taken into consideration only if the relevant information exists; social security and health insurance payments - made by the employers during the period of lost working days; loss of productivity - productivity per day lost due to the occupational accident and loss of turnover.

The methodic sequence is as follows:

- Description of the main statistical features of accidents, working days lost, number of employees etc.
- Estimation of the main factors during the research period for losing working days.
- Calculation of the amount of indirect costs and modelling the equation for this purpose.

There are many approaches to calculate these costs, but in the present study we used an equation, similar to the one, proposed by Javad Vatani (Vatani et al, 2016). They sum up the direct and indirect costs altogether and put them into an equation concerning the loss of turnover (Vatani et al, 2016). The following equation was used in the present study:

COI= CC + SsHiC + PrC , (1)

where COI is the abbreviation of Costs of Occupational Injuries;

CC - compensation costs during the first three days after the accident and the time of sick leave;

SsHiC – social security and health insurance costs;

PrC - loss of productivity.

Specifics appear in compensations for the first three days of employee absence. For this purpose we provide the following equation:

$$CC = \frac{0.7\ .\ (days\ lost\ due\ to\ accidendts).(number\ of\ accidents).3\ .(daily\ costs\ for wages\ and\ salaries)}{365} \quad (2)$$

The other parts of the equation (1) are as follows:

SsHiC = *(number of sick leaves per year)(average duration of a sick leave - 3) . 0.048 .(wages and salaries)* (3)

PrC = $(apparent\ daily\ labor\ productivity).(days\ lost\ due\ to\ accidents)$ (4)

The officially published statistical data on occupational accidents in the economic sectors "Manufacture of wood and of products of wood, except furniture" and "Manufacture of Furniture" for the period 2008 – 2014 have been used for the purpose of the present study.

3. RESULTS AND DISCUSSION

The woodworking and furniture industry in Bulgaria is one of the oldest and well established sectors of the national economy, creating about 3% of the gross domestic product, which accounts for about 10% of the volume of the industrial sector.

The total number of the registered companies in the woodworking and furniture sector is more than 4000. The vast majority of these companies (about 95%) are small and micro enterprises.

The sector "Manufacturing of wood and products of wood, except furniture" includes the following sub-sectors: sawmilling, planning and impregnation of wood, manufacture of veneer sheets and wood-based panels, manufacture of assembled parquet floors, manufacture of other builders' carpentry and joinery, manufacture of wooden containers, manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials.

The sector "Manufacture of furniture" comprises the following sub-sectors: manufacture of office and shop furniture, manufacture of kitchen furniture, manufacture of mattresses, manufacture of other furniture.

The number of accidents at work in both industries for the studied period 2008-2014 is presented on Figure 1.

Figure 1. *Number of occupational accidents in the studied sectors of the Bulgarian economy*

The number of occupational accidents during the period 2008-2009 in both economic sectors tends to decrease as a direct consequence of the global economic crisis and recession. After that year the number of occupational accidents in the furniture industry sectors was increased. It was not a stable process, but it stayed on the trend of almost 6% on average basis. On the contrary, the accidents at work in the woodworking industry decreased over the studied period with some small fluctuations. Through additional analysis we reveal that in both industries factors that influence the number of accidents do not depend on number of employees or working hours. It can be concluded that working discipline and investments in new machinery/equipment and the adoption of adequate health and safety measures are crucial to the number of accidents.

The analysis of the indices number of employees and number of lost days (see Figure 2) reveals that the number of employed people in both sectors constantly increased, while the days lost due to occupational accidents have their own distribution. In our opinion the random nature and discrete occurrence of work-related accidents is one of the main impacting factors.

Figure 2. *Indexes of number of employees and lost days due to accidents,*
a) Woodworking, b) Production of furniture, 2008=1

The estimation of the costs, presented in equations (1-4), is illustrated on Figure 3.

Figure 3. *COI for the two investigated sectors*

The presented data show that sector Manufacture of Furniture is characterized by an upward trend, unlike the sector of woodworking which has a negative increment. The average index of improvement of COI in furniture production is almost 17% for the period after 2009. At the same time woodworking has a negative index – almost – 2%, but much higher deviation. It can be concluded that the situation in both sectors is not the desired one. Reasons for these processes are following:

- In the Manufacture of Furniture all types of costs have a positive increment: CC-23%, SsHiC – 13% and PrC - 16%. (see Figure 4).

-

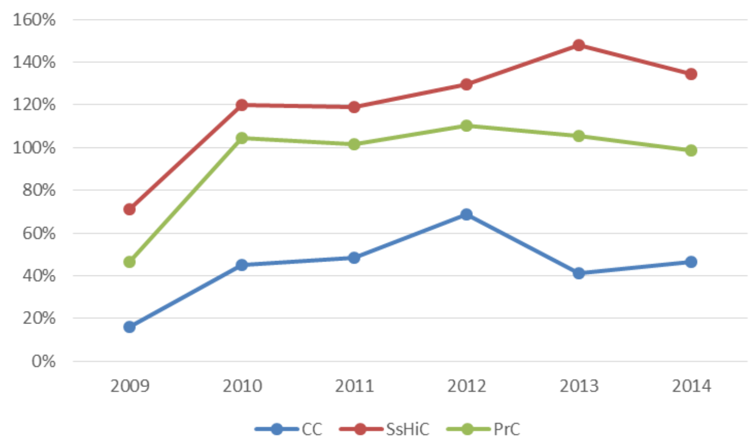

Figure 4. *Indices of COI elements in the furniture sector*

Woodworking sector has only one increasing type of costs, namely SsiH – 3.8%. The other costs decreased from about 10% to 13 % (see Figure 5).

