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Computation of Temperature Conductivity of Frozen Wood during its Defrosting

Računanje toplinske vodljivosti smrznutog drva tijekom postupka odmrzavanja

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ABSTRACT • *An approach for the computation of the temperature conductivity of frozen wood during its defrosting has been suggested. The approach takes into account the physics of the processes of melting of both the frozen bound and free water in the wood in respective temperature ranges. It reflects for the first time also the influence of the fiber saturation point and of the volume shrinkage of each wood species on its temperature conductivity coefficient in frozen state.*
In the present paper, the suggested approach for the computation of the temperature conductivity of poplar, spruce, beech, oak, walnut and acacia in the temperature range between −60 °C and −1 °C is used. It is determined that the temperature conductivity of wood, during melting of frozen bound water in it, is up to some tens of times larger than the temperature conductivity of wood during melting of frozen free water in it.
The obtained results can be used both for technological and other engineering calculations and analysis of processes of thermal and hydrothermal treatment of wood materials, as well as in software of systems for model based automatic control of such treatment.

Key words: *temperature conductivity, frozen wood, frozen bound water, frozen free water, computation*

SAŽETAK • *U radu se daje preporuka za izračunavanje toplinske vodljivosti smrznutog drva tijekom procesa odmrzavanja. U pristupu se uzima u obzir fizika procesa topljenja smrznute vezane i slobodne vode u drvu u odgovarajućim temperaturnim rasponima. Predloženim se pristupom po prvi put uzima u obzir utjecaj točke zasićenosti vlakanaca i volumnog utezanja svake vrste drva na njezin koeficijent vodljivosti topline u smrznutom stanju.*
U radu se predlaže pristup za izračunavanje toplinske vodljivosti drva topole, smreke, bukve, hrasta, oraha i bagrema u temperaturnom rasponu između –60 °C i –1 °C. Utvrđeno je da je toplinska vodljivost drva tijekom topljenja smrznute vezane vode u drvu do nekoliko desetaka puta veća od toplinske vodljivosti drva tijekom topljenja smrznute slobodne vode u njemu.
Dobiveni se rezultati mogu upotrijebiti za tehnološke i druge inženjerske proračune i analize procesa toplinske i hidrotermičke obrade drvnog materijala, kao i pri izradi softvera za sustave automatskog upravljanja tim procesima.

Ključne riječi: *toplinska vodljivost, smrznuto drvo, smrznuta vezana voda, smrznuta slobodna voda, proračun*

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1 INTRODUCTION
1. UVOD

For the technological and other engineering calculations of processes of thermal and hydrothermal treatment of wood materials, the wood temperature conductivity coefficient a is often used. It is known that it represents the relationship of the thermal conductivity coefficient λ to the multiplication of the specific heat capacity c and density ρ of the material. During calculations of heating or cooling of non-frozen wood, its temperature conductivity coefficient can be determined according to that relationship using the values of c, λ, and ρ of the wood for specific temperature and moisture content.

During the calculation of the freezing or defrosting processes of wood, however, it is necessary to take into account the impact both of the specific heat capacity of the wood itself, and of the heat of the phase transition of water in the wood from its liquid to hard aggregate condition and vise versa upon the wood temperature conductivity coefficient.

The heat of the water phase transition in the wood can be represented by the specific heat capacity of the frozen hygroscopically bound (c_{bw}) and the frozen free (c_{fw}) water in the wood. As a result of in-depth dissertation studies, Chudinov (1966) discovers that the melting of the frozen free water in the wood takes place at temperatures in the range between −2 °C and −1 °C. The author also discovers that the melting of the frozen hygroscopically bound water in the wood ends at −2 °C, and besides this, the quantity of this frozen water increases with the decrease in temperature, but even during extremely small climatic temperatures on earth, a definite part of it, u_{nfw}, remains in a non-frozen state.

Subsequently for the determination of a during the calculation of the wood defrosting processes, it makes sense to use the so called effective specific wood capacity c_e, which in the range $-2\ °C < t \leq -1\ °C$ is equal to the sum of c and (c_{fw}), and when $t \leq -2\ °C$ and simultaneously $u_{nfw} < u \leq u_{fsp}$, then $c_e = c + c_{bw}$ (Chudinov, 1966; Deliiski, 2003b).

For a precise determination of the wood temperature conductivity coefficient, it is also necessary to take into account the impact of the fiber saturation point of the wood u_{fsp}, which for the various wood species changes in a large range between 0.2 kg·kg^{-1} and 0.4 kg·kg^{-1} (Perelygin, 1965; Nikolov and Videlov, 1987; Chudinov, 1966, 1968; Reginač *et al*., 1990; Shubin, 1990; Požgaj *et al*., 1997; Trebula and Klement, 2002; Pervan, 2009; Kurjatko *et al*., 2010; Videlov, 2003; Deliiski, 2003b; Dzurenda and Deliiski, 2010).

The aim of the present work is to suggest an approach for the computation of the temperature conductivity of the wood during defrosting of the ice, which is created by both the hygroscopically bound and free water in the wood, using the mathematical descriptions of thermo-physical characteristics of frozen wood, made earlier by one of the authors.

2 MATHERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Computation of a at temperatures $T \leq 271.15$ K and wood moisture content $u \geq 0$ kg·kg^{-1}
2.1. Izračun koeficijenta toplinske vodljivosti pri temperaturi $T \leq 271.15$ K i sadržaju vode $u \geq 0$ kg·kg^{-1}

As described in the introduction, during the calculations of the wood defrosting processes at $T \leq 271.15$ K (i.e. at $t \leq -2$ °C) and $u_{fsp} \geq u > u_{nfw}$, the wood temperature conductivity must be determined according to the following equation (Deliiski, 2003b):

$$a(T,u,u_{fsp}) = \frac{\lambda(T,u,u_{fsp})}{\left[c(T,u,u_{fsp}) + c_{bw}(T,u,u_{fsp})\right]\cdot \rho(\rho_b,T,u,u_{fsp},S_v)} \quad (1)$$

where a is temperature conductivity of the wood with frozen bound water in it (m^2·s^{-1}), λ is thermal conductivity of the wood (W·m^{-1}·K^{-1}), c is specific heat capacity of the wood itself (J·kg^{-1}·K^{-1}), c_{bw} is specific heat capacity of the frozen bound water in the wood, (J·kg^{-1}·K^{-1}), ρ is wood density (kg·m^{-3}), ρ_b is basic wood density equal to dry mass divided to green volume (kg·m^{-3}), S_v is volume shrinkage of the wood (%), u is wood moisture content (kg·kg^{-1}), u_{fsp} is wood moisture content at fibre saturation point (kg·kg^{-1}), T is temperature (K).

The thermal conductivity λ and the own specific heat capacity c of the frozen wood during its defrosting is described mathematically using the data experimentally determined in the dissertations of Kanter (1955) and Chudinov (1966) for its change as a function of t and u. The same experimental data for λ and c, obtained by Kanter and Chudinov, are widely used in both the European literature (Sergovski, 1975; Shubin, 1990; Trebula, 1996; Trebula and Klement, 2002; Videlov, 2003) and the American specialized literature (Steinhagen, 1986, 1991; Khatabbi and Shteinhagen, 1992, 1993, 1995), when calculating various processes of thermal treatment of wood.

In the description of a apart from t and u, the independent parameter u_{fsp} has been input, which is different for the separate wood species and reflects the influence of the anatomic characteristics of the wood on λ and c_e (Deliiski 2003b; Deliiski and Dzurenda, 2010). The mathematical description of the wood density ρ, depending on the moisture content u, u_{fsp}, the basic density, ρ_b, and (only in the hygroscopic range) the volume shrinkage, S_v, which influence it, has been carried out using the experimental values set by (Sergovski, 1975) and shown in (Deliiski, 1977, 2003b, 2011).

The wood thermal conductivity λ in equation (1) can be calculated with the help of the equations (Deliiski, 1994, 2003b, 2013c):

$$\lambda = \lambda_0 \cdot \gamma \cdot \left[1 + \beta \cdot (T - 273.15)\right] \quad (2)$$

where

$$\lambda_0 = \mathrm{K_{ad}} \cdot \nu \cdot \left[0.165 + \left(1.39 + 3.8 \cdot \mathrm{u}\right) \cdot \left(3.3 \cdot 10^{-7} \cdot \rho_b^2 + 1.015 \cdot 10^{-3} \cdot \rho_b\right)\right] \quad (3)$$

$$v = 0.15 - 0.07 \cdot u \ @ \ u \le u_{fsp} + 0.1 \ \text{kg·kg}^{-1} \quad (4)$$

$$v = 0.1284 - 0.013 \cdot u \ @ \ u > u_{fsp} + 0.1 \ \text{kg·kg}^{-1} \quad (5)$$

The equations, which have been suggested by Chudinov (1966, 1968) and shown in (Deliiski, 1977) can be used for the determination of the values of the coefficient K_{ad} in equation (3), which takes into account the influence on λ_0 of the heat flux towards the separate anatomic directions of the wood. Deliiski (2003b) determined more precise values of K_{ad} for ten wood species. For wood species discussed below in this paper, the following values of K_{ad} cross sectional to the fibers (i.e. of $K_{ad} = K_c$) have been determined: K_c = 1.13 for oak, K_c = 1.15 for acacia, K_c = 1.24 for walnut, K_c = 1.28 for beech, K_c = 1.33 for spruce, K_c = 1.42 for poplar wood.

The coefficients γ and β in equation (2) are calculated by the following equations:

- For non-frozen wood, i.e. when $T_{dfr} < T \le 423.15$ K and simultaneously with this $u > u_{nfw}$ or when $u \le u_{nfw}$ and simultaneously with this 213.15 K $\le T \le$ 423.15 K:

$$\gamma = 1.0 \quad (6)$$

$$\beta = (2.05 + 4 \cdot u) \cdot \left(\frac{579}{\rho_y} - 0.124 \right) \cdot 10^{-3} \quad @ \ u \le u_{fsp} + 0.1 \ \text{kg·kg}^{-1} \quad (7)$$

$$\beta = 3.65 \cdot \left(\frac{579}{\rho_y} - 0.124 \right) \cdot 10^{-3} \quad @ \ u > u_{fsp} + 0.1 \ \text{kg·kg}^{-1} \quad (8)$$

$$u_{fsp} = u_{fsp}^{293.15} - 0.001 \cdot (T - 293.15) \quad (9)$$

- For frozen wood, i.e. when 213.15 K $\le T \le T_{dfr}$ and simultaneously with this $u > u_{nfw}$:

$$\gamma = 1 + 0.34 \cdot \left[1.15 \cdot (u - u_{fsp}) \right] \quad (10)$$

$$\beta = 0.002 \cdot (u - u_{fsp}) - 0.0038 \cdot \left(\frac{579}{\rho_b} - 0.124 \right) \quad (11)$$

$$u_{nfw} = 0.12 + (u_{fsp} - 0.12) \exp[0.0567 \cdot (T - 271.15)] \quad @ \ 213.15 \ \text{K} \le T \le 271.15 \ \text{K} \quad (12)$$

$$T_{dfr} = 271.15 + \frac{\ln \dfrac{u_{nfw} - 0.12}{u_{fsp} - 0.12}}{0.0567} \quad @ \ 0.12 \ \text{kg.kg}^{-1} \le u = u_{nfw} \le u_{fsp}^{271.15} \quad (13)$$

$$T_{dfr} = 271.15 \ @ \ u > u_{fsp}^{271.15} \quad (14)$$

$$u_{fsp} = u_{fsp}^{293.15} - 0.001 \cdot (T_{dfr} - 293.15) \ @ \ T \le T_{dfr} \quad (15)$$

In equations (12) and (13) u_{nfw} is the amount of the non-frozen bound water in the wood (in kg·kg^{-1}) at given temperature $T \le$ 271.15 K and in equations (13), (14), and (15) T_{dfr} is the temperature (in K), at which the melting of the frozen bound water in wood with given u is completed. In equations (9) and (15) $u_{fsp}^{293.15}$ is the fiber saturation point of the wood at T = 293.15 K, i.e. at t = 20 °C, and in equations (13) and (14) $u_{fsp}^{271.15}$ is the fiber saturation point of the wood at T = 271.15 K K, i.e. at t = −2 °C (Stamm, 1964; Deliiski 2013b, 2013c).

The values for basic wood density ρ_b and for moisture content at fibre saturation point at T = 293.15 K of wood species discussed below in this paper are shown in Table 1.

The specific heat capacity of the frozen wood itself c in equation (1) can be calculated with the help of the following equations (Deliiski 1990, 2011; Deliiski and Dzurenda, 2010):

$$c = K_c \cdot \frac{526 + 2.95 \cdot T + 0.0022 \cdot T^2 + 2261 \cdot u + 1976 \cdot u_{nfw}}{1 + u} \quad (16)$$

$$K_c = 1.06 + 0.04 \cdot u + \frac{0,00075 \cdot (T - 271.15)}{u_{nfw}} \quad (17)$$

where u_{nfw} is determined according to equation (12).

For the calculation of the specific heat capacity of the frozen bound water in the wood, c_{bw}, the following equation (Deliiski, 2003b, 2004, 2011) has been obtained:

$$c_{bw} = 1.8938 \cdot 10^4 \cdot (u_{fsp} - 0.12) \frac{\exp[0.0567 \cdot (T - 271.15)]}{1 + u} \quad @ \ u_{fsp} \ge u > u_{nfw} \quad (18)$$

Table 1 Basic density, wood moisture content at fibre saturation point at 20 °C, and volume shrinkage of some wood species (acc. to Perelygin, 1965; Nikolov and Videlov, 1987; Reginač *et al*., 1990; Požgaj *et al*., 1997; Kurjatko *et al*., 2010)
Tablica 1. Osnovna gustoća, sadržaj vode pri zasićenosti vlakanaca pri 20 °C te volumno utezanje nekih vrsta drva (prema Perelygin, 1965.; Nikolov and Videlov, 1987.; Reginač *et al*., 1990.; Požgaj *et al*., 1997.; Kurjatko *et al*., 2010.)

№ *Red. br.*	**Wood species** *Vrsta drva*	**Basic density ρ_b** *Gustoća drva* kg·m^{-3}	**Fiber saturation point $u_{fsp}^{293.15}$** *Točka zasićenosti vlakanaca* kg·kg^{-1}	**Volume shrinkage** *Volumnmo utezanje* S_v, %
1.	Poplar / *topola*	355	0.35	13.3
2.	Spruce / *smreka*	380	0.26 – core; 0.32 – sapwood	11.4
3.	Walnut / *orah*	555	0.24 - core	12.9
4.	Beech / *bukva*	560	0.31	17.3
5.	Acacia / *bagrem*	660	0.20 – core; 0.30 – sapwood	11.2
6.	Oak / *hrast*	670	0.22 – core; 0.29 – sapwood	11.9

The density of the frozen wood, ρ, in equation (1) can be calculated with the help of the following equations (Deliiski, 2013b):

$$\rho = \rho_{\mathrm{b}} \cdot \frac{1+u}{1-\frac{S_{\mathrm{v}}}{100}\cdot\left[u_{\mathrm{fsp}}^{293.15} - 0.001\cdot\left(T_{\mathrm{dfr}} - 293.15\right) - u\right]}$$

$$@ \quad u \le u_{\mathrm{fsp}} \ \ \& \ \ T \le T_{\mathrm{dfr}} \tag{19}$$

$$\rho = \rho_{\mathrm{b}}(1+u) \quad @ \quad u > u_{\mathrm{fsp}} \tag{20}$$

In equation (19) S_v is the volume shrinkage of the wood (in %), whose values are given in the last column of Table 1.

2.2. Computation of *a* at temperatures 271.15 K < *T* ≤ 272.15 K and wood moisture content *u* > u_{fsp}
2.2. Izračun koeficijenta toplinske vodljivosti pri temperaturi 271.15 K < *T* ≤ 272.15 K i sadržaju vode *u* > u_{fsp}

During the calculations of defrosting processes of wood, which contains free water, i.e. when the condition 271.15 < *T* ≤ 272.15 & *u* > u_{fsp} holds, the wood temperature conductivity must be determined according to the following equation (Deliiski, 2003b):

$$a(T,u,u_{\mathrm{fsp}}) = \frac{\lambda(T,u,u_{\mathrm{fsp}})}{[c(T,u,u_{\mathrm{fsp}}) + c_{\mathrm{fw}}(T,u,u_{\mathrm{fsp}})]\cdot\rho(\rho_{\mathrm{b}},T,u,u_{\mathrm{fsp}})} \tag{21}$$

where *a* is temperature conductivity of wood with frozen free water in it ($m^2 \cdot s^{-1}$), *λ* is thermal conductivity of the frozen wood ($W \cdot m^{-1} \cdot K^{-1}$), *c* is specific heat capacity of wood with frozen free water in it ($J \cdot kg^{-1} \cdot K^{-1}$), c_{fw} is specific heat capacity of the frozen free water in the wood, ($J \cdot kg^{-1} \cdot K^{-1}$). The remaining variables in equation (21) are the same, as in the equation (1).

For the determination of *a* by equation (21) the values of λ and *c* must be calculated at $T = \frac{271.15 + 272.15}{2} = 271.65$ K according to above given equations. The value of ρ in equations (1) and (21) must be determined by equations (19) and (20) correspondingly.

For calculation of c_{fw} in (21) the following equation (Deliiski 2003b, 2004, 2011) has been obtained:

$$c_{\mathrm{fw}} = 3.34\cdot 10^5 \cdot \frac{u - u_{\mathrm{fsp}}}{1+u} \tag{22}$$

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

For the computation of the wood temperature conductivity according to equations (1) and (21) a software program has been prepared in FORTRAN (Dorn and McCracken 1972), and it has been input in the calculation environment of Visual Fortran Professional developed by Microsoft.

With the help of the program, computations have been made for the determination of *a* in three cases: at 223.15 K ≤ *T* ≤ 271.15 K (i.e. – 60 ° C ≤ *t* ≤ –2 °C) & 0 ≤ *u* ≤ u_{fsp}, at −60 °C ≤ *t* ≤ −2 °C & u_{fsp} ≤ *u* ≤ 1.2 $kg \cdot kg^{-1}$, and at 271.15 K < *T* ≤ 272.15 K (i.e. −2 °C < *t* ≤ −1 °C) & *u* > u_{fsp}. The temperature conductivity cross sectional to the fibers of beech *(Fagus Silvatica* L.*)*, poplar *(Populus alba* L.*)*, oak *(Quercus petraea* Liebl.*)*, walnut *(Juglans regia* L.*)*, acacia *(Robinia pseudoacacia* J.*)* and spruce *(Picea abies* L.*)* has been calculated.

3.1 Wood temperature conductivity cross sectional to the fibers at −60 °C ≤ *t* ≤ −2 °C & 0 ≤ *u* ≤ u_{fsp}
3.1. Toplinska vodljivost drva poprečno na vlakanca pri temperaturi -60 °C ≤ *t* ≤ -2 °C i sadržaju vode 0 ≤ *u* ≤ u_{fsp}

Fig. 1 and Fig. 2 show, according to equation (1), the calculated change in the temperature conductivity

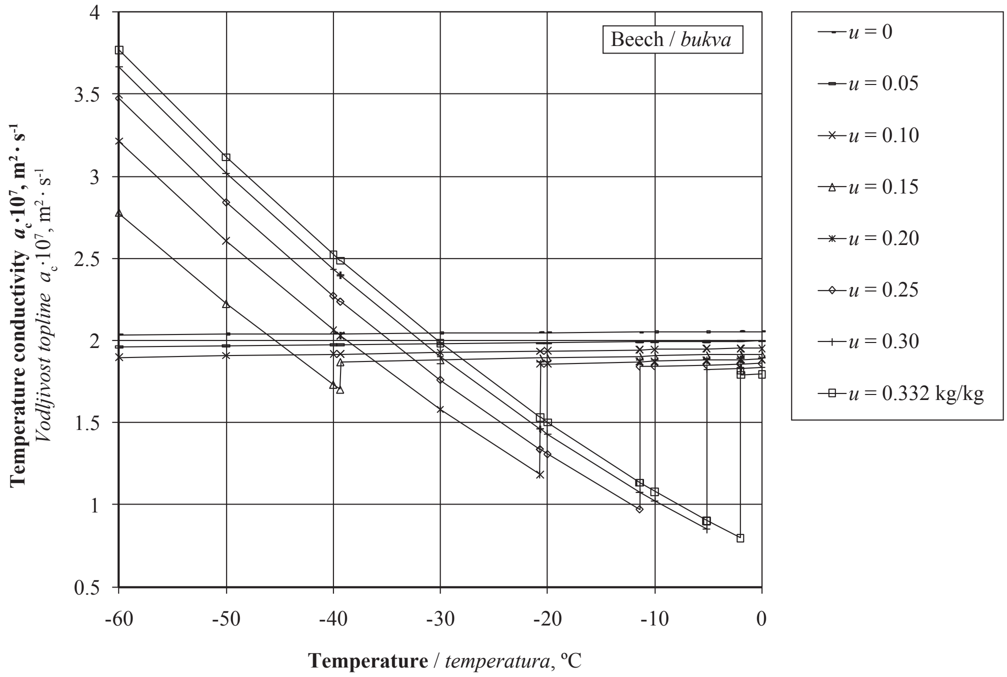


Figure 1 Change in the temperature conductivity of frozen beech wood with ρ_b = 560 $kg \cdot m^{-3}$ and $u_{fsp}^{293.15}$ = 0.31 $kg \cdot kg^{-1}$ cross sectional to the fibres, depending on *t* and *u* ≤ u_{fsp}

Slika 1. Promjena toplinske vodljivosti smrznute bukovine gustoće ρ_b = 560 $kg \cdot m^{-3}$ i točke zasićenosti vlakanaca $u_{fsp}^{293.15}$ = 0,31 $kg \cdot kg^{-1}$ poprečno na vlakanca u ovisnosti o temperaturi *t* i pri *u* ≤ u_{fsp}

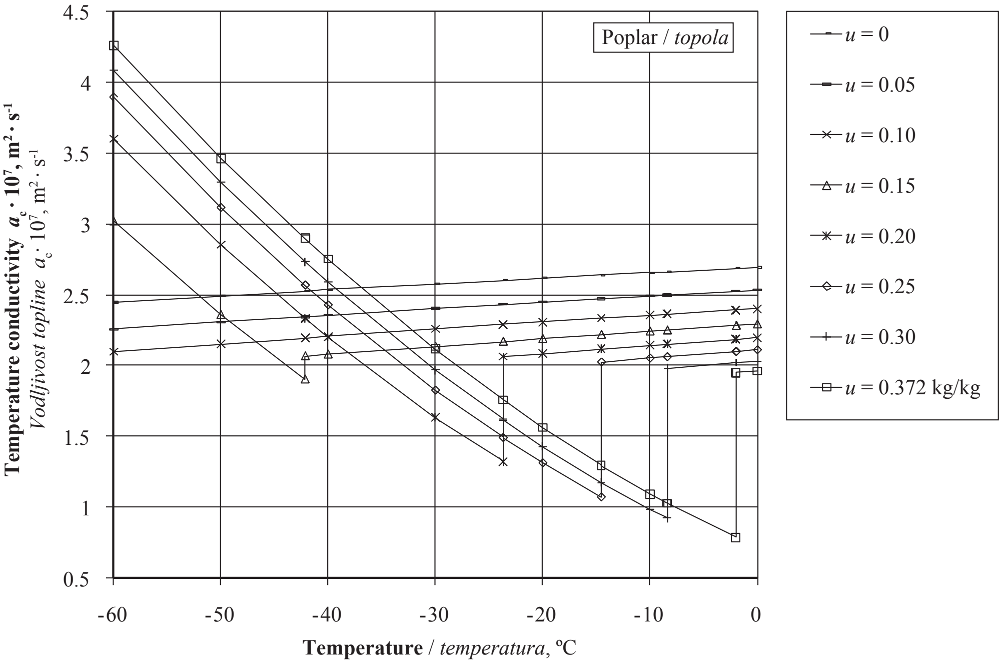


Figure 2 Change in the temperature conductivity of frozen poplar wood with ρ_b = 355 kg·m^{-3} and $u_{fsp}^{293.15}$ = 0.35 kg·kg^{-1} cross sectional to the fibres, depending on t and $u \leq u_{fsp}$
Slika 2. Promjena toplinske vodljivosti smrznute topolovine gustoće ρ_b = 355 kg·m^{-3} i točke zasićenosti vlakanaca $u_{fsp}^{293.15}$ = 0,35 kg·kg^{-1} poprečno na vlakanca u ovisnosti o temperaturi t i pri $u \leq u_{fsp}$

cross sectional to the fibers, a_c, of frozen beech and poplar wood, respectively, in the hygroscopic range, depending on t and u. During the computations, the values from Table 1 of ρ_b, $u_{fsp}^{293.15}$, and S_v have been used. The values of a_c for wood not containing ice, i.e. for u = 0 kg·kg^{-1}, u = 0.05 kg·kg^{-1} and u = 0.10 kg·kg^{-1}, as well as for $t > t_{dfr} = T_{dfr} - 273.15$ at $u \geq 0.15$ kg·kg^{-1} are calculated according to the equations for non-frozen wood, which are given in (Deliiski, 2003b, 2011; Dzurenda and Deliiski, 2010).

The obtained values of t_{dfr} according to equations (13) and (14) depending on u for the studied wood species during the calculation of a_c are given in Table 2. The value of u_{fsp} obtained according to equation (15) at T_{dfr} = 271.15 K (Chudinov, 1966), when the maximum possible amount of frozen bound water in the wood completely melts, for beech wood with $u_{fsp}^{293.15}$ = 0.31 kg·kg^{-1} is equal to u_{fsp} = 0.332 kg·kg^{-1} and for poplar wood with $u_{fsp}^{293.15}$ = 0.35 kg·kg^{-1} is equal to u_{fsp} = 0.372 kg·kg^{-1}. This values of u_{fsp} are used as maximum values of $u = u_{fsp}$ during the computation of a_c.

The graphs in Fig. 1 and Fig. 2 show that an increase in t at a given value for u leads to a decrease in a for wood containing ice as a consequence of the increase in c_{bw} (refer to equation (18)) and to an increase in a for wood, which does not contain ice. Also, the slope for the change in a of wood, which contains frozen bound water depending on t is much larger than the slope for the change in a of wood without ice. The change in a depending on t with sufficient precision for practical calculations can be taken as being linear.

From the analysis of Fig. 1 and Fig. 2, it can also be seen that at a given value of t, an increase in u for wood containing ice, formed in it from freezing of hygroscopically bound water, causes an increase in a. At temperatures, equal to t_{dfr} (see Table 2), a jump takes place in a. This jump in a is explained by the completing of the phase transition of the frozen bound water in the wood at these values for t and u, when the influence on λ and c of a significant difference in the specific heat capacity of the bound water in a liquid and hard aggregate condition is observed.

The presence of such a jump in a demonstrates the correct reflection in equation (1), and in the mathematical description of λ (Deliiski, 2013c) and c of the setting in the theory of wood thermal treatment (Chudinov, 1968), according to which exactly at temperature t_{dfr} for given value of u the melting of the frozen bound water in the wood is completed.

Table 2 Change in t_{dfr} (in °C) of frozen wood depending on wood moisture content and wood species
Tablica 2. Promjena temperature t_{dfr} (u °C) smrznutog drva u ovisnosti o sadržaju vode i vrsti drva

Wood species *Vrsta drva*	**Wood moisture content *u***, kg·kg^{-1} / *Sadržaj vode u drvu, kg·kg^{-1}*					
	0.15	0.20	0.25	0.30	0.332	0.372
Beech / *bukva*	−39.25	−20.68	−11.39	−5.15	−2.00	−2.00
Poplar / *topola*	−42.14	−23.69	−14.53	−8.37	−5.28	−2.00

3.2. Wood temperature conductivity cross sectional to the fibers at -60 °C ≤ t ≤ -2 °C & u_{fsp} ≤ u ≤ 1.2 kg·kg^{-1}
3.2. Toplinska vodljivost drva poprečno na vlakanca pri temperaturi -60 °C ≤ t ≤ -2 °C i sadržaju vode u_{fsp} ≤ u ≤ 1,2 kg·kg^{-1}

Fig. 3 shows, according to equation (1), the calculated change in the temperature conductivity cross sectional to the fibers, a_c, of frozen beech and poplar wood above the hygroscopic range, depending on t and u. During the computations, the values from Table 1 of ρ_b and $u_{fsp}^{293.15}$ for beech and poplar wood have been used. The values of a_c for wood not containing ice, i.e. for $t > t_{dfr} = -2$ °C (see equation (14)) at all studied values of u have been calculated according to the equations for non-frozen wood, which are given in (Deliiski, 2003b, 2011; Dzurenda and Deliiski, 2010).

The graphs in Fig. 3 show that an increase in t at a given value for u and an increase in u at a given value for t leads to the change in a both for wood not containing and containing ice from the free water, which is the same as the one shown above for wood, containing only frozen bound water.

The graphs in Fig. 3 also show that at $t = t_{dfr} = -2$ °C jumps take place in a for the wood with $u > u_{fsp}$. These jumps are explained by the phase transition into water of the whole amount of the ice, formed by the free water in the wood during defrosting above the hygroscopic range. Namely, at the value of $t = t_{dfr} = -2$ °C, the influence on a of a significant difference in the temperature conductivity of the free water in a liquid and hard aggregate state occurs.

3.3. Wood temperature conductivity cross sectional to the fibers at -2 °C < t ≤ -1 °C & $u > u_{fsp}$
3.3. Toplinska vodljivost drva poprečno na vlakanca pri temperaturi −2 °C ≤ t ≤ −1 °C i sadržaju vode $u > u_{fsp}$

Fig. 4 and Fig. 5 show, according to equation (21), the calculated change in the temperature conductivity of frozen wood from above mentioned six wood species, containing frozen free water, depending on $u > u_{fsp}$ in the temperature range -2 °C < t ≤ -1 °C. During the computations, the values of ρ_b and $u_{fsp}^{293.15}$ from Table 1 have been used.

The values of a are determined for the entire possible range for the change in the free water in the wood, i.e. for $u_{fsp} < u \leq u_{max}$, where the maximum possible moisture content u_{max} depends on the density ρ of the respective wood specie. The results are shown separately in Fig. 2 and Fig. 3 for the moisture ranges $u_{fsp} < u \leq 0.4$ kg·kg^{-1} and 0.4 kg·kg^{-1} < $u \leq u_{max}$, due to the very big differences in the values of a in both ranges.

The results from the calculations show that for values of u, which are very close to u_{fsp}, but are slightly larger than u_{fsp}, the values of a in the temperature range -2 °C < t ≤ -1 °C are comparable with those that a has right after the melting of the frozen bound water in the wood. This fact fully corresponds to the physics of the wood defrosting process.

However, as u increases in relation to u_{fsp}, the values of a decrease significantly along a hyperbolic line: from 3.2 to 3.9 times at $u = 1.1u_{fsp}$, from 17 to 23 times at $u = 2u_{fsp}$, from 32 to 36 times at $u = 3u_{fsp}$, up to about 40 times at $u = 5u_{fsp}$ (when the density of the wood species allows to have such a high moisture content). A reason for this is the strong increasing quantity of the frozen free water in the wood with an increase of $u > u_{fsp}$ and the related increase in the specific heat capacity c_{fw}, which is a part of the denominator in equation (21).

The drastic decrease of the wood temperature conductivity in the range -2 °C < t ≤ -1 °C for all anatomic directions of wood, which contains frozen free water, causes a significant slowing down of the change in temperature in the frozen wood materials subjected to thermal treatment in this range up to the moment when this frozen water melts completely. This fact is illustrated by many graphs in the specialized literature (Deliiski, 2003b, 2004, 2009, 2013a; Dzurenda and Deliiski, 2010; Steinhagen, 1986, 1991; Khatabbi and Shteinhagen, 1992, 1993, 1995). It confirms the correct reflection in equation (21) of the physical laws that influence a in the shown temperature range.