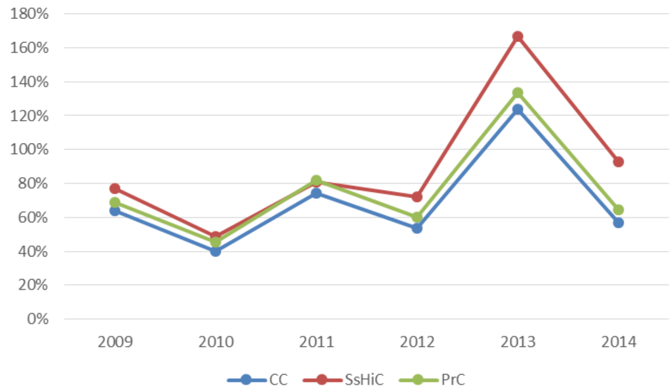

Figure 5. *Indices of COI elements in woodworking*

4. CONCLUSIONS

The promotion and adoption of healthy and safe working environment contributes significantly to labour productivity and promotes economic growth, competitiveness and welfare of enterprises. It is vital that employers and policy-makers have an idea about the magnitude of the problem in order to enhance their efforts for improving the working conditions.

The establishment of an accurate assessment of the cost of occupational accidents at a sectoral level is a complex task. A thorough study should, when possible, include all types of costs and stakeholders, with costs calculated for each. The number of occupational accidents should be drawn from the existing statistical data while acknowledging the possibility for underreporting of work-relatedness, especially in case if minor injuries. However, these accidents could carry significant costs.

In woodworking the duration of sick leaves increases which consequently increases the amount of the SsHiC. Additional investments in occupational safety and health (OSH) education and training are required. In the Manufacture of Furniture the level of investments in health and safety measures remains the main reason for work-related accidents. In woodworking the investments in machinery are on average 98 EUR per euro COI, and in the Manufacture of Furniture - 74 EUR per euro COI. We can recommend investments in both new machinery and adequate OSH training to be increased and deviation coefficients to be diminished, especially regarding the sector of woodworking, where this coefficient has the value of 40% after the 2010.

Investing in the adoption of proper OSH measures clearly has major implications for companies but also for governments, social security institutions, and the society as a whole. Thus all stakeholders need to be committed to constantly invest in OSH, accepting it as the core component of good management and performance rather than a burden on their businesses.

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APPLYING THE IGES GRAPHICS FORMAT FOR CONNECTING CAD/CAM SYSTEMS

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ABSTRACT

Very important parts of a CAD/CAM system for wood processing are the methods and procedures for connecting designprocess and manufacturing process. For that purpose, we developed a CNC editor for creating NC part programs using a CAD system for defining the workpiece geometry. The main possibilities of the CNC editor are to generate NC part program from an IGES file, make presentation of the tool path and transfer the NC part program to the NC unit of the machine. The software was developed using Microsoft Visual Basic programming language.

Key words: CAD/CAM system, numerical control, wood processing, IGES, NC part program

1. INTRODUCTION

Flexible technology today presents the leading manufacturing the technology. Numerical control is one of these flexible methods for automation of production processes. It is used in small series production, as well as single series production.

Very important parts of that manufacturing system are the procedures and methods for programming numerical control machines. In general, these methods can be manual, automatic and methods for NC programming with support of CAD systems. This paper describes some experience during creating software for NC programming using CAD systems or some other applications for graphics design.

2. BASIC PHASES FOR CREATING NC PART PROGRAM

Three main phases can be determined during creating of NC programs:

- geometry modeling,
- NC part program generation,
- graphic simulation and testing of the NC program.

The chart on Fig.1 presents the sequential flow of the procedures, as well as their mutual connection.