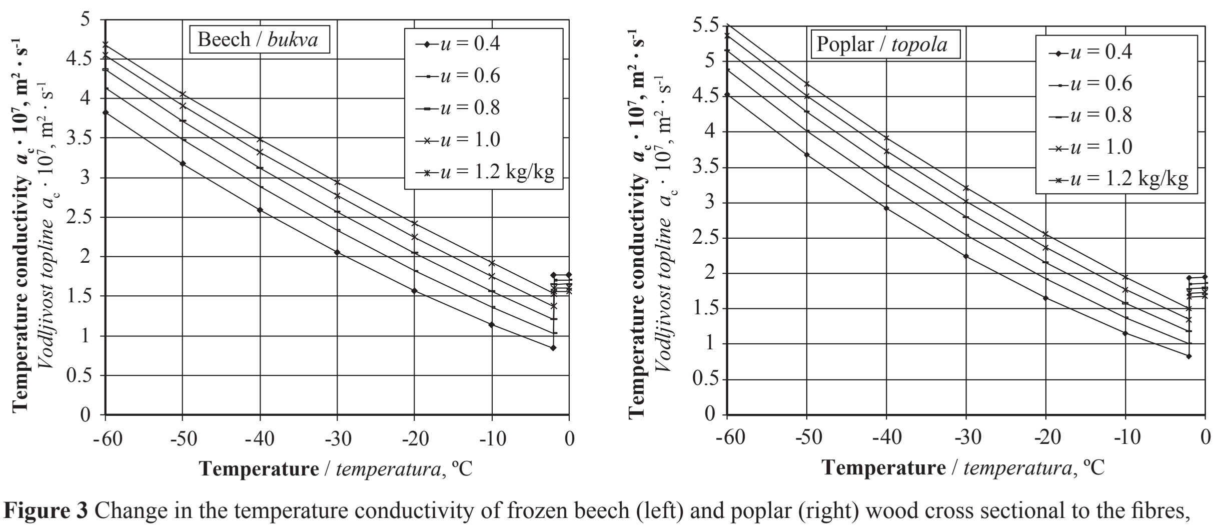


Figure 3 Change in the temperature conductivity of frozen beech (left) and poplar (right) wood cross sectional to the fibres, depending on t and $u > u_{fsp}$
Slika 3. Promjena toplinske vodljivosti smrznute bukovine (lijevo) i topolovine (desno) poprečno na vlakanca, u ovisnosti o temperaturi t i pri $u > u_{fsp}$

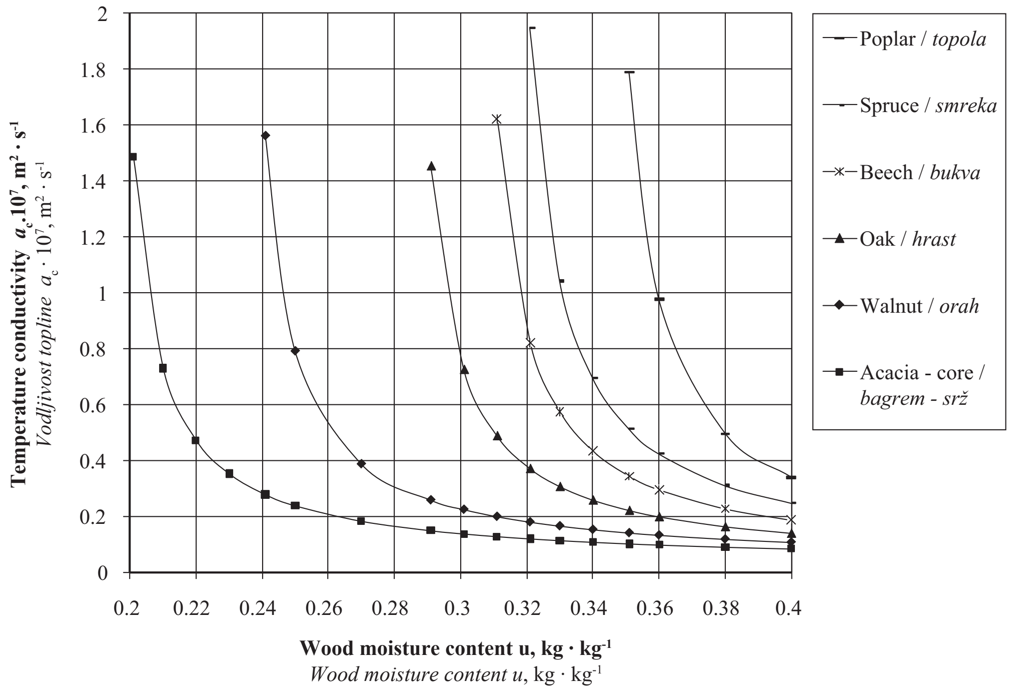


Figure 4 Change in the wood temperature conductivity of poplar, spruce, beech, oak, walnut and acacia cross sectional to the fiber depending on $u_{fsp} < u \leq 0.4$ kg·kg⁻¹ in the range -2 °C $\leq t < -1$ °C
Slika 4. Promjena toplinske vodljivosti topolovine, smrekovine, bukovine, hrastovine, orahovine i bagremovine poprečno na vlakanca, u ovisnosti sadržaju vode $u_{fsp} < u \leq 0.4$ kg·kg⁻¹ i pri temperaturi -2 °C $\leq t < -1$ °C

3.4 Computation of the 2D temperature distribution in frozen logs during their defrosting
3.4. Proračun 2D raspodjele temperature u smrznutom trupcu tijekom odmrzavanja

The above results have been used for the calculation of log defrosting according to the following mathematical model (Deliiski, 2003b):

$$\frac{\partial T}{\partial \tau} = a_r(T, u, u_{fsp}, \rho_b, S_v) \cdot \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T}{\partial r} \right) + a_p(T, u, u_{fsp}, \rho_b, S_v) \cdot \frac{\partial^2 T}{\partial z^2} \tag{23}$$

with an initial condition

$$T(r, z, 0) = T_0 \tag{24}$$

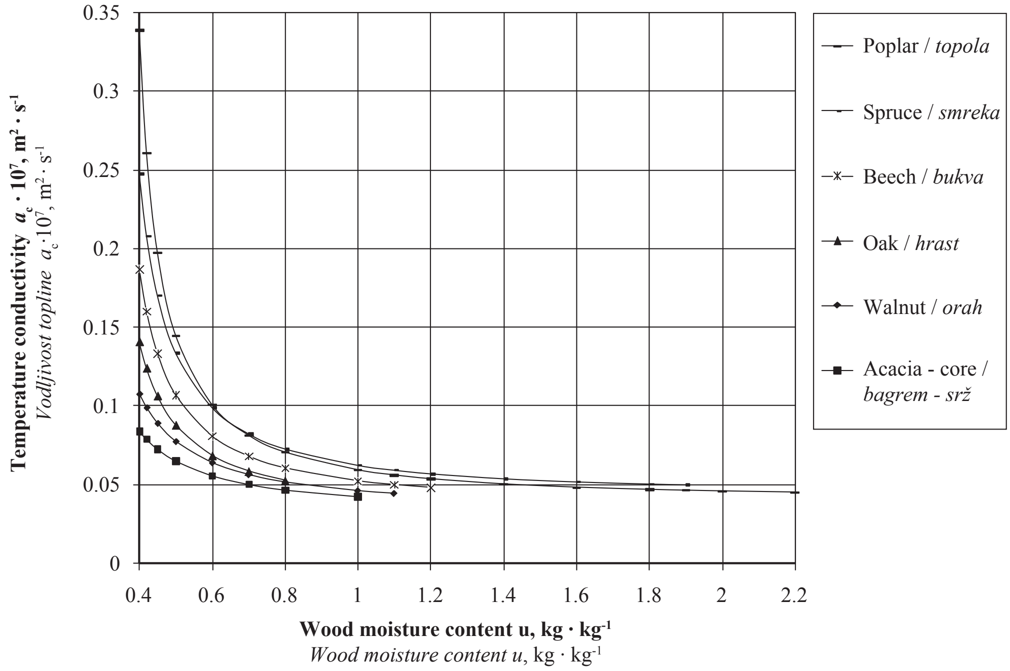
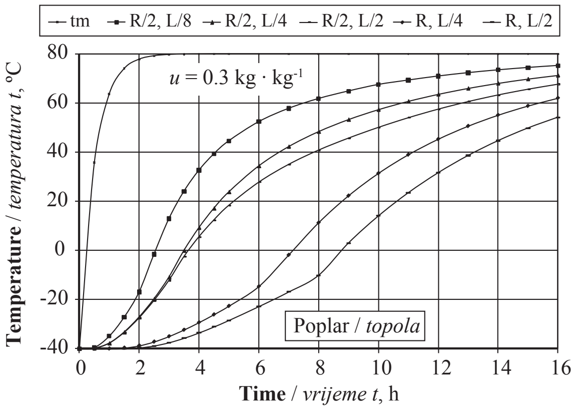


Figure 5 Change in the wood temperature conductivity of poplar, spruce, beech, oak, walnut and acacia cross sectional to the fiber depending on 0.4 kg·kg⁻¹ $< u \leq u_{max}$ in the range -2 °C $\leq t < -1$ °C
Slika 5. Promjena toplinske vodljivosti topolovine, smrekovine, bukovine, hrastovine, orahovine i bagremovine poprečno na vlakanca, u ovisnosti o sadržaju vode 0.4 kg·kg⁻¹ $< u \leq u_{max}$ i pri temperaturi -2 °C $\leq t < -1$ °C



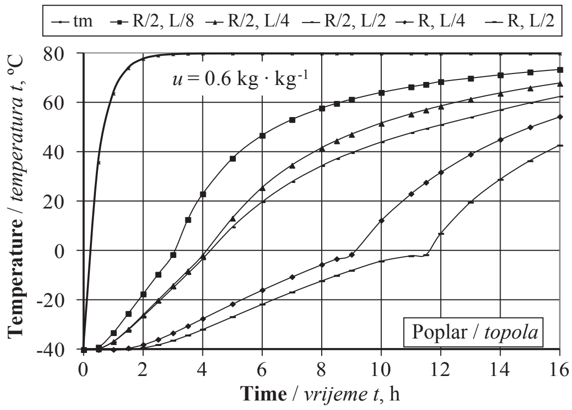


Figure 6 Change in t in the longitudinal section of poplar logs with R = 0.2 m, L = 0.8 m, t_0 = −40 °C, u = 0.3 kg·kg^{-1} (left) and u = 0.6 kg·kg^{-1} (right) during their defrosting at t_m = 80 °C
Slika 6. Promjena temperature u longitudinalnom presjeku topolova trupca promjera R = 0,2 m, duljine L = 0,8 m, temperature t_0 = -40 °C, sadržaja vode u = 0,3 kg·kg^{-1} (lijevo) i sadržaja vode u = 0,6 kg·kg^{-1} (desno) tijekom procesa odmrzavanja pri temperaturi t_m = 80 °C

and a boundary condition for thermal treatment of the logs in agitated hot water at their prescribed surface temperature:

$$T(0, z, \tau) = T(0, z, \tau) = T_m(\tau), \qquad (25)$$

where a_r and a_p are temperature conductivities of the wood in radial direction and parallel to the fiber, respectively (m^2·s^{-1}), r is radial coordinate: $0 \le r \le R$, R is radius of the log (m), z is longitudinal coordinate: $0 \le z \le L/2$, L is length of the log (m), T is temperature (K), T_0 is initial temperature of the log subjected to defrosting (K), T_m is temperature of the processing (heating) medium (K), u is wood moisture content (kg·kg^{-1}), u_{fsp} is wood moisture content at fibre saturation point (kg·kg^{-1}), ρ_b is basic density of the wood (kg·m^{-3}), S_v is volume shrinkage of the wood (%), τ is time (s).

For the numerical solution of the mathematical model, which is presented in common form by equations (23), (24), and (25), a software package has been prepared in the calculation environment of Visual Fortran Professional. With the help of the software package, computations have been made for the determination of the 2D non-stationary change in the temperature in frozen poplar logs subjected to defrosting with R = 0.2 m, L = 0.8 m, t_0 = −40 °C and two values of wood moisture content u = 0.3 kg·kg^{-1} and u = 0.6 kg·kg^{-1} during their 16 hours of heating in agitated hot water with t_m = 80 °C. The log with u = 0.3 kg·kg^{-1} contains almost the maximum possible amount of frozen bound water in the wood and does not contain frozen free water. The log with u = 0.6 kg·kg^{-1} contains not only frozen bound water but also contains a significant amount of frozen free water.

The increasing of the heating medium temperature, t_m, from the value of $t_{m0} = t_0$ to t_m = 80 °C = const grows exponentially with time constant, equal to 1800 s. This increasing of t_m at the beginning of log heating can be seen in the Fig. 6. The values of R, L, t_m, and u have been selected so as to correspond to cases common in practice. The duration of 16 h of log heating at t_m = 80 °C has been proven as sufficient for complete melting of the ice in the studied logs.

During the computations, the values from Table 1 of ρ_b, $u_{fsp}^{293.15}$, and S_v for poplar wood have been used. The calculations have been done with values of $a_r = 1.04a_c$ and $a_p = 1.95a_r$ (Deliiski, 2003b), where a_c is the temperature conductivity of the poplar wood cross sectional to the fibers, whose values for u = 0.3 kg·kg^{-1} and u = 0.6 kg·kg^{-1} can be seen in Fig. 2, Fig. 3 (right), and Fig. 5.

Fig. 6 shows the computed change in the surface temperature of the logs, which is equal to t_m, and also in the temperature in 5 characteristic points in the ¼ of the longitudinal section of logs (because of its symmetry to the remaining ¾ of the section). The coordinates of the characteristic points are given in the legend of the graphs.

The curves of the log axe situated on characteristic points with coordinates (R, L/4) and (R, L/2) on the right part of Fig. 6 show the specific almost horizontal sections of retention of the temperature for a long period of time in the range from −2 °C to −1 °C, while in these points a complete melting of the frozen free water in the wood occurs. Such retention of the temperature in the range from –2 °C to –1 °C has been observed in wide experimental studies during the defrosting process of pine logs with frozen free water in them (Steinhagen, 1986; Khattabi and Steinhagen, 1992, 1993).

The reason for the temperature retention in the range from −2 °C to −1 °C is the very low value of the temperature conductivity coefficient a_c, which is equal to 0.1·10^{-7} m^2·s^{-1} for the poplar wood with u = 0.6 kg·kg^{-1} in this range (see Fig. 5). In the range $-40\ °C \le t \le -2\ °C$, the value of a_c of the same frozen poplar wood changes from a_c = 3.24·10^{-7} m^2·s^{-1} to a_c = 1.01·10^{-7} m^2·s^{-1} (see Fig. 3-right), i.e. it is from 32.4 to 10.1 times larger comparing with a_c = 0.1·10^{-7} m^2·s^{-1}. Because of this, the temperature in the logs with frozen free water in them increases much faster in the range $-40\ °C \le t \le -2\ °C$ than in the range $-2\ °C < t \le -1\ °C$.

Analogically, the almost horizontal sections in the change of the wood temperature are absent during defrosting of the ice, formed only by bound water in the wood (see the left part of Fig. 6).

4 CONCLUSIONS
4. ZAKLJUČAK

The present paper describes the approach suggested by the authors for the computation of the temperature conductivity of frozen wood materials at temperatures below −1 °C during their defrosting. The approach takes into account to a maximum degree the physics of the processes of melting of the ice, formed by both the bound and the free water in the wood. It reflects the influence of the temperature, moisture content and density of the wood, and for the first time also the influence of the fiber saturation point of each wood species on its temperature conductivity in a frozen state.

The obtained results for poplar, spruce, beech, oak, walnut, and acacia show that, when all other conditions are equal, the wood temperature conductivity during melting of the frozen bound water is up to some tens of times larger than the wood temperature conductivity during melting of the frozen free water in the wood. This fact determined for the first time quantitatively for the studied wood species causes a significant slowing down of the change in temperature in the frozen wood materials subjected to thermal treatment up to the moment, when the frozen free water melts completely.

It has been determined that the change in a depending on t with sufficient precision of calculations can be taken as linear for practical reasons, when $t < -2$ °C for all $0 \le u \le u_{fsp}$ and hyperbolic when -2 °C $< t \le -1$ °C and simultaneously with this $u > u_{fsp}$.

The results of this work can be used for both technological and other engineering calculations and analysis of processes of thermal and hydrothermal treatment of wood materials, as well as in system software for model based automatic control (Hadjiski, 2003, 2013) of such treatment. The suggested methodology for the computation of the temperature conductivity of frozen wood during its defrosting can also be used for science based dimensioning of the mentioned processes with the help of all classical approaches, which are well known from the textbooks and other specialized literature.

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5 REFERENCES
5. LITERATURA

1. Chudinov, B. S., 1966: Theoretical Research of Thermo Physical Properties and Thermal Treatment of Wood. DSc Dissertation, Krasnoyarsk, SibLTI (in Rusian).
2. Chudinov, B. S., 1968: Theory of Thermal Treatment of Wood. Publisher “Nauka”, Moscow (in Russian).
3. Deliiski, N., 1977: Computation of the Non-stationary Temperature Distribution in the Wood during its Heating by Heat Conductivity. Part I: Mathematical Model of the Wood Heating Process by Heat Conductivity. Holz Roh-Werkstoff, 35 (4): 141-145. (in German). http://dx.doi.org/10.1007/BF02625331
4. Deliiski, N., 1990: Mathematical Description of the Specific Heat Capacity of Non-frozen and Frozen Wood. Proceedings of the VIII[th] International Symposium on Fundamental Research of Wood. Warscow, 229-233 (in German).
5. Deliiski, N., 1994: Mathematical Description of the Thermal Conductivity Coefficient of Non-frozen and Frozen Wood. Proceedings of the 2[nd] International Symposium on Wood Structure and Properties ’94, TU-Zvolen, 127-134.
6. Deliiski, N., 2003a: Microprocessor System for Automatic Control of Logs’ Steaming Process. Drvna industrija, 54 (4): 191-198.
7. Deliiski, N., 2003b: Modeling and Technologies for Steaming of Wood Materials in Autoclaves. DSc. Dissertation, University of Forestry, Sofia, 2003 (in Bulgarian).
8. Deliiski, N., 2004: Modelling and Automatic Control of Heat Energy Consumption Required for Thermal Treatment of Logs. Drvna industrija, 55 (4): 181-199.
9. Deliiski, N., 2009: Computation of the 2-Dimensional Transient Temperature Distribution and Heat Energy Consumption of Frozen and Non-frozen Logs. Wood Research, 54 (3): 67-78.
10. Deliiski, N., 2011: Transient Heat Conduction in Capillary Porous Bodies, p. 149-176. In: Convection and Conduction Heat Transfer. InTech Publishing House, Rijeka. http://dx.doi.org/10.5772/21424
11. Deliiski, N., 2013a: 3D Modeling and Visualization of the Non-stationary Temperature Distribution during Heating of Frozen Wood. Drvna industrija, 64 (4): 293-303.
12. Deliiski, N., 2013b: An Engineering Approach for the Calculation of the Wood Density in the Hygroscopic Diapason during Wood Defrosting. 10[th] International Symposium “Selected Processes at the Wood Processing”. September 11-13, Ružomberok, Slovakia, Volume of articles, 9 c.
13. Deliiski, N., 2013c: Computation of the Wood Thermal Conductivity during Defrosting of the Wood. Wood research, 58 (4): 637-650.
14. Deliiski, N.; Dzurenda, L., 2010: Modeling of the Thermal Processes in the Technologies for Wood Thermal Treatment. TU Zvolen, Slovakia (in Russian).
15. Hadjiski, M., 2003: Mathematical Models in Advanced Technological Control Systems. Automatic & Informatics, 37 (3): 7-12. (in Bulgarian).
16. Hadjiski, M., 2013: Functionality and Structure Development Advanced Industrial Control System. Automatic & Informatics, 47 (4): 7-14. (in Bulgarian).
17. Dorn, W. S.; McCracken, D. D., 1972: Numerical Methods with FORTRAN IV: Case Studies. New York, John Willey & Sons, Inc.
18. Dzurenda, L.; Deliiski, N., 2010: Thermal Processes in the Technologies for Wood Processing. Zvolen, Technical University in Zvolen (in Slovak).
19. Kanter, K. R., 1955: Investigation of the Thermal Properties of Wood. PhD Thesis, Moscow, MLTI (in Russian).
20. Khattabi, A.; Steinhagen, H. P., 1992: Numerical Solution to Two-dimensional Heating of Logs. Holz Roh-Werkstoff, 50: 308-312. http://dx.doi.org/10.1007/BF02615359

21. Khattabi, A.; Steinhagen, H. P., 1993: Analysis of Transient Non-linear Heat Conduction in Wood Using Finite-difference Solutions. Holz Roh- Werkstoff, 51: 272-278. http://dx.doi.org/10.1007/ BF02629373
22. Khattabi, A.; Steinhagen, H. P., 1995: Update of "Numerical Solution to Two-dimensional Heating of Logs". Holz Roh- Werkstoff, 53: 93-94. http://dx.doi.org/10.1007/BF02716399
23. Kurjatko, S. *et al*., 2010: Quality Parameters of the Wood Influencing its Finale Usage. Zvolen, Technical University in Zvolen (in Slovak).
24. Nikolov, S.; Videlov, C., 1987: Manual for Wood Drying. Zemizdat, Sofia, (in Bulgarian).
25. Perelygin, L. M., 1965: Wood Science. SVTL, Bratislava (in Slovak).
26. Pervan, S., 2009: Technology for Treatment of Wood with Water Steam. University in Zagreb (in Croatian).
27. Požgaj, A.; Chovanec, D.; Kurjatko, S.; Babiak, M., 1997: Structure and Properties of Wood. 2nd edition, Priroda a.s., Bratislava (in Slovak).
28. Reginač, L. *et al*., 1990: Wood Science II. VSLD in Zvolen (in Slovak).
29. Sergovski, P. S., 1975: Hydrothermal Treatment and Conserving of Wood. Publisher "Lesnaya promyshlennost", Moscow (in Rusian).
30. Shubin, G. S., 1990: Drying and Thermal Treatment of Wood. Publisher "Lesnaya promyshlennost", Moskow (in Russian).
31. Stamm, A. J., 1964: Wood and Cellulose Science. The Ronald Press Company, New York.
32. Steinhagen, H. P., 1986: Computerized Finite-difference Method to Calculate Transient Heat Conduction with Thawing. Wood Fiber Sci., 18 (3): 460-467.
33. Steinhagen, H. P., 1991: Heat Transfer Computation for a Long, Frozen Log Heated in Agitated Water or Steam - A Practical Recipe. Holz Roh- Werkstoff, 49: 287-290. http://dx.doi.org/10.1007/ BF02663790
34. Trebula, P., 1996: Drying and Hydrothermal Treatment of Wood. Technical University in Zvolen (in Slovak).
35. Trebula, P.; Klement, I., 2002: Drying and Hydrothermal Treatment of Wood. Technical University in Zvolen (in Slovak).
36. Videlov, H., 2003: Drying and Thermal Treatment of Wood. Publishing House of the University of Forestry, Sofia (in Bulgarian).

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Some Physical and Mechanical Properties of Borate-Treated Oriental Beech Wood

Određena fizikalna i mehanička svojstva orijentalne bukovine impregnirane boratima

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ABSTRACT • *This study was designed to determine some physical properties such as surface roughness and oven dry density, and some mechanical properties such as modulus of elasticity (MOE) of borate-treated wood specimens. Wood specimens were prepared from Oriental beech (Fagus orientalis L.). Ammonium pentaborate octahydrate (APBO), ammonium tetrafluoroborate (ATFB), and sodium tetrafluoroborate (STFB) were used as borates. Before tests, wood specimens were impregnated with 0.25, 0.50, 1.50, and 3.00 percent aqueous solutions of borates.*
The results showed that borate treatment caused increases in oven dry density and surface roughness, while it decreased MOE values of Oriental beech.

Keywords: *borates, oven dry density, modulus of elasticity, surface roughness, Oriental beech*

SAŽETAK • *Cilj istraživanja bio je odrediti neka fizikalna obilježja kao što su hrapavost površine i gustoća u apsolutno suhom stanju te određena mehanička svojstva kao što su modul elastičnosti (MOE) uzoraka drva impregniranih boratima. Uzorci drva izrađeni su od orijentalne bukovine (Fagus orientalis L.). Amonij pentaborat oktahidrat (APBO), amonij tetrafluoroborat (ATFB) i natrij tetrafluoroborat (STFB) upotrijebljeni su kao borati. Prije ispitivanja, uzorci drva impregnirani su otopinom vode i 0,25 %, 0,50 %, 1,50 % i 3,00 % borata.*
Rezultati su pokazali da impregniranje drva orijentalne bukovine boratima pridonosi porastu gustoće u apsolutno suhom stanju i povećanju hrapavosti površine, a smanjuju se vrijednosti modula elastičnosti drva.

Ključne riječi: *borati, gustoća u suhom stanju, modul elastičnosti, hrapavost površine, orijentalna bukovina*

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1 INTRODUCTION
1. UVOD

Throughout the course of history, wood has remained one of the most important renewable natural resources available to man. It is a natural, cellular, composite material of botanical origin possessing unique structural and chemical characteristics that render it desirable for a broad variety of end users. (Yalinkilic, 2000). However, wood possesses several undesirable properties that impair its performance and limit its application. Flammability of wood is one of the most severe problems leading to huge loss of life and property (Lee *et al.*, 2004). The flammability of wood can be reduced by treating wood with fire retardants. Most existing fire retardants are effective in reducing different fire parameters of wood such as ignitability, heat release, and flame spread. In recent years, there has been a rapid increase in the application of chemicals to wooden materials in order to improve their physical, mechanical, biological, and fire properties (Brelid *et al.*, 2000; Chao and Lee, 2003; Su, 1997; Yalinkilic *et al.*, 1999). Borates have several advantages as wood preservative in addition to imparting flame retardancy, providing sufficient protection against wood destroying organisms and low volatility. Moreover, they are colorless and odourless (Hafizoglu *et al.*, 1994; Murphy, 1990; Drysdale, 1994; Chen *et al.,* 1997). Threshold levels of boron against microorganisms and insects were extensively studied by many researchers (Drysdale, 1994; Grace *et al.*, 1992; Tamashiro *et al.*, 1991; Lloyd, 1993). Borates provide protection against all forms of wood destroying organisms, including decay fungi (such as wet and dry rot), wood boring beetles (such as common furniture beetle, house longhorn beetle, and powder post beetles) and termites (including dry wood and subterranean) (Lloyd *et al.*, 1995). Baysal and Yalinkilic (2005) studied decay resistance of wood against brown and white rot fungi, impregnated with boron containing compound named PHN . They found that PHN imparted complete decay resistance against brown rot and white rot fungi *Tyromycetes palustris* and *Coriolus versicolor*, respectively. Simsek *et al.* (2010) investigated decay resistance of Oriental beech wood impregnated with some borates such as ammonium pentaborate octahydrate (APBO), ammonium tetrafluoroborate (ATFB), and sodium tetrafluoroborate (STFB). Results indicated that borate-treated wood showed considerable resistance against decay fungus compared to that of untreated control specimen. Kartal *et al.* (2004) reported that boron-containing quaternary ammonia compound, didecyl dimethyl ammonium tetrafluoroborate (DFB) treatment at 0.1 % concentration was efficient against subterranean termites, *Captotermes formosanus* Shiraki bases on mass loss in both leached and unleached wood specimens. Also, it is well known that boron compounds work efficiently as fire retardant chemicals for cellulosic materials. The fire retardant properties of boron containing compounds were surveyed by many scientists and proven to be effective since late 19th centuries (Lyons, 1970). Yuksel *et al.* (2014) investigated combustion properties of Oriental beech impregnated with boric acid, borax, and sodium perborate. They found that mass loss and temperature values of borate-treated wood specimens were lower than untreated wood specimens at all combustion stages. Jin *et al.* (2014) studied fire resistance of disodium octoborate tetrahydrate, and boric acid impregnated Southern pine wood by TG analysis. They found that while the mass loss rate decreased, the char yield increased impregnated with borates after TG analysis. However, borates are generally leachable from treated wood in ground contact conditions (Yalinkilic *et al.*, 1995). Therefore, the utilization of boron compounds is restricted to indoor conditions. Many attempts have already been made to reduce leaching of borates from treated wood through chemical fixation of boron. Baysal *et al.* (2004) investigated leaching of boric acid from Sugi wood when boric acid mixed with furfuryl alcohol. Results of the leaching tests indicated that boric acid readily lost its boron content in the early cycles of the leaching periods. When furfuryl alcohol was mixed with borates, boron was released to the leaching water at slower amounts, suggesting the possibility of longer protection of treated wood in service. Dauvergne *et al.* (2000) reported that the mixture of boric acid, glycerol, and glyxocal impregnated Wood pine results in less boron leaching due to formation of complexes. Lloyd *et al.* (1990) reported that the addition of polyols to borate solutions greatly increased the boron stability through borate/polyolchelate complexion.

Wood strength is affected when wood is treated with preservatives or fire retardant (FR) chemicals (Winandy and Margeret, 1988). Many of the metallic oxides commonly used in water-borne preservative formulations react with the cell wall components by undergoing hydrolytic reduction upon contact with wood carbohydrates. This process, known as fixation, oxidizes the wood cell wall component and may reduce wood strength (Dauvergne *et al.*, 2000). The relative impact of various water-borne preservative systems is directly related to the preservative chemistry and severity of its fixation/precipitation reaction (Winandy, 1996). Water-borne preservative treatments generally reduce the mechanical properties of wood more than oil-type preservative treatments, because water-borne preservative chemicals physically react with the wood cell wall material (Fruno and Gato, 1978). Toker *et al.* (2008) studied about the compression strength parallel to grain (CSPG) of Oriental beech and Calabrian pine impregnated with boric acid, borax and sodium perborate. They found that CSPG of both wood specimens impregnated with borates were lower than the untreated wood specimens. Simsek *et al.* (2010) studied modulus of rupture (MOR) of Oriental beech wood impregnated with ammonium pentaborate octahydrate (APBO), ammonium tetrafluoroborate (ATFB) and sodium tetrafluoroborate (STFB). They found that MOR of borate- treated Oriental beech was lower than untreated wood.

This study was performed to determine some physical properties such as surface roughness and oven dry density, and some mechanical properties such as modulus of elasticity of Oriental beech wood impregnated with aqueous solutions (0.25 %, 0.50 %, 1.50 %, and 3.00 %) of ammonium pentaborate octahydrate (APBO), ammonium tetrafluoroborate (ATFB) and sodium tetrafluoroborate (STFB).

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

2.1 Preparation of test specimens and chemicals
2.1. Priprema uzoraka drva i kemikalija

Wood specimens measuring 20 (tangential) x 20 (radial) x 360 (longitudinal) mm, 20 (tangential) x 20 (radial) x 20 (longitudinal), and 75 (tangential) x 6 (radial) x 150 (longitudinal) mm were prepared from air-dried sapwood of Oriental beech for MOE, oven dry density and surface roughness tests, respectively. Aqueous solutions of ammonium pentaborate octahydrate (APBO), ammonium tetrafluoroborate (ATFB) and sodium tetrafluoroborate (STFB) were dissolved in distilled water at concentrations of 0.25 %, 0.50 %, 1.50 %, and 3.00 %. Ammonium pentaborate octahydrate was purchased from Alfa-Aesar Chemicals while ammonium tetrafluoroborate and sodium tetrafluoroborate were purchased from Sigma–Aldrich Chemicals. Purities of APBO, ATFB, and STFB were 99.5 %, ≥98 %, and 97-100 %, respectively.

2.2 Impregnation method
2.2. Metoda impregnacije

Wood specimens were impregnated with aqueous solutions of borates according to ASTM D 1413-76 (1976). Treatment solutions were prepared the day before the impregnation for homogenizing. A vacuum desiccator used for the impregnation process was connected to a vacuum pump through a vacuum trap. Vacuum was applied for 60 min at 760 mmHg before supplying the solution into the chamber followed by another 60 min at 760 mmHg diffusion period under vacuum. Retention of boron was calculated from the following equation:

$$\text{Retention}\left(\frac{\text{kg}}{\text{m}^3}\right) = \frac{G \text{ x } C}{V} \text{ x } 10$$

Where:
G – the amount of solution absorbed by the wood
$G = T_2 - T_1$,
T_2 – the weight of wood after impregnation (g),
T_1 – the weight of wood before impregnation (g),
C – the concentration of the solution as a percentage,
V – the volume of the specimen in cm^3.

2.3 Surface roughness (R_z)
2.3. Hrapavost površine (R_z)

Roughness parameter, which is mean peak-to-valley height (*Rz*), can be calculated from the peak-to valley values of five equal lengths within the profile. Surface roughness measurement was made in the direction parallel to grain according to DIN 4768 (1990).

2.4 Oven dry density
2.4. Gustoća drva u suhom stanju

Oven dry density values of wood specimens were determined according to TS EN 2472 standard (1976) and the values were calculated with the following equation:

$$d_0\left(\frac{\text{g}}{\text{cm}^3}\right) = \frac{W_{(0)}}{V_{(0)}}$$

Where
d_o – oven dry density value of wood specimens
W_o – oven dry weight of wood specimens
V_0 – oven dry volume of wood specimens.

2.5 Modulus of elasticity (*MOE*)
2.5. Modul elastičnosti (*MOE*)

The modulus of elasticity of wood specimens was determined according to TS EN 310 (1999). Wood specimens had been conditioned at 20 °C and 60 % RH for two weeks prior to testing. The *MOE* of wood specimens treated with borates was calculated using the following formula:

$$MOE\left(\frac{\text{N}}{\text{mm}^2}\right) = \frac{P \text{ x } I^3}{4 \text{ x } b \text{ x } h^3 \text{ x } Y}$$

Where P is the maximum load (N), I is span (mm), b is the width of specimen (mm), h is thickness of specimen (mm), and Y is the deflection (mm).

2.6 Evaluations of test results
2.6. Analiza dobivenih rezultata

Test results were evaluated by a computerized statistical program composed of analysis of variance and following Duncan tests at the 95 % confidence level. Statistical evaluations were made on homogeneity groups (HG), of which different letters reflected statistical significance.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Surface roughness of borate-treated Oriental beech wood specimens
3.1. Hrapavost površine uzoraka orijentalne bukovine impregniranih boratima

Surface roughness (R_z) values of wood specimens before and after borate treatment are given in Table 1. Our results showed that borate treatments increased surface roughness of Oriental beech. The increase of *Rz* was changed nearly from 30 % to 92 % after borate treatments. Therefore, it was concluded that the surface of borate-treated Oriental beech was rougher after treatment. The wooden materials with rough surface need more sanding process than those with smooth surface. However, sanding process causes a decrease in t of material (Follrich *et al.* 2006). Our results showed that increased solution concentration of borates did not adversely influence surface roughness of Oriental beech. Among the treatment solutions, 3.00 % APBO caused the lowest increase of surface roughness, while the treatment with 3.00 % ATFB caused the highest increase of surface roughness of Oriental beech. Ayrilmis *et al.* (2006) investigated the effect of various fire retardants on surface roughness of plywood. They found that samples treated with 6 % concentration of boric acid had the highest R_z value. Also, they reported that the R_z values of borax, boric acid and monoammonium phosphate at higher concentration (6 % or 11 %) were always rougher than at lower concentrations (3 %) except for 11 % concentration of diammonium phosphate. However, the roughness of wood is a complex phenomenon. Several factors, such as anatomical structure of wood, growing characteristics, machining properties and pre-treatments of wood before machining, should be considered for the evaluation of the surface roughness of wood (Aydın and Colakoglu, 2003; Aydın and Colakoglu, 2005; Temiz *et al.*, 2005).

3.2 Oven dry density values of borate-treated Oriental beech wood specimens
3.2. Vrijednosti gustoće u suhom stanju uzoraka orijentalne bukovine impregniranih boratima

The oven dry density values of wood specimens are given in Table 2. The oven dry densities of borate-treated Oriental beech wood specimens were ranged from 0.566 to 0.685 g/cm^3. The oven dry density values of borate-treated wood specimens were higher compared to untreated wood specimen. The highest oven dry density value of wood specimens was obtained as 0.685 g/cm^3 for those treated with 3.00 % APBO. The lowest oven dry density value was obtained as 0.547 g/cm^3 for untreated Oriental beech. According to our results, there was a statistical difference in oven dry density values between untreated Oriental beech and impregnated Oriental beech with 3 % concentration of all borates. Toker (2007) found that oven dry density values of boric acid, borax and sodium perborate treated wood specimens were higher than values of untreated wood specimens. Our results are consistent with data from Toker (2007). Density plays an important role in influencing both physical and mechanical properties of wood and wood-based materials (Akbulut *et al.*, 2004). There is, in fact, a close correlation between mechanical properties, hardness, abrasion resistance and heat value of wood on the one hand, and density on the other (Kollman and Cote, 1968). Also, wood density is an important factor determining possible uses of wood. For instance, strength, flexibility and surface hardness of heavy wood are higher than those of light wood. It gives better protection against corrosive effects. In some situations, it is desirable for wood to be soft, easy processing and have lower shrinkage and swelling. This can be possible when wood is light (Ors and Keskin, 2008). According to our results, borate treatment increased oven dry density values of wood specimens.

3.3 MOE of borate treated Oriental beech wood specimens
3.3. Modul elastičnosti uzoraka orijentalne bukovine impregniranih boratima

The MOE of wood specimens are given in Table 3. The MOE values of borate-treated wood specimens were lower compared to untreated wood specimen. Our results showed that borate treatments decreased MOE of Oriental beech (1.42 - 15.18 %). The highest MOE value of wood specimen was 11821 N/mm^2 for untreated Oriental beech. The lowest MOE value was 10026 N/mm^2 for treated specimens with 3.00 % APBO. In general, the MOE values of wood specimens were the lowest for those treated with 3.00 %, 1.50 %, 0.50 % and 0.25 %, respectively. No statistical difference was found in MOE values between untreated Oriental beech wood and borate-treated Oriental beech wood. Colakoglu *et al.* (2003) found that MOE levels of laminated veneer lumber treated with 5 % boric acid were reduced by 3.8 % compared to untreated control. Gerhards (1970) found that fire-retardant chemical treatment and kiln-drying reduce the *MOE* of wood by an average of 5 %. Toker *et al*. (2009) re-

Table 1 Surface roughness (R_z) values of borate-treated Oriental beech wood specimens
Tablica 1. Vrijednosti hrapavosti površine uzoraka orijentalne bukovine impregniranih boratima

Chemicals *Kemikalija*	**Concentration** *Koncentracija* %	**Before impregnation** *Prije impregnacije*		**After impregnation** *Nakon impregnacije*		**Change** *Promjena* %
		Mean[a]	SD	Mean[a]	SD	
Untreated / *neimpregnirano*	-	32.92	12.37	-	-	-
APBO	0.25	34.54	7.99	51.02	14.57	+47.71
	0.50	28.93	2.36	46.07	5.28	+59.25
	1.50	28.22	6.38	50.95	6.31	+80.55
	3.00	37.12	11.12	48.28	6.60	+30.06
ATFB	0.25	33.77	7.78	59.79	6.99	+77.05
	0.50	35.49	15.61	60.87	18.18	+71.51
	1.50	35.55	20.81	59.76	19.62	+68.10
	3.00	28.29	11.77	54.35	20.04	+92.12
STFB	0.25	29.66	3.10	46.44	4.11	+56.57
	0.50	26.13	8.25	48.75	8.39	+86.57
	1.50	33.25	14.90	54.83	15.64	+64.90
	3.00	27.99	8.16	53.15	7.79	+89.89

Note: [a] Results reflect observations of five wood specimens / *Rezultati se odnose na pet uzoraka drva*.
SD – Standard deviation / *standardna devijacija*; APBO – Ammonium pentaborate octahydrate / *amonij pentaborat oktahidrat*; ATFB – Ammonium tetrafluoroborate / *amonij tetrafluoroborate*; STFB – Sodium tetrafluoroborate / *natrij tetrafluoroborat*

Table 2 Oven dry density values of borate-treated Oriental beech wood specimens
Tablica 2. Vrijednosti gustoće u suhom stanju uzoraka orijentalne bukovine impregniranih boratima

Chemicals *Kemikalija*	**Concentration** *Koncentracija* %	**Retention** *Retencija* kg/m³	**Mean**[a] g/cm³	**SD**	**HG**	**Change** *Promjena* %
Untreated / *neimpregnirano*	-	-	0.547	0.018	A	-
APBO	0.25	1.37	0.568	0.054	A	3.84
	0.50	2.13	0.585	0.051	AB	6.95
	1.50	7.16	0.614	0.056	ABC	12.25
	3.00	18.24	0.685	0.018	C	25.23
ATFB	0.25	1.66	0.572	0.055	AB	4.57
	0.50	2.79	0.566	0.016	A	3.47
	1.50	9.10	0.684	0.052	C	25.05
	3.00	16.21	0.670	0.025	C	22.49
STFB	0.25	1.68	0.588	0.019	AB	7.50
	0.50	2.50	0.643	0.030	BC	17.55
	1.50	8.33	0.646	0.017	BC	18.10
	3.00	15.26	0.678	0.052	C	23.95

Note: [a] Results reflect observations of ten wood specimens / *Rezultati se odnose na deset uzoraka drva*.
HG - Homogeneity groups obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95 % confidence level. / *homogenost grupe dobivena statističkim testom označena je istim slovima i upućuju na statistički nesignifikantne razlike uz pouzdanost 95 %*; SD – Standard deviation / *standardna devijacija*; APBO – Ammonium pentaborate octahydrate / *amonij pentaborat oktahidrat*; ATFB – Ammonium tetrafluoroborate / *amonij tetrafluoroborat*; STFB – Sodium tetrafluoroborate / *natrij tetrafluoroborat*

ported that *MOE* values of borate-treated Oriental beech wood were lower compared to untreated Oriental beech wood. Yildiz *et al.* (2004) reported that there was an almost 10 % decrease in *MOE* of yellow pine (*Pinus sylvestris* L.) wood samples treated with CCA. Our results are consistent with the findings of the aforementioned studies. According to our results, borate treatments decreased *MOE* of Oriental beech by 1.42 % to 15.18 %. It may be due to the fact that waterborne preservative formulations do react with the cell wall components by undergoing hydrolytic reduction upon contact with wood sugars. This process, known as fixation, oxidizes the wood cell wall components and may reduce wood strength (Winandy and Margeret, 1988). Our results showed that, generally, higher concentration levels of borates resulted in lower *MOE* values of Oriental beech wood specimens. The National Forest Products Association (NFPA) (1973) recommends that the allowable stresses for fire-retardant treated wood for design purposes be reduced by 10 % as compared to untreated wood; the allowable loads for fasteners are also reduced by 10 %. Also, it requires a 10 to 20 % reduction in allowable design stress, depending on mechanical property under consideration (NFPA, 1986). Therefore, our results meet NFPA requirements.

Table 3 Modulus of elasticity (MOE) values of borate-treated Oriental beech wood specimens
Tablica 3. Vrijednosti modula elastičnosti uzoraka orijentalne bukovine tretiranih boratima

Chemicals *Kemikalija*	**Concentration** *Koncentracija* %	**Retention** *Retencija* kg/m³	**Mean**[a] g/cm²	**SD**	**HG**	**Change** *Promjena* %
Untreated / *neimpregnirano*	-	-	11821	1274	A	-
APBO	0.25	0.76	10990	1147	A	-7.03
	0.50	1.23	10656	1086	A	-9.86
	1.50	3.29	10389	916	A	-12.11
	3.00	9.58	10026	1029	A	-15.18
ATFB	0.25	0.46	11653	1277	A	-1.42
	0.50	1.54	11523	1349	A	-2.52
	1.50	4.65	11275	1125	A	-4.62
	3.00	8.44	10761	1048	A	-8.97
STFB	0.25	0.73	11145	1186	A	-5.72
	0.50	1.72	11034	1240	A	-6.66
	1.50	5.97	11374	1127	A	-3.78
	3.00	14.32	10502	1043	A	-11.16

Note: [a] Results reflect observations of ten wood specimens / *Rezultati se odnose na deset uzoraka drva*.
HG - Homogeneity groups obtained by statistical analysis with similar letters reflecting statistical insignificance at the 95% confidence level. / *homogenost grupe dobivena statističkim testom označena je istim slovima i upućuje na statistički nesignifikantne razlike uz pouzdanost 95 %*; SD – Standard deviation / *standardna devijacija*; APBO – Ammonium pentaborate octahydrate / *amonij pentaborat oktahidrat*; ATFB – Ammonium tetrafluoroborate / *amonij tetrafluoroborat*; STFB – Sodium tetrafluoroborate / *natrij tetrafluoroborat*

4 CONCLUSIONS
4. ZAKLJUČAK

Surface roughness, oven dry density, and MOE of borate-treated Oriental beech were investigated in this study. Borate impregnation was concluded to cause increase in oven dry density and surface roughness, and decrease in MOE of Oriental beech.

In conclusion, borate treatments increased oven dry density values of Oriental beech wood specimens. Wood density affects the possible uses of wood. Heavy wood has better protection against corrosive effects because of its strength, flexibility and surface hardness than light wood (Ors and Keskin, 2008). However, it caused rougher wood surface and lower MOE of Oriental beech. In rougher wood surface, losses occurring in the planing machine are increased and low quality surfaces are attained. Modulus of elasticity is a measure of stiffness of a material. Therefore, *MOE* values are important for designing wood constructions (Yildiz *et al.,* 2004). Our results showed that borate treatments decreased *MOE* of Oriental beech by 1.42 % to 15.18 %. However, our results met the requirements of the National Forest Products Association (NFPA) for design purposes.

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5 REFERENCES
5. LITERATURA

1. ASTM-D 1413-76, 1976: Standard test method of testing wood preservatives by laboratory soilblock cultures. Annual book of ASTM standards, pp. 452-460.
2. Akbulut, T.; Kartal, S. N.; Green, III F., 2004: Fiberboards treated with N'-N (1,8 Naphthalyl) Hydroxylamine (NHA-Na), borax, and boric acid. Forest Prod J, 54 (10): 59-64.
3. Aydın, I.; Colakoglu, G., 2003: Roughness on wood surfaces and roughness measurement methods. Kafkas Univ, Journal Artvin Forestry Faculty, 4 (12): 92-102.
4. Aydın, I.; Colakoglu, G., 2005: Effects of surface inactivation, high temperature drying and preservative treatment on surface roughness and colour of alder and beech wood. Applied Surface Science, 252 (2): 430-440. http://dx.doi.org/10.1016/j.apsusc.2005.01.022
5. Ayrilmis, N.; Korkut, S.; Tanrıtanır, E.; Winandy, J. E.; Hiziroglu, S., 2006: Effect of various fire retardants on surface roughness of plywood. Build Environ, 41 (7): 887-892. http://dx.doi.org/10.1016/j.buildenv.2005.04.011
6. Baysal, E.; Ozaki, S. K.; Yalinkilic, M. K., 2004: Dimensional stabilization of wood treated with furfuryl alcohol catalysed by borates. Wood Science and Technology, 38: 405-415. http://dx.doi.org/10.1007/s00226-004-0248-2
7. Baysal, E.; Yalinkilic, M. K., 2005: A comparative study on stability and decay resistance of some environmentally friendly fire-retardant boron compounds. Wood Science and Technology, 39: 169-186. http://dx.doi.org/10.1007/s00226-004-0264-2
8. Brelid, P. L.; Simonson, R.; Bergman, O.; Nilsson, T., 2000: Resistance of acetylated wood to biological degradation. Holz Roh Werkst, 58 (5): 331-337. http://dx.doi.org/10.1007/s001070050439
9. Chao, W. Y.; Lee, A. W., 2003: Properties of Southern pine wood impregnated with styrene. Holzforschung, 57 (3): 333-336. http://dx.doi.org/10.1515/HF.2003.049
10. Chen, P. Y. S.; Puttman, M. E.; Williams, L. H.; Stokke, D. D., 1997: Treatment of hardwood lumber with borate preservation. Forest Prod J, 47 (6): 63-68.
11. Colakoglu, G.; Colak, S.; Aydin, I.; Yildiz, U. C.; Yildiz, S., 2003: Effects of boric acid treatment on mechanical properties of laminated beech veneer lumber. Silva Fenn, 37 (4): 505-510. http://dx.doi.org/10.14214/sf.488
12. Dauvergne, E. T.; Soulounganga, P.; Gerardin, P.; Loubinoux, B., 2000: Glycerol/ glyoxal, a new boron fixation system for wood preservation and dimensional stabilization. Holzforschung, 54 (2): 123-126. http://dx.doi.org/10.1515/HF.2000.021
13. DIN 4768, 1990: Determination of values of surface roughness parameters R_a, R_z, R_{max} using electrical contact (stylus) instruments. Concepts and measuring conditions, Deutsches Institut für Norming, Berlin, Germany.
14. Drysdale, J. A., 1994: Boron treatments for the preservation of wood-a review of efficacy do to for fungi and termites. The Int. Res. Group on Wood Preservation, IRG/WP.
15. Follrich, J.; Muller, U.; Gindl, W., 2006: Effects of thermal modification on the adhesion between spruce wood (*Picea abies* Karst.) and a thermoplastic polymer. Holz als Roh- und Werkstoff, 64: 373-376. http://dx.doi.org/10.1007/s00107-006-0107-y
16. Fruno, T.; Gato, T., 1978: Structure of interface between wood and synthetic polymer (XI). The role of polymer in the cell wall on the dimensional stability of wood polymer composite. Mokuzai Gakkaishi, 24 (5): 287-293.
17. Gerhards, C. C., 1970: Effect of fire-retardant treatment on bending strength of wood. Res. Pap. FPL, US Department of Agriculture, Forest Serv., Forest Prod. Lab., Madison, WI, pp.145.
18. Grace, J. K.; Yamamoto, R. T.; Tamashiro, M., 1992: Resistance of borate-treated Douglas-fir to the Formusan subterranean termite. Forest Prod J, 42 (2): 61-65.
19. Hafizoglu, H.; Yalinkilic, M. K.; Yildiz, U. C.; Baysal, E.; Demirci, Z.; Peker, H., 1994: Utilizations of Turkey's boron reserves in wood preservation industry. Project of the Scientific and Technical Research Council of Turkey (Tübitak) (In Turkish).
20. Jin, S.; Yan, L.; Jing-Yu, W.; Fei, W.; Zhen-Zhong, G., 2014: Fire resistance of boron- containing fire-retardant by TG analysis. Journal of Chemical and Pharmaceutical Research, 6 (1): 332-337.
21. Kartal, S. N.; Hwang, W. J.; Shinoda, K.; Imamura, Y., 2004: Laboratory evaluation of boron- containing quaternary ammonia compound, didecyl dimethyl ammonium tetrafluoroborate (DFB) for control of decay and termite attack and fungal staining of wood. Holz als Roh- und Werkstoff, 64: 62-67. http://dx.doi.org/10.1007/s00107-005-0050-3
22. Kollmann, F.; Cote, W. A., 1968: Principles of wood science and technology I. Solid wood. Springer-Verlag, pp. 149-151. http://dx.doi.org/10.1007/978-3-642-87928-9
23. Lee, H.; Chen, G. C.; Rowell, R. M., 2004: Thermal properties of wood reacted with a phosphorus pentoxide-

amine system. J. Appl. Polym. Sci., 91 (4): 2465-2481. http://dx.doi.org/10.1002/app.13408
24. Lloyd, J. D.; Dickinson, D. J.; Murphy, R. J., 1990: The probable mechanisms of action of boric acid and borates as wood preservatives. International Research Group on Wood Preservation. IRG/WP/1450. IRG Secretariat, Stockholm, Sweden.
25. Lloyd, J. D., 1993: The mechanisms of boron-containing wood preservatives. Ph.D Thesis, Imperial College of Science, Technology of Medicine, Department of Biology, pp. 352.
26. Lloyd, J. D.; Manning, M. J., 1995: Developments in borate preserving technology. B.W.P.D.A. Annual Convention, Borax Inc., U.K.
27. Lyons, J. W., 1970: The chemistry and uses of fire retardants. Wiley Intersciences, New York, pp. 165-168.
28. Murphy, R. J., 1990: Historical perspective in Europe. In: Hemel, M. (ed). Proceedings of the First International Conference on Wood Protection with Diffusible Preservatives, 28-30 Nov., Nashville, Tennessee, pp. 9-13.
29. NFPA, 1973: National design specification for stress-grade lumber and its fastenings. Washington (DC): National Forest Products Association.
30. NFPA, 1986: National design specification for wood construction. Washington (DC). National Forest Products Association.
31. Ors, Y.; Keskin, H., 2008: Ağaç Malzeme Bilgisi. Gazi Kitabevi, 8th Press, Ankara, pp. 199 (In Turkish).
32. Simsek, H.; Baysal, E.; Peker, H., 2010: Some mechanical properties and decay resistance of wood impregnated with environmentally-friendly borates. Construction and Building Materials, 24: 2279-2284. http://dx.doi.org/10.1016/j.conbuildmat.2010.04.028
33. Su, Wen-Yu., 1997: Development of fire-retardant wood composites using boron compounds and their evaluation methods. Ph.D. Thesis, Kyoto University, Kyoto, Japan.
34. Tamashiro, M.; Yamamoto, R. T.; Grace, J. K., 1991: Treatment of Douglas-fir heartwood with disodium octaborate terahydrate (Tim-Bor) to prevent attack by the Formusan subterranean termite. The International Research Group on Wood Preservation, 22 nd., Annual Meeting Kyoto, Japan.
35. Temiz, A.; Yildiz, U. C.; Aydin, I.; Eikenes, M.; Alfredsen, G.; Colakoglu, G., 2005: Surface roughness and colour characteristics of wood treated with preservatives after accelerated weathering test. Appl Surf Sci, 250 (1-4): 35-42. http://dx.doi.org/10.1016/j.apsusc.2004.12.019.
36. Toker, H., 2007: Determination of effects of boron compounds on some physical mechanical and biological properties of wood. Ph.D. Thesis, Gazi University Science Enstitute, Ankara, Turkey, pp. 213 (In Turkish).
37. Toker, H.; Baysal, E.; Ozcifci, A.; Altinok, M.; Sonmez, A., 2008: An investigation on compression strength parallel to grain values of wood impregnated with some boron compounds. Wood Research, 53 (4): 59-68.
38. Toker, H.; Baysal, E.; Simsek, H.; Senel, A.; Sonmez, A.; Altinok, M., 2009: Effects of some environmentally-friendly fire-retardant boron compounds on modulus of rupture and modulus of elasticity of wood. Wood Research, 54 (1): 77-88.
39. TS EN 2472, 1976: Wood-determination of density for physical and mechanical tests. Turkish Standards Institute, Ankara, Turkey (In Turkish).
40. TS EN 310, 1999: Wood based panels-The determination of static bending strength and modulus of elasticity. Turkish Standards Institute, Ankara, Turkey (In Turkish).
41. Winandy, J. E.; Margaret, E. H., 1988: Wood protection techniques and the use of treated wood in construction: Proceedings. Memphis, TN. Madison, WI: Forest Prod. Res. Soc., pp. 54-62.
42. Winandy, J. E., 1996: Effects of treatment, incising, and drying on mechanical properties of timber: National conference on wood transportation structures. Gen. Tech. Rep. FPL-GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Product Laboratory.
43. Yalinkilic, M. K.; Baysal, E.; Demirci, Z., 1995: Effect of boron preservatives on hygroscopicity of Brutia pine wood. Eng. Sci. J Pamukkale Univ, 1 (2-3): 161-168, (In Turkish).
44. Yalinkilic, M. K.; Takahashi, M.; Imamura, Y.; Gezer, E. D.; Demirci, Z.; Ilhan, R., 1999: Boron addition to non or low formaldehyde cross-linking reagents to enhance biological resistance and dimensional stability for wood. Holz Roh Werkst, 57 (1): 151-163. http://dx.doi.org/10.1007/s001070050358
45. Yalinkilic, M. K., 2000: Improvement of boron immobility in the borate treated wood and composite materials. Ph.D.Thesis, Kyoto University, Kyoto, Japan.
46. Yuksel, M.; Baysal, E.; Toker, H.; Simsek, H., 2014: Combustion characteristics of Oriental beech wood impregnated with commonly used borates. Wood Research, 59 (1): 39-50.
47. Yildiz, U. C.; Temiz, A.; Gezer, E. D.; Yildiz, S., 2004: Effects of wood preservatives on mechanical properties of yellow pine (*Pinus sylvestris* L.) wood. Build Environ, 39 (9): 1071-1075. http://dx.doi.org/10.1016/j.buildenv.2004.01.032

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Pyrolysis of Firwood (*Abies bornmülleriana* Mattf.) Sawdust: Characterization of Bio-Oil and Bio-Char

Piroliza jelove (*Abies bornmülleriana* Mattf.) piljevine: karakterizacija bioulja i biougljena

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ABSTRACT • *This paper describes the research of slow pyrolysis of firwood (Abies bornmülleriana Mattf.) sawdust by using fixed-bed reactor. The effect of temperature ranging between 350 and 600 °C on gas, liquid and solid products was examined. The maximum bio-oil yield of 45.9 % was obtained at the final pyrolysis temperature of 500 °C. The elemental analysis and heating value of bio-oil and bio-char were determined, and then the chemical composition of the bio-oil was investigated using chromatographic and spectroscopic techniques such as Gas Chromatography–Mass Spectrometry (GC/MS) and Proton Nuclear Magnetic Resonance (^{1}H-NMR). The liquid product was mainly composed of phenolics, including 2-methoxy-phenol, 2-methyl-phenol, phenol, as well as aldeyhdes, acids, esters, alcohols and ketones. The chemical characterization has shown that the bio-oil obtained from residues of forestry production, such as firwood sawdust, can be used as an environmental feedstock, which is an ideal candidate for alternative fuels. Moreover the bio-char can be used as an energy source and active carbon.*

Keywords: *Bio-oil, Fir wood, GC/MS,^{1}H-NMR, Pyrolysis*

SAŽETAK • *U radu je opisano istraživanje spore pirolize jelove (Abies bornmülleriana Mattf.) piljevine uz primjenu fiksnog reaktora. Analiziran je učinak temperature u rasponu od 350 do 600 °C na plinovite, tekuće i krute proizvode pirolize. Maksimalni prinos bioulja od 45,9 % dobiven je na konačnoj temperaturi pirolize od 500 °C. Napravljena je elementarna analiza i određena ogrjevna vrijednost bioulja i biougljena, a zatim je ispitan kemijski sastav bioulja uz pomoć kromatografskih i spektroskopskih tehnika kao što su plinska kromatografija i masena spektrometrija (GC/MS) te protonska nuklearna magnetska rezonancija (^{1}H-NMR). Tekući proizvodi pirolize sastavljeni su uglavnom od fenola, uključujući 2-metoksi-fenol, 2-metil-fenol, fenol, kao i od aldehida, kiselina, estera, alkohola i ketona. Kemijska su svojstva pokazala da je bioulje dobiveno od ostataka proizvodnje u šumarstvu, poput jelove piljevine, raspoloživa sirovina iz okoliša koja je idealna za alternativna goriva. Osim toga, biougljen se može koristiti kao izvor energije i kao aktivni ugljen.*

Ključne riječi: *bioulje, jelovina, GC/MS, ^{1}H-NMR, piroliza*

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1 INTRODUCTION
1. UVOD

Renewable energy is of growing importance in satisfying environmental concerns over fossil fuel usage. Wood and other forms of biomass, including energy crops and agricultural and forestry wastes, are some of the main renewable energy resources available. This growing interest also resulted in intensive research of thermal conversion techniques for biomass, consisting of combustion, gasification and pyrolysis (Bridgwater, 2003; Janse*et al.,* 2000). Pyrolysis is an attractive technology for converting biomass into gases, liquids (bio-oil), and char at relatively low temperature ranging between 300 and 600 °C in the absence of oxygen (Murata *et al.,* 2012; Bu *et al.,* 2011).

Bio-oil is referred to by many names such as pyrolysis oil, bio-crude-oil, bio-fuel-oil, wood liquids, wood oil, liquid smoke, wood distillates, pyroligneous tar, and pyroligneous acid. The bio-oil is usually dark brown and free flowing with a distinctive smoky smell. Bio-oil is a mixture of about 200 types of major and minor organic compounds and can be used for the production of chemicals and substituted for fuel–oils in many stationary applications for heat or electricity generation. The gas products can be used in engines and turbines for power generation. Bio-char can also be used as a fuel (Bridgwater, 2004; Uzun and Sarıoğlu, 2009; Enginar*et al.,* 2009; Özcimen and Ersoy-Mericboyu, 2010).

As a clean fuel, bio oil has a number of practical advantages including the following:

- it is renewable and locally produced from organic waste,
- it can be stored and transported similarly to petroleum-based products,
- it is a neutral greenhouse gas and can generate carbon dioxide,
- it generates lower NOx emissions than light fuel oil in gas turbines and diesel fuel in stationary diesel engines (Sadaka, 2009).

Numerous researchers have investigated various pyrolysis processes that were developed to maximize the formation of liquid products used as fuels or chemical feedstock. Şensöz (2003) pyrolyzed pine bark (*Pinusbrutia*Ten.) in an externally heated fixed-bed reactor at 300 °C and 500 °C with heating rates of 7 and 40 °C/min. The product yields were significantly influenced by the process conditions. The bio-oil was obtained at 450 °C, at which the liquid product yield was maximum. In addition, the solid and liquid products were analyzed to determine their elemental composition and calorific value. Chemical fractionation of bio-oil showed that only low quantities of hydrocarbons were present, while oxygenated and polar fractions dominated (Şensöz, 2003). Ingram *et al.* (2008) have investigated pyrolysis of pinewood, pine bark, oak wood and oak bark in a continuous auger reactor. They found that the yield of bio-oil from pine was 40 to 55 % at 450 °C (Ingram *et al.,* 2008). Wangand co-workers produced bio-oil from pine wood sawdust at different temperature ranges and analyzed the fuel properties of bio-oil. They reported that the degradation of hemicellulose started at 200 to 300 °C, forming many sorts of liquid products, such as saccharide, furan, carboxylic acid, ketone and aldehyde, with the occurrence of dehydration, decarboxylation and decarbonylation, while cellulose remained unimpaired in its polymerized structure. Cellulose was substantially decomposed at 300 to 50 °C, leading to a great increase in the yields of liquid and gaseous products, and simultaneously the solid residue became aromatized, which was characteristic of a concentrated lignin structure. The residue was largely decomposed to numerous guaiacols and phenols at 450 to 700 °C (Wang *et al.,* 2009).

In this work, fir wood sawdust (*Abiesbornmülleriana*Mattf.) was pyrolyzed at various temperatures, using a fixed bed type reactor. The aim of this study was to elucidate the effect of temperature during slow pyrolysis on yields of the bio-oil, gas and bio-char. The chemical properties of bio-oil were characterized by GC/MS, ^{1}H-NMR and elemental analysis. Also, the characterization of bio-char was performed in terms of its elemental composition and Fourier transform infrared spectroscopy (FT-IR).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Materials and sample preparation
2.1. Materijali i priprema uzoraka

Fir wood (*Abiesbornmülleriana*Mattf.) was used in this study as the raw lignocellulosic biomass, which is one of the widespread and abundant species in the northwestern and Marmara regions of Turkey. Fir wood is an important commercial wood; it can be used for furniture and building materials, which produces large amounts of sawdust and wood residues every year. The raw sawdust sample supplied by the Department of Furniture and Decoration at Karabük University was ground and sieved to less than 1 mm, and it was then dried for 12 hours at 100 to 105 °C prior to use as a pyrolysis sample.

The proximate analysis was performed according to the ASTM standard test methods for measuring moisture contents, combustible matter and ash contents, and namely ASTM D 4442-92, ASTM E897-88 and ASTM D-1102-84, respectively. The chemical composition of feedstock was determined according to Wise and John, 1952, Rowell *et al*. 2005 and TAPPI standards (T-257, T-222, T-204). The ultimate analysis was conducted using an elemental analyzer (LECO CHNS-932). The oxygen content of the biomass was found by the difference. The H/C and O/C molar ratios were calculated from elemental composition. The HHV of the fir wood sawdust was calculated based on Dulong formula (Wang *et al.,* 2007)

2.2 Thermal analysis
2.2. Toplinska analiza

The thermal decomposition of raw material was examined by using a thermogravimetric analyzer (Per-

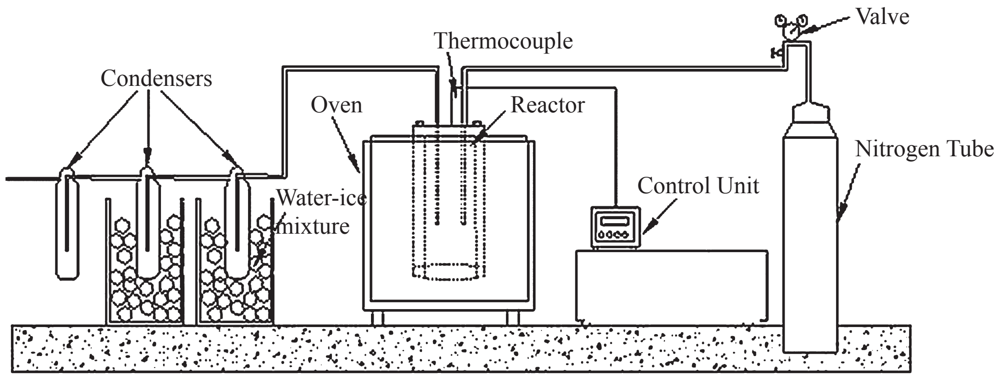


Figure 1 Schematic diagram of pyrolysis apparatus
Slika 1. Shematski prikaz uređaja za pirolizu

kin Elmer Pyris 1). For the TGA experiment, approximately15 mg of sample was used with a 10 °C/min. heating rate. Nitrogen was used as the carrier gas, with a flow rate of 25 ml/min. After that, the sample was heated from 25 °C to 600 °C.

2.3 Pyrolysis
2.3. Piroliza

Pyrolysis experiments were performed in a fixed-bed reactor under a nitrogen atmosphere. The reactor has a steel cylinder with an internal diameter of 6 cm and a height of 21 cm. A schematic diagram of pyrolysis apparatus is shown in Figure 1. During the experiments, heating rate and pyrolysis temperatures were controlled with a PID (Proportional–Integral–Derivative) controller. The temperature was measured every minute in the reactor using a type K thermocouple. In the pyrolysis experiment, a sample of 50 g was weighed and placed into the reactor, which was heated by an electric furnace. The temperature was increased from room temperature to 350, 400, 450, 500, 550 and 600 °C, while the heating rates were increased 15 °C/min. Experimental apparatus was held at an adjusted temperature either for a minimum of 30 min or until no further significant release of gas was observed. A condenser was connected to the output of the reactor and the liquid was condensed in a collector to be weighed. The bio-char collected in the reactor was weighed at the end of the experiment. The gas yield was calculated by taking the difference. Experiments were repeated at least three times within the experimental error of less than ±0.5 %.

2.4 Characterizations
2.4. Karakterizacija

Liquid products were extracted with an equal quantity of diethyl ether. The diethyl ether extracts were analyzed by instrumental techniques such as Elemental, GC/MS and ^{1}H-NMR. The carbon, hydrogen and nitrogen contents of bio-oils were determined using a LECO CHNS-932 Elemental Analyzer. The oxygen content of bio-oils was found by the difference. The chemical composition of the liquid product was analyzed by GC/MS (Agilent 6890). A capillary column (HP-5, 30m×0.25mm i.d.×0.25 μm) was employed to separate organic mixtures. Diethyl ether was used as solvent to dilute the dehydrated liquid product to a concentration appropriate for analysis. Helium was used as carrier gas at constant flow of 1.2 mL. The GC oven temperature was programmed to start at 40 °C, held for 10 min, then raised at a rate of 2 °C to 170 °C, held for 5 min, then raised to 250 °C at a rate of 8 °C held for 15 min, then raised to 300 °C at a rate of 15 °C, and held at this final temperature for 10 min. The injector temperature was 250 °C with split mode. The end of the column was directly introduced into the ion source of Agilent 5973 series mass selective detector operated with electron impact ionization mode. G1035A software with a NIST library was used as data acquisition system. The ^{1}H-NMR spectrum of the bio-oil was obtained at an H frequency of 300 MHz using a BrukerUltrashield instrument. The bio-oil sample was dissolved in $CDCl_3$.

The bio-char was characterized by elemental analysis, using a LECO CHNS-932 Elemental Analyzer. Dulong formula was used to determine the HHV of the liquid and solid products (Wang *et al.,* 2007). Functional group chemical analysis of the bio-char was carried out using Fourier transform infrared (FT-IR) spectrometry (Nicolet iS10FT-IR spectrum instrument).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Characteristics of fir wood sawdust
3.1. Obilježja jelove piljevine

The main characteristics of the biomass (fir wood sawdust) are listed in Table 1. The dry wood sample contained 0.36 % ash. Elemental analysis showed that it contained 46.99 % C, 6.37 % H, and 46.64 % O_2 (in mass percent, dry basis).

3.2 TGA analysis of fir wood sawdust
3.2. TGA analiza jelove piljevine

Thermogravimetric (TG) and derived thermogravimetric (DTG) curves of fir wood sawdust are shown in Figure 2. According to Figure 2, the moisture was removed from the raw material up to 100 °C and the main decompositions of fir wood started around 250 °C with a sharp incline to 600 °C. Wörmeyer *et al.,* 2011 reported that the rapid weight loss between 200 and 600 °C is due to the breakup of inter-unit linkages

Table1 Main characteristics of fir wood sawdust
Tablica 1. Glavna obilježja jelove piljevine

Characteristics / *Obilježje*	**Method** / *Metoda*	**Value** / *Vrijednost*
Moisture content, % / *sadržaj vode, %*	ASTM D-4442-92	6.81
Proximate analysis[a], % / *neposredna analiza, %*		
Volatiles / *hlapljive tvari*	ASTM E-897-88	78.32
Ash / *pepeo*	ASTM D-1102-84	0.36
Fixed carbon / *fiksni ugljik*	Calculated from difference / *izračunano iz razlike*	14.51
Ultimate analysis[a], % / Konačna analiza, %		
Carbon / *ugljik*		46.99
Hydrogen / *vodik*		6.37
Oxygen / *kisik*	Calculated from difference / *izračunano iz razlike*	46.64
H/C molar ratio / *H/C molarni omjer*		1.61
O/C molar ratio / *O/C molarni omjer*		0.74
Component analysis[a], % / *Analiza sastavnica, %*		
α-cellulose / α-celuloza	Rowell *et al*., 2005	43.53
Holocellulose / *holoceluloza*	Wise and John,1952	73.70
Lignin / *lignin*	TAPPI T 222 om-02	30.33
Extractive / *ekstraktivi*	TAPPI T 204 cm-97	2.69
HHV[b] , MJ/kg	Calculated from Dulong Formula	16.65

[a]Weight percentage on dry basis / *postotak na bazi suhe tvar* / [b](HHV) calculated by the Dulong Formula, that is, HHV (MJ/kg) = 0.338C+1.428(H-O/8)+0.095S

and evaporation of monomeric phenol units (Wörmeyer*et al.,* 2011). Thermogravimetric analysis (TGA) has been widely used, because it is an easy technique to evaluate pyrolysis of wood and other lignocellulosic biomass. Similar trend was observed in previous studies (Yang *et al.,* 2007; Ertaş and Alma, 2010; Wagenaar *et al.,* 1993).

3.3 Product yields
3.3. Udjeli proizvoda pirolize

Pyrolysis of fir wood sawdust was carried out in the temperature range of 350 to 600 °C at intervals of 15 °C, and each yield of pyrolytic products (bio-oil, gas and bio-char) is shown in Figure 3. These experiments revealed that the quantitative composition of pyrolysis products was clearly affected by the temperature. At 350 °C, the solid product (bio-char) yield reached its highest value (38.8 %). Since increasing the pyrolysis temperature decreases char yield, the char yield decreased down to 26.5 % at 600 °C. The bio-oil yield was 39.9 % at the pyrolysis temperature of 350 °C.The yield of bio-oil was maximized at approximately 46 % at 500 °C, and at the final temperature of 600 °C, the bio-oil yield was decreased to 44.8 %. This was

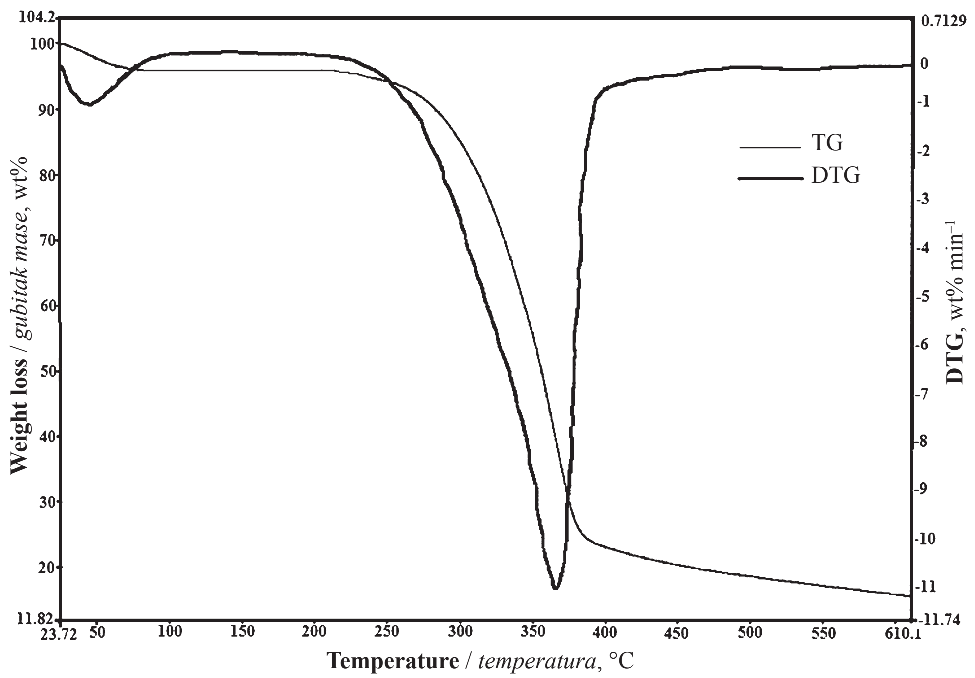


Figure 2 TG and DTG curves of fir wood under nitrogen atmosphere
Slika 2. TG I DTG krivulje jelove piljevine u atmosferi dušika

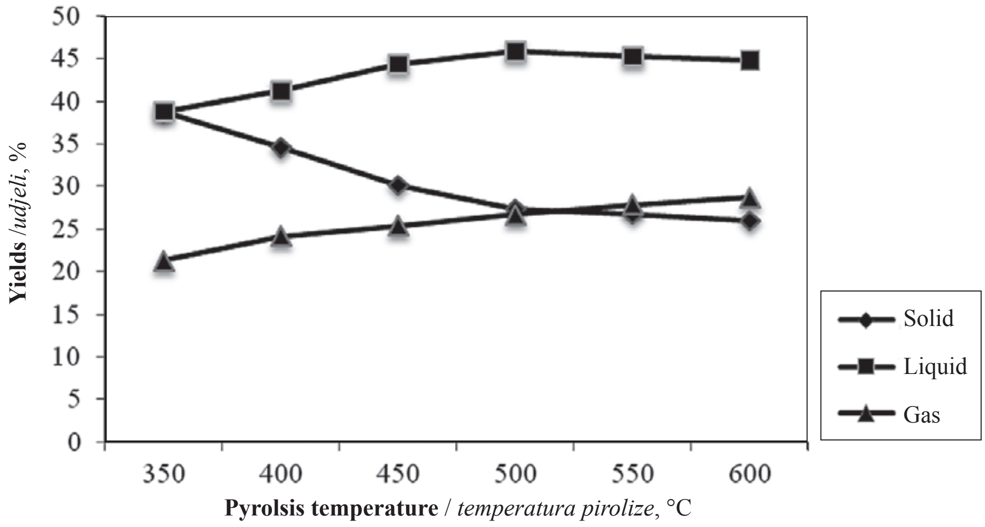


Figure 3 Yields of pyrolysis products
Slika 3. Udjeli proizvoda pirolize

due to the secondary reactions of the heavy-molecular-weight compounds in the pyrolysis vapors, which is known to become active at temperatures over 500 °C (Fagbemi*et al.,* 2001). As reported in previous studies, pyrolysis temperature plays an important role on the yields of pyrolysis products (Chen *et al.,* 2008;Heo*et al.,* 2010; Lee *et al.,*2005; Duman*et al.,* 2011; Özbay, 2012).