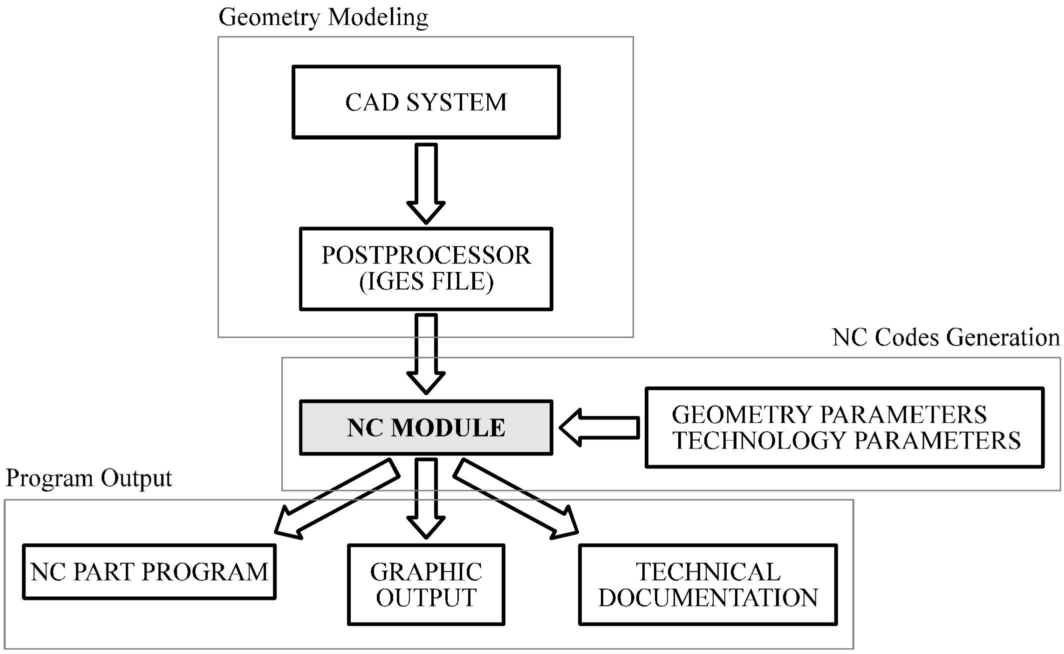

Figure 1. *Process of developing NC part program - main phases*

The procedure for geometry modeling realizes the NC programmer, using the CAD system, or any other program package for graphic design, which has the possibility for IGES file generation. This IGES file (Initial Graphics Exchange Specification) is output from this stage. It contains all the geometry characteristics of the designed object (workpiece).

The next step for the programmer is to put the generated IGES file in to the main program, called CNC-EDITOR. This program will generate the NC codes, test the NC part program using graphic presentation of the tool path and transfer the NC part program to the numerical control unit. As an additional option, the programmer can produce the technology documentation and print the NC part program listing.

2.1. Defining geometry and technology parameters

As it is shown on the flowchart on Fig.1, the transformation process from IGES file to NC part program is executed in several steps.

The first step for the programmer is to select geometry and technology parameters. This can be done by opening the appropriate windows, using the main menu (Fig.4).

Selection of geometry parameters includes defining coordinate system, measuring unit, working plane.

When the programmer open the technology parameters window (fig.2), he need to define the following process characteristics:

- material used for the workpiece,
- material that the tool is made of,
- number of the tool,
- tool diameter,
- spindle speed,
- cutting speed,
- power unit parameters,
- surface quality,
- workpiece feed speed.

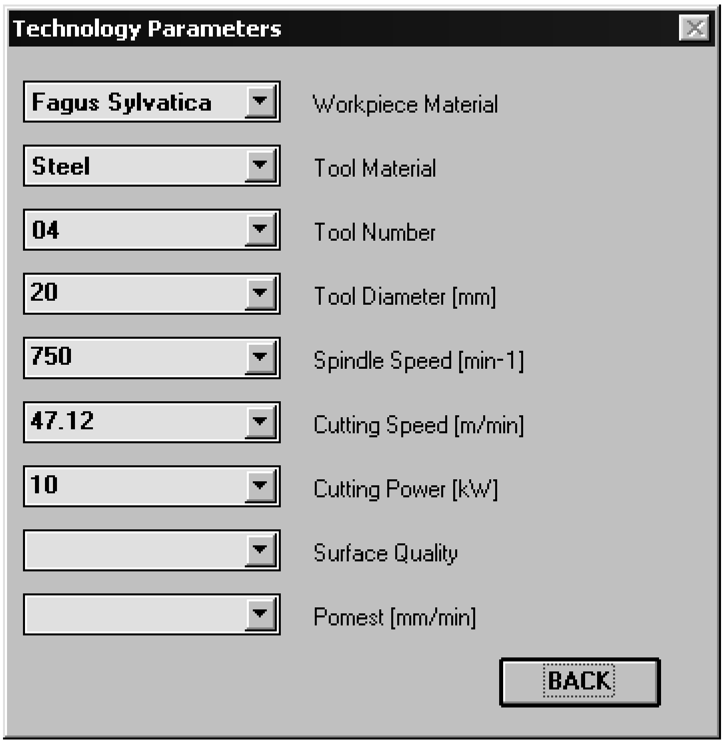

Figure 2. *Technology parameters window*

For most of these characteristics, the program suggests the programmer some default values, that he can accept or change.

2.2. NC Codes generation

The next step is executing of the procedure shown on Fig.2. The algorithm reads the first sentence from the parameter section of the IGES file. The first data of that sentence defines the type of entity. This value determines the meaning of the other data from the sentence that actually present the coordinates of the entity. There are two main types of entities in the algorithm for 2-dimensional modeling:

- line (typical number of entity 110),
- arc (typical number of entity 100).

Using these two basic types of entities makes it possible to cover almost all different cases of 2D geometry modeling. We even recommended for programmers to approximate circular interpolation with linear interpolation.