3.4 Characterization of bio-oil
3.4. Karakterizacija bioulja

The bio-oil selected for the characterization was obtained at the pyrolysis conditions that gave the maximum bio-oil yield. The elemental composition, H/C and O/C molar ratio and HHV of bio-oil are listed in Table 2.

As it shown in Table 2, the oxygen content was lower in bio-oil than in raw material. Since the decrease in oxygen content of the bio-oil (31.23 %) compared to the original feedstock (46.64 %) is significant, it can be used as the transport fuel. Furthermore, comparison of H/C ratios with conventional fuels indicates that H/C ratios of the bio-oil obtained in this study are less than those of light and heavy petroleum products. The higher heating value, calculated by Dulong formula, was 25.12 MJ/kg. The heating value of the bio-oil was higher than that of the raw material (16.65 MJ/kg). It can be seen that a significant decrease in the oxygen content resulted in an increase in the heating value. Results were in accordance with the previous studies reported in literature (Pütün*et al.,*2005; Sheng and Azevedo, 2005).

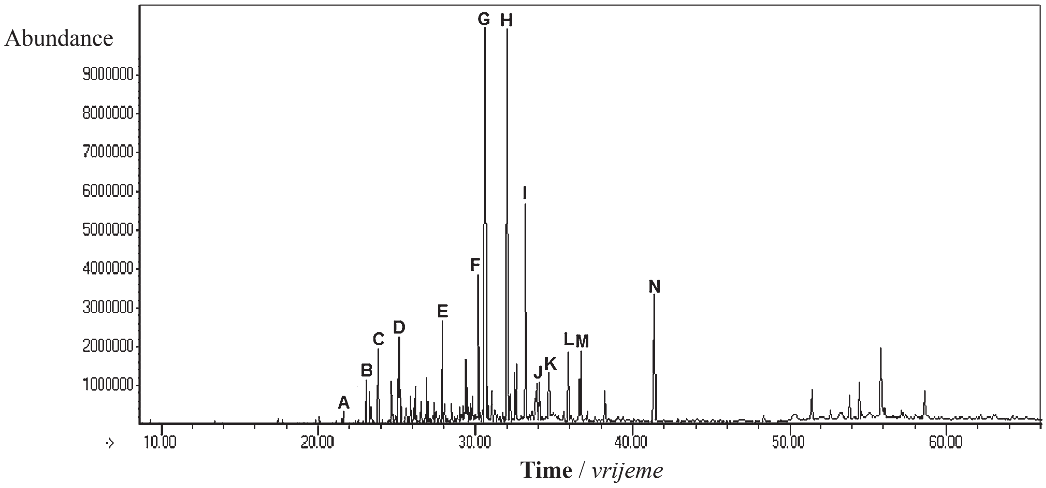
Biomass pyrolysis vapors consist of volatile compounds and non-volatile oligomers. GC/MS was only able to determine the volatile organic compounds. In the research, the ion chromatogram was obtained from the pyrolysis of the fir wood sawdust. A total of 32 major compounds were identified as given in Table 3. The GC/MS chromatogram of the bio-oil is illustrated in Figure 4. The compounds identified in bio-oil are also listed in Table 3. As shown in Table 3, the bio-oil was mainly composed of phenolics, including 2-methoxy-phenol, 2-methyl-phenol, 4-methyl-phenol, 4-ethyl-2-methoxy-phenol, 2-methoxy-4-vinyl-phenol, 2,6-dimethyl-phenol, 3-methyl-phenol,phenol and 2-methoxy-4-(2-propenyl)-phenol, 2-methoxy-4-(1-propenyl)-phenol, 2-methoxy-4-propenyl-phenol as well as aldeyhdes, acids, esters, alcohols and ketones. Phenols and methoxy group are generally considered as the pyrolysis products of lignin, while hemicelluloses can be decomposed to acetic acid andaldehydes such as furfural, and cellulose can be decomposed to ketones, aldehydes and furans (**Özbay***et al,* 2013, Pütün*et al.,* 2005; Ren *et al.,* 2012; Heigenmoser*et al.,* 2013; Özçifçi and Özbay, 2013).

Phenols derived from biomass pyrolysis oils are valuable chemicals and can be used as intermediates in the synthesis of pharmaceuticals, for the production of adhesives and the synthesis of specialty polymers, while furfural is a useful organic reagent for the production of medicines, resins, food additives, fuel additives and other special chemicals (Žilnik and Jazbinšek, 2012; Shen *et al.,* 2010; Shen and Gu, 2009). The

Table 2 Elemental composition of bio-oil[b]
Tablica 2. Elementarni sastav bioulja

Component *Komponenta*	**C** %	**H** %	**O**[a] %	**H/C**	**O/C**	**HHV** MJ/kg
Value / *vrijednost*	61.93	6.84	31.23	1.31	0.37	25.12

[a] By difference, [b]obtained at 500 °C (HHV) calculated by the Dulong Formula, that is, HHV (MJ/kg) = 0.338C+1.428(H-O/8)+0.095S



A: 2-cyclopenten-1-one, **B:** 2-methyl-2-cyclopenten-1-one, **C:**furfural **D:** 2-furanmethanol, **E:** 1,2-cyclopentenedione, **F:** 2-hydroxy-3-methyl-2-cyclopenten-1-on, **G:** 2-methoxy-phenol, **H:** 4-methyl-phenol, **I:** 4-ethyl-2-methoxy-phenol, **J:** 2-methoxy-4-(2-propenyl)-phenol, **K:** 3-methyl-phenol, **L:** 2-methoxy-4-(2-propenyl)-phenol, **M:** 2-methoxy-4-vinyl-phenol, **N:** 2-methoxy-4-propenyl-phenol

Figure 4 GC/MS chromatogram of bio-oil
Slika 4. GC/MS kromatogram bioulja

chemical composition of bio-oil was matched with previous GC/MS studies (Lu *et al.,* 2011; Beis*et al.,* 2002, Acıkgoz and Kockar, 2009; Liaw*et al.,* 2012; Luo *et al.,* 2004; Bu *et al.,* 2011).

The ^{1}H-NMR spectrum of the bio-oil is given in Figure 5. It can be seen that the bands between 6.5 and 9 ppm were assigned to aromatic structures. Resonances between 5 and 6.5 ppm indicate that the aromatic species were largely phenolic compounds. Aromatic ring-joining methylene protons were observed in the bio-oil and their characteristic peaks were in the resonances ranging between 3.3-4.5 ppm. The results showed that larger proportions of aliphatic structural units existed in the bio-oil from the pyrolysis of fir wood. These findings are consistent with the results of GC/MS analysis. Onay (2007) noticed that the bio-oils mainly contain aliphatic protons at carbon atoms bonded to other aliphatic carbon atoms (Onay, 2007). The products found in the bio-oil correspond well to the literature data (Demiral and Ayan, 2011; Lu *et al.,* 2010).

3.5 Characterization of bio-char
3.5. Karakterizacija biougljena

Elemental composition and an HHV value of the bio-char are presented in Table 4. As shown in Table 4, the bio-char, obtained from pyrolysis of fir wood sawdust, consisted of 77.28 % carbon and 18.81 % oxygen. It has an HHV of 28.35 MJ/kg. An H/C molar ratio of 0.60 and an O/C molar ratio of 0.18 were found. The elemental compositions of the bio-char were found to be better than that of the original feedstock since their carbon content was the highest. This carbon-rich product shows potential as an alternative solid fuel in the form of briquettes and pellets (Kim *et al*., 2011).

Figure 6 shows the FT-IR spectra of both raw material and bio-char. Changes in functional groups of

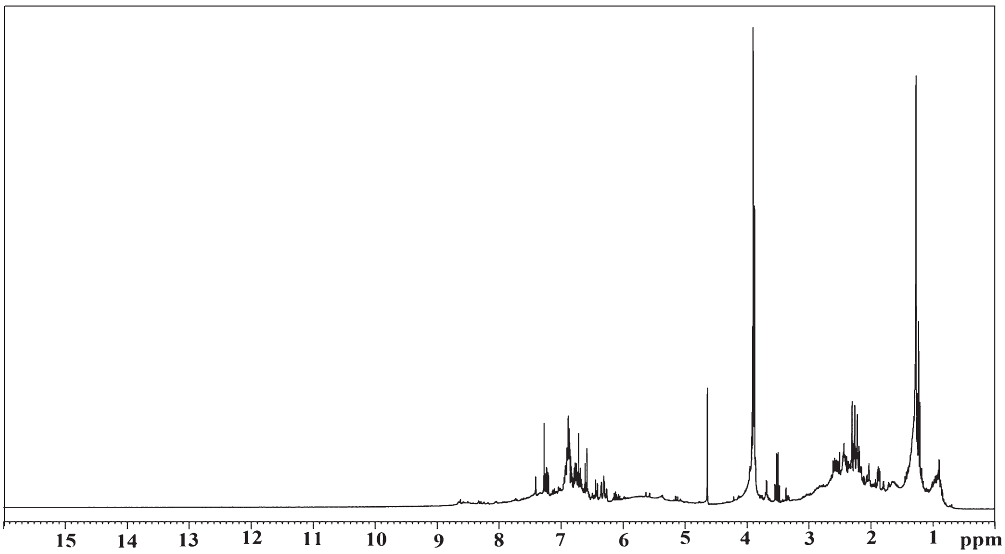


Figure 5 ^{1}H-NMR spectrum of bio-oil
Slika 5.^{1}H-NMR spektar bioulja

Table 3 Main organic components of bio-oils[a] with GC/MS analysis
Tablica 3. Glavne organske komponente bioulja[a] dobivene GC/MS analizom

No	RT (min)	**Name of compounds** / *Naziv komponente*	**Area** / *Područje* %	**Category** / *Kategorija*
1	23.02	2-cyclopenten-1-one	1.38	Ketone
2	23.31	2-methyl-2-cyclopenten-1-one	0.84	Ketone
3	25.13	furfural	2.06	Aldehyde
4	25.85	1-(2-furanyl)-ethanone	0.62	Ketone
5	26.21	3-methyl-2-cyclopenten-1-one	0.96	Ketone
6	26.52	2,3-dimethyl-2-cyclopenten-1-one	0.43	Ketone
7	27.40	butanoic acid	0.56	Acid
8	27.89	2-furanmethanol	2.78	Alcohol
9	29.42	1,2-cyclopentenedione	1.55	Ketone
10	29.68	2-hydroxy-3,4-dimethyl-2-cyclopenten-1-one	0.38	Ketone
11	29.83	3,4-dimethoxytoluene	0.59	Benzene
12	30.18	2-hydroxy-3-methyl-2-cyclopenten-1-one	3.96	Ketone
13	30.62	2-methoxy-phenol	11.82	Phenol
14	30.77	2-methoxy-3- methyl-phenol	0.69	Phenol
15	31.06	3-ethyl-2-hydroxy-2-cyclopenten-1-one	0.80	Ketone
16	32.00	4-methyl-phenol	13.06	Phenol
17	32.15	ethanone	0.73	Ketone
18	32.23	maltol	0.70	Alcohol
19	32.50	2-methyl-phenol	1.50	Phenol
20	32.59	phenol	2.25	Phenol
21	33.18	4-ethyl-2-methoxy-phenol	7.12	Phenol
22	33.87	2,6-dimethyl-phenol	1.07	Phenol
23	33.94	4-methyl-phenol	1.36	Phenol
24	34.10	3-methyl-phenol	1.53	Phenol
25	34.66	2-methoxy-4-(1-propenyl)-phenol	1.67	Phenol
26	35.94	2-methoxy-4-(2-propenyl)-phenol	3.35	Phenol
27	36.67	2-methoxy-4-vinyl-phenol	3.11	Phenol
28	38.28	2-methoxy-4-propenyl-phenol	1.63	Phenol
29	41.38	2-methoxy-4-propenyl-phenol	8.52	Phenol
30	51.39	4-hydroxy-3-methoxy-benzaldehyde	3.01	Aldehyde
31	55.81	1,2-benzenediol	4.81	Phenol
32	58.57	4-methyl 1,2-benzenediol	2.72	Phenol
Total / *Ukupno*			87.56	

[a]obtained at 500 °C / *dobiveno pri 500 °C*

Table 4 Elemental composition of bio-char[b]
Tablica 4. Elementarni sastav biougljena[b]

Component *Komponenta*	**C** %	**H** %	**O**[a] %	**H/C**	**O/C**	**HHV**[c] MJ/kg
Value *Vrijednost*	77.28	3.91	18.81	0.60	0.18	28.35

[a] by difference, [b]obtained at 500 °C; [c]HHV calculated by Dulong Formula, that is, HHV (MJ/kg) = 0.338C+1.428(H-O/8)+0.095S

bio-char were determined when FT-IR spectra of bio-char and raw material were compared. FT-IR spectrum of the bio-char was simplified. In FT-IR spectrum of raw material, the O-H stretching vibration band observed between 3600 and 3200 1/cm, the C-H stretching vibration band observed between 2935 and 2885 1/cm and the C=O stretching vibration band observed between 1740 and 1700 1/cm were not found in the bio-char obtained from the pyrolysis of fir wood sawdust. The bio-char loses both hydroxyl and aliphatic groups and the aromatic character increases quite rapidly above 450 °C (Sharma *et al.,* 2004).

4 CONCLUSIONS
4. ZAKLJUČAK

In this paper, the fir wood sawdust was pyrolyzed to convert into bio-oil and bio-char using a fixed-bed reactor at different pyrolysis temperatures, and their chemical properties were characterized. The yields of pyrolytic products distribution, bio-oil, bio-char and gases, was significantly influenced by pyrolysis temperatures. The maximum bio-oil yield of 45.9 wt% was obtained at the final pyrolysis temperature of 500 °C. The bio-oil derived from fir wood sawdust consisted of about 32 major compounds, including phenols, organic acids, aldehydes, ketones and alcohols. The chemical properties have shown that the bio-oil obtained from fir wood sawdust could be use as a feedstock, and that it was an ideal candidate for alternative fuels. Moreover, the bio-char can be used as an energy source and active carbon.

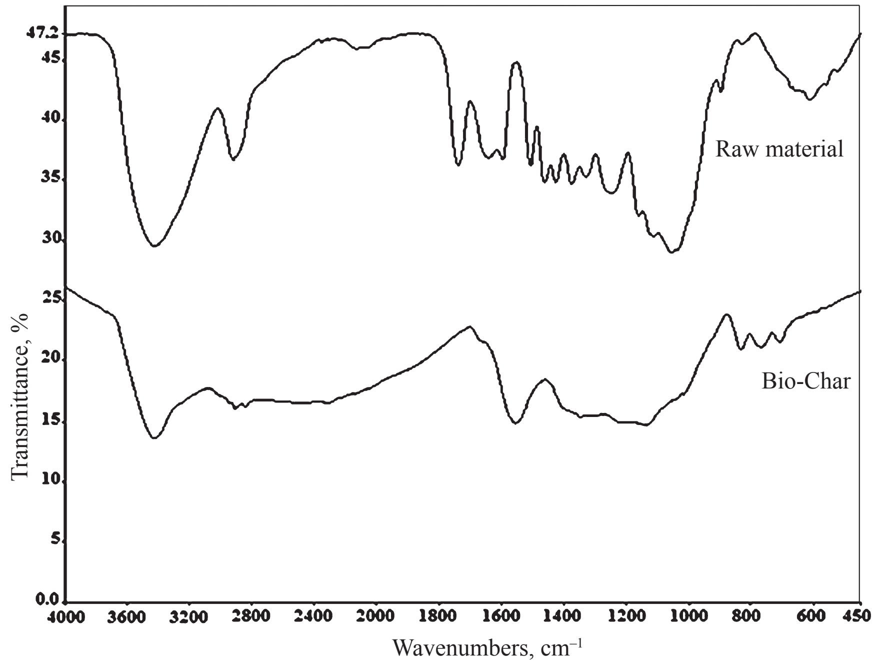


Figure 6 FTIR spectra of raw material and bio-char
Slika 6. FTIR spektar sirovine i biougljena

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5 REFERENCES
5. LITERATURA

1. Acıkgoz, C.; Kockar, O. M., 2009: Characterization of slow pyrolysis oil obtained from linseed (*Linumusitatissimum* L.). Journal of Analytical and Applied Pyrolysis, 85: 151–154. http://dx.doi.org/10.1016/j.jaap.2008.08.011
2. American Society for Testing and Materials. 1997: Standard test method for direct moisture content measurement of wood and wood-base materials. ASTM Standarts D 4442-92. Easton, M.D., USA.
3. American Society for Testing and Materials. 2004: Standard test method for volatile matter in analysis sample refuse derived fuel. ASTM Standarts E-897-88., Easton, M. D., USA.
4. American Society for Testing and Materials. 1983: Standard test method for ash in wood. ASTM Standarts D-1102-84., Easton, M. D., USA.
5. Bridgwater, A. V., 2003: Renewable fuels and chemicals by thermal processing of biomass. Chemical Engineering Journal, 91 (2-3): 87-102. http://dx.doi.org/10.1016/S1385-8947(02)00142-0
6. Bridgwater, A. V., 2004: Biomass fast pyrolysis. Thermal Science, 8 (2): 21-49. http://dx.doi.org/10.2298/TSCI0402021B
7. Bu, Q.; Lei, H.; Ren, S. J.; Wang, L.; Holladay, J.; Zhang, Q.; Tang, J.; Ruan, R., 2011: Phenol and phenolics from lignocellulosic biomass by catalytic microwave pyrolysis. Bioresource Technology, 102: 7004-7007. http://dx.doi.org/10.1016/j.biortech.2011.04.025
8. Beis, S. H.; Onay, Ö.; Koçkar, Ö. M., 2002: Fixed-bed pyrolysis of safflower seed: Influence of pyrolysis parameters on product yields and compositions. Renewable Energy, 26(1): 21-32. http://dx.doi.org/10.1016/S0960-1481(01)00109-4
9. Chen, M.; Wang, J.; Zhang, M.; Chen, M.; Zhu, X.; Min, F.; Tan, Z., 2008: Catalytic effects of eight inorganic additives on pyrolysis of pine wood sawdust by microwave heating. Journal of Analytical and Applied Pyrolysis, 82 (1): 145-150. http://dx.doi.org/10.1016/j.jaap.2008.03.001
10. Demiral, İ.; Ayan, E. A., 2011: Pyrolysis of grape bagasse: Effect of pyrolysis conditions on the product yields and characterization of the liquid product. Bioresource Technology, 102: 3946-3951. http://dx.doi.org/10.1016/j.biortech.2010.11.077
11. Duman, G.; Okutucu, C.; Uçar, S.; Stahl, R.; Yanık, J., 2011: The slow and fast pyrolysis of cherry seed. Bioresource Technology, 102: 1869-1878. http://dx.doi.org/10.1016/j.biortech.2010.07.051
12. Encinar, J. M.; González, J. F.; Martinez, G.; Román, S., 2009: Catalytic pyrolysis of exhausted olive oil waste. Journal of Analytical and Applied Pyrolysis, 85 (1-2): 197-203. http://dx.doi.org/10.1016/j.jaap.2008.11.018
13. Ertaş, M.; Alma, H. M., 2010: Pyrolysis of laurel (*Laurus nobilis* L.) extraction residues in a fixed-bed reactor characterization of bio-oil and bio-char. Journal of Analytical and Applied Pyrolysis, 88 (1): 22-29. http://dx.doi.org/10.1016/j.jaap.2010.02.006
14. Fagbemi, L.; Khezami, L.; Capart, R., 2001: Pyrolysis products from different biomasses: application to the thermal cracking of tar. Applied Energy, 69: 293-306. http://dx.doi.org/10.1016/S0306-2619(01)00013-7
15. Heigenmoser, A.; Liebner, F.; Windeisen, E.; Richter, K., 2013: Investigation of thermally treated beech (*Fagus sylvatica*) and spruce (*Picea abies*) by means of multifunctional analytical pyrolysis-GC/MS. Journal of Analytical and Applied Pyrolysis,100: 117-126. http://dx.doi.org/10.1016/j.jaap.2012.12.005
16. Heo, S. H.; Park, H. J.; Park, Y.-K.; Ryu, C.; Suh, D. J.; Suh, Y.-W.; Yim, J.-H.; Kim, S.-S., 2010: Bio-oil production from fast pyrolysis of waste furniture sawdust in a

fluidized bed. Bioresource Technology, 101 (1): 91-96. http://dx.doi.org/10.1016/j.biortech.2009.06.003
17. Ingram, L.; Mohan, D.; Bricka, M.; Steele, P.; Strobel, D., 2008: Pyrolysis of wood and bark in an auger reactor: Physical properties and chemical analysis of the produced bio-oils. Energy&Fuels, 22: 614-625. http://dx.doi.org/10.1021/ef700335k
18. Janse, A. M. C.; Westerhout, A. M. C; Prins W., 2000: Modelling of flash pyrolysis of a single wood particle. Chemical Engineering and Processing 39: 239-252. http://dx.doi.org/10.1016/S0255-2701(99)00092-6
19. Kim, K. H.; Eom, I. Y.; Lee, S. M., Choi, D.; Yeo, H.; Choi, I.-G.;. Choi, J. W., 2011: Investigation of physicochemical properties of bio-oils produced from yellow poplar wood *(Liriodendron tulipifera)* at various temperatures and residence times. Journal of Analytical and Applied Pyrolysis 92: 2-9. http://dx.doi.org/10.1016/j.jaap.2011.04.002
20. Lee, K. H.; Kang, B. S.; Park, Y. K.; Kim, J. S., 2005: Influence of reaction temperature, pretreatment, and a char removal system on the production of bio-oil from rice straw by fast pyrolysis, using a fluidized bed. Energy & Fuels, 19: 2179-2184. http://dx.doi.org/10.1021/ef050015o
21. Liaw, S.-S.;Wang, Z.; Ndegwa, P.; Frear, C.; Ha, S.; Li, C.-Z.; Garcia-Perez, M., 2012: Effect of pyrolysis temperature on the yield and properties of bio-oils obtained from the auger pyrolysis of Douglas Fir wood. Journal of Analytical and Applied Pyrolysis, 93: 52-62. http://dx.doi.org/10.1016/j.jaap.2011.09.011
22. Lu, Q.; Wang, Z.; Dong, C.; Zhang, Z.; Zhang, Y.; Yang, Y.; Zhu, X., 2011: Selective fast pyrolysis of biomass impregnated with $ZnCl_2$: Furfural production together with acetic acid and activated carbon as by-products. Journal of Analytical and Applied Pyrolysis, 91 (1): 273-279. http://dx.doi.org/10.1016/j.jaap.2011.03.002
23. Lu, Q.; Zhang, Z.-F.; Dong, C.-Q.; Zhu, X.-F., 2010: Catalytic Upgrading of Biomass Fast Pyrolysis Vapors with Nano Metal Oxides: An Analytical Py-GC/MS Study. Energies, 3: 1805-1820. http://dx.doi.org/10.3390/en3111805
24. Luo, Z.; Wang, S.; Liao, T.; Zhou, J.; Gu, Y.; Cen, K., 2004: Research on biomass fast pyrolysis for liquid fuel. Biomass&Bioenergy, 26: 455-462. http://dx.doi.org/10.1016/j.biombioe.2003.04.001
25. Murataa, K.; Liua,Y.; Inabaa, M.; Takaharaa, I., 2012: Catalytic fast pyrolysis of jatropha wastes. Journal of Analytical and Applied Pyrolysis, 94: 75-82. http://dx.doi.org/10.1016/j.jaap.2011.11.008
26. Onay, O., 2007: Fast and catalytic pyrolysis of pistaciakhinjuk seed in a well-swept fixed bed reactor. Fuel, 86: 1452-1460. http://dx.doi.org/10.1016/j.fuel.2006.12.017
27. Özbay, G., 2012: Liquefaction of wood and wood-based composed materials sawdust by thermal and catalytic pyrolysis method. PhD Thesis, Karabük University, Graduate School of Natural and Applied Sciences, Karabük, 96-99, 2012.
28. Özçifçi, A.;Özbay, G., 2013: Bio-oil production from catalytic pyrolysis method of furniture industry sawdust. Journal of the Faculty of Engineering and Architecture of Gazi University, 28, (3): 473-479.
29. Özbay, G.; Özçifçi, A.; Karagöz, S., 2013: Catalytic pyrolysis of waste melamine coated chipboard. Environmental Progress & Sustainable Energy, 32 (1): 156-161. http://dx.doi.org/10.1002/ep.10612
30. Özçimen, D.; Ersoy-Meriçboyu, A., 2010: Characterization of biochar and bio-oil samples obtained from carbonization of various biomass materials. Renewable Energy, 35: 1319-1324. http://dx.doi.org/10.1016/j.renene.2009.11.042
31. Pütün, A.; Özbay, N.; Önal, E. P.; Pütün, E., 2005: Fixed-bed pyrolysis of cotton stalk for liquid and solid products. Fuel Processing Technology, 86: 1207-1219. http://dx.doi.org/10.1016/j.fuproc.2004.12.006
32. Rowell, R. M.; Pettersen, R.; Han, J. S.; Rowell, J. S.; Tshabalala, M. A., 2005: Handbook of wood chemistry and wood composites, CRC Press, Boca Raton, pp. 72-487.
33. Ren, S.; Hanwu Lei, H.; Wang L.; Quan, Q.; Chen, S.; Wu, J.; Julson, J.; Ruan, R., 2012: Biofuel production and kinetics analysis for microwave pyrolysis of Douglas fir sawdust pellet. Journal of Analytical and Applied Pyrolysis, 94: 163-169. http://dx.doi.org/10.1016/j.jaap.2011.12.004
34. Sadaka, S., 2009: Pyrolysis. Associate Scientist Center of SustinableEnviroment Technologies, Iowa State Universty, Nevada, 2-22.
35. Shen, D. K.; Gu, S., 2009: The mechanism for thermal decomposition of cellulose and its main products. Bioresource Technology, 100: 6496-6504. http://dx.doi.org/10.1016/j.biortech.2009.06.095
36. Shen, D. K.; Gu, S.; Bridgwater, A. V., 2010: Study on the pyrolyticbehaviour of xylan-based hemicellulose using TG–FTIR and Py–GC–FTIR. Journal of Analytical and Applied Pyrolysis, 87: 199-206. http://dx.doi.org/10.1016/j.jaap.2009.12.001
37. Sheng, C.; Azevedo, J. L. T., 2005: Estimating the higher heating value of biomass fuels from basic analysis data. Biomass and Bioenergy, 28 (5): 499-507. http://dx.doi.org/10.1016/j.biombioe.2004.11.008
38. Sharma, R. K.; Wooten, J. B.; Baliga, V. L.; Lin, X.; Chan, W. G.; Hajaligol, M. R., 2004: Characterization of chars from pyrolysis of lignin. Fuel, 83: 1469-1482. http://dx.doi.org/10.1016/j.fuel.2003.11.015
39. Şensöz, S., 2003: Slow pyrolysis of wood barks from PinusbrutiaTen. and product compositions. Bioresource Technology, 89 (3): 307-311. http://dx.doi.org/10.1016/S0960-8524(03)00059-2
40. Technical Association of the Pulp and Paper Industry (1993). Sampling and preparing wood for analysis. TAPPI T 257cm-12, Tappi Pres. Atlanta, GA, USA.
41. Technical Association of the Pulp and Paper Industry (2002). Acid-insoluble lignin in wood and pulp. TAPPI T 222 om-02, Tappi Pres. Atlanta, GA, U.S.A.
42. Technical Association of the Pulp and Paper Industry (1997). Solvent extractives of wood and pulp. TAPPI T 204 cm-97, Tappi Pres. Atlanta, GA, USA.
43. Uzun, B. B.; Sarıoğlu, N., 2009: Rapid and catalytic pyrolysis of corn stalks.Fuel Processing Technology, 90: 705-716. http://dx.doi.org/10.1016/j.fuproc.2009.01.012
44. Wagenaar, B. M.; Prins, W.; van Swaaij, W. P. M., 1993: Flash pyrolysis kinetics of pine wood. Fuel Processing Technology, 36: 291-302. http://dx.doi.org/10.1016/0378-3820(93)90039-7
45. Wang, C.; Du, Z.; Pan, J.; Li, J.; Yang, Z., 2007: Direct conversion of biomass to bio-petroleum at low temperature. Journal of Analytical and Applied Pyrolysis, 78 (2): 438-444. http://dx.doi.org/10.1016/j.jaap.2006.10.016
46. Wang, Z.; Cao, J.; Wang, J., 2009: Pyrolytic characteristics of pine wood in a slowly heating and gas sweeping fixed-bed reactor. Journal of Analytical and Applied Pyrolysis, 84 (2): 179-184. http://dx.doi.org/10.1016/j.jaap.2009.02.001

47. Wise, L. E.; John, E. C., 1952: Wood chemistry. Reinhold Publication Co, New York, 1-2: 1330.
48. Wörmeyer, K.; Ingram, T.; Saake, B.; Brunner, G.; Smirnova, I., 2011.: Comparison of different pretreatment methods for lignocellulosic materials. Part II: Influence of pretreatment on the properties of rye straw lignin. Bioresource Technology, 102: 4157-4164. http://dx.doi.org/10.1016/j.biortech.2010.11.063
49. Yang, H.; Yan, R.; Chen, H.; Lee, D. H.; Zheng, C., 2007: Characteristics of hemicellulose, cellulose and lignin pyrolysis. Fuel, 86 (12-13): 1781-1788. http://dx.doi.org/10.1016/j.fuel.2006.12.013
50. Žilnik, L. F.; Jazbinšek, A., 2012: Recovery of renewable phenolic fraction from pyrolysis oil. Separation and Purification Technology, 86: 157-170. http://dx.doi.org/10.1016/j.seppur.2011.10.040.

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Evaluation of Weathering of Furfurylated Wood Decks after a 3-year Outdoor Exposure in Greece

Procjena utjecaja atmosferilija na drvene podove zaštićene furfuralom nakon tri godine izloženosti vanjskim uvjetima u Grčkoj

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ABSTRACT • *Furfurylation is a modification process carried out in order to improve the biological resistance and dimensional stability of wood. In this research work, a three-year outdoor weathering test of furfurylated wood was performed using the following wood materials: a deck of furfurylated radiata pine (Pinus radiata), a deck of furfurylated maple (Acer spp.), a deck of furfurylated southern yellow pine (Pinus spp.), and a control deck of Ipê wood (Handroanthus spp.) that was used for comparative reasons. The decks, without any protection or finishing, were exposed for 36 months in Karditsa, Greece in order to evaluate some physical and structural properties of wood such as colour, staining, distortion, surface cracking and end splitting. All tested decks exhibited colour changes that were perceptible by the naked eye and much higher during the first twelve months of weathering. The three furfurylated wood decks showed smaller total colour changes as compared to those of Ipê control deck. In respect to surface cracking, furfurylated radiata pine deck generally showed minor surface cracks, while furfurylated maple deck presented the lowest degree of surface and end splitting. In overall, the furfurylated wood decks tested performed very well and showed no signs of black staining (except for the southern yellow pine deck) and no fungal or mould decay after three years of outdoor exposure.*

Key words: *furfurylated wood, wood decks, weathering test, Kebony wood*

SAŽETAK • *Furfuralizacija je postupak modifikacije koji se provodi kako bi se poboljšala biološka otpornost i dimenzionalna stabilnost drva. U ovom je istraživačkom radu provedeno trogodišnje izlaganje drva modificiranog furfuralom atmosferilijama na otvorenom, pri čemu su upotrijebljeni ovi drvni proizvodi: pod od furfuralom obrađenog drva bora (Pinus radiata), pod od furfuralom obrađenog drva javora (Acer spp.), pod od furfuralom obrađenog drva južnoga žutog bora (Pinus spp.) te kontrolni uzorak poda od ipe drva (Handroanthus spp.), koji je služio za usporedbu. Drveni podovi, bez ikakve zaštite ili površinske obrade, izloženi su 36 mjeseci u gradu Karditsi u Grčkoj kako bi se procijenila neka fizikalna i strukturna svojstva drva kao što su boja, obojenost, defor-*

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macije, površinske pukotine i cijepanje na čelima. Na svim ispitanim uzorcima zamijećena je promjena boje koja se vidi golim okom i mnogo je jača tijekom prvih dvanaest mjeseci izlaganja. Tri uzorka poda od drva modificiranog furfuralom pokazala su manje ukupne promjene boje u usporedbi s promjenama boje kontrolnog uzorka od ipe drva. Vezano za površinske pukotine, rezultati su pokazali da su na modificiranom drvu bora nastale vrlo male površinske pukotine, dok je na uzorcima od modificiranog drva javora uočeno najmanje površinskih pukotina i cijepanja drva na čelima uzoraka. Općenito, uzorci podova od furfuralom modificiranog drva pokazala su dobru otpornost na atmosferilije i na njima nije bilo znakova crnjenja (osim uzoraka od žutoga bora) a na uzorcima ni nakon tri godine izloženosti na otvorenome nisu primijećene ni gljivice ili plijesni.

Ključne riječi: *drvo modificirano furfuralom, drveni podovi, test izlaganja atmosferilijama, drvo Kebony*

1 INTRODUCTION
1. UVOD

During the recent years, wood modification has attracted increasing interest as an alternative method for improving the durability of wood without the use of toxic substances. According to Hill (2006): *"the modified wood should itself be non-toxic under service conditions and there should be no release of any toxic substances during service or at the end of service life"*. Wood constituents can be physically changed and their structure can be chemically modified. Both of these changes can lead to a more durable wood (Rowell, 1991). There is a number of ways to chemically modify the cell wall polymers and the most abundant reactivity regions are the hydroxyl groups. The hydroxyl groups in the wood polymers (cellulose, lignin, hemicelluloses) are the most reactive sites. Moreover, these are responsible for the dimensional instability through their hydrogen bonding to water. Chemical modification of wood by reacting hydroxyl groups with a covalently bounded less hydrophilic group leads to an increased dimensional stability (Rowell, 1991; Larsson-Brelid, 1998; Rowell, 2005; Hill, 2006). Presently, very little is known about the mode of action for modified wood, while some main hypotheses have been suggested by Hill (2006): *"a) the equilibrium moisture content is lowered in modified wood, and hence it is harder for fungi to get the moisture required for decay; b) there is a physical blocking of the entrance of decay fungi to micropores of the cell walls; and/or, c) inhibition of action of specific enzymes"*. Amongst other significant technologies, one important modification technology is that of wood furfurylation (Schneider, 1995; Westin, 1996; Lande *et al.*, 2004; Lande, 2008). Furfurylated wood is modified by furfuryl alcohol, which is a renewable chemical (Larsson-Brelid, 2013) derived from agricultural waste like sugarcane and corn. The modification with furfuryl alcohol is carried out by impregnating the wood structure with a polymerisable mixture of furfuryl alcohol and catalyst. After that the wood structure is heated to polymerise. The purpose of furfurylation is to improve the wood properties like resistance to decay and moisture (Lande *et al.*, 2004 and 2008). Early research on this type of wood modification was implemented by Alfred Stamm (1977), and in the early '90s it was continued by Schneider and Westin, who almost simultaneously developed similar catalytic systems for the furfurylation of wood (Schneider, 1995; Westin, 1996). They both used cyclic carboxylic anhydrides. Furfuryl alcohol molecules can, due to their high polarity, penetrate very well into the wood cell wall and polymerise in situ. This yields a permanent swelling of the wood cell walls. Wood furfurylation leads then to a high protection against biodegradation by fungi, bacteria and marine borers, while it increases the hardness, lowers the equilibrium moisture content, and improves largely the dimensional stability of wood. Furthermore, the leachates from furfurylated wood have negligible toxic effects (Pilgård *et al.*, 2010). Anti-shrinking/swelling efficiency has been reported to range from 30 % to 80 % depending upon chemical formulations and wood species used (Lande *et al.*, 2004). A moderate loading of furfuryl alcohol polymer into wood provides a biological resistance suitable for ground contact or marine use (Lande *et al.*, 2004; Westin and Alfredsen, 2007; Venås, 2008; Lande *et al.*, 2008). This modified wood has a dark brown colour, which is attractive, as it makes it look like the dark, expensive tropical hardwoods (Larsson-Brelid, 2013). Low loading gives sufficient biodegradation protection for above-ground exterior uses (Westin and Alfredsen, 2007). As reported by Lande *et al.* (2008), furfurylated wood has greater hardness and rupture properties as compared to untreated wood, while it is more brittle. In terms of weathering performance, Temiz *et al.* (2007) reported that furfurylated wood showed only slightly higher resistance to accelerated weathering than untreated wood.