The sentence from the IGES file that determines line, besides typical number of entity, contains 6 other numerical values that define the X, Y and Z coordinates of the start and the end point of the line.

The arc in the IGES specification always is determined by three points - arc center, start point and end point. This tells us that the IGES sentence defining arc contains eight values. The first value is always equal 100 (typical number of entity - arc), the second is entity elevation according to Z-axis. The third and fourth value define the X and Y coordinates of the arc center, fifth and sixth value define X and Y coordinates of the start point, seventh and eighth value define X and Y coordinates of the end point.

When the coordinates are identified, the program creates the NC code. For every sentence from the IGES file, adequate NC sentence is put in the NC part program. This NC code defines the movement of the tool and determines the tool path.

At the end, when all the data from the IGES file are been read, the program automatically writes to the NC part program the final NC codes and closes it.

Now, the first version of the NC part program is ready for the programmer to review it, make corrections and interventions. The software offers possibility for changing instructions, inserting new lines and erasing lines.

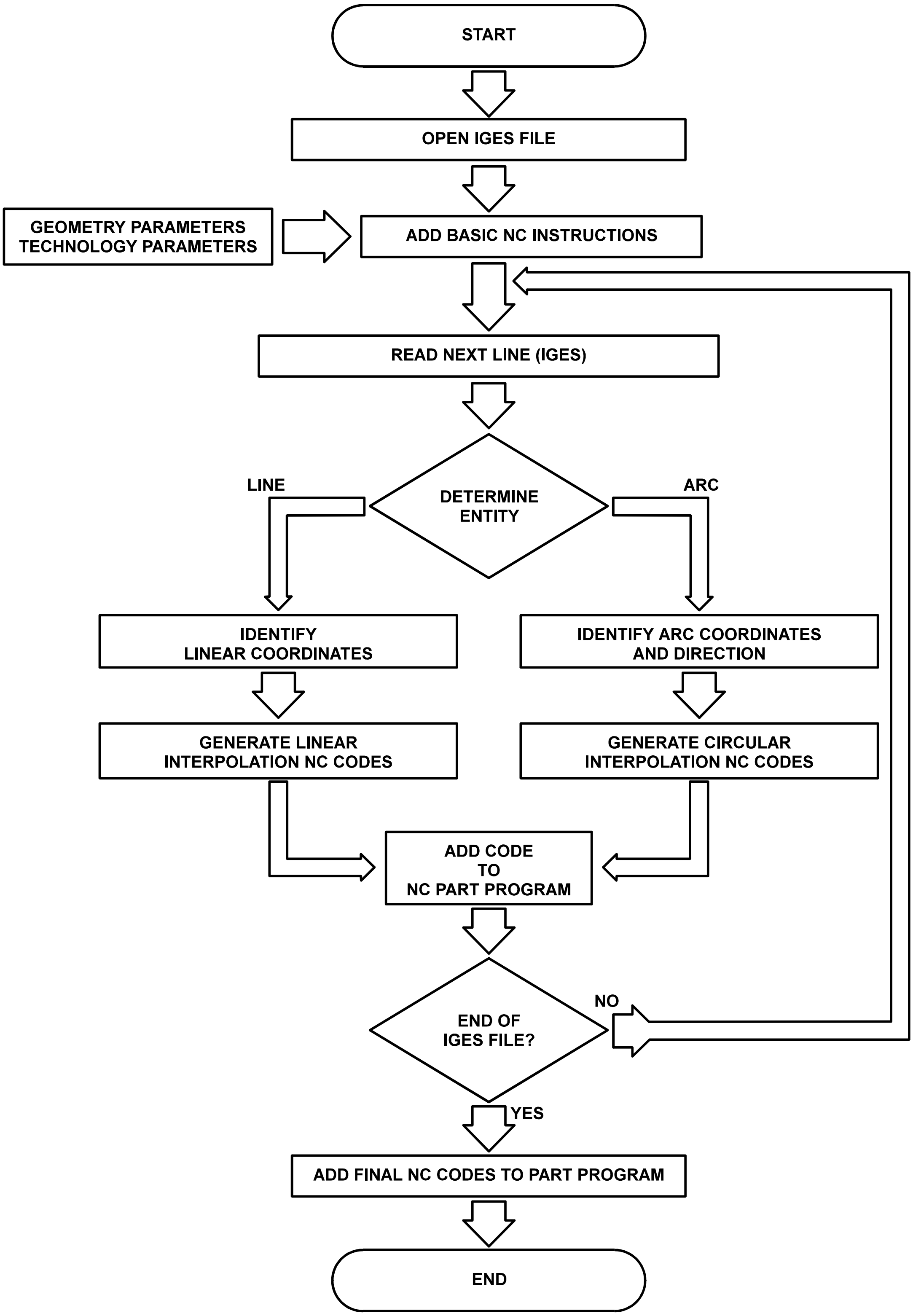

Figure 3. *Procedure for NC codes generation*

2.3. Graphic presentation and testing

The last step of the transforming process from IGES file to NC part program is testing the NC codes. In this final phase, the programmer makes graphic presentation of the tool movements, on the basis of the generated NC part program.