Today, furfurylated wood is produced at a commercial scale by the manufacturing company Kebony AS in Norway (Larsson-Brelid, 2013). The process is based on a full cell (vacuum/pressure) impregnation with a solution followed by an intermediate vacuum drying step before steam curing and drying (post curing). The impregnation liquid is an aqueous solution containing mostly furfuryl alcohol, catalysts and buffering agents (Larsson-Brelid, 2013). Several outdoor tests have been performed up to date in order to demonstrate the high durability and biological resistance of furfurylated wood in exterior applications (Westin and Alfredsen, 2007; Venås, 2008; Lande *et al.*, 2008; Larsson-Brelid, 2013).

Therefore, the aim of this work was to evaluate some physical and structural properties of furfurylated wood decks, such as colour, staining, distortion, surface cracking and end-splitting, after a 36-month outdoor weathering test in a typical southern Europe climatic area like Greece.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Materials
2.1. Materijali

For the conduction of this work, the following wood materials were used: (i) one deck of furfurylated radiata pine *(Pinus radiata)*, (ii) one deck of furfurylated maple *(Acer spp.)*, (iii) one deck of southern yellow pine, SYP, *(Pinus spp.)*, and (iv) one deck of Ipê *(Tabebuia spp.)* as a control deck. The first three decks were prepared and delivered by Kebony AS (Norway), while Ipê deck was assembled by the Research Lab of Wood Science and Technology (WST) in Karditsa, Greece. All decks had surface dimensions of 80 cm x 120 cm and were made by planks having a 22 mm thickness; they were assembled together using stainless screws and having a 6 mm free width in between them. All wood planks used were without protection or finishing.

2.2 Methods
2.2. Metode

The wood decks having tangential surfaces were placed horizontally on polystyrene sheets in the terrace of WST to facilitate free distortion, and exposed outdoors for the period May 2011 to May 2014, at Karditsa, Greece. During the 36-month period (months 6, 12, 24 and 36), some physical and structural properties of the wood decks like colour, black staining, distortion, cracking and end-splitting, were monitored. Concerning colour determination, twelve colour measurement points were marked up on each deck (Fig. 1). Careful cleaning of the surfaces was made prior to each measurement. The determination of the colour coordinates was carried out by using a BYK-Gardner type colourimeter, having a circular measuring area with a diameter of 20 mm. Applying the CIELAB colour system, the colour parameters L^* (lightness), a^* (redness) and b^* (yellowness) as well as the total colour changes (ΔE^*) were determined in each weathering time interval (6th, 12th, 24th and 36th month). The total colour changes (ΔE^*), which were caused by weathering, were calculated using the following equation:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Where: ΔL^*, Δa^* and Δb^* are the changes of the colour coordinates L^*, a^* and b^* for the respective time intervals, compared to the initial non-weathered surfaces.

Evaluation of black staining was made by visual observation. All decks were carefully examined for any black stains or spots due to discolouration or negative effects of high moisture over long periods, or other reasons. The distortions in wood decks were measured (Fig. 3) with a dial gauge equipped with a straight stainless steel bar over the axes shown in Fig. 2 for each wooden plank. Initial control for distortions was made in all tested materials at the beginning of the work (May 2011). It is well known that distortions such as cupping are influenced by the shrinking-swelling anisotropy. However, furfurylated wood has been found to exhibit up to 60 % reduction in anisotropy (Lande *et al.*, 2004; Lande *et al.*, 2008).

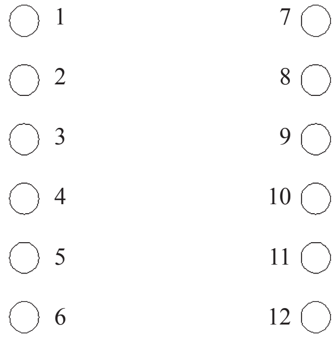

Figure 1 Colour measurement points on each of the testing decks (Note: the standard platform size of each deck was 80 cm x 120 cm; 5 planks in total; the mounting gap was ca. 3mm)
Slika 1. Točke mjerenja boje na svakom uzorku drvenog poda (napomena: standardna veličina uzorka ploče poda bila je 80 cm x 120 cm; ukupno je bilo pet ploča poda; praznina pri ugradnji bila je oko 3 mm)

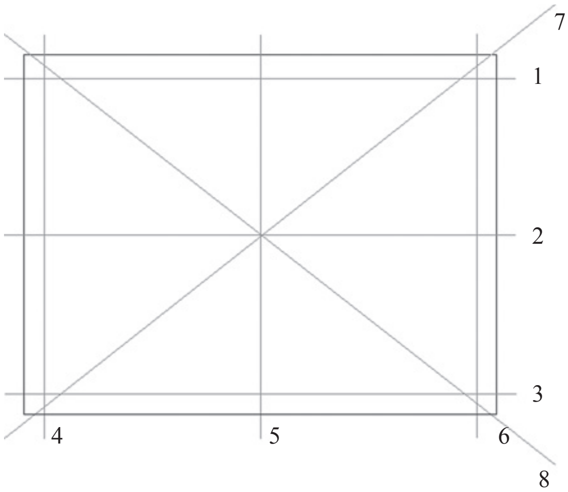

Figure 2 Distortion measurement axes
Slika 2. Osi mjerenja deformacije

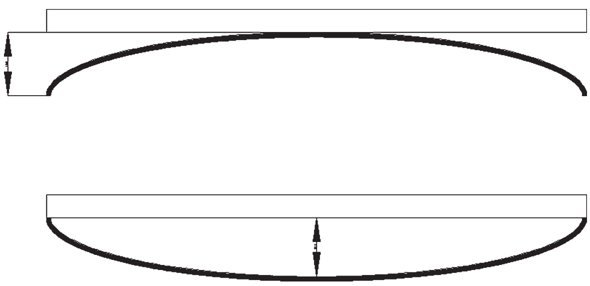

Figure 3 Determination of distortion as measured in a wood deck
Slika 3. Određivanje deformacije drvenih podova

In terms of surface cracking and end-splitting, initial control was made in all tested materials, and photographs were taken. All wood materials initially contained no cracks. For each time interval, the decks were observed carefully and respective photographs of the surface and edge cracks were taken. It should be noted that periodical measurements of the moisture content were made during the test by measuring the mass weight of each testing deck, with a conventional balance.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

All tested decks appeared to exhibit extensive greying effects on their surfaces after three consecutive years of outdoor weathering, while no signs of fungal decay or mould was observed in the decks. The mean values of the determined colour coordinates and total colour changes of the wood decks are shown in Table 1. Total colour changes (ΔE*) are plotted in Fig. 4. Lightness (*L**) changes are presented both in absolute values (Fig. 5), and in proportional changes (Fig. 6). The homogeneity of the colour changes, that is, the standard deviation changes of ΔE* values, is also presented in Fig. 7.

Concerning the changes in lightness, from Figs. 5 and 6, it can be concluded that after 36 months, the specimens tested showed increased *L** values due to the weathering effect. Ipê and furfurylated maple showed the largest lightness increases (28 % and 19 %, respectively) compared to the initial values, while furfurylated radiata pine and SYP samples showed the lowest increases (3 % each). Throughout the second weathering year, the changes in lightness were much smaller compared with those of the first year. All wood decks showed reductions in redness, but in positive values of the parameter *a** (redness factor).

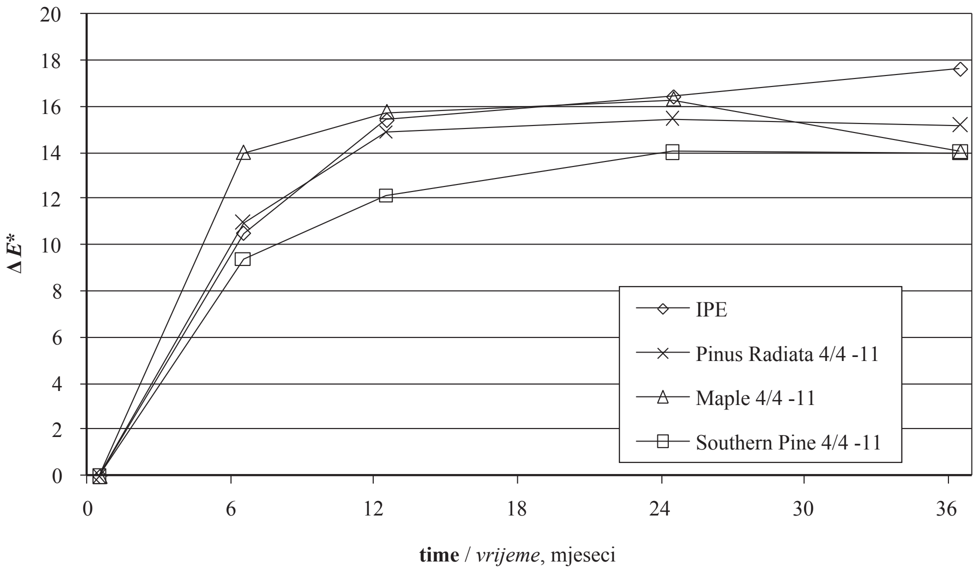

Figure 4 Total colour changes (Δ*E** value) of the wood decks throughout the weathering period
Slika 4. Ukupna promjena boje (vrijednost Δ*E**) drvenih podova tijekom razdoblja izlaganja atmosferskim utjecajima

Table 1 Mean values of the determined colour coordinates and total colour changes of furfurylated (FF) wood decks & control Ipê deck throughout the weathering period
Tablica 1. Srednje vrijednosti određenih koordinata boje i ukupne promjene boje furfuralom modificiranog drva i kontrolnog uzorka tijekom razdoblja izlaganja

Colour parameter *Parametar boje*	**Deck type** *Vrsta poda*	**Months of weathering (time intervals)** / *Mjeseci izlaganja*				
		0	6	12	24	36
Mean *L**	Ipê (control) / *kontrolni uzorak*	40.59	49.68	48.51	47.05	51.47
	FF Radiata pine / *FF borovina*	33.95	43.17	43.96	43.94	45.42
	FF Maple / *FF javorovina*	39.54	49.18	41.31	43.55	47.04
	FF Southern yellow pine / *FF žuta borovina*	30.42	37.21	38.28	39.67	40.86
Mean *a**	Ipê (control) / *kontrolni uzorak*	9.61	7.81	2.19	-1.15	1.71
	FF Radiata pine / *FF borovina*	9.01	6.76	2.01	1.39	2.27
	FF Maple / *FF javorovina*	9.80	5.60	1.89	1.59	2.66
	FF Southern yellow pine / *FF žuta borovina*	7.07	7.22	1.86	0.82	1.67
Mean *b**	Ipê (control) / *kontrolni uzorak*	16.47	12.98	7.20	8.03	6.50
	FF Radiata pine / *FF borovina*	15.23	11.63	7.52	6.96	8.88
	FF Maple / *FF javorovina*	19.05	11.44	6.34	6.26	10.09
	FF Southern yellow pine / *FF žuta borovina*	11.35	11.21	7.52	6.59	7.17
Mean Δ*E**	Ipê (control) / *kontrolni uzorak*	0	10.53	15.41	16.43	17.63
	FF Radiata pine / *FF borovina*	0	10.99	14.89	15.46	15.19
	FF Maple / *FF javorovina*	0	13.98	15.73	16.28	14.02
	FF Southern yellow pine / *FF žuta borovina*	0	9.37	12.12	14.05	14.00

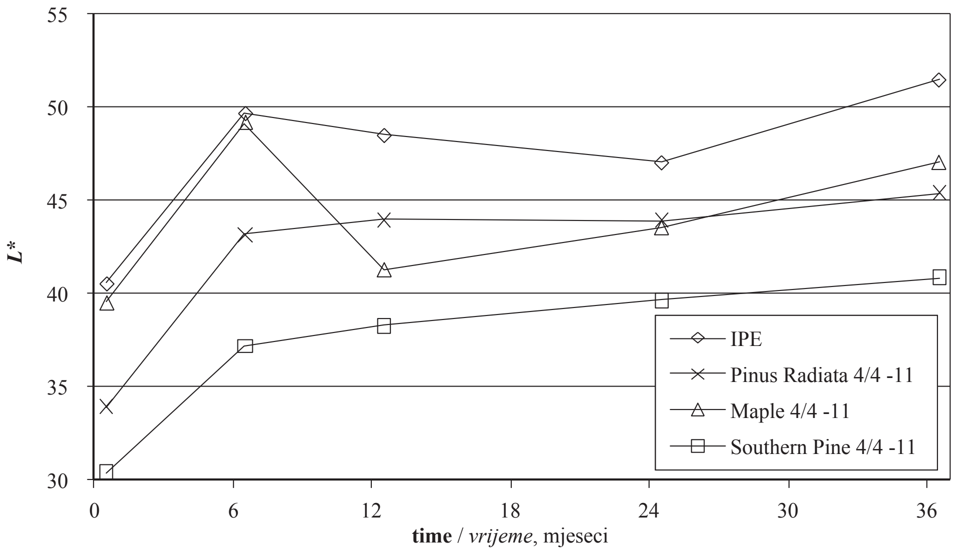

Figure 5 Absolute changes in lightness (L* value) of the wood decks throughout weathering
Slika 5. Apsolutna promjena svjetline (vrijednost *L**) drvenih podova tijekom razdoblja izlaganja atmosferskim utjecajima

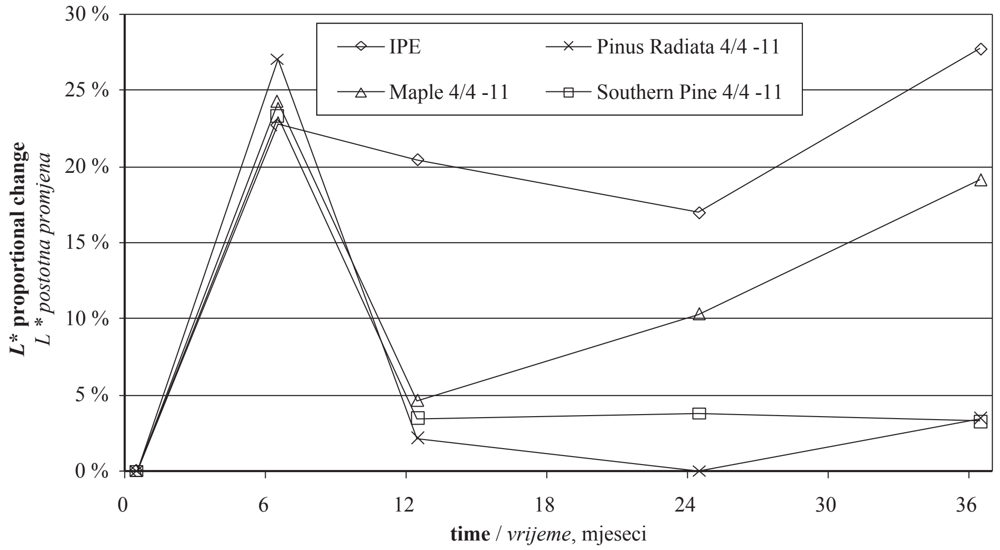

Figure 6 Proportional (%) changes in lightness (L* value) of the wood decks throughout weathering
Slika 6. Proporcionalna (%) promjena svjetline (vrijednost *L**) drvenih podova tijekom razdoblja izlaganja atmosferskim utjecajima

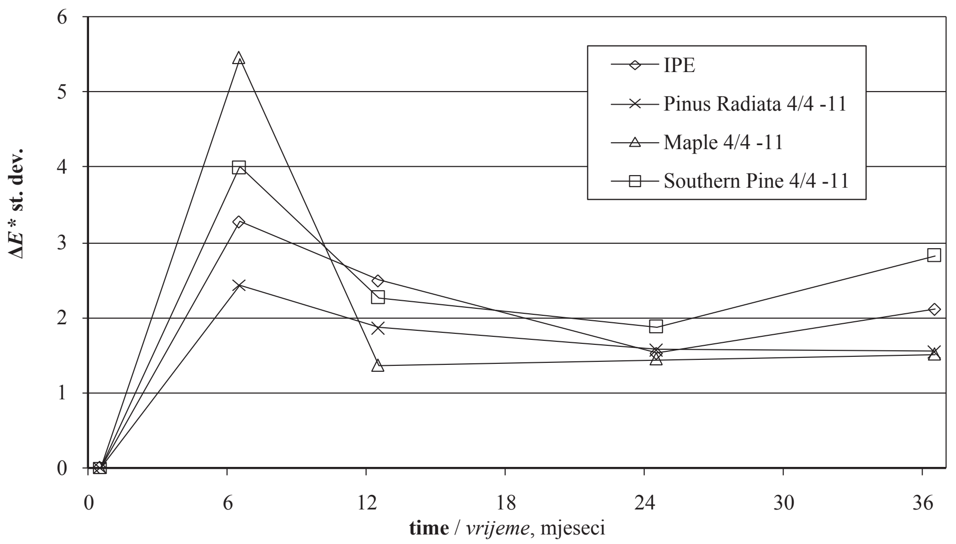

Figure 7 Standard deviation changes of ΔE^* values of the wood decks throughout weathering
Slika 7. Standardna devijacija ukupne promjene boje (vrijednost ΔE^*) drvenih podova tijekom razdoblja izlaganja atmosferskim utjecajima

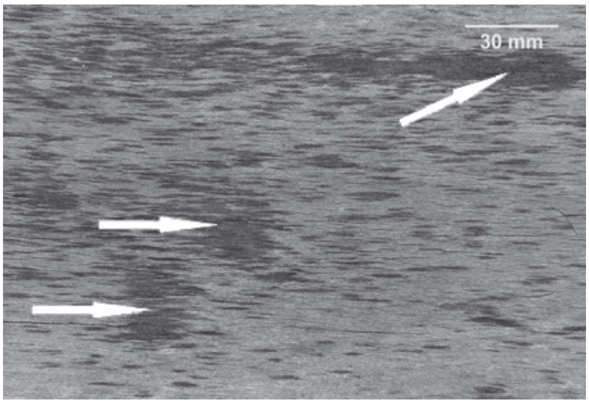

Figure 8 Some mild grey spots appearing in the furfurylated maple wood deck (at the end of 3rd year)
Slika 8. Neke blage sive pjege koje su se pojavile na podu od furfuralom modificiranog drva javora

Natural weathering induced reduction in yellowness in all of the decks; this was larger throughout the first year, but much smaller throughout the second and third weathering year. Concerning the total colour changes, after 36 months of weathering, all tested decks exhibited Δ*E** values in the range of 14.0 to 17.6; apparently, these colour changes were perceptible by the human eye. Furfurylated decks showed less total colour differences (14.0-15.2) as compared with the control deck (17.6). Among the furfurylated decks, the lowest total colour changes took place in SYP and maple decks (14.0 and 14.02, respectively) and the largest ones in radiata pine deck (15.19). As expected, the total colour changes were larger throughout the first year of weathering, and quite milder throughout the following two years of weathering.

In terms of the homogeneity of colour changes, furfurylated maple deck showed the most severe changes during the first six months of weathering and much lower ones during the next years. This could be attributed to the formation of some grey spots on the surface of furfurylated maple deck (Fig. 8). This may be attributed to the remaining chemicals from the treatment, and/or higher concentration of catalyst used.

Furthermore, furfurylated SYP deck showed some black staining spots (Fig. 11) in the surface during the third year of weathering.

It was observed that the approx. moisture content of wood decks ranged between 10-22 %, showing that the fibre saturation point (~30 %) never surpassed during the test. Consequently, it seems that the moisture content of wood has only a limited influence on the colour coordinates, if moisture content is below the fibre saturation point (Németh *et al.*, 2013).

The results from the distortion measurements are shown in Table 2. From that, it can be concluded that after 36 months of outdoor weathering, among all tested decks, the least distorted deck was that of furfurylated maple wood deck, followed by the furfurylated radiata pine wood deck. Noticeably, the most distorted deck was the Ipê control deck.

Table 2 Distortion absolute values (in mm) of all tested decks after the 36-month outdoor exposure (*Note: Comparison is made among the testing wood decks)*
Tablica 2. Apsolutne vrijednosti deformacije za sve uzorke drvenih podova nakon 36 mjeseci izlaganja na otvorenome (napomena: usporedba je napravljena između uzorcima u eksperimentu)

No	**Control** *Kontrolni uzorak*	**Radiata pine** *Borovina*	**Maple** *Javorovina*	**Southern pine** *Južna žuta borovina*
1	1.07	0.31	0.08	0.95
2	0.94	0.82	0.13	1.13
3	0.99	1.34	0.05	1.49
4	0.81	0.98	3.01	2.46
5	0.46	0.96	0.14	0.31
6	2.18	0.65	0.02	0.24
7	2.96	1.03	0.09	1.31
8	3.29	1.79	0.77	0.07

- Intense distortion / *intenzivna deformacija*

- Mild distortion / *blaga deformacija*

Figure 9 Radiata pine (Kebony) deck surface cracking appearance after 36 months of weathering
Slika 9. Površinske pukotine na uzorcima poda od drva bora nakon 36 mjeseci izlaganja utjecaju atmosferilija

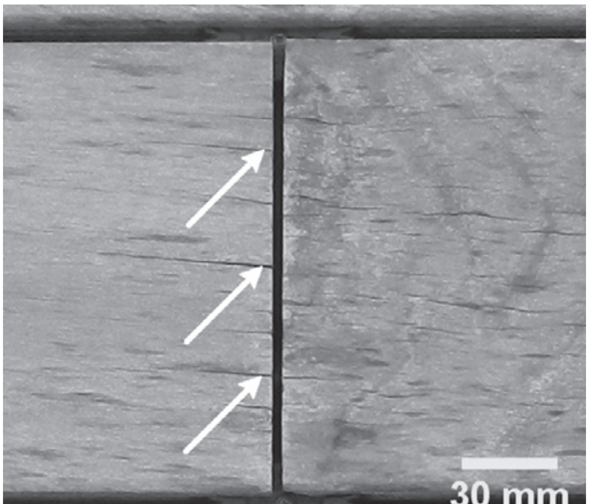

Figure 10 Maple (Kebony) deck surface cracking appearance after 36 months of weathering
Slika 10. Površinske pukotine na uzorcima poda od drva javora nakon 36 mjeseci izlaganja utjecaju atmosferilija

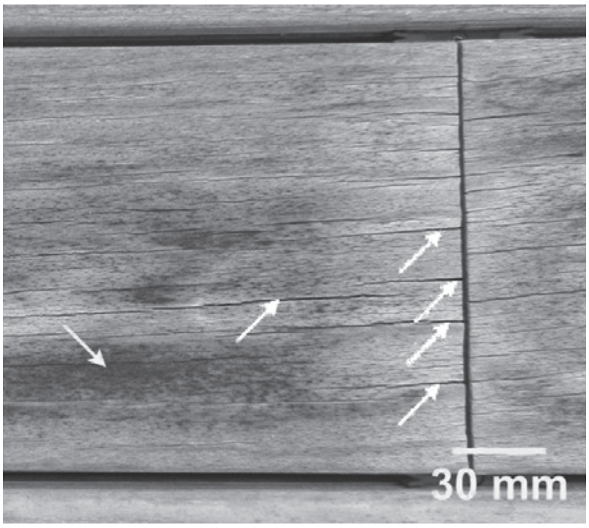

Figure 11 SYP (Kebony) deck surface cracking appearance *(red arrows)* and black staining spots *(yellow arrow)* after 36 months
Slika 11. Površinske pukotine (crvene strelice) i crne mrlje (žuta strelica) na uzorcima poda od drva žutoga bora nakon 36 mjeseci izlaganja utjecaju atmosferilija

Figure 12 Ipê wood deck prior to (up) and after 36 months of weathering (down)
Slika 12. Kontrolni uzorak prije (gore) i nakon razdoblja izlaganja (dolje)

After a thorough visual examination of the surface cracks, Ipê wood deck showed to have the fewest cracks on its surface, closely followed by furfurylated radiata pine deck (Fig. 9) which had only a few minor cracks. Mild was also the cracking appearance of the furfurylated maple wood deck (Fig. 10). Furfurylated SYP deck (Fig. 11) appeared to have a few surface cracks (8-9, in total) with a width of less than 1 mm; some black staining spots appeared sporadically on the surface (Fig. 11) of the furfurylated SYP deck.

After the three-year weathering period, the furfurylated wood decks were examined for end-splitting. It was observed that the furfurylated maple deck had the mildest edge effects (Fig. 14) with the smallest end-splitting followed by the control Ipê deck and furfurylated radiata pine deck (Figs. 12 and 13, respectively).

Figure 13 Furfurylated radiata pine wood deck prior to (up) and after 36 months of weathering (down)
Slika 13. Uzorak poda od furfuralom modificiranog drva bora prije (gore) i nakon 36 mjeseci izlaganja (dolje)

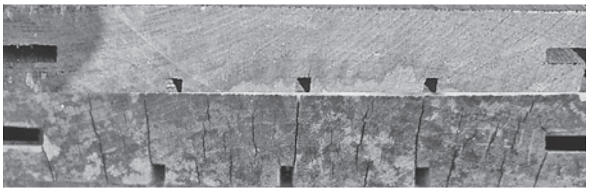

Figure 14 Furfurylated maple wood deck prior to (up) and after 36 months of weathering (down)
Slika 14. Uzorak poda od furfuralom modificiranog drva javora prije (gore) i nakon 36 mjeseci izlaganja (dolje)

Figure 15 Furfurylated SYP deck prior to (up) and after 36 months of weathering (down)
Slika 15. Uzorak poda od furfuralom modificiranog drva žutoga bora prije (gore) i nakon 36 mjeseci izlaganja (dolje)

4 CONCLUSIONS
4. ZAKLJUČAK

In this work, a three-year outdoor weathering test of furfurylated (Kebony) wood decks was carried out. The furfurylated radiata pine, southern yellow pine and maple wood decks tested were exposed outdoors for 36 months in Karditsa, Greece, and their physical and structural properties, namely, colour, staining, distortions, surface cracking and end-splitting were evaluated. The conclusions drawn in this work can be summarised as follows:

- All tested decks exhibited colour changes that were perceptible by the naked eye and were much higher during the first 12 weathering months and quite lower during the following ones.
- The furfurylated decks showed smaller total colour changes as compared to the control deck of Ipê wood.
- Concerning surface cracking, furfurylated radiata pine deck generally showed very minor surface cracks, while furfurylated maple deck presented the lowest degree of surface and edge cracking (end-splitting).
- In relation to distortions, the least distorted wood deck was that of furfurylated maple deck; whereas, the control Ipê deck was by far the most distorted wood deck.

In overall, all furfurylated wood decks tested, along with the control Ipê deck, behaved very well during this 36-month outdoor test, having no signs of fungal or mould decay after three years of exposure.

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5 REFERENCES
5. LITERATURA

1. Hill, C., 2006: Wood Modification: Chemical, thermal and other processes, Stevens C.V, England, John Wiley and Sons, pp. 239. http://dx.doi.org/10.1002/0470021748
2. Lande, S.; Westin, M.; Schneider, M., 2004: Eco-efficient wood protection - furfurylated wood as alternative to traditional wood preservation. Management of Environmental Quality: An International Journal 15 (5): 529-540. http://dx.doi.org/10.1108/14777830410553979
3. Lande, S., 2008: Furfurylation of wood – Wood modification by the use of furfuryl alcohol. PhD thesis. Norwegian University of Life Science, Ås, Norway.
4. Lande, S.; Eikenes, M.; Westin, M.; Schneider, M., 2008: Furfurylation of wood: chemistry, properties and commercialization. Development of Commercial Wood Preservatives. American Chemical Society (ACS) Symposium Series, 982, 337-355. http://dx.doi.org/10.1021/bk-2008-0982.ch020
5. Larsson-Brelid, P., 1998: Acetylation of solid wood. PhD thesis. Chalmers University of Technology, Stockholm, Sweden.
6. Larsson-Brelid, P., 2013: Benchmarking and state of the art for modified wood. SP Report 2013: 54, SP Technical Research Institute of Sweden – Wood Technology, Stockholm, Sweden, pp. 30.
7. Németh, R.; Ott, A.; Takáts, P.; Bak, M., 2013: The effect of moisture content and drying temperature on the colour of two poplars and Robinia wood. Bioresources, 8 (2): 2074-2083. http://dx.doi.org/10.15376/biores.8.2.2074-2083
8. Pilgård, A.; De Vetter, L.; van Acker, J.; Westin, M., 2010: Toxic hazard of leachates from furfurylated wood – Comparison between two different aquatic organisms. Environmental Toxicology and Chemistry, 29 (5): 1067-1071. http://dx.doi.org/10.1002/etc.132
9. Rowell, R. M., 1991: Chemical modification of wood. Eds Hon, D. N. S., and Shiraishi, N. Handbook on Wood and Cellulosic Materials. Marcel Dekker, New York, pp. 703-756.
10. Rowell, R. M., 2005: Handbook of Wood Chemistry and Wood Composites, Taylor and Francis, Boca Raton, Florida, USA, pp. 487.
11. Schneider, M. H., 1995: New cell wall and cell lumen wood polymer composites. Journal of Wood Science and Technology, 29: 135-158. http://dx.doi.org/10.1007/BF00229341
12. Stamm, A. J., 1977: Dimensional stabilization of wood with furfuryl alcohol. In: Wood Chemical Aspects. I. Goldstein (ed). American Chemical Society (ASC) Symposium Series 43, Washington DC, USA, pp. 141-149. http://dx.doi.org/10.1021/bk-1977-0043.ch009
13. Temiz, A.; Terziev, N.; Eikenes, M.; Hafren, J., 2007: Effect of accelerated weathering on surface chemistry of modified wood. Applied Surface Science 253: 5355-5362. http://dx.doi.org/10.1016/j.apsusc.2006.12.005
14. Venås, T. M., 2008: A study of mechanisms related to the fungal decay protection rendered by wood furfurylation. PhD thesis. University of Copenhagen, Faculty of Life Science, Danish Technological Institute, Building and Construction, Copenhagen, Denmark.
15. Westin, M., 1996: Development and evaluation of new alternative wood preservation treatments. Final report to the Swedish Council for the Forestry and Agricultural Research (SJFR), pp. 25.
16. Westin, M.; Alfredsen, G., 2007: Durability of modified wood in three different soil types (TMCs) In: Proc. of the 3rd European Conference on Wood Modification. Cardiff, United Kingdom, pp. 309-316.

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Comparison of Natural Frequencies Values of Circular Saw Blade Determined by Different Methods

Usporedba vrijednosti vlastitih frekvencija lista kružne pile određenih različitim metodama

Preliminary paper • Prethodno priopćenje
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ABSTRACT • *In most cases high cutting speed is used when cutting wood by circular saw. This results in oscillating of circular saw blade, which may lead to destroying the tool, machine or hurting the operator. The aim of this paper is to show that it is possible to apply any of the methods used in the research as an equivalent method for obtaining the values of natural frequencies of circular saw blade. The article deals with three methods for obtaining the values of natural frequencies. The first method is modal analysis, the second method is the determination of values measured experimentally and the last method calculates the values by Bessel functions. A circular saw blade was used with the diameter of 350 mm and 36 teeth on the blade.*

Key words: *circular saw blade, critical rotational speed, natural frequencies, finite element method*

SAŽETAK • *Tijekom rezanja drva kružnim pilama vrlo se često primijenjuje velika brzina rezanja, što uzrokuje oscilacije lista kružne pila te katkad može rezultirati uništavanjem alata odnosno stroja ili dovesti do ozljede radnika. Cilj je ovoga rada prikazati mogućnosti primjene različitih metoda za određivanje vrijednosti vlastitih frekvencija lista kružne pile. U članku se prikazuje primjena triju metoda za određivanje vrijednosti vlastitih frekvencija lista kružne pile. Prva je metoda modalna analiza, druga je metoda eksperimentalno određivanje vlastitih frekvencija uz pomoć mjernog uređaja, a treća je metoda izračunavanje vrijednosti frekvencija s pomoću Besselovih funkcija. U eksperimentu je upotrijebljen list kružne pila promjera 350 mm s 36 zubi.*

Ključne riječi: *list kružne pile, kritična brzina vrtnje, vlastite frekvencije, metoda konačnih elemenata*

1 INTRODUCTION
1. UVOD

Circular saw dynamic features such as workpiece characteristics, circular saw blade accuracy, and static and dynamic properties of the tool influence the accuracy of sawing, surface roughness, operating noise level, tool life, etc.

As the circular saw blade is the most common device for cutting wood and wood based materials in the wood industry, it is important to deal with the problem of oscillation of circular saw blade. Vibrations are

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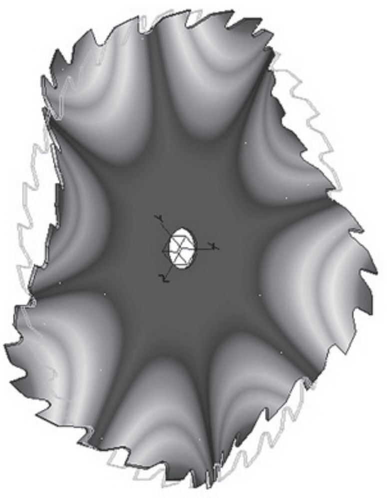


Figure 1 Model of circular saw blade by modal analysis in deformed state (n = 4; m = 0; f = 439.45 Hz)
Slika 1. Model lista kružne pile u deformiranom stanju dobiven modalnom analizom (n= 4; m = 0; f = 439,45 Hz)

emitted during the cutting process and when the critical rotational speed is reached, the circular saw blade becomes unstable. So the reduction of the amplitude of oscillations is essential for improving the parameters such as surface quality, precision of cutting, increase of the yield and longer tool life, but also for reducing noise. Therefore, it is necessary to find solutions to eliminate these adverse effects.

There are many methods for determining natural frequencies (the next step is to calculate critical rotational speed). The values calculated using various equations do not give an idea of how the circular saw blade behaves. For better understanding, a software program was used in this paper that displays the deformation of the circular saw blade as a result of oscillation. The results of circular saw blade static modal analysis (for nodal diameter n=4, and nodal circles m=0) is shown in Figure 1.

Instability of circular saw blade was the subject of many scientific studies. Many scientists dealt with experimental methods of circular saw blade oscillation (Mote, 1965; Pahlitzsch and Rowinski, 1966; Stakhiev, 1970, 1998, 2000; Schajer and Mote, 1983; Yu and Mote, 1987; Nishio and Marui, 1996; Siklienka and Svoreň, 1997; Orlowski *et al*., 2007; Javorek, Ľ. *et al*., 2010; Veselý *et al*., 2012). Some authors studied the application of the finite element method using different software programs to determine the oscillation of saw blade (Gogu, 1988; Holϕyen, 1987, Leopold and Münz, 1992; Michna and Svoreň, 2007; Ekevad *et al*., 2009). The analytical solution that uses the Bessel function was studied by Southwell (1922) and Kirshoff (1982).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

In practice, one of the most important questions is how to evaluate the critical rotational speed of circular saw blade. To solve this problem, it is necessary to determine the values of natural frequencies. The parameters of the circular saw blade used in this paper are shown in Table 1.

Table 1 Parameters of the circular saw blade
Tablica 1. Parametri lista kružne pile

Outer diameter / *Vanjski promjer*	350 mm
Inner diameter / *Unutarnji promjer*	30 mm
Number of teeth / *Broj zubiju*	36
Thickness of body / *Debljina*	2.4 mm
Height of tooth / *Visina zuba*	13 mm

For clamping circular saw blade, clamping collars were used with the diameter d_c = 110 mm.

This paper considers three methods for obtaining the values of natural frequencies:
- Bessel functions
- FEM (academic version ProEngineer WF 4)
- Experimental measurement.