If the NC part program needs any interventions after the graphic simulation, the programmer returns to the second stage, where he makes corrections to geometric and technology parameters. Then, he tests again the new NC code. He can do this procedure as many times as he needs.

Finally, when the NC part program satisfies all the criteria and requirements, it can be transferred to the NC unit of the machine.

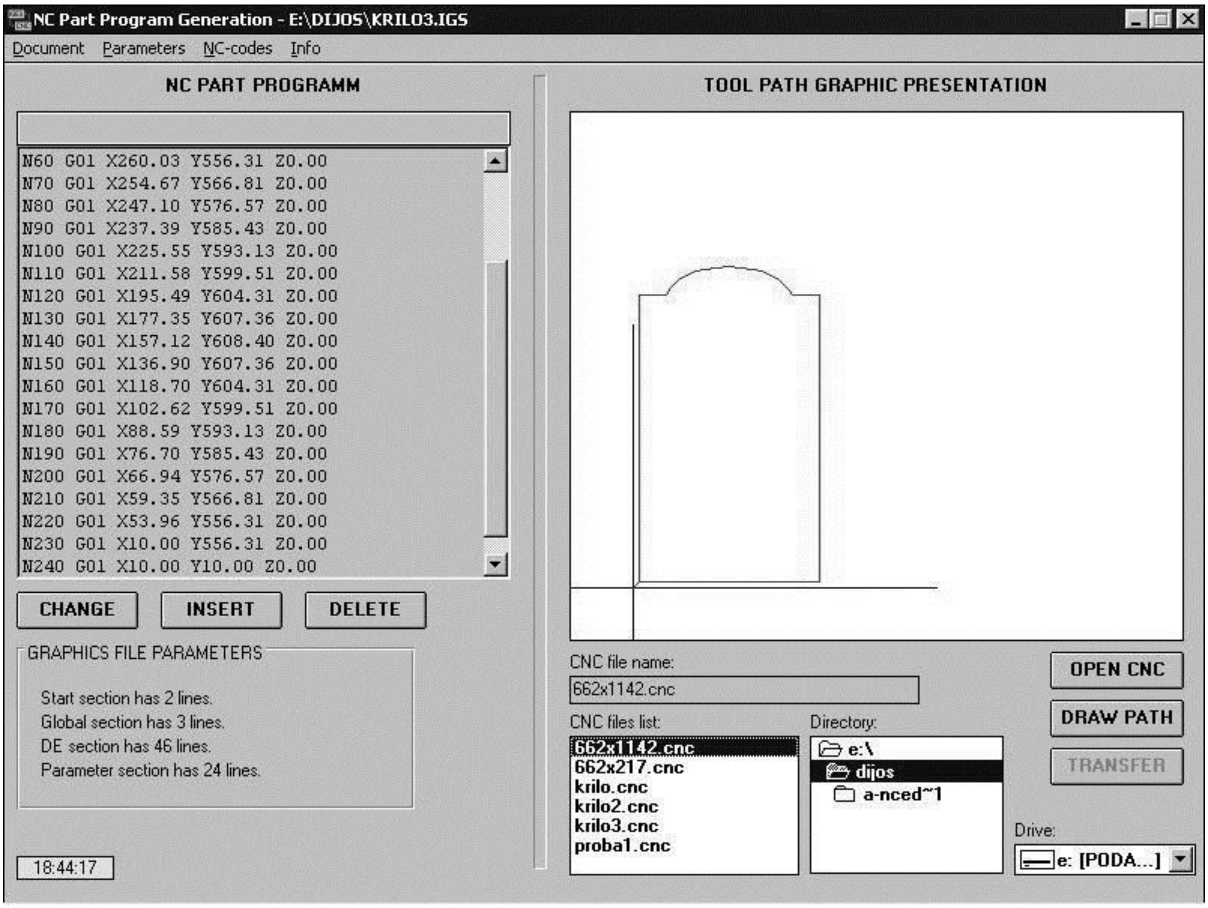

Figure 4. *Software for NC part program generation - main window*

3. CONCLUSIONS

In our research, we managed to create a module for connecting design process with the process of wood processing. For the design process, as a CAD system, we used AutoCAD Release12 package. There we created IGES files, which contain geometry characteristics of the processed object. We put this IGES file in the CNC-Editor that we created and transformed it into a NC part program. We also developed a procedure for graphic presentation of the tool movement, corresponding to the generated NC part program.

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INFLUENCE OF ROUGHNESS OF WOOD ON ADHESION OF POLYURETHANE WOOD FINISH

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ABSTRACT

Surface properties of wood condition direct its application in many areas. The surface roughness depends on the factors that can be controlled through the way and regime of processing and also by factors that can be controlled. According to the anatomical wood structure there are several types of roughness.

For the surface treatment process, the most important operation is grinding, since the surface, prepared at that stage of treatment, is immediately processed by liquid and solid materials.

The aim of the study of this paper is to establish the dependence between the roughness of the massive tree wood surface, formed in various surface preparation types, and adhesion of the polyurethane colorless lacquer.