2.1 Bessel functions
2.1. Besselove funkcije

Differential equation of vibration of circular saw blade can be expressed as follows (Benhao, *et al.* 2009):

$$\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\cdot\frac{\partial}{\partial r}+\frac{1}{r^2}\cdot\frac{\partial^2}{\partial\theta^2}\right)\cdot$$
$$\cdot\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\cdot\frac{\partial}{\partial r}+\frac{1}{r^2}\cdot\frac{\partial^2}{\partial\theta^2}\right)W(r,\theta,t)+\frac{\rho\cdot h}{D}\cdot\ddot{W}=0 \tag{1}$$

Here, the bending stiffness of the blade is:

$$D=\frac{E\cdot h^3}{12\cdot(1-\nu^2)} \tag{2}$$

Where:
h – thickness of circular saw blade / *debljina lista kružne pile*, mm
E – modulus of elasticity / *modul elastičnosti*, N·m^{-2} (E=2.1× 10^{11})
n – Poisson ratio / *Poissonov omjer* (n=0.33).

The differential equation is solved by separation of variables. The resulting function can be written in the form:

$$W(r,\theta,t)=w(r,\theta)\cdot e^{i\cdot\omega\cdot t}=R(kr)\cdot\cos n\cdot\theta\cdot e^{i\cdot\omega\cdot t} \tag{3}$$

Where:
n – number of nodal diameters / *broj čvornih promjera.*

Function *R(k,r)* is solved by Bessel functions.

$$R(k,r)=A_nJ_n(k,r)+B_nN_n(k,r)+C_nI_n(k,r)+D_nK_n(k,r) \tag{4}$$

Where: $k^4=\dfrac{\rho\cdot h}{D}$ (5)

r – density / *gustoća*, kg·m^{-3} (r=7800 kg·m^{-3})
J_n – the Bessel function of the first kind of order n / *Besselova funkcija prve vrste reda n*
N_n – the Bessel function of the second kind of order n / *Besselova funkcija druge vrste reda n*

I_n – the modified Bessel function of the first kind of order n / *modificirana Besselova funkcija prve vrste reda n*

K_n – the modified Bessel function of the second kind of order n / *modificirana Besselova funkcija druge vrste reda n*

A_n, B_n, C_n, D_n are (to be) determined constants / *utvrđene konstante*.

After the theoretical solution, the formula obtained for natural frequency was:

$$\omega = \frac{h}{D^2} \cdot \sqrt{\frac{E \cdot \alpha}{12 \cdot \rho \cdot (1-\nu)}} \tag{6}$$

Where

D – diameter of circular saw blade / *promjer lista kružne pile*, mm

α – coefficient (depending on n and clamping ratio) / *koeficijent* (*ovisan o n i o omjeru pričvršćenja lista*)

Natural frequency can be expressed by the following formula:

$$f = \frac{\omega}{2 \cdot \pi} \tag{7}$$

2.2 Modal analyses
2.2. Modalna analiza

Pro/Engineer WF4 software with FEM module was used for the theoretical modal analysis. The values of natural frequencies were obtained for n = 1, 2, 3, 4 in static modal analysis. The parameters for computing by FEM were: clamping diameter – 110 mm (absolutely rigid); outer diameter of the model – 350 mm; number of teeth – 36.

The resulting values of modal analysis are influenced by various parameters (material, type of model mesh, number of elements, etc). Five modal analyses were made with different element sizes. In the modal analysis Shell 5, shell elements of the model were used with the maximum size of 5 mm. In the modal analysis Shell 10, shell elements of the model were used with the maximum size of 10 mm and in the modal analysis Shell 20, the maximum element size was 20 mm. The density of circular saw blade mesh for modal analysis Shell 10 is shown in Fig. 2.

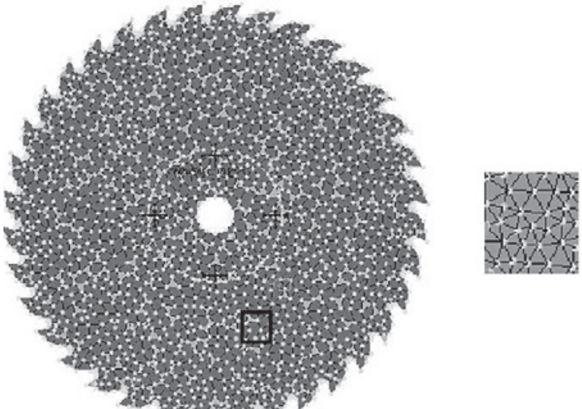


Figure 2 Mesh density of circular saw blade and detail
Slika 2. Gustoća mreže lista kružne pile; detalj

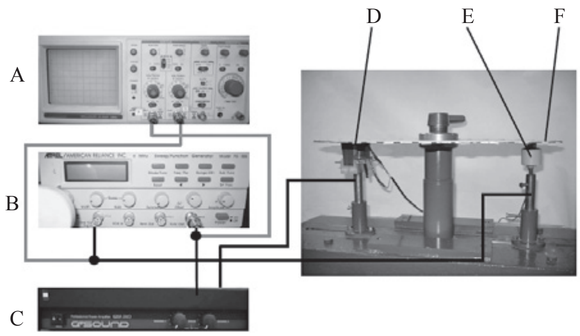


Figure 3 Scheme of experimental stand (Orłowski and Javorek, 2009); A - digital oscilloscope, B - tone generator, C – amplifier, D - Electromagnetic (solenoid) driver, E – non-contact displacement transducer, F - circular saw blade
Slika 3. Shema provedbe eksperimenta (Orłowski and Javorek, 2009.)**:** A – digitalni osciloskop, B – ton-generator, C – pojačalo, D – elektromagnetski vozač, E – beskontaktni davač pomaka, F – list kružne pile.

2.3 Experimental measurements
2.3. Eksperimentalna mjerenja

Solid circular saw blade, whose parameters are presented above in Table 1, was used for experimental measurements of natural frequencies. The method (harmonic test) was presented in more detail in the paper of Siklienka and Svoreň (1997).

Natural frequencies of the non-rotating circular saw blade $f_{(n=0)}$ were measured for n = 1, 2, 3, 4 on an experimental stand in the Technical University in Zvolen (Fig. 3).

3 RESULTS AND DISCUSSION
3. RESULTATI I DISKUSIJA

In the next paragraph, mathematical and experimental results are presented in the same sequence as in paragraph Material and Methods. The calculated values of natural frequencies determined by the Bessel function are shown in Table 2.

Table 2 Calculation values of natural frequencies determined by Bessel functions (B.F.)
Tablica 2. Izračunane vrijednosti vlastitih frekvencija Besselovim funkcijama

n	1	2	3	4
f, Hz	147	179	297.6	500.5

Leopold and Münz (1992) showed that the type (shell/solid) and number of elements had no significant influence on calculation accuracy of natural frequencies of circular saw blade. Our results confirm the same (see the values in Table 3 and 4).

Table 3 and 4 show two very similar frequency values for n=1. These values of natural frequency of cosine and sine components were called split mode by Yu and Mote (1987).

When comparing values in different columns (Shell 5) and (Shell 20), i.e. for maximum and minimum density of mesh, the difference is practically neg-

Table 3 Calculated values of natural frequencies determined by modal analysis with shell elements
Tablica 3. Izračunane vrijednosti vlastitih frekvencija primjenom modalne analize s ravninskim elementima

n	Shell 5	Shell 10	Shell 20
	f, Hz	*f*, Hz	*f*, Hz
1	147.57	147.59	147.56
		149.16	149.14
2	172.81	172.83	172.8
3	271.36	271.4	271.36
4	439.45	439.52	439.46

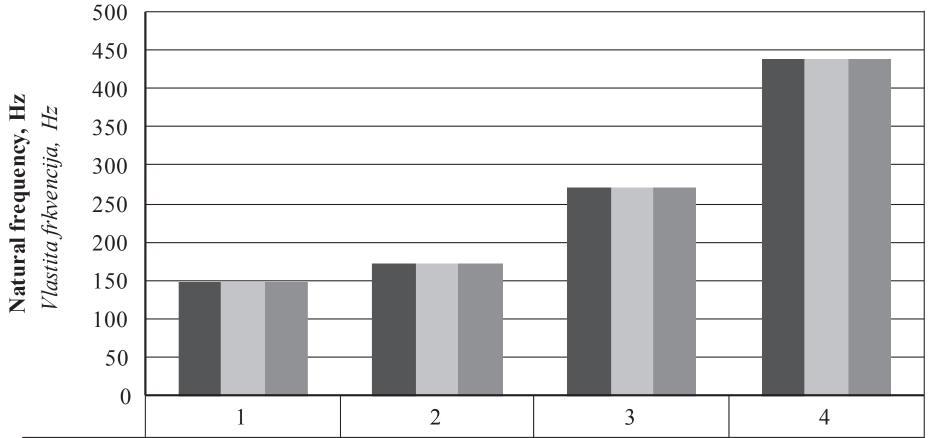
Table 4 Calculated values of natural frequencies determined by modal analysis with solid elements
Tablica 4. Izračunane vrijednosti vlastitih frekvencija primjenom modalne analize s volumenskim elementima

n	solid_10	solid_20
	f, Hz	*f*, Hz
1	147.35	147.08
	148.91	148.68
2	172.68	172.37
3	271.69	271.2
4	440.38	439.63

ligible (see Fig. 4), but time of computing for Shell 20 is shorter than for Shell 5.

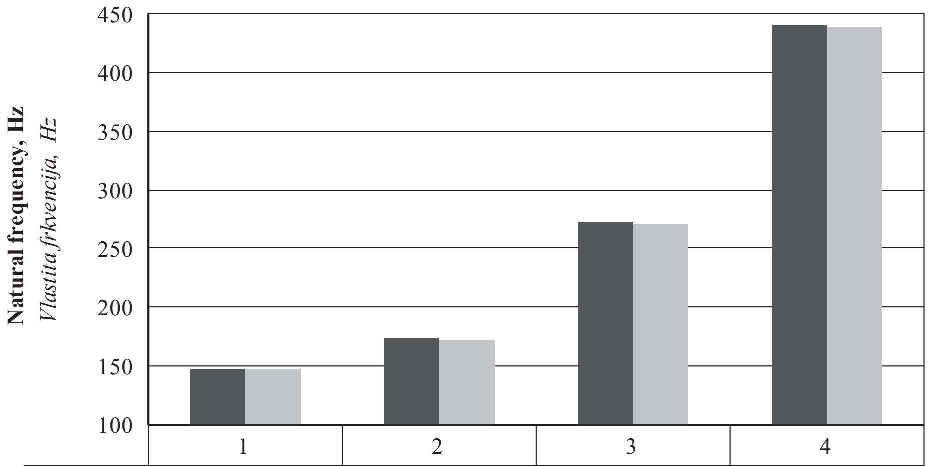
The modal analysis with solid elements was made on a circular saw blade with the element size of 10 mm (Solid 10) and 20 mm (Solid 20). The calculated results are shown in Table 4, and graphically in Figure 5.

The values of natural frequencies, which were determined by experimental measuring, (using the apparatus in Fig. 3), are shown in Table 5. The criteria for



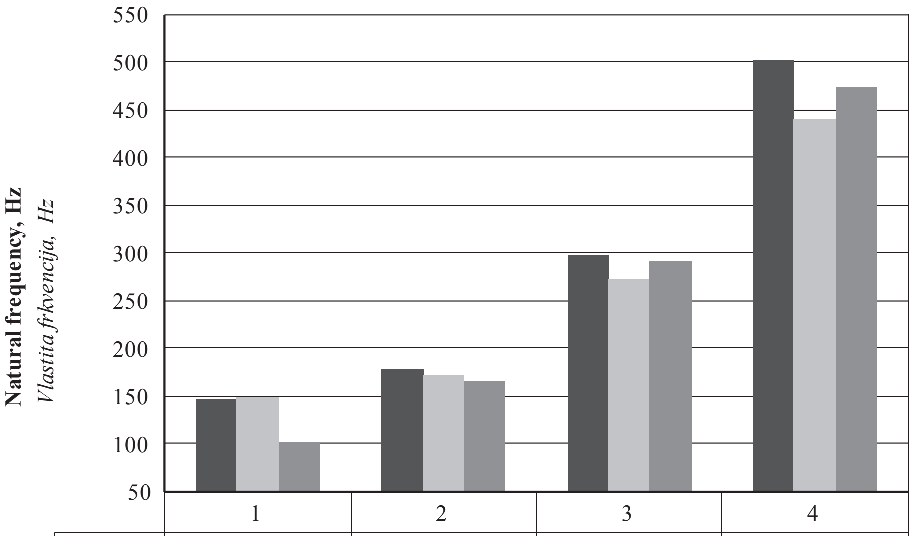
	1	2	3	4
Shell 5	147.57	172.81	271.36	439.45
Shell 10	147.59	172.83	271.4	439.52
Shell 20	147.56	172.8	271.36	439.46

Figure 4 Values of natural frequencies determined by modal analysis of circular saw blade with shell elements
Slika 4. Vrijednosti vlastitih frekvencija dobivene primjenom modalne analize kružne pile s ravninskim elementima



	1	2	3	4
Solid 10	147.35	172.68	271.69	440.38
Solid 20	147.08	172.37	271.2	439.63

Figure 5 Values of natural frequencies determined by modal analysis of circular saw blade with solid elements
Slika 5. Vrijednosti vlastitih frekvencija dobivenih modalnom analizom kružne pile s volumenskim elementima



	1	2	3	4
B. F.	147	179	297.6	500.5
Shell 5	147.57	172.81	271.36	439.45
E. M.	101	166	292	473

Figure 6 Comparison of natural frequencies determined by different methods
Slika 6. Usporedba vrijednosti vlastitih frekvencija lista kružne pile dobivenih različitim metodama

Table 5 Experimentally measured values of natural frequencies
Tablica 5. Eksperimentalno izmjerene vrijednosti vlastitih frekvencija

n	1	2	3	4
f, Hz	101	166	292	473

accepting the searched frequency was the quality, brightness and sharpness of Chladni patterns on the tested saw disc.

As shown in Figure 6, the values of natural frequencies for n = 1 are the same for B.F. and Shell 5.

Values are relatively identical for n = 2, and for n = 3 the values determined by modal analysis are pretty lower than the values determined by other two methods, which are identical. For n = 4, the differences between values are relatively high. It could be said that the values determined by modal analysis are in accordance with the values determined by other methods used in the paper.

4 CONCLUSIONS
4. ZAKLJUČCI

On the basis of the experiments, it could be stated that:

1. Application of finite element method with various types of elements (shell/solid) and dimensions (5 / 10 / 20) resulted in approximate data of natural frequencies for shape modes n = 1, 2, 3, 4. This corresponds to the results of other authors cited in references.
2. The values of natural frequencies determined by all three methods are acceptable. Considering the difference in the values of natural frequencies, for n=1, between values determined by experimental method and with the use of Bessel functions, and between values determined by experimental method and by finite element methods, it seems that the mathematical apparatus is not able to solve exactly the state of thin plate (saw disc is thin plate).
3. The good conformity of the three results shows that manufacturers could use the available software that can simulate relatively exactly the behaviour of the studied phenomena - in our case natural frequencies and other parameters in the real operating conditions. The use of software will save the time and money of manufacturers for production of circular saw blades and their testing.

5 REFERENCES
5. LITERATURA

1. Benhao, J.; Minqi, S.; Yeqian, G.; Zheng, W.; Nanfeng, Z., 2009: Overspeed Test of Circular Saw Blade. In: Proceedings 19th International Wood Machining Seminar, Nanjing, 21. – 23. October, 228-233.
2. Ekevad, M.; Cristóvão, L.: Grönlund, A., 2009: Different methods for monitoring flatness and tensioning in circular – saw blades. In: Proceedings 19th International Wood Machining Seminar, Nanjing, 21. – 23. October, 121-131.
3. Gogu, G., 1988: Berechnung der Eigenfreguenzen von Kreissägeblättern mit der Finite-Element-Methode. Holz als Roh- und Werkstoff, 46 (3): 91-100. http://dx.doi.org/10.1007/BF02612051
4. Holφyen, S., 1987: Vibrations and natural frequencies of angular slot circular saws. Holz als Roh- und Werkstoff, 45 (3): 101-104.
5. Javorek, Ľ.; Murín, L.; Svoreň J., 2010: Effect of shape of compensating slots in the body of a circular saw blade on noise level in the cutting process. ProLigno – Scientific Journal in the field of wood engineering, 6 (4): 5-12.

6. Kirshoff, G. R., 1982: Gesammelte Abhandlungen. Leipzig, 237-285.
7. Leopold, J.; Münz, V. V., 1992: Dynamische und statische Untersuchungen von Kreissägeblättern mittels der Finite-Elemente-Methode. Holzbearbeitung, 6: 52-56.
8. Michna, S.; Svoreň, J., 2007: Application of CAD, CAE with FEM for estimation ranges of values of critical rotational speed of Circular saw blades. Acta Facultatis Technicae, 9 (1): 201-206.
9. Mote, C. D., 1965: Free Vibration of Initially Stressed Circular Disk. Journal of Engineering for Industry, 5: 258-264. http://dx.doi.org/10.1115/1.3670808
10. Nishio, S.; Marui, E., 1996: Effects of Slots on Lateral Vibration of Circular Saw Blade. Proccedings of Tenth Wood Maschining Seminar, 159-164. http://dx.doi.org/10.1016/0890-6955(95)00088-7
11. Orlowski, K.; Sandak, J.; Tanaka, Ch., 2007: The critical rotational speed of circular saw: Simple measurement method and its practical implementation. Journal of Wood Science 53 (5): 388-393. http://dx.doi.org/10.1007/s10086-006-0873-5
12. Orłowski K.; Javorek, L., 2009: Limitations of the Chladni patterns method of the determination of circular saw blade critical rotational speed. In.: Annals Warsaw University of Life Science – Forestry and Wood Technology, 69: 152-157.
13. Pahlitzsch, G.; Rowinski, B., 1966: Über der Swingungsverhalten von Kreissägeblättern. 2. Mitteilung: Ermittlung und Auswirkungen der Kritische Drehzahlen und Eigenfreguenzen der Sägeblätter. Holz als Roh-und Werkstoff, 24 (8): 341-346. http://dx.doi.org/10.1007/BF02619215
14. Schajer, G. S.; Mote, C. D., 1983: Analysis of roll tensioning and its influence on circular saw stability. Wood Sci. Technol., 17 (4): 287-302. http://dx.doi.org/10.1007/BF00349916
15. Siklienka, M.; Svoreň, J., 1997: Frekvencie vlastných tvarov kmitov pílových kotúčov pri statickom kmitaní. TU Zvolen, Scientific studies.
16. Southwell, R. V., 1922: On the free transverse vibrations of a uniform circular disc clamped at its centre, and on the effects of rotation. Proceedings of the Royal Society of London, Series A 101. http://dx.doi.org/10.1098/rspa.1922.0032
17. Stakhiev, Y. M., 1970: Rezonansnyje kolebanija diskovych pil. Izv. VUZ. Lesnoj žurnal, 13 (5): 78-84.
18. Stakhiev, Y. M., 1998: Research on circular saw vibration in Russia: From theory and experiment to the needs of industry. Holz als Roh- und Werkstoff, 56 (2): 131-137. http://dx.doi.org/10.1007/s001070050284
19. Stakhiev, Y. M., 2000: Today and tomorrow circular saw blades: Russian version. Holz als Roh- und Werkstoff, 58 (4): 229-240. http://dx.doi.org/10.1007/s001070050417
20. Veselý, P.; Kopecký, Z.; Hejmal, Z.; Pokorný, P., 2012: Diagnostics of circular saw blade vibration by displacement sensors. Drvna industrija, 63 (2): 81-86. http://dx.doi.org/10.5552/drind.2012.1130
21. Yu, R. C.; Mote, C. D., 1987: Vibration of Circular saws Containing Slots. Holz als Roh- und Werkstoff, 45 (4): 155-160. http://dx.doi.org/10.1007/BF02627571

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Determination of Displacement in a Loaded Wooden Chair by Using Digital Image Correlation

Određivanje pomaka opterećenoga drvenog stolca primjenom korelacije digitalne slike

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SAŽETAK • *The subject of the research is a ready to assemble (RTA) chair constructed of plywood by a CNC machine. The standard test of seat and back of the chair according to the Czech Standard CSN EU 1728 was supplemented with an optical method of digital image correlation (DIC). The aim of the research was to discover mechanical principles of the construction and to develop a methodology of standardized furniture testing. Results of experimental measurement show the response of the chair construction in a form of displacement fields, strain fields, charts and vectors depicting displacement of the observed points. The results can be used to improve mechanical properties of the construction, as well as to develop a shape of the product or specific parts of the product. Besides furniture testing laboratories and research institutes, engineers from development departments of furniture making companies or industrial designers can easily use the presented method.*

Key words: *standard furniture testing, digital image correlation, chair, plywood, CNC*

SAŽETAK • *Predmet istraživanja bio je stolac spreman na sklapanje (RTA), izrađen od uslojenog drva na CNC stroju. Standardni test sjedala i naslona stolca prema češkom standardu CSN EU 1728 dopunjen je optičkom metodom korelacije digitalne slike (DIC). Cilj istraživanja bio je otkriti mehanička načela konstrukcije te obogatiti metodologiju standardiziranog ispitivanja namještaja. Rezultati eksperimentalnih mjerenja prikazuju reakciju konstrukcije stolca u obliku polja pomaka, polja naprezanja te grafikona i vektora koji predočuju pomake promatranih točaka. Rezultati se mogu iskoristiti za poboljšanje mehaničkih svojstava konstrukcije, kao i za razvoj oblika proizvoda ili ispitivanih dijelova. Osim u laboratoriju za ispitivanje namještaja ili u istraživačkim institutima, prikazanom se metodom lako mogu koristiti inženjeri razvojnih odjela u tvrtkama za proizvodnju namještaja ili industrijski dizajneri.*

Ključne riječi: *standardno ispitivanje namještaja, korelacija digitalne slike, stolac, ploča od uslojenog drva, CNC stroj*

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1 INTRODUCTION
1. UVOD

Information technology development and industry automation resulted in the development of CNC technologies, nowadays also used in furniture manufacturing. RTA furniture made of wood composites by CNC machines is the most often serially manufactured furniture. While the furniture has been produced for more than twenty years, experience with constructing it and with its strength properties is limited. Until recently, the trial and error approach was the only way to research the methods of development of furniture and wooden products. Development of technologies, new materials and informatics not only in production and marketing, but also in furniture design, brings about many methods that allow engineers and designers to adopt new approaches to their work. Despite the fact that standardized furniture testing, e.g. according to European Standards (EN), is not compulsory for producers in most cases, it is commonly implemented. Numerical simulations have been applied by furniture industry in a limited way so far (e.g. Mirra Office Chair; Larder and Wiersma, 2007). However, they are supported by research rather significantly. From a large number of studies, we would like to mention the research on behaviour of constructions of upholstered furniture (Smardzewski and Prekrat, 2009), sitting furniture (Prekrat *et al*., 2012; Horman *et al*., 2010; Smardzewski and Gawroński, 2003), box-type furniture (Nicholls and Crisan, 2002; Tankut *et al*., 2012), bed (Koňas, 2008), desk (Novotný *et al*., 2011), as well as the research on behaviour of wood product joints (Mihailescu, 2003; Černok *et al*., 2004; Prekrat and Smardzewski, 2010; Serrano and Enquist, 2010). The issue of strength design of furniture and various research methods is rather comprehensively described by Eckelman (2003), Smardzewski (2004) and Joščák (1999).

Although optical research methods are relatively well described and applied in other industries, they are still rare in furniture making and logging. The issue of Digital Image Correlation (DIC) methodology in relation to a shape, and deformation measurement is described e.g. by Sutton (2008) or Cintrón and Saouma (2008). Nestorović *et al*. (2011) employed DIC (3D) and numerical simulation to define material properties of veneer composite structure laminate, analysing a chosen shell of a chair. Smardzewski *et al*. (2008) analysed nonlinear behaviour of polyurethane furniture foams combining experimental testing, DIC measurement and numerical modelling. Also Enquist (2005) applied 3D DIC measurement for different purposes in furniture design and material testing. Miyauchi *et al*. (2006) analysed strain distributions of wooden dovetail joints using DIC. Also Masuda and Tabata (2000) combined DIC and numerical simulation (FEM) when testing pinned joints in wood under tension load. Betts *et al*. (2010) applied DIC to locate a neutral axis in wood beams strained by bending. Muszyński *et al*. (2002) employed DIC to research wood deformations with an axial creep test under varying climate conditions. Besides DIC, there are also other optical methods used in research and development of wood products, e.g. optical triangulation measuring the quality of surfaces (Costa, 2012) and precision of production against 3D models, laser vibrometers used for testing mechanical characteristics of furniture connections (Weyrauch *et al*., 2013), speckle pattern interferometers used for testing deformation of wooden joints (Umezaki *et al*., 2004) or photo tensometers used for testing gluing strength of wood joints (Mihulja *et al*., 2008).

The main objective of this study is to assess the mechanical behaviour of RTA chair constructed of plywood using an optical method based on digital image correlation. Another goal is to develop the methodology of standardized furniture testing so that it can also be used in research and development of furniture construction – industrial products.

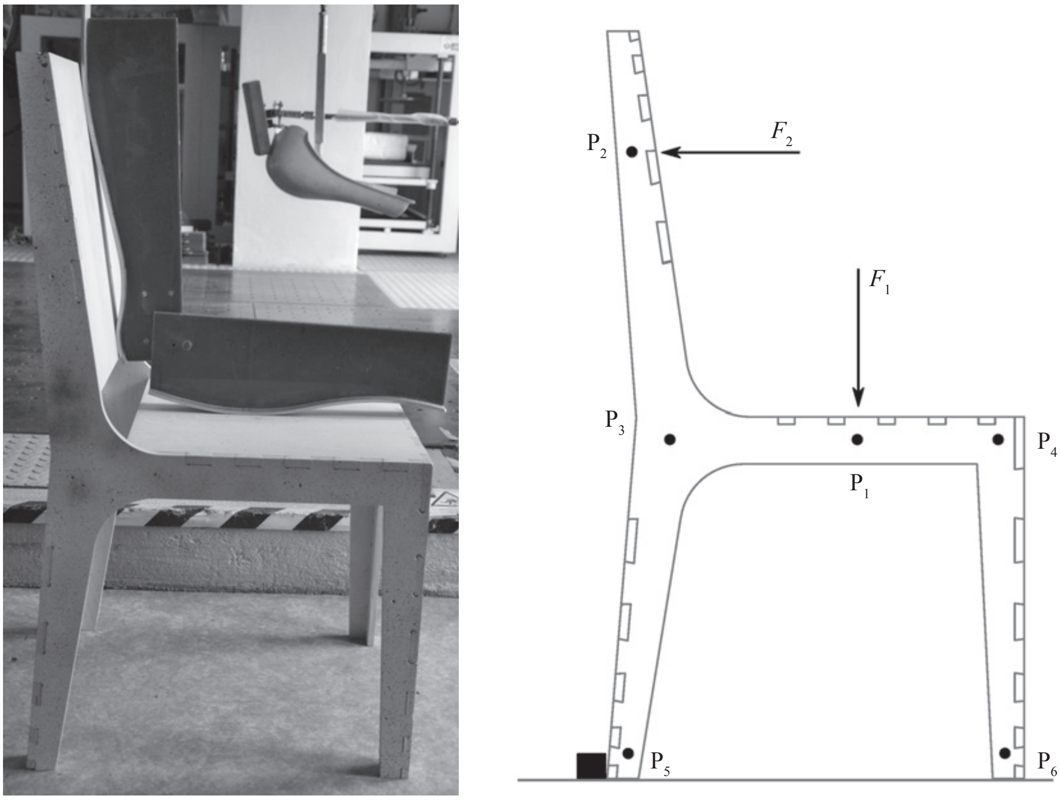
2 MATERIALS AND METHODOLOGY
2. MATERIJAL I METODE

The chair was created parametrically in environment modelling of the CAD and CAM program, with dimensions 900 by 490 by 430 mm. It was made by a CNC machining centre (with a nesting table) of 12 mm thick birch (*Betula pendula*) plywood, with integrated dovetail not-glued joints – RTA furniture. Similar principles of constructing furniture based on mass production were described e.g. by Oh *et al* (2006). The chair was assembled from six parts. It was designed as self-locking (Figure 1a).

The chair construction was mechanically loaded in an accredited furniture testing laboratory according to the Czech Standard CSN EN 1728, Article No. 6.4 – Static strain test of a seat and back of a chair.

A universal pneumatic testing device was set up according to the template (Figure 1) and design. The device was loaded to the seat with the force of 1300 N and to the back with the force of 450 N in 10 cycles, from P1 and P2 points determined by the loading diagram (Figure 2 and Article 5.2 of the Standard). To prevent the chair from moving on the floor, it was supported with adjustable stops. Afterwards, the values of displacement in the horizontal and vertical direction for P1 – P6 points were assessed.

Experimental optical measurement was carried out by the DSLR (Digital Single-Lens Reflex) camera Nikon D5100 (16Mpix resolution) and Nikkor 50 mm F1.8 AF-S lens, which were set perpendicularly to the examined surface – the side frame of the chair. To achieve constant intensity of the recorded surface image, it was necessary to keep stable lighting conditions within image acquisition. For this purpose, the examined surface of the chair construction was lightened by a pair of diffuse lights. The frequency of recording was set up to 1 fps, the bit depth of images was 8-bit (256 shades of grey). 8-bit images are necessary for further processing and for computing the displacement fields. The open-source tethering software DigiCamControl (by Duka, I.), connected to the DSLC camera using the



a. b.

Figure 1 a) Chair construction and template for determination of straining points P1 and P2, b) Scheme of experimental chair testing with P1 – P6 points

Slika 1. a) Konstrukcija stolca i predložak za određivanje točaka deformacije P1 i P2, b) shema eksperimentalnog ispitivanja stolca s označenim točkama od P1 do P6

USB port, was used to transfer data to a mobile PC station. Correlation computation of displacement and strain fields was carried out in the Vic-2D (by Correlated Solutions Inc.) program. Motion tracking of P1 – P6 points was carried out in the open-source program Blender (by Blender Foundation) and verified subsequently by the Vic-2D program. To guarantee the valid computation by the DIC method, it is necessary to cover the recorded surfaces with (ideally) a two-component contrasting colour (e.g. black and white) before testing. To fulfil this condition, a spray system was used from the distance, which provided speckles of recommended size of 3 – 6 pixels (Sutton *et al*., 2009).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The first goal of the work was to compute the displacement fields on the chair side frame using the DIC method. The result is shown in Figure 2 and 3, where the back and the seat are in the second cycle of experimental testing (image No. 20). As it can be seen, the DIC computation brought reliable results based both on quantitative (standard deviation was lower than 0.05) and qualitative evaluation (displacement contours follow mechanical behaviour assumptions resulting from a loading mode). The ultimate value of horizontal displacement was observed at the top of backrest (u = 3.92 mm, Fig. 2) and the ultimate value of vertical displacement was observed at the front leg (v = 1.185 mm, Figure 3).

The next step in the analysis was to look at the strain fields computed from displacements. The strain field in horizontal direction (ε_{xx}) is shown in Figure 4; the vertical strain component (ε_{yy}) is shown in Figure 5 (also for image No. 20). The results indicate that vertical strain is the highest in the dovetail connections on top of the chair seat. Nonetheless, its highest absolute strain did not exceed ~ 0.3 %, so we can affirm that all strains occurring there are elastic – below the proportional limit of all possible loading modes in wood and birch plywood (Bodig and Jayne, 1993; Wood Handbook, 2010). The horizontal strain is the highest in the backrest dovetail connections and its maximal absolute value is ~ 1.56 %. This value is often measured above the proportional limit, so the question is whether plastic strain occurred or not. A detailed visual analysis of the connection indicated that the plastic strain most likely did not occur – the fibres of surface ply did not fail in any mode.

The reason why such high strains were obtained is that the computed strains at the connection interferences might be influenced by their geometric intolerances. It means that the virtual strain gages used for computing consider the gap between connection parts as solid parts of the chair, i.e. gaps are considered as parts of the applied stochastic colour pattern. Three fundamental findings resulted from that: a) it is neces-

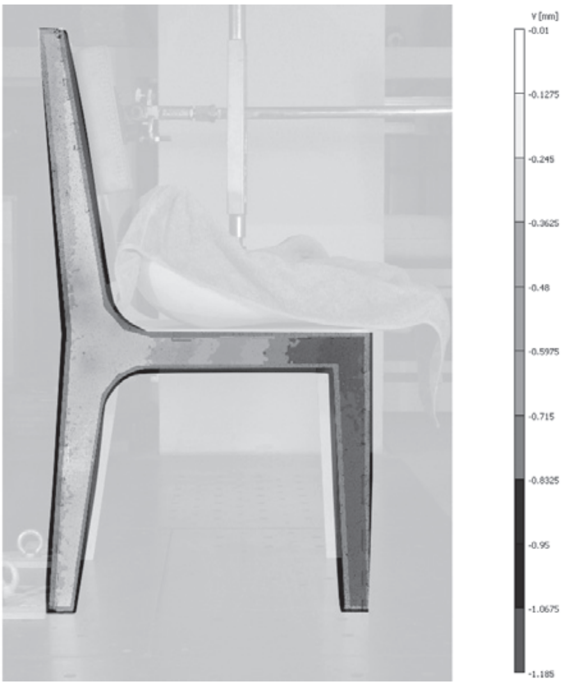


Figure 2 Horizontal displacement field, mm (for image No. 20)
Slika 2. Područje horizontalnog pomaka, mm (za prikaz broj 20)

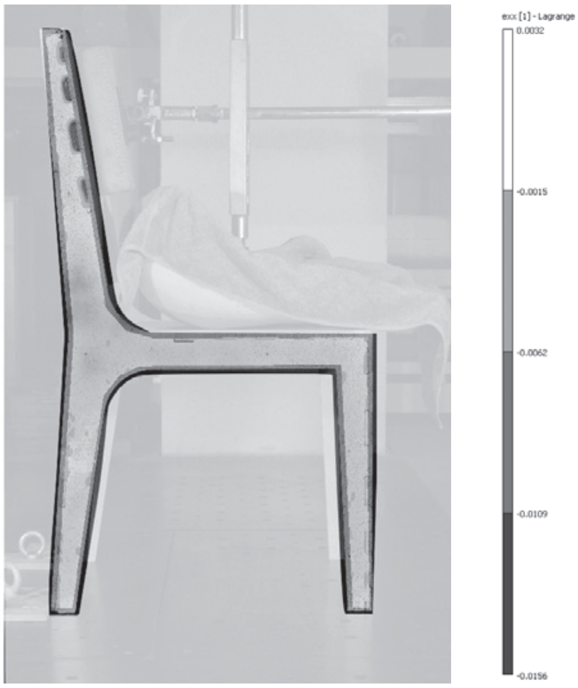


Figure 4 Strain field in horizontal direction (ε_{xx})
Slika 4. Područje naprezanja u horizontalnom smjeru (ε_{xx})

sary to analyse the dovetail connection from closer distance in greater detail, which would bring more information on strains in connection parts themselves and contact (nonlinear) behaviour; b) the strains obtained around the connections with bigger geometric intolerances should be analysed carefully to avoid errors; c) obtained displacements are reliable and not negatively influenced by virtual gages since they are computed beforehand from pixel moves. Therefore, the chosen acquisition distance is appropriate for kinematic assessment of the chair and brings a new perspective (2D data) on furniture testing.

Displacement of observed nodal points is shown by charts in Figures 6 – 11. Ten loading cycles in the seat and the back are significant in all charts (1 cycle ~ 12 images). The following differences in maximum and minimum values of deviations (displacement) related to the observed points are of our interest. The most noticeable displacement was achieved in the horizontal direction (the *X* axis), especially in P2 point (the back of the chair). The value achieved was approximately 6 mm (Figure 7). The displacement shows that, compared to the other observed parts of the construction, the back of the chair is relatively flexible.