Key words: roughness, processing, grinding, adhesion

1. INTRODUCTION

Surface properties of wood such as color, texture, unevenness, they all condition its application in many fields. Color and texture can be controlled by selecting kind of wood and its cross-section (radial, tangential and transversal). Surface unevenness (roughness) is determined by factors which can be controlled - by a *processing method, processing mode*, *tools* and some factors related to a workpiece, such as moisture content and fiber *direction*, as well as by factors which cannot be controlled, such as *wood structure*.

Surface unevenness is described as emboss, roughness or unevenness of border surface between material and surrounding area [1]. For porous materials, such as wood, it is hard to define surface and hence the surface unevenness (roughness). In this case, surface can be considered as a combination of several surface roughness modes. First degree roughness is determined by anatomical wood structure; second degree roughness is processing method characteristic (controlled factors) and third degree roughness is a consequence of variations in some processing method, such as uncontrolled machine vibrations, damaged tools, variations in wood density, reaction wood and extracts [2].

Suchsland [3] groups roughness according to anatomical structure of wood:

- Submicroscopic roughness (texture of microfibrils bundle)
- Microscopic roughness (cell size, tracheids)
- Technical roughness (growth ring structure)

For surface processing, the most significant operation of wood mechanical processing is sanding since the fact that the surface prepared in this phase is immediately finished with liquid and solid materials and directly affects the quality of processed surface. Measurement, i.e. control of roughness in some phases of mechanical wood processing is significant for:

- Surface processing and adhesive technologies regarding influence of roughness on adhesion, i.e. bond strength;
- Camber calculation;
- Tool sharpness control, considering established relation between surface roughness and blade bluntness [1].

According to Potrebić [4] it is required to make surface smooth because:

- Smooth surface provides regular reflexion;
- Smooth background reduces coating unevenness, which further reduces coating thickness, i.e. coting consumption;
- Wood surface is cleaned from impurities which collected during works.

At surface wood processing, roughness affects the following:

- Absorption and dispersion of liquid materials;
- Gloss of lacquered surfaces;
- Adhesive power of coating:
- Material consumption

2. AIM

The aim of this study was to establish dependence between surface roughness of massive oak tree as a result of various conditions of surface processing and adhesion of colorless polyurethane wood lacquer. Namely, influence of sanding belt numbering and order in application of different numbering during sanding on the finish adhesion, precisely, adhesive power indicated as resistance to tearing perpendicular to surface.

3. PREVIOUS STUDIES

Multiple importance of roughness, taking over definitions and roughness classification, as well as methods for determining it in the field of metal processing, and then influence of some factors in the surface preparation process, they all conditioned numerous studies in the field of wood and wood panel roughness.

Since there are no specially established roughness parameters and measurement methods, but those are taken from metal processing, there is a series of studies investigating possibilities of their application on wood surface [4, 5, 6, 7, 8 , 9, 10, 11, 12]. In this way, it is established that surface profile amplitude parameters in M system: *R max* – the biggest roughness height (in German literature *Rauhtiefe*), *Ra* – average arithmetic profile distance (in the English literature marked as *CLA – center line average*) and $R_{z(ISO,DIN)}$ – average roughness height ($Rz_{(DIN)} = Rt$) meet wood surface roughness qualification requirements. However, at the same time, due to specific wood structure it is not enough to specify only one parameter. Except for these parameters for evaluation of wood roughness, there are also parameters in the literature: "*level depth*" or "*smoothness depth*" *Ru* (Glättungsitiefe) as a distance between the profile center line and upper line; RMS (root mean square) as a geometric mean value for profile deviation in relation to the profile center line: roughness factor *R* as a relation of actual and geometric surface. Moreover, a pneumatic measurement method is sometimes, but rarely used to obtain roughness volume (*RV*) and roughness depth (*RD*).

Among numerous direct and indirect roughness measurement methods, at present, almost only a contact method is applied, with advantages to eliminate subjectivity, to simply and quick acquire numerical data and graphs, and with disadvantages to evaluate only narrow surface lines. Since cell width varies among wood kinds, as well as among early and late wood, a contact needle diameter of at least 1/64 inches [5] is recommended to overcome such variety of anatomical wood structure.

Studies regarding wood surface roughness and sanding with different numbering of sandpaper can be roughly assigned into two groups. The first group includes studies dealing with establishing roughness without establishing optimum values. The second group includes studies dealing with influence of different roughness on some properties of processed surface.

Potrebić [13] and Janković [14] establish surface roughness after sanding with sandpapers numbering from 24 to 200 which falls with curvilinear trend in hyperbolic shape with increasing numbering. In addition to this, Potrebić established a relation between some roughness parameters

Rmax (by light section method), *Rmax*, *Rz* and *Ra* measured in steam beech. Jirouš-Rajković [9] established surface roughness after sanding of samples veneered with beech and oak veneer with different combination of sandpaper with sharp and blunted sandpaper with and without moistening. In this case, quality of processed surface is identified with sanding fineness, i.e. with smallest level of roughness. With such assumption, the most quality surface is obtained by sanding with moistening. In addition to this, the same combinations of sandpaper numbering do not yield the same sanding quality on beech and oak veneer, which further refers to specificity of anatomic structure of oak, i.e. to significant roughness structure. Potrebić [15] further established cut veneer surface roughness on which bases it can be concluded about considerable influence of the wood type, i.e. anatomic structure, participation of growth rings and participation of lines in some growth ring areas.

Pahlitzsch [16] reports results from some researchers which studied influence of sanding grain on amount of sanding waste and established increase of sanding waste with increase of grain and this proved as linear in most researchers. Pahlitzsch also reports dependence of surface quality on sanding time, pressure, cutting speed and sanding coating (grain). In most researchers, roughness remains constant with sanding time which is explained by reduction of sanding coating consumption influence in smaller diameter of sanding grains which were applied in these experiments and which is probably a consequence of stronger influence of wood structure. According to results by that time, roughness did not depend on pressure, and differences in study results were conditioned by roughness measurement methods. Roughness did not either depend on the cutting speed. Hence, grain size has decisive influence on surface roughness, i.e. on quality, which growth conditions slight non-linear roughness increase.

Particularly significant analysis in the area of wood surface roughness are studies form the aforementioned second group. These studies evaluate surface quality through properties of some surface, and not only through sanding fineness which is not necessarily a guarantee for high level of other properties. Except for influence of adhesion, we should mention other studies reporting influence of roughness on wood gloss which could later, but to a small degree, further influence on gloss of surface coated with colorless lacquer [17] and influence of roughness on dispersion of NC lacquer finish, where dispersion increases to some level with increase of roughness [18].

Influence of roughness on bond adhesion, i.e. on bond strength has been established through shearing force [2, 3]. In these studies, roughness was identified by roughness factor (R = Ar/Ag), particularly area of early and late wood on microtome cut samples. The results were also in terms of surface processing for they imply correspondence with behavior of coated materials of wood surface.

Bond strength of tangentially pasted surfaces of pine increases with roughness factor growth on the basis of simultaneous increase of actual adhesion surface between bond material and wood to a point where simultaneous decrease of wood strength causes wood tearing. Bond strength of the flat wood is greater than bond strength of late wood, which can be explained by increased adhesion surface, while difference in elasticity model and ability of shape change in early and late wood [3] is secondary. Laterally and frontally bonded samples of Douglas fir show that bonds in only early wood achieve strength of massive late wood, while bonds of only late wood achieve only 15% of massive late wood strength. In combined bonds, strength is determined by early week wood which can be explained by the fact that adhesion of the bond material is insufficient in late wood; that cohesion of bond material is insufficient to transfer stresses between surfaces; or both [2].

These results are in accordance with comments and results of studied conducted by E.G. Shur et al [19]. Basic wood features influencing on processed surface quality of conifers (Douglas fir) in outdoor use are primarily share and way of late wood area distribution, and then contrast between early and late wood, extract contents, moisture contents and faults such as nodes and raisin pockets. In this case, coating shows poor properties, namely, short duration on wood with wide stripes of late wood and almost complete loss of adhesion on late wood areas. On wood with narrow stripes, coating also proved as poor with expressed cracks, but with relatively small loss of adhesion. The best wood for processing is wood with a small number of narrow areas of late wood.

Study results of bonding also correspond to results of microscopic views of cracks occurring in wood without and with coating exposed to weather in weather meter [20]. The cracks are microcracks and they are found in cell walls and between walls of adjacent cells. Coating slows down development of cracks. Cracks through topped pores in radial walls of early wood more likely occur than in late wood. This provides explanation for more frequent damage of lacquer finish on early wood on radial surfaces (scots pine and thuja). Cracks in cell walls and between walls of adjacent cells of late wood, but not of early wood, offer explanation for early delamination of coating from tangential surfaces of late wood in comparison to tangential surfaces of early wood.

Influence of surface roughness, i.e. sanding of beech samples with different combinations of sandpaper numbering on nitrocellulose lacquer adhesion was investigated by Riđić [21]. Roughness was identified with parameters *Ry*, *Rtm*, *R3z* and *Ra*, and adhesion for each parameter with tearing force perpendicular to surface. This study showed that there is influence of roughness on adhesion, that results differ for foundation lacquer layer, finish lacquer layer applied separately and two layers of foundation lacquer. Influence also differs in relation to some parameters, and the author comments that it cannot be concluded about nature of influence of roughness on adhesion.

4. MATERIAL AND METHODS

Massive oak wood samples, dimensions 80x200x10 mm, processed by sanding with vibrational sanding machine, with sandpaper of different numbering combination, according to a pattern from Table 1. Selection of sandpaper numbering combination was made according to usual combinations in practice for two-stage and three-stage sanding.

Table 1. *Used sandpaper numbering*

Combination of numbering	I	II	III	IV	V	VI	VII
Sandpaper numbering	80	80-120	80-120-150	100	100-150	100-150-180	100-150-200

Roughness measurement was done with contact method by an instrument *Form Talysurf* (*Taylor-Hobson*), and the result is presented with parameters *Ry*, *Rmax*, *Rtm* according to ISO 468. A contact needle is a diamond needle shaped like pyramid truncated at 90° with top dimensions 1.3µm x 3.8µm and a curve radius of 0.002 µm. The pressure thrust is 0.7-1 mN. Pick-up is a laser one.