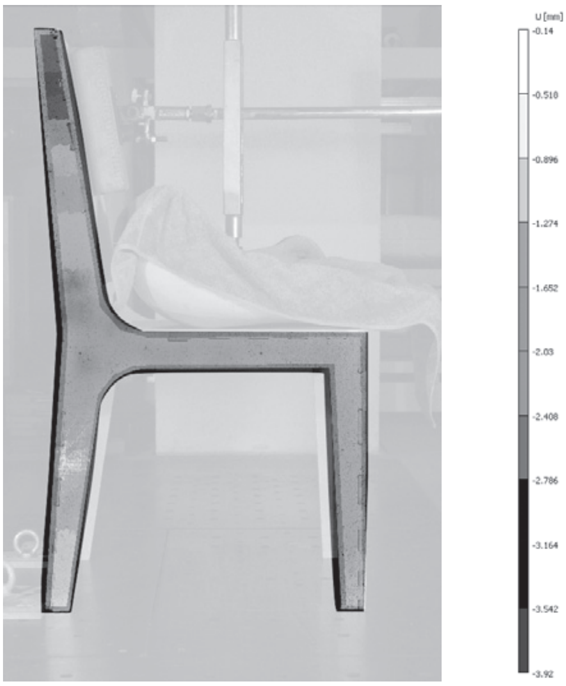


Figure 3 Vertical displacement field, mm (for image No. 20)
Slika 3. Područje vertikalnog pomaka, mm (za prikaz broj 20)

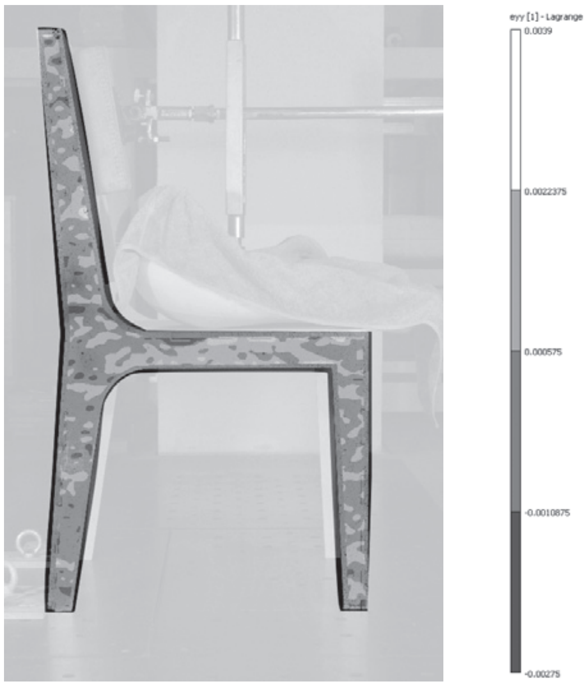
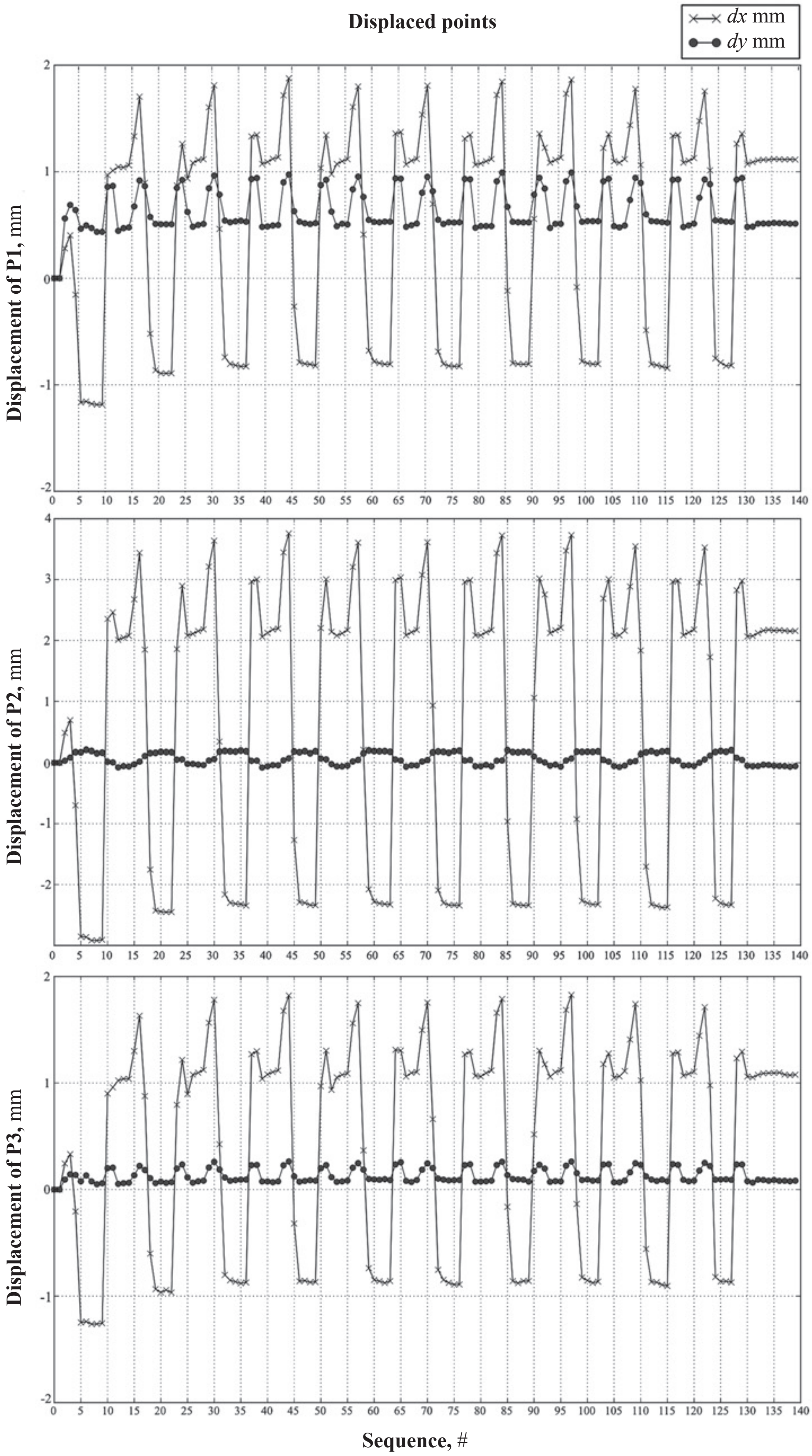
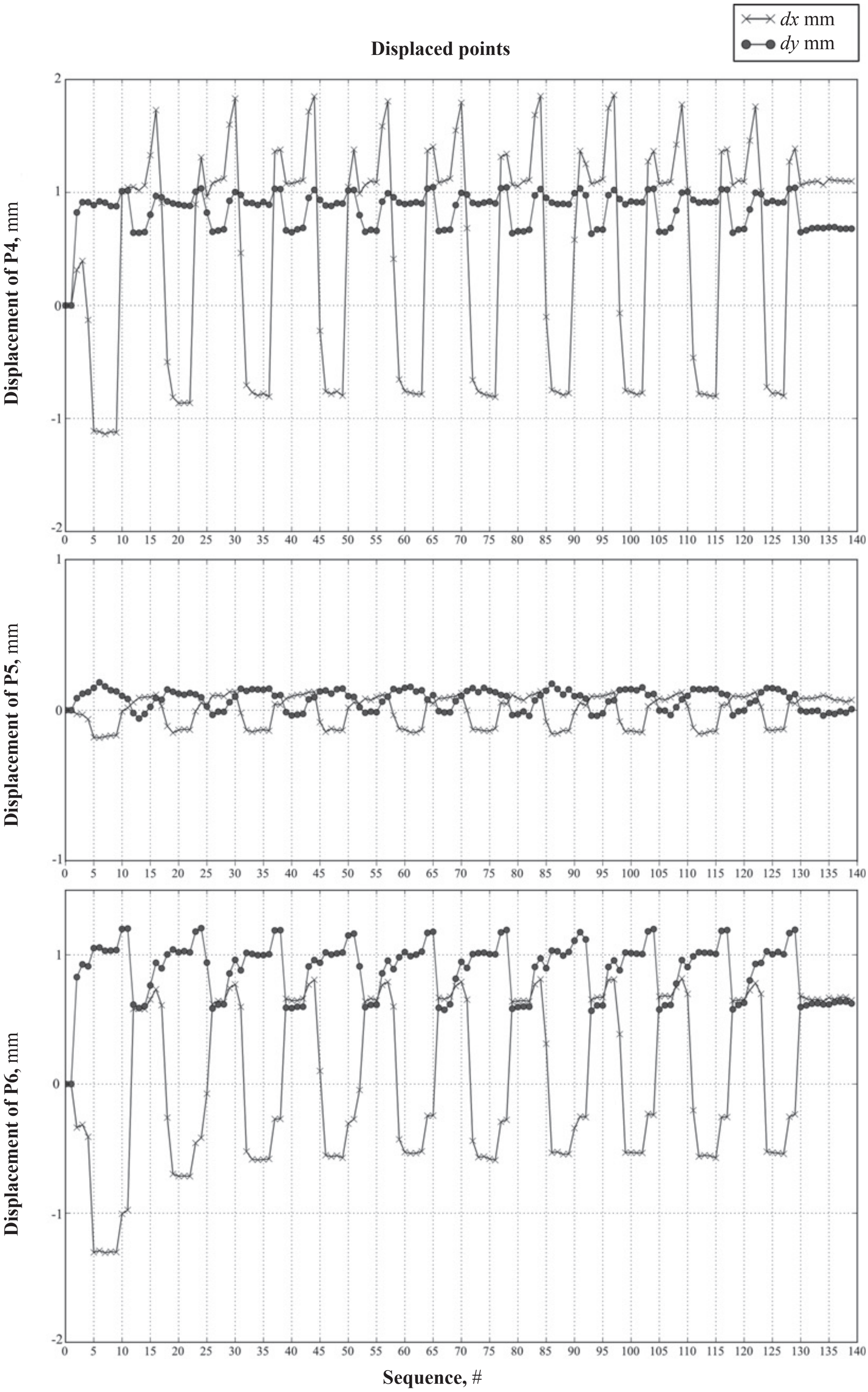


Figure 5 Strain field in vertical direction (ε_{yy})
Slika 5. Područje naprezanja u vertikalnom smjeru (ε_{xx})

The result is similar to the outcome obtained by Enquist (2005) within his research. The second highest value in the horizontal direction was measured in P3 point (connection of the seat and the back; approximately 2.6 mm (Figure 8). Nearly the same value of displacement in both directions was measured in points P1 (the seat) and P4 (connection of the seat and the front leg); in the *X* axis approximately 2.5 mm, in the *Y* axis 1 mm (Figures 6 and 9). The most noticeable displacement in the vertical direction was measured in P6



Figures 6 – 8 Charts showing displacement of P1 – P3 points in horizontal and vertical direction (axis *X* and *Y* in millimetres)
Slike 6. – 8. Dijagrami pomaka u točkama P1 do P3 u horizontalnome i vertikalnom smjeru (osi *X* i *Y* u milimetrima)



Figures 9 – 11 Charts showing displacement of P4 – P6 points in horizontal and vertical direction (axis *X* and *Y* in millimetres)
Slike 9. – 11. Dijagrami pomaka u točkama od P4 do P6 u horizontalnome i vertikalnom smjeru (osi *X* i *Y* u milimetrima)

point (front leg); approximately 1.2 mm (Figure 11). Considering the position on the fixed pad, the displacement should be considerably lower (similarly as in P5 point, Figure 10). However, as the flat pack construction was the subject of the research, the effect was most likely caused by a small inaccuracy occurred when the chair was assembled. One more inaccuracy probably appeared when the chair was placed into the testing device – the front legs of the chair were set a bit imprecisely. Due to absence of stops at the front legs, dis-

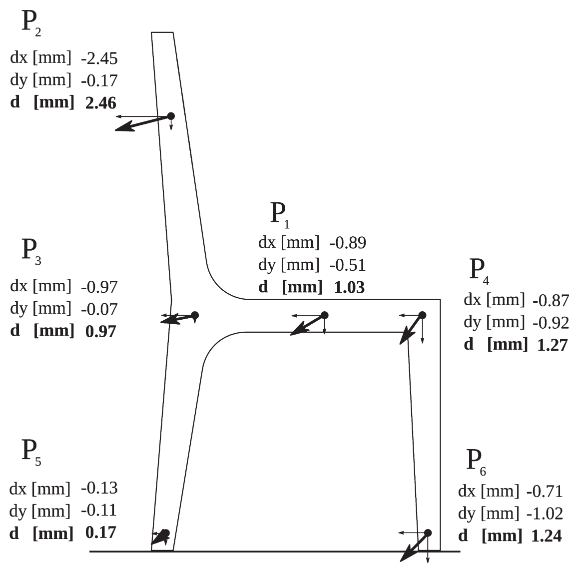


Figure 12 Vectors of displacement of the chosen points occurred within construction straining (for image No. 20)
Slika 12. Vektori pomaka izabranih točaka stolca u kojima se pojavljuju deformacije konstrukcije

placement in the horizontal direction in P6 point was higher; approximately 2 mm. The charts offer a possibility of comparing the chosen points of a construction or similar constructions (e.g. different prototypes of a product), as well as a possibility of testing the constructions durability when the number of cycles reaches thousands and fatigue of material and joints often occurs.

Final vectors of the displacement of all observed points in the second testing cycle (image No. 20) are shown in Figure 12. Directions of the vectors are similar but the obtained values are considerably lower (seven or eight times) than values of vectors measured by Enquist testing a chair with armrests. It is possible to say that our chair is stiffer (lower deflections) in bending than the one tested by Enquist (2005). Different construction of the chairs explains the difference in measured values. The chair tested by Enquist (2005) can be considered as a rod construction (of massive wood) with mortise and screw joints. The construction of the chair tested in this research is a plate type (of plywood) with dovetail joints, which usually reaches higher values of load capacity and solidity.

4 CONCLUSION
4. ZAKLJUČAK

The results based on measured experimental data can be summed up as follows:

- The tested chair construction shows the highest displacement in the back;
- The tested chair construction shows the largest strain in dovetail connections between the back and the side and between the seat and the side;
- The maximum deviation of the observed surface was detected in P2 point (the back of the chair);
- Individual load cycles are recognizable in the charts of the point displacement;
- The final vectors directions of the tested chair displacement are similar to the chair tested by Enquist (2005). Values of the final vectors related to the tested chair are considerably lower than values of the chair tested by Enquist (2005);

Considering the method applied, it is possible to say that the DIC can be easily used for and applied to furniture testing due to its relative simplicity and low requirements on devices used, undemanding data processing and assessment carried out by accredited laboratories or research institutes. Development departments of furniture making companies can apply the methodology to increase their competitiveness and innovation potential. By means of deeper analysis of data, it is possible to detect badly dimensioned construction connections or to optimize the construction in terms of shape or used materials.

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5 REFERENCES
5. LITERATURA

1. Betts, C. A.; Miller, T. H.; Gupta, R., 2010: Location of the neutral axis in Wood Beams: A preliminary study. Wood Material Science and Engineering, 5: 173-180. http://dx.doi.org/10.1080/17480272.2010.500060
2. Bodig, J.; Jayne, B. A., 1993: Mechanics of wood and wood composites. Malabar, Krieger Publish. Comp., p. 712.
3. Cintrón, R.; Saouma, V., 2008: Strain measurements with the Digital Image Correlation system Vic-2D. Department of Civil Environmental and Architectural Engineering, University of Colorado, Boulder, Colorado, p. 23.
4. Costa, M. F. M., 2012: Optical triangulation-based microtopographic inspection of surfaces. Sensors, 12: 4399-4420. http://dx.doi.org/10.3390/s120404399
5. Černok, A.; Joščák, P.; Lang, M., 2004: Výpočtový model kolíkového spoja. Nábytok 2004, Faculty of Wood Technolgy, Technical University in Zvolen, 12 p.
6. Eckelman, C., 2003: Product engineering and strength design of furniture. Purdue University, West Lafayette, Indiana, p. 204.
7. Enquist, B., 2005: Use of optical measurement techniques in furniture design. Department of Architecture, Chalmers University of Technology, Göteborg, Sweden, p. 13.
8. Horman, I.; Hajdarević, S.; Martinović, S.; Vukas, N., 2010: Numerical analysis of stress and strain in a wooden chair. Drvna industrija, 61 (3): 151-158.
9. Joščák, P., 1999: Pevnostné navrhovanie nábytku. Faculty of Wood Technolgy, Technical University in Zvolen, 246 p.
10. Koňas, P., 2006: Finite element model of the bed. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, LIV (2): 67-72. http://dx.doi.org/10.11118/actaun200654020067
11. Larder, L.; Wiersma, J., 2007: CEA takes a front seat. ANSYS Advantage, 1 (1): 2.
12. Masuda, M.; Tabata, K., 2000: Analyses of fracture of wood in pinned joints using the finite small area fracture

criterion and image correlation method, Proceedings of World Conference on Timber Enineering, July 31 – August 3, 2000, Whistler Resort, British Columbia, Canada, p.8, Available at: http://timber.ce.wsu.edu/Resources/papers/toc.pdf
13. Mihulja, G.; Bogner, A.; Župčić, I., 2008: Gluing strength of wood measured with nonstandard pressure-shear method. Wood Research, 53 (1): 91-104.
14. Miyauchi, K.; Masuda, M.; Murata, K., 2006: Analysis of strain distributions of wooden dovetail joints using digital image correlation method. Journal of the Society of Materials Science, Japan, 55 (4): 367-372. http://dx.doi.org/10.2472/jsms.55.367
15. Mihailescu, T., 2003: Finite element analysis of mortise and tenon joint in parametric form. Transilvania University, Faculty of Wood Industry, Brasov, 145 p.
16. Muszyński, L.; Lagaňa, R.; Shaler, S. M., 2002: Optical measurements of wood deformations in changing climate. SEM Annual Conference and Exposition on Experimental and Applied Mechanics - Measurements in Advanced Materials and Systems, 4 p.
17. Nicholls, T.; Crisan, R., 2002: Study of the stress-strain state in corner joints and box-type furniture using Finite Element Analysis (FEA). Holz als Roh- und Werkstoff , 60: 66-71. http://dx.doi.org/10.1007/s00107-001-0262-0
18. Nestorović, B.; Skakić, D.; Grbac, I., 2011: Determining the characteristics of composite structure laminae by optical 3D measuremtent of deformation with numerical analysis. Drvna industrija, 62 (3): 193-200. http://dx.doi.org/10.5552/drind.2011.1103
19. Novotný, M.; Neugebauer, R.; Šimek, M., 2011: Static analysis of an office desk construction. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis. LIX (6): 247-254. http://dx.doi.org/10.11118/actaun201159060247
20. Oh, Y.; Johnson, G.; Gross, M. D.; Do, E. Y. L., 2006: The designosaur and the furniture factory. International Conference on Design Computing and Cognition, Eindhoven, Netherlands, pp. 123-140. http://dx.doi.org/10.1007/978-1-4020-5131-9_7
21. Prekrat, S.; Smardzewski, J., 2010: Effect of gluline shape on strength of mortise and tenon joint. Drvna industrija, 61 (4): 223-228.
22. Prekrat, S.; Smardzewski, J.; Brezović, M.; Pervan, S., 2012: Quality of corner joints of beech chairs under load. Drvna industrija, 63 (3): 205-210. http://dx.doi.org/10.5552/drind.2012.1220
23. Serrano, E.; Enquist, B., 2010: Assesment of the strain distribution in wood adhesive bonds by contact-free measurement and finite element analyses. Swedish national testing and research institute, Borås, Sweden, p.7.
24. Smardzewski, J., 2004: Modelowanie półsztywnych węzłow konstukcyjnych mebli. Wydawnictwo Akademii Rolnicznej im. Augusta Cieszkowskiego w Poznaniu, p. 224.
25. Smardzewski, J.; Gawroński, T., 2003: Gradient optimisation of skeleton furniture with different connections. Electronic Journal os Polish Agricultureal Universities, 6 (1), Available at: http://www.ejpau.media.pl/volume6/issue1/wood/abs-01.html
26. Smardzewski, J.; Grbac, I.; Prekrat, S., 2008: Nonlinear mechanics of hyperelastic polyuretane furniture foams. Drvna industrija, 59 (1): 23-28.
27. Smardzewski, J.; Prekrat, S., 2009: Optimisation of a sofa frame in the integrated CAD-CAE environment. Electronic Journal of Polish Agricultureal Universities, 12 (4), Available at: http://www.ejpau.media.pl/volume12/issue4/abs-01.html
28. Sutton, M. A., 2008: Digital image correlation for shape and deformation measurements. Springer handbook of experimental solid mechanics. Ed. Sharpe, W.N. Springer-Verlag, Heidelberg, pp. 565-600.
29. Sutton, M. A.; Orteu J. J., Schreier, H. W., 2009: Digital image correlation for shape and deformation measurements Basic Concepts, Theory and Applications. Springer Springer-Verlag, Heidelberg, p. 342.
30. Tankut, A. N.; Tankut, N.; Karaman, A., 2012: Creep performance of Ready-to-Assemble (RTA) fasteners in bookcase construction. Proceedings from XXIII. International Conference Ambienta, Zagreb, October 12, 2012, pp. 195-208.
31. Umezaki, E.; Suzuki, T.; Takahashi, M., 2004: Measurement of deformation of wood joints using electronic spackle pattern interferometry. JSME International Journal, Series A, 47 (3): 274-279. http://dx.doi.org/10.1299/jsmea.47.274
32. Weyrauch, A.; Scheffler, M.; Kröppelin, U., 2013: Comparison of test methods for furniture corner connections. Proceedings of the XXVIth International Conference Research for Furniture Industry, Faculty of Wood Technology, Poznań University of Life Science, September 20, 2013, Poland, p. 7. http://furnituredesign.pl/publications
33. *** 2013: EN 1728 Furniture – Seating furniture – Testing methods for the determination of strength and Durability.
34. *** 2010: Wood handbook – Wood as an Engineering Material, Centennial edition. USDA Forest Service – FPL, Madison, p. 509.

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Strategic Business Performance Management System in Wood Processing Industry in Slovakia

Sustav upravljanja strateškim poslovanjem u drvoprerađivačkoj industriji Slovačke

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ABSTRACT • *Measuring and managing of business performance is a complex and difficult process, which at the present time passes through significant changes in theory and practice. Previously used indicators, methods and models were mainly based on financial indicators and methods of financial management. The problem of proving and relatively accurately quantifying the impact of financial indicators for the overall business performance in theory and practice of management has been fairly well solved. However, to identify and quantify the impact of qualitative non-financial indicators and methods of the management on the overall performance has so far been an issue that requires further scientific research in specific conditions of Slovak wood-processing industry. Based on statistical results of our research, wood processing industry enterprises should apply the selected methods and models of strategic business performance management. By applying the selected strategic methods and models, such as Balanced Scorecard, Business Intelligence, strategic planning and controlling, innovations and others, wood processing companies in Slovakia will achieve a better performance.*

Key words: *business performance, strategic performance management system, financial indicators, wood-processing industry, Slovakia*

SAŽETAK • *Mjerenje i vođenje poslovanja složen je i težak proces koji u ovome trenutku u teoriji i korporativnoj praksi doživljava velike promjene. Prethodno korišteni indikatori, metode i modeli uglavnom su se temeljili na financijskim pokazateljima i metodama financijskog upravljanja. Isticanje i relativno precizno kvantificiranje utjecaja financijskih pokazatelja na ukupnost poslovanja u teoriji i praksi upravljanja prilično je dobro riješeno. Međutim, identificirati i kvantificirati utjecaj kvalitativnih nefinancijskih pokazatelja i načina upravljanja njima na ukupnu učinkovitost čini se da je pitanje koje zaslužuje adekvatan prostor u znanstvenim istraživanjima u određenim uvjetima slovačke drvoprerađivačke industrije. Na temelju statističkih rezultata našeg istraživanja, poduzećima drvne industrije preporučujemo da primijene odabrane metode i modele upravljanja strateškim poslovanjem. Aplikacijom odabranih strateških metoda i modela kao što su sustav uravnoteženih ciljeva - Balanced*

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Scorecard, informacijski sustav Business Intelligence, strateško planiranje i kontroling, inovacije i dr., mogli bi se postići bolji rezultati poslovanja drvoprerađivačkih poduzeća u Slovačkoj.

Ključne riječi: *poslovni rezultati, sustav upravljanja strateškim poslovanjem, financijski pokazatelji, drvoprerađivačka industrija, Slovačka*

1 INTRODUCTION
1. UVOD

The world of business environment in modern economies and cities has changed dramatically the way of pursuing business and nowadays heavily depends on the performance in generating and utilizing new knowledge, imagination, creativity, innovations and technologies (Kourtit, 2011). In order to stay competitive, firms measure, monitor, and analyze their performance. Performance management systems are regularly implemented as balanced and dynamic solutions requiring considerable human (Kropivsek *et al.*, 2011) and financial resources, and offering support to the decision-making process by gathering, elaborating, and analyzing information (Vukšic, 2013). Calculation based on performed activities and processes – so called Activity-Based Costing (ABC) is becoming an important tool for the costs performance management (Rajnoha and Chromjaková, 2009). Besides implementing the ABC model, it is very important to integrate into this process of continuous improvement of enterprise efficiency the value added measures by single processes through process identification, which do not bring the added value in the whole production process (Rajnoha and Dobrovič, 2011). By the application of the new management IS, it will be possible to provide many market opportunities (Aláč *et al.*, 2010).

Strategic Performance Measurement Systems (SPMS) are used in a wide number of organizations to support performance planning, measurement and control. SPMS are designed to present managers with financial and nonfinancial measures covering different perspectives which, in combination, provide a way of translating strategy into a coherent set of performance measures (Chenhall, 2005). SPMS typically provide information on financial and nonfinancial performance measures (Oblak and Zadnik Stirn, 2000) in an effort to both report on past performance and help managers influence future performance. Financial measures assess the short-term impact of managerial decisions in areas such as revenue growth, asset utilization, and cash flows (Kaplan, 2001; Rappaport, 2005), while nonfinancial measures capture variables that are likely to influence future financial performance, such as customer service and quality products. SPMS are expected to help organizations achieve and maintain strategic alignment in their decisions, resource allocations and activities, in order to obtain results and increase shareholder value both in times of stability and during times of change in strategic direction (Bento, 2014). Strategic investment decision-makings should be regarded in each business entity as the crucial factor for its long-term prosperity. An acquired decision affects the performance of the company as well as its competitiveness in long time (Merková *et al.*, 2013). The Balanced Scorecard (Kaplan, 1992) was first proposed by Kaplan and Norton and it is the most popular form of SPMS.

Initial studies in performance measurement tested the impact of certain performance measures on actual financial performance in particular industries (Banker, 2000). Over the past decade, studies focused on the performance effects of specific SPMS characteristics such as the use of more subjective nonfinancial measures (Ittner, 2003) and the actual performance impact of overall SPMS adoption (Burney, 2007). Van der Stede *et al.*, (2006) provided intriguing evidence of the importance of including a diverse set of performance measures in the SPMS, finding that companies that used a higher number of performance measures actually achieved better performance. Apart from individual value system for each employee, it is also necessary to respect the value system of the whole organization. Consequently, it is necessary to elaborate the concept of business value management and to utilize the system of Balanced Scorecard - BSC (Hitka and Rajnoha, 2003). Production results highly depend on motivation factors, so this kind of research is necessary if wood processing and furniture manufacturing companies want to increase the production results and competitive strength in the international market (Jelačić *et al.*, 2008). On the other hand, Kaplan and Norton (2008) provided anecdotal evidence that breakdowns in the SPMS actually lead to deteriorating company performance. More recently, Bisbe and Malagueño (2012) found evidence that the effect of SPMS on organizational performance is reduced in situations where environmental dynamism is high. Petter *et al.*, (2012) argued that information system success leads to improved company performance, while others have concluded that there is no relationship between information systems and performance measurement (Soudani, 2012).

According to the management control literature, the uses for which the SMPS are designed may have a significant influence in their outcomes (Chenhall, 2005) and Mouritsen (2005) has pointed out that the ability of management control systems to support change is influenced by system design. Ittner (2001) argued that SPMS research should examine the decision purposes for which a SPMS is designed, in order to allow appropriate interpretation of the outcomes of the use of performance measures, given that they might be appropriate for some purposes but not for others.

According to Bento (2014), the literature of performance measurement shows that SPMS can have a significant impact on business results. Their study expands on the performance management literature by integrating variables from three disciplinary areas: information systems, accounting and management to provide an interdisciplinary approach to performance management research. Results show that IT variables, combined with system variables and organizational variables, have a significant relationship with the SPMS impact on business results across industries, geographical locations and organizational sizes.

Several other empirical studies conducted in recent years in the world have confirmed the relationship between strategic planning and achieved business performance (Rudd, 2008). On that basis, we can conclude that strategic planning has a positive impact on business performance regardless of the sector in which it operates (Andersen, 2000). Some Spanish authors made some interesting empirical studies and recently they have analyzed SPMS and its impact on business performance in terms of strategic planning and strategic decision-making. Using a combination of archival data and the questionnaires received from 267 medium and large companies in Spain, evidence was provided of a positive relationship and dependence between SPMS and business performance in a highly dynamic environment (Bisbe and Malagueño, 2012). Similar research conducted in Spain also focused on the relation between the use of SPMS and the quality of the strategic planning process. Empirical data were obtained from surveys of 349 medium and large Spanish companies and their evaluation confirmed the positive relationship between the use and dependence between SPMS and quality of strategic plans and company decisions (Gimbert, 2010). Most authors state in their scientific studies that SPMS can help business to define and achieve its strategic objectives, align behaviors and attitudes, and ultimately to have a positive impact on business performance. However, SPMS can also be criticized for a number of reasons, such as the promotion of inappropriate behavior of managers, suppression of innovation and learning, and so on (Micheli and Manzoni, 2010). Another important research in this area has focused on exploring the strategic planning process and its links to business performance in a highly turbulent and unstable environment. The authors emphasize that strategic planning has the potential to produce positive effects on business performance in a highly unstable environment and that planning is an important value added for the company in terms of its higher performance (Brews and Purohit, 2007). Based on these studies, it can be concluded that regular use of the SPMS in a company may favor the more comprehensive and elaborate system of strategic planning, which is further reflected in higher business performance. It should also be noted that strategic planning is an integral part of SPMS.

In a long run, our research deals with the issue of increasing the potential of the renewable natural resources industry and increasing its efficiency and competitiveness through the specific methodology of industry performance measurement and management within the specific conditions of the wood-processing industry in the Slovak Republic. Based on our previous research, the global performance of wood-processing industry in Slovakia measured by various indicators appears positive in recent years (Merková *et al*., 2012). Then we posed some other research questions: Why is this happening? What strategic factors influence better performance of some wood-processing companies? Selected research results and answers to these research questions are presented further below.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

If the company can reduce its overall costs while maintaining the total revenues, it will have a positive impact on the achieved profit. If the company can ensure the inflow of new customers, it might expect higher total revenues and possibly higher overall profits. If the company invests funds into the quality management system, it could achieve higher quality, and under certain circumstances, it could bring higher sales and better market position. If the company invests in training its employees, then the company could achieve a higher level of knowledge, and it would help to generate better performance indicators in the longer term. Maximum degree of certainty of achieving the expected results, through various levels of probability, to the limits of the maximum uncertainty with different targets, indicators, and management actions, may or may not venture to bring greater efficiency. Obviously this research area is not clearly determined. It should be mentioned that our present business environment is far from showing a high degree of stability and certainty, as experienced in the past. A major research hypothesis has been expressed, according to which many non-financial, strategic or qualitative indicators and methods applied in management have an impact on the overall business performance, which can be measured despite the complexity of the issue to determine the relevant ones. Based on this assumption, the main objective was set. We decided to verify this claim, and bring up new and so far insufficiently verified knowledge in the field of business performance management.

The main objective of our research was to analyze the utilization rate of traditional and modern indicators, methods and models of Strategic Business Performance Management on a sample of randomly selected companies in different industries of the Slovak Republic with a primary focus on the wood processing industry, and to identify on the basis of relevant mathematical and statistical methods causal relation-follow links and determine their impact on achievable business performance.

The analyzed parameters were measurement and management of strategic business performance. They were selected by statistical methods and determined by their effect on the overall business performance evaluated on the basis of ROE (Return on Equity in %). The following five hypotheses were defined for the research in the field of Strategic Business Performance Management:

H 1: It is assumed that business performance will be affected by the type of organizational structure. Increased performance will be present in companies with a matrix, project or network structure. The traditional functionally oriented organizational structure will be typical for the companies with lowest performance.

H 2: It is assumed that, if companies use some strategic management tools and systems to support strategic performance management, they will achieve higher performance. Higher performance will also be achieved in enterprises applying long-term strategic business planning and controlling.

H 3: Another hypothesis is the strategic business performance management methodology BSC (Balanced Scorecard). We believe that, if the BSC methodology is not introduced in the company or if it is only partially used (only irregular reporting of selected indicators), business performance is lower. If the BSC methodology is used comprehensively, systematically and regularly, it will improve the efficiency of the company.

H 4: This hypothesis focused on the Information support to strategic business performance management. The implementation of MIS (Management Information System) or BI (Business Intelligence) Information Systems will improve the efficiency of the company compared to companies that do not consider introducing this type of information system.

H 5: The duration of use of strategy parameters is important for the best performance. We expect that the tools, methods and concepts can have an impact on higher performance if they are used for more than 2 years.

The impact of strategic parameters was examined in companies divided into 7 files. They differed by surveyed sectors and by activities of the company. The initial group consisted of all surveyed industries (164 companies), from which the samples were created separately targeted at companies of wood processing industry, engineering industry and automotive industry.

A file was created of companies from all the three industries. The final two sets were based on the main activity (focus) and manufacturing companies, while the last set consisted of trade and service companies. Table 1 presents the basic information about the statistical research files.

Business performance expressed through ROE was the basic sorting parameter. Companies were initially analyzed on the basis of distribution according to performance achievements within 6 performance groups – categories (group from 0 to 5; group 0 – the worst performance with negative ROE, group 5 – the best performance with ROE above 10 %). In the current state of knowledge, we realize that ROE is not the best indicator and that it would be better to use, for example, the EVA (Economic Value Added) indicator. To determine this indicator, each company needs to know the cost of capital and to provide an exact value for the purposes of research, which seemed impossible to get. The following disaggregated range was used in each researched company to determine the actual size of the ROE:

- negative value /ROE < 0/,
- positive value - from 0 % to 2 %,
- positive value - from 2 % to 4 %,
- positive value - from 4 % to 7 %,
- positive value - from 7 % to 10 %,
- positive value - above 10 %.

The scale was used rather than a particular value of ROE because of the sensitivity of the issue. Sufficient number of scales (6) in our subsequent mathematical and statistical research will allow the variability of classifying businesses into different performance categories, as it required the application of mathematical and statistical methods. In the case of low frequencies, we narrowed the six performance categories for the following three performance categories of companies:

- Inefficient companies (negative value of ROE < 0, positive value of ROE - from 0 % to 2 %) –EVA will probably be negative.
- Companies reaching average performance (positive value of ROE - from 2 % to 4 %, positive value of ROE - from 4 % to 7 %) –Eva probably +/- 0 or slightly positive value.

Table 1 Analyzed data sets
Tablica 1. Osnovna skupina analiziranih podataka

File / *Skupina*	**Sector, focus** / *Sektor, područje djelovanja*	**Frequency** *Učestalost*
File 1 / *Skupina 1.*	All examined sectors / *svi promatrani sektori*	164 companies *164 poduzeća*
File 2 / *Skupina 2.*	Wood processing industry /*drvoprerađivačka industrija*	34 companies *34 poduzeća*
File 3 / *Skupina 3.*	Engineering industry / *strojarska industrija*	30 companies *30 poduzeća*
File 4 / *Skupina 4.*	Automotive industry / *autoindustrija*	16 companies *16 poduzeća*
File 5 / *Skupina 5.*	Selected industries (Wood processing industry, Engineering industry, Automotive industry) / *odabrane industrije (drvoprerađivačka, strojarska, autoindustrija)*	80 companies *80 poduzeća*
File 6 / *Skupina 6.*	Manufacturing companies / *proizvodna poduzeća*	106 companies *106 poduzeća*
File 7 / *Skupina 7.*	Trade and service companies / *trgovačka i uslužna poduzeća*	58 companies *58 poduzeća*

- Powerful companies (positive value of ROE - from 7 % to 10 %, positive value of ROE - over 10 %) – EVA will probably be relatively high positive.

Strategic parameters have been studied mainly as nominal variables. For this reason, for the statistical analysis of the impact of strategic parameters on the business performance, we have applied pivot tables and pivot coefficients, which were recommended by scientific literature. In these tests, we have divided the observed companies into categories, and then we compared the observed and theoretical frequency in these categories. Viewed statistics were Pearson's chi-square and the level of statistical significance "p", M-V chi-square and value of "p", Pearson Contingency coefficient, Contingency coefficient corrected, Phi coefficient for 2 x 2 tables and Cramer's V for more members graded categories.