One layer of polyurethane colorless universal lacquer is applied, 32.29 ± 3.72 µm thick (t arrangement, α=0.05). After drying in the air for 28 days, adhesion was measured by stamping method at three locations on each plate. A stamp, with diameter of 20 mm, i.e. area of 314 mm^2 is pasted with epoxy glue onto the lacquer surface for 48 h. After this time, tearing perpendicular to surface was performed on *Tira test 2300* tearing machine. The result of tearing is a force causing break and visually evaluated view of the break.

5. RESULTS

Measurement results for roughness with parameters *Rmax*, *Ra* and *Rtm* are presented in Table 2.

Table 2. *Influence of sandpaper numbering combination on roughness and adhesion of PU lacquer*

Group	R max (µm)	σ	Ra (µm)	σ	Rtm (µm)	σ	F (N/mm^2)	σ
I	93.37	49.54	8.55	3.93	44.54	19.43	4.09	0.34
II	48.16	30.87	5.25	2.24	28.32	15.22	3.98	1.36
III	74.59	66.24	5.02	2.78	26.70	15.98	3.69	0.93
IV	50.72	23.66	5.43	1.64	31.56	11.12	3.96	1.09
V	48.48	20.77	5.17	1.86	29.84	8.95	4.06	0.85
VI	49.68	23.21	4.41	2.13	25.40	10.82	3.08	0.80
VII	46.61	23.40	4.02	1.09	23.31	7.39	2.61	0.68

As expected, results do not show the same trend, first due to definitions of parameters themselves, and second due to oak structure characteristics. As presented results for *Rmax* (=*Ry*) present the biggest height of roughness on the observed length, regarding anatomic structure of oak tree, there are no irregularities in value change between some sanding groups. Large distribution of values around mean X in some groups tells about both *Rmax* as roughness parameter and roughness as a foundation. *Ra* value, which represents balanced profile value, also shows a high level of value distributionin some sanding groups.

Influence of roughness, i.e. sanding paper numbering in given combinations is presented in Table 2. A measure of adhesion is a tearing force given as unit force per unit area, i.e. as tension stress.

Results for parameters *Ra* and *Rt* are in accordance for sanding groups, I, VI and VII, while for other groups the trend is not the same. It is reasonable considering small differences in values, and also distribution of individual values which in *Rm* depends both on distribution around average value for the group and distribution of values *Rt1* to *Rt5* for each *Rtm* which is their average value. Roughness has influence on coating adhesion. There is trend analogy only in groups I, VI and VII. Roughly estimated, this means that value of adhesion expressed in tearing force perpendicular to surface decreases with reduction of roughness, i.e. with increase of sanding fineness which is in accordance with previous analyses [2, 18]. There cannot be noticed any law between groups II to V, which is a result of two causes. First, foundation, i.e. oak tree, has considerable influence where a wide span in vessel width conditions dominance of structural roughness above the selected one, which was also established as a problem in previous analyses [9]. Second, relation of adhesion with roughness parameters is not harmonized and due to differences between parameters themselves *Ra*, *Rt* and *Rmax* in groups II to V. This means that significant influence of roughness on adhesion on oak tree can be seen only in very roughly and very finely processed surfaces.

A view of the break shows that tearing mostly occurred in a layer between the lacquer and wood, i.e. that the break is an adhesion one. A break which was not adhesion, happened in all cases in a wood layer, or more precisely in an area of early wood. A term "mostly" refers to participation of late wood on the samples. An explanation of such situation can be found in strength and adhesion properties of early and late wood [2, 18, 19, 20].

6. CONCLUSION

From this study, the following conclusions can be made:

- Roughness conditioned by different preparation of foundation, i.e. sanding, affects coating adhesion (polyurethane, colorless). Roughly speaking, adhesion expressed by the tearing force perpendicular to surface increases with surface roughness increase.
- Foundation is crucial. In foundations such as oak tree with wide vessels and large variations in vessel diameters, structural roughness is dominant in relation to processed.
- Roughness parameters *Ra*, *Rt* and *Rmax* do not always present the same trend considering processing method, particularly in foundations with expressed structural roughness. Inconsistency of results, i.e. influence of structural roughness in oak tree can be noticed during processes in which the last applied sandpaper numbering were 100, 120 and 150. Within the same scope, it cannot be concluded about the adhesion trend with the statistical significance. For processing with the last applied sandpaper numbering 80, 180 and 200, the results are in accordance with roughness parameters trend.
- Within the same foundation, early and late wood area have significant influence on adhesion of coating. In the area of late wood, adhesion break occurs, and in the area of early wood, break occurs in the wood. According to previous analyses in this field, longer durability in the area of early wood on tangential surfaces is expected.
- Fineness of processing in surface preparation phase, i.e. sanding fineness and low roughness achieved during this, are not always a guarantee of surface quality. As processed surface quality include usable properties of area and durability, influence of surface preparation should also be observed through those factors, and only through a low level of roughness.

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