We formulated the basic (null) hypothesis H_0, H_1 alternative hypothesis and the significance level α for testing statistical hypotheses. The aim was to try to challenge the hypothesis H_0. The alternative hypothesis H_1 was contrary to the basic hypothesis. Decision on rejecting H_0 was carried out based on:

- $\alpha < p$ H_0 not rejected,
- $\alpha \geq p$ H_0 rejected in favor of H_1.

Null hypothesis - H_0: There is no relationship between strategic parameters and business performance.

Alternative hypothesis - H_1: There is a relationship between strategic parameters and business performance.

Significance level $\alpha = 0.05$.

The resulting response based on the total number of 164 surveyed companies was scientifically prepared, and the research results were obtained by applying the selected methods of descriptive statistics, shown in more detail in the next section with a specific focus on the wood industry (34 surveyed companies).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of chi-square statistical tests recorded a value of p <0.05 in a file of companies of wood processing industry as follows:

- By applying management tools and systems to support performance management "long-term strategic planning and systematic creation of company-wide business strategies and sub-strategies", companies have achieved average and above-average performance (groups 2-5).
- The methods used in the context of business planning and controlling "Incomplete calculation of variable costs based on contributions cover", is only typical for companies with average performance (ROE 2-7 %), and "Modern ABC method", is typical for the highest performance group 4 and 5, and over 7 % of the ROE.
- Other non-financial strategic indicators and tools "The number of complaints and customer satisfaction" indicator affect the average and above-average performance of a group and "Technological Innovation"; by applying this indicator companies reach ROE over 4 %.

In these analyses, the assumptions were not satisfied about the minimum frequency in cells of contingency tables by differentiating ROE to the 6 original groups, or the gradual merging of three and two performance groups. There is enough evidence to unequivocally state that the strategic tools presented significantly affect business performance.

Statistically significant dependence has not been proven in further analysis of the relationship between strategic parameters and business performance in the wood processing industry according to the results of chi-square tests with p-value > 0.05. It was not appropriate to investigate contingent factors or levels of residues.

From further characteristics of wood processing industry, several strategic parameters were selected, and they are presented in Table 2 to Table 5 and in Figures 1 and 2.

Considering the type of organizational structure, it follows that wood processing companies use the traditional function-oriented organizational structure to the greatest extent (68 % of companies), and the most numerous group in terms of performance is 0-2. This may be affected by the overall poor condition, and the result of the fact that the wood processing companies achieve the lowest average ROE of all monitored sectors.

The results of strategic management tools (strategic planning, controlling and reporting) in a set of

Table 2 Type of organizational structure in the companies of wood processing industry
Tablica 2. Tip organizacijske strukture u drvoprerađivačkim poduzećima

Type of organizational structure in the companies of wood processing industry *Tip organizacijske strukture u drvoprerađivačkom poduzeću*	**Performance (ROE) - 0**	**Performance (ROE) - 1**	**Performance (ROE) - 2**	**Performance (ROE) - 3**	**Performance (ROE) - 5**	**Row totals** *Ukupno*
Process / *procesna*	1	0	2	0	0	3
Divisional / *divizionalna*	0	2	0	0	0	2
Traditional functional *tradicionalna funkcijska*	6	6	5	3	3	23
Matrix / *matrična*	0	0	1	0	0	1
Any type / *bilo koja od navedenih*	1	3	0	0	1	5
Total / *ukupno*	8	11	8	3	4	34

Table 3 Use of strategic management tools in the companies of wood processing industry
Tablica 3. Primjena alata za strateško upravljanje u drvoprerađivačkim poduzećima

Using of strategic management tools in the companies of wood processing industry (strategic planning, controlling and reporting) / *Primjena alata u strateškom upravljanju u drvo-prerađivačkim poduzećima (strateško planiranje, kontroling i izvještavanje)*	**Perfor-mance (ROE) - 0**	**Perfor-mance (ROE) - 1**	**Perfor-mance (ROE) - 2**	**Perfor-mance (ROE) - 3**	**Perfor-mance (ROE) - 5**	**Row totals** / *Ukupno*
No / *ne*	2	4	1	0	0	7
Relative share / *u relativnom udjelu*	5.88 %	11.76 %	2.94 %	0.00 %	0.00 %	20.59 %
Yes / *da*	6	7	7	3	4	27
Relative share / *u relativnom udjelu*	17.65 %	20.59 %	20.59 %	8.82 %	11.76 %	79.41 %
Total / *Ukupno*	8	11	8	3	4	34
Relative share / *u relativnom udjelu*	23.53 %	32.35 %	23.53 %	8.82 %	11.76 %	100.00 %

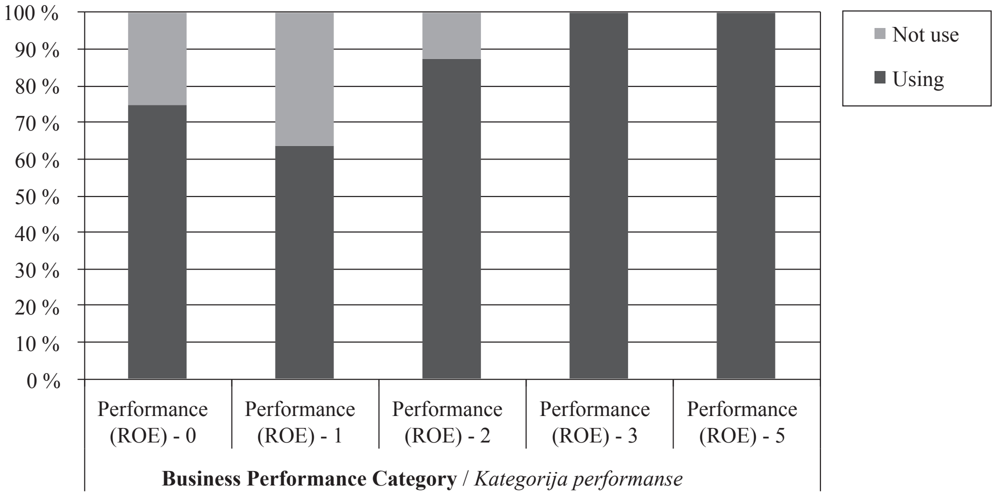

Figure 1 Use of strategic management tools in the companies of wood processing industry in Slovakia
Slika 1. Primjena alata za strateško upravljanje u drvoprerađivačkim poduzećima u Slovačkoj

wood processing companies show that companies that did not use these selected management tools in their practice, failed to reach a better performance than group 2. Although 80 % of companies of wood processing industry use these strategic management tools and systems, performance groups 0-2, with negative or low value of ROE, are the most numerous.

The analysis of contingency tables in the sector of wood processing industry showed that companies do not use the BI information system. Two categories were occupied, 8 companies consider the introduction of BI in the longer term, and 26 companies do not consider this possibility at all. BSC is a similar methodology, used by a company (purely foreign capital). Companies indicate an average or above-average satisfaction in terms of satisfaction with the tools and concepts.

In the research, some conclusions can be made on the basis of average values of performance in each category, determined by strategic parameters in the wood processing industry (Table 6).

Table 6 presents the analysis of five variables. In terms of organizational structure, the most powerful organizational structure is the matrix organizational structure in companies of wood processing industry.

Table 4 Use / introduction of BI in the companies of wood processing industry in Slovakia
Tablica 4. Primjena / uvođenje BI-a u drvoprerađivačkim poduzećima u Slovačkoj

Use of BI / *Primjena BI-a*	**Perfor-mance (ROE) - 0**	**Perfor-mance (ROE) - 1**	**Perfor-mance (ROE) - 2**	**Perfor-mance (ROE) - 3**	**Perfor-mance (ROE) - 5**	**Row totals** *Ukupno*
Not considering this possibility *ne razmatramo tu mogućnost*	6	8	7	1	4	26
	17.65 %	23.53 %	20.59 %	2.94 %	11.76 %	76.47 %
Considering the introduction in longer term *razmatramo tu mogućnost u dugoročnom planu*	2	3	1	2	0	8
	5.88 %	8.82 %	2.94 %	5.88 %	0.00 %	23.53 %
Total / *ukupno*	8	11	8	3	4	34
Relative share / *u relativnom udjelu*	23.53 %	32.35 %	23.53 %	8.82 %	11.76 %	100.00 %

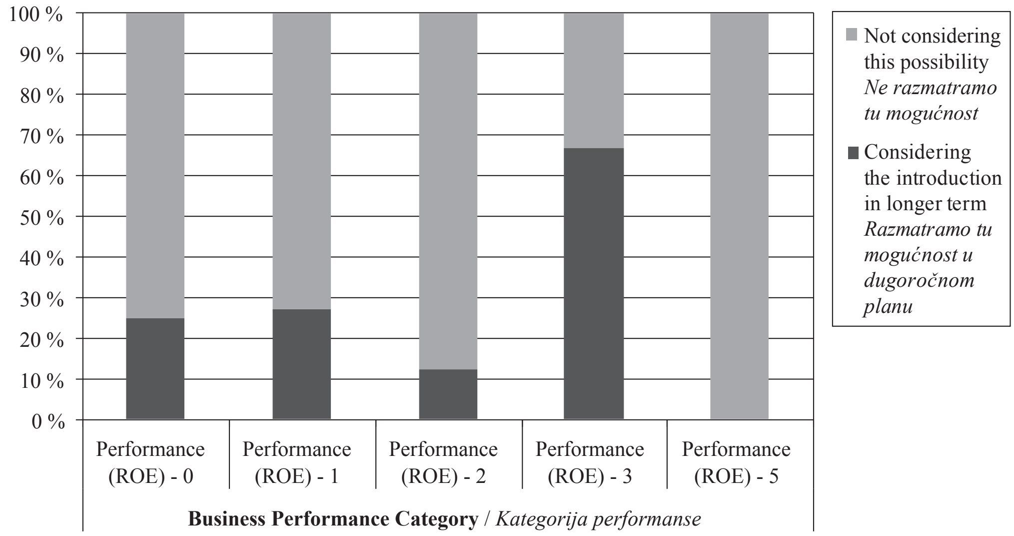

Figure 2 Use / introduction of BI in the companies of wood processing industry in Slovakia
Slika 2. Primjena / uvođenje BI-a u drvoprerađivačkim poduzećima u Slovačkoj

Table 5 Use of selected concepts / tools for strategic performance management in the companies of wood processing industry
Tablica 5. Primjena odabranih koncepcija / alata za strateško upravljanje poslovanjem u poduzećima drvoprerađivačke industrije

	*Selected concepts / tools for strategic performance management in the companies of wood processing industry / *Odabrane koncepcije/alati za strateško upravljanje poslovanjem u drvoprerađivačkim poduzećima*	**do not use** *ne primjenjujemo*	**plan to use** *planiramo primjenjivati*	< **2 years** *2 godine*	**2-5 years** *2-5 godina*	> **5 years** *5 godina*	**low satisfaction** *nezadovoljni*	**average satisfaction** *zadovoljni*	**high satisfaction** *vrlo zadovoljni*
1	Financial indicators based on data from financial accounting / *financijski indikatori utemeljeni na podacima iz računovodstva*	5		4	7	18		15	14
%		14.71		11.76	20.59	52.94		44.12	41.18
2	Outcomes of management accounting *rezultati upravljanja računovodstvom*	17	6	2		9		6	5
%		50.00	17.65	5.88		26.47		17.65	14.71
3	Controlling / *kontroling*	19	3	5	2	5		6	5
%		55.88	8.82	14.71	5.88	14.71		17.65	14.71
4	Balanced Scorecard (BSC) / *sustav uravnoteženih ciljeva*	32	1			1			1
%		94.12	2.94			2.94			2.94
5	Economic Value Added (EVA) *dodana ekonomska vrijednost*	26	3	1	3	1		4	2
%		76.47	8.82	2.94	8.82	2.94		11.76	5.88
6	ABC costing (Activity Based Costing) *troškovi prema aktivnostima*	27	3	1	3			1	3
%		79.41	8.82	2.94	8.82			2.94	8.82
7	BI (Business Intelligence) information system *informacijski sustav BI-a*	28	6						
%		82.35	17.65						
8	Quality Management System *sustav upravljanja kvalitetom*	19	5	2	2	6		5	4
%		55.88	14.71	5.88	5.88	17.65		14.71	11.76
9	Lean management and Kaizen *vitko upravljanje i Kaizen*	31		2		1	1	1	1
%		91.18		5.88		2.94	2.94	2.94	2.94
10	The concept of CRM (Customer Relationship Management) / *koncepcija upravljanja odnosima s korisnicima*	28	3	1	2			3	
%		82.35	8.82	2.94	5.88			8.82	
11	KPI system (Key Performance Indicators) *KPI sustav (ključni indikatori poslovanja)*	29		2	1	2		3	2
%		85.29		5.88	2.94	5.88		8.82	5.88

* Notice: presented concepts were selected from worldwide research in the area of application of various models and methods for business performance managing, by authors Rigby and Bilodeau - Rigby, D., Bilodeau, B. (2013). Management Tools and Trends 2013. Boston: Bain & Company. http://www.bain.com/Images/BAIN_BRIEF_Management_Tools_%26_Trends_2013.pdf

Table 6 Average performance categories - file 2: wood processing industry
Tablica 6. Prosječne kategorije djelovanja - skupina 2: drvoprerađivačka industrija

Type of organizational structure / *Tip organizacijske strukture*						
Answers / *Odgovori*	**Process** *Procesna*	**Divisional** *Divizionalna*	**Traditional functional** *Tradicionalno funkcijska*	**Matrix** *Matrična*	**Any type** *Bilo koji tip*	**All categories** *Sve kategorije*
ROE Average / *prosječna točka pokrića*	1.333333	1.000000	1.739130	2,000000	1,600000	1,647059
Frequency / *učestalost*	3	2	23	1	5	34

The way of linking business strategy with a system of measurement and business performance management *Način povezivanja poslovne strategije sa sustavom mjerenja i upravljanja poslovanjem*				
Answers / *Odgovori*	0 – Insufficiently *Nedovoljno*	1 – Well *Dobro*	2 – Very well *Vrlo dobro*	All categories *Sve kategorije*
ROE Average / *Prosječna točka pokrića*	1.230769	1.000000	2.055556	1,647059
Frequency / *Učestalost*	13	3	18	34

Use of methods of strategic business planning and controlling *Primjena metoda poslovnoga strateškog planiranja i kontrolinga*			
Answers / *Odgovori*	Not using *Ne primjenjuje se*	Using but without BI *Primjena bez korištenja BI-a*	All categories *Sve kategorije*
ROE Average *Prosječna točka pokrića*	1.000000	1.733333	1.647059
Frequency / *Učestalost*	4	30	34

Use of software tools to measure and manage business performance *Primjena softverskih paketa za mjerenje i upravljanje poslovanjem*			
Answers / *Odgovori*	Not using software *Bez primjena softvera*	Using software *Primjena softvera*	All categories *Sve kategorije*
ROE Average *Prosječna točka pokrića*	1.400000	1.689655	1.647059
Frequency / *Učestalost*	5	29	34

Use of Management Information Systems (MIS) in the company / *Primjena upravljačko-informacijskih sustava u poduzeću*			
Answers *Odgovori*	Not using MIS *Bez MIS-a*	Using MIS *Primjena MIS-a*	All categories *Sve kategorije*
ROE Average *Prosječna točka pokrića*	1.500000	1.666667	1.647059
Frequency / *Učestalost*	4	30	34

When there is a connection between business strategy and system of measurement and management performance, a better performance is recorded than when there is no such connection. Enterprises that use the methods of strategic business planning achieve better business performance than enterprises that do not use them. Companies that use some software tools or MIS information system achieve better business performance than companies that do not use MIS. However, the results of software for measuring and managing of business performance and information systems show only a slight difference between the groups of companies of wood processing industry that use and do not use the selected tools.

4 CONCLUSION
4. ZAKLJUČAK

The results of our scientific research show that companies from the selected Slovak industries, which achieve above average performance, are strongly focused on managing their strategic performance by applying many modern management concepts and methods.

Based on the results presented in this paper, the following can be concluded in the area of the research hypotheses, which were set out at the beginning of the strategy research.

H 1: Do not reject H_0. The impact of a particular organizational structure on the business performance has not been established. A correlation has been found between business performance and the use of organizational structure, but without specifying a particular type of structure.

H 2: H_0 is rejected in favor of H_1 for the concept of strategic long-term business planning and controlling system. Assumption failed in the examination of all management tools. The impact was demonstrated of strategic planning and controlling studied separately (used/not used) to a higher – over average performance above the valued of ROE of 4 % in used concepts.

H 3: Do not reject H_0. BSC methodology itself does not affect the business performance of wood-processing enterprises. However, in the statistical file consisting of all analyzed industries (Table 1 - File 1), this dependence has been confirmed. BSC methodology enables industrial enterprises to achieve higher performance.

H 4: Do not reject H_0. BI information system itself does not affect the business performance of wood-processing enterprises. However, in the statistical file consisting of all analyzed industries (Table 1 - File 1), this dependence has been confirmed. The use of BI information system has an impact on better business performance. The analysis highlighted two categories - companies that use BI system, they achieve the value of ROE over 4 %, companies that do not consider the introduction of a BI information system, reach lower performance.

H 5: Do not reject H_0. However, in the statistical file consisting of all analyzed industries (Table 1 - File 1), this dependence has been confirmed. H_0 is rejected in favor of H_1 at the financial performance indicators, controlling, quality management system, in which the time use of these strategic parameters is important for the performance achieved. The results show that the use of financial indicators to measure and manage business performance brought to higher levels of performance after 2 years, in the quality management system after 5 years, and companies typically achieve ROE above 4 %. However, in the concept of controlling, which is used for more than five years, performance is reflected by ROE above 7 %.

Based on our research, it has been shown that an important tool to improve the overall business performance also in conditions of Slovak wood-processing industry seems to be a system of strategic performance management. However, compared to the automotive or engineering industry (results of our research related to automotive and engineering industry will be published in a separate scientific paper) this has not been confirmed with a sufficiently high degree of statistical relevance. Still, we believe that traditional business management based only on financial performance must be supplemented and confronted also in conditions of wood-processing industry with the methods and models for strategic business performance management.

5 REFERENCES
5. LITERATURA

1. Aláč, P.; Demoč, V.; Barcík, Š., 2010: Implementation and Analysis of Information System in a Wood Processing Company. Drvna industrija, 61: 119-127.
2. Andersen, T., 2000: Strategic planning, autonomous actions and corporate performance. Long Range Planning, 33: 184-200. http://dx.doi.org/10.1016/S0024-6301(00)00028-5
3. Banker, R.; Potter, G.; Srinivasa, D., 2000: An empirical investigation of an inventive plan that includes nonfinancial performance measures. The Accounting Review, 85: 65-92. doi: http://dx.doi.org/10.2308/accr.2000.75.1.65
4. Bento, A.; Bento, R.; White, L. F., 2014: Strategic performance management systems: Impact on business results. Journal of Computer Information Systems, 24: 25-33. http://iacis.org/
5. Bisbe, J.; Malagueño, R., 2012: Using strategic performance measurement systems for strategyformulation: Does it work in dynamic environments? Management Accounting Research, 23: 296-311. http://dx.doi.org/10.1016/j.mar.2012.05.002
6. Brews, P.; Purohit, D., 2007: Strategic Planning in Unstable Environments. Long Range Planning, 40: 64-83. http://dx.doi.org/10.1016/j.lrp.2006.12.001
7. Burney, L.; Widener, S., 2007: Strategic performance measurement systems, job-relevant information, and managerial behavioral responses – role stress and performance. Behavioral Research in Accounting, 19: 43-69. http://dx.doi.org/10.2308/bria.2007.19.1.43
8. Gimbert, X.; Bisbe, J.; Mendoza, X., 2010: The Role of Performance Measurement Systems in Strategy Formulation Processes. Long Range Planning, 43: 477-497. http://dx.doi.org/10.1016/j.lrp.2010.01.001
9. Hitka, M.; Rajnoha, R., 2003: Balanced Scorecard and analysis of workers motivation in manufacturing company. Drvna Industrija, 54: 93-99.
10. Chenhall, R., 2005: Integrative strategic performance measurement systems, strategic alignment of manufacturing, learning and strategic outcomes: an exploratory study. Accounting, Organizations and Society, 30: 395-422. http://dx.doi.org/10.1016/j.aos.2004.08.001
11. Ittner, C. D.; Larker, D. F.; Randall, T., 2003: Performance implications of strategic performance measurement in financial services firms. Accounting, Organizations, and Society, 28: 715-741. http://dx.doi.org/10.1016/S0361-3682(03)00033-3
12. Ittner, C.; Larker, D.; 2001: Assessing empirical research in managerial accounting: a value-based management perspective. Journal of Accounting and Economics, 32: 349-410. http://dx.doi.org/10.1016/S0165-4101(01)00026-X
13. Jelačić, D.; Grladinović, T.; Sujová, A.; Galajdová, V., 2008: Motivation factors in wood processing and furniture manufacturing, Drvna industrija, 59 (1): 11-21.
14. Kaplan, R. S.; Norton, D. P., 2008: Mastering the Management System. Harvard Business Review, 86: 63-77.
15. Kaplan, R. S.; Norton, D. P., 2001: The Strategy-Focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment. Boston, MA: Harvard Business School Press.
16. Kaplan, R. S.; Norton, D. P., 1992: The Balanced Scorecard: Measures that drive performance. Harvard Business Review, 70: 71-79.
17. Kourtit, K.; Nijkamp, P., 2011: Creativity and Diversity: Strategic Performance Management of High-Tech SMEs in Dutch Urban Areas. Drivers of innovation, entrepreneurship and regional dynamics, 12: 143-176.
18. Kropivšek, J.; Jelačić, D.; Grošelj, P., 2011: Motivating employees of Slovenian and Croatian wood industry companies in times of economic downturn, Drvna industrija, 62: 97-103. http://dx.doi.org/10.5552/drind.2011.1040
19. Merková, M.; Rajnoha, R.; Novák, P., 2012: Quantitative and qualitative diagnostic methods for measuring the effects of foreign direct investment in terms of the wood--processing industry in the Slovak Republic. Drewno, 55: 65-87. doi: 10.12841
20. Merková, M.; Drábek, J.; Jelačić, D., 2013: Application of Risk Analysis in Business Investment Decision-Making. Drvna industrija, 64: 313-322. http://dx.doi.org/10.5552/drind.2013.1317

21. Micheli, P.; Manzoni, J., 2010: Strategic Performance Measurement: Benefits, Limitations and Paradoxes. Long Range Planning, 43: 465-476. http://dx.doi.org/10.1016/j.lrp.2009.12.004
22. Mouritsen, J., 2005: Beyond accounting change: design and mobilisation of management control systems. Journal of Accounting & Organizational Change, 1: 97-113. doi: http://dx.doi.org/10.1108/18325910510635317
23. Oblak, L.; Zadnik Stirn, L., 2000. The possibility of solving economic and environmental protection problems in wood industry companies by the application of the method of fuzzy goal programming. Ekológia, 19, 409-419
24. Petter, S.; DeLone, W.; McLean, E., 2012: The Past, Present and Future of IS Success. Journal of the Association for Information Systems, 13: 341-362. doi: http://aisel.aisnet.org/jais/vol13/iss5/2
25. Rajnoha, R.; Chromjaková, F., 2009: Activity Based Costing and efficiency of its application in the wooden houses production. Drewno, 52: 105-127. doi: 10.12841
26. Rajnoha, R.; Dobrovič, J., 2011: Simultaneous management of economics and business processes by added value knowledge. E & M – Ekonomie a Management, 14: 53-69.
27. Rajnoha, R. *et al*., 2013: Meranie a riadenie výkonosti podnikov. Zvolen: Vydavateľstvo TU vo Zvolene. 313 p.
28. Rappaport, A., 2005: Shareholder scoreboard: the best and worst performers of the WSJ 1000. Wall Street Journal.
29. Rudd, J.; Greenley, G.; Beatson, A.; Lings, I., 2008: Strategic planning and performance: Extending the debate. Journal of Business Research, 61: 99-108. http://dx.doi.org/10.1016/j.jbusres.2007.06.014
30. Soudani, S., 2012: The Usefulness of an Accounting Information System for Effective Organizational Performance. International Journal of Economics & Finance, 4: 136-145. http://dx.doi.org/10.5539/ijef.v4n5p136
31. Van der Stede, W. A.; Chow, C.; Lin, T., 2006: Strategy, Choice of Performance Measures, and Performance. Behavioral Research in Accounting, 18: 185. http://dx.doi.org/10.2308/bria.2006.18.1.185
32. Vukšic, V. B.; Pejic Bach, M.; Popovič, A., 2013: Supporting performance management with business process management and business intelligence: A case analysis of integration and orchestration. International Journal of Information Management, 33: 613-619. http://dx.doi.org/10.1016/j.ijinfomgt.2013.03.008

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Analysis of Behaviour of Prefabricated Staircases with One-Sided Suspended Stairs

Analiza ponašanja montažnih konzolnih stubišta

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ABSTRACT • *The article introduces a potential use of a combination of the method of numerical modelling and experimental tests for the treatment of the structure of a wooden prefabricated staircase with one-sided suspended stairs. Numerical modelling was used to find critical details, which were experimentally tested on partial models in the scale 1:1. The results of the numerical modelling in combination with experimental testing were used for designing a prototype of a wooden prefabricated staircase with one-sided suspended stairs. The designed prototype of a staircase in two versions was experimentally tested in the scale 1:1 in compliance with Czech design standards ČSN 73 0035, ČSN 73 2030 and ETAG008 – Guideline for European technical approval of prefabricated stair kits in edition January 2002 in terms of ultimate and serviceability state design.*

Key words: *analysis of behavior, prefabricated staircase, numerical modelling, experimental testing*

SAŽETAK • *Članak obrađuje potencijalnu primjenu kombinacije metode matematičkog modeliranja i eksperimentalnih ispitivanja za obradu konstrukcije drvenih montažnih konzolnih stubišta. Numeričko modeliranje primijenjeno je za pronalazak kritičnih detalja koji su eksperimentalno testirani na parcijalnim modelima u mjerilu 1:1. Rezultati numeričkog modeliranja, u kombinaciji s eksperimentalnim ispitivanjem, primijenjeni su za izradu prototipa drvenih montažnih konzolnih stubišta. Dizajnirani prototip stubišta u dvije verzije eksperimentalno je ispitan u mjerilu 1:1 radi utvrđivanja ponašanja stubišta u upotrebi, u skladu s češkim standardima ČSN 73 0035, ČSN 73 2030 i ETAG008 - Smjernica za europske tehničko odobrenje setova montažnog stubišta, iz siječnja 2002. godine.*

Ključne riječi: *analiza ponašanja, montažno stubište, numeričko modeliranje, eksperimentalna ispitivanja*

1 INTRODUCTION
1. UVOD

When connecting two height levels during building of residential houses, the current trend is to use light and airy staircases with attractive and modern design. Staircases are often perceived by architects and end users, i.e. investors, as architecture elements that help to create a visual style and well-being of a modern home (Jiricna, 2001). The right choice of a staircase contributes to elegance, originality, and a unique style of a building (Karre, 2005).

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The choice of the construction system of staircases is also related to the choice of material (Habermann, 2002). Nowadays, various material alternatives are combined; for example it is possible to see frequent use of wood with other material, e.g. stainless steel, glass, stone and fibreglass. In addition, there are many examples of use of just a single material, most commonly wood.

Some examples of staircases that meet the mentioned qualities, i.e. elegance, originality, airiness, and unique and modern style, include staircase bolts with inserted treads, or with central staircase bolt, or spiral staircases. The mentioned types of staircases are produced by a wide range of companies in the Czech Republic and in EU countries. The extensive list of companies includes e.g. SWN Moravia, s.r.o., TREPP-ART s.r.o., Bucher GmbH, Kenngott Treppen GmbH, and others.

Within a project of MPO ČR IMPULS, registration number FI-IM2/053 titled "Research and Development of a New Generation of Staircases to Residential and Civil Buildings", the issue was the construction of wooden prefabricated staircases with one-sided suspended stairs. In accordance with the objectives of the project, a new generation of prefabricated staircases with one-sided suspended stairs was developed in the form of a prototype of a staircase in two versions. The modernized generation of prefabricated staircases improved the universality and variability of the construction system, brought lower costs on production thanks to material saving and simpler production and assembly.

The development of a new generation of staircases and the design of its prototype took advantage of a method of numerical modelling in combination with experimental testing. The combination was also used by other authors (Pousette, 2003; Pousette, 2006; Labans and Kalniņš, 2012; Franke and Quenneville, 2011; Fleischmann *et al.*, 2005). The method of numerical modelling is used for the issues of construction mechanics, or dynamics, i.e. static analysis, dynamic analysis of analyzed structure or a detail with the use of a finite element method (Tankut *et al.*, 2014). Using the outputs of numerical modelling, an evaluation of an analysed structure can be performed according to standard regulations, and critical construction points identified. These points can be modified and re-analysed thanks to the method of numerical modelling. Subsequently, the first phase of verifying details behaviour with the use of experimental tests of partial testing models will be performed. After verifying the correct design of details, an experimental analysis of the construction should be performed in the second phase, in order to find whether the designed structure complies with the existing standard criteria.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

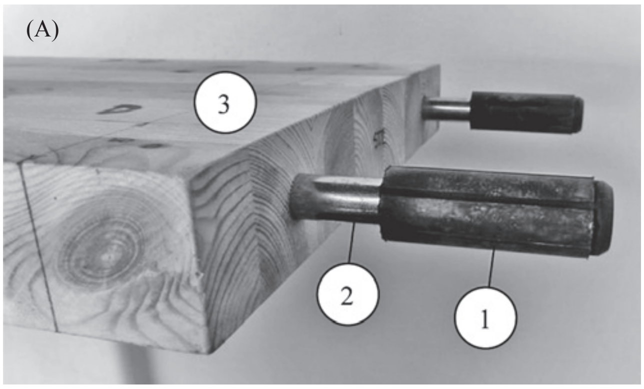
2.1 Structure of prefabricated staircases with one-sided suspended stairs
2.1. Konstrukcija montažnoga konzolnog stubišta

A prefabricated staircase with one-sided suspended stairs (Fig. 1) consists of stairs without risers, which leads to a lighter construction.

The stairs at the side of the wall are usually anchored in the bearing wall with the use of 2 steel bars and partly anchored in the staircase bolt. In order to eliminate footfall sound spreading into bearing walls, the bars are put in rubber cases in the wall. A part from this type of mounting, the mounting used in the design of the staircase prototype can be used as well. At the outer side, the stairs are suspended with the system of bars anchored in a massive handrail. The height position of stairs is delineated with the use of distance elements, which are placed in between stairs on a stair edge. The details of the wooden prefabricated staircase are shown in Fig. 2.

The staircase is predominantly made of glued wooden profiles of European beech (*Fagus sylvatica*), European white oak (*Quercus petrea*), Scotch pine (*Pinus sylvestris*) and spruce (*Picea abies*), which improve

Figure 1 Prefabricated staircase with one-sided suspended stairs (Jema Svitavy a.s., 2006)
Slika 1. Montažno konzolno stubište (Jema Svitavy a.s., 2006.)



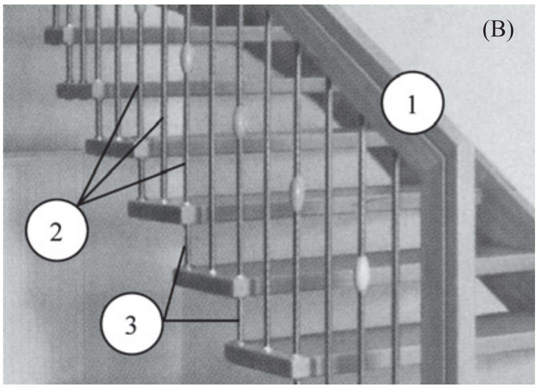


Figure 2 Details of the wooden prefabricated staircase: (A) Detail at the side of the wall (1 – rubber cases, 2 – steel bars, 3 – stair); (B) Detail at the side of the massive handrail (1 – massive handrail, 2 – system of bars, 3 – distance elements) (Jema Svitavy a.s., 2006)

Slika 2. Detalji drvenoga montažnog stubišta: (A) detalj sa strane zida (1 – gumeni dijelovi, 2 – čelične šipke, 3 – gazište stube); (B) detalj masivnog rukohvata (1 – masivni rukohvat, 2 – sustav šipaka, 3 – elementi koji određuju udaljenost stuba) (B: Jema Svitavy a.s., 2006.)

the shape durability and eliminate the effect of torsion of profiles, in the versions of connected profiles and non-connected profiles. The thickness of profiles ranges between 40 and 65 mm. The non-wooden parts are designed from stainless steel, or surface treated steel.

2.2 Static analysis of behaviour of prefabricated staircases with one-sided suspended stairs
2.2. Statička analiza ponašanja montažnoga konzolnog stubišta

In order to study the behaviour of prefabricated staircases with one-sided suspended stairs, a straight staircase was selected, which represents the most unfavourable arrangement in terms of statics.

Regarding the use of prefabricated staircases for building residential houses, a staircase made form Scotch pine (*Pinus sylvestris*) with the construction height of 3.0 m, aligned span of 4.862 m and ground distance of 3.98 m was considered (Fig. 3a). Dimensions of stairs without risers of 900 mm comply with the requirements of a Czech design standard ČSN 73 4130 for residential houses. The width of stairs at the walking line of 314 mm was designed with the stairs overlap of 10 mm. The thickness of stairs of 50 mm was designed taking into account the existing way of production. The dimensions of the handrail and newels were designed to be made of glued wooden profile 50 × 140 mm.

At the outer side, the stairs were suspended with the use of a system of steel bars (24 pieces) of profile of ⌀12/2 mm to the bearing massive handrail, which is taken along the outer side of the whole staircase. Each stair was suspended on three bars (Fig. 1) and (Fig. 2) and was connected with the previous and the following stair with the use of wood distance elements (Fig. 1a). At the wall side, the stairs were placed with the use of 2 steel bars ⌀16 mm that were embedded in the bearing wall through rubber cases (Fig. 2a).

2.3 FE modelling
2.3. FE modeliranje

A static analysis by FEM software systems was performed for loading in compliance with Czech design standard ČSN EN 1991-1-1 (73 0035) Eurocode 1: Action on Structures – Part 1-1: General actions - Densities, self-weight, imposed loads for buildings. Within the analyses dead load was considered, i.e. self-weight and live load, which was considered as uniform load, concentrated load of stairs, and concentrated load acting in vertical and horizontal direction of the handrail. The load was considered in characteristic and design values, which were set in compliance with article 6.10 of Czech design standard ČSN EN 1990 (73 0002) Eurocode: Basis of structural design.

The initial static analysis of behaviour of the selected prefabricated staircase with one-sided suspended stairs and the performance of a standard evaluation of this structure, according to Czech design standard ČSN EN 1995-1-1 (73 1701) Design of timber structures, Part 1-1: General - Common rules and rules for buildings, was performed with the use of a 3D beam analysis model and software IDA NEXIS 32 (2002).

In order to perform a detailed analysis of behaviour of the prefabricated staircase with one-sided suspended stairs, a 3D analysis model and partial analysis models of details (connection of the top and bottom newel with the handrail, a detail of the mounting of a stair on steel bars, detail of the connection of stairs through distance elements) were developed in the software ANSYS (2012a).

A 3D analysis model, where a fixed connection of all construction parts was assumed, was developed with the use of finite elements type of SOLID45, SOLID92, SOLID95 and SURF154 (ANSYS, 2012b). 3D models (Fig. 3) were developed for stairs, rubber cases, connecting screws, screw washers, bars, distance elements, handrail, and top and bottom newels.

Partial analysis models of massive handrail and bottom newel connections (Fig. 3b) using submodelling methods (ANSYS, 2012c) were developed with the use of finite elements of the type of SOLID92 (ANSYS, 2012b). The real glued connection between the handrail and newels was considered for these models. The connections were modelled with contact elements TARGE170 and CONTA174 (ANSYS, 2012b). In this case, the contact elements allowed the contact to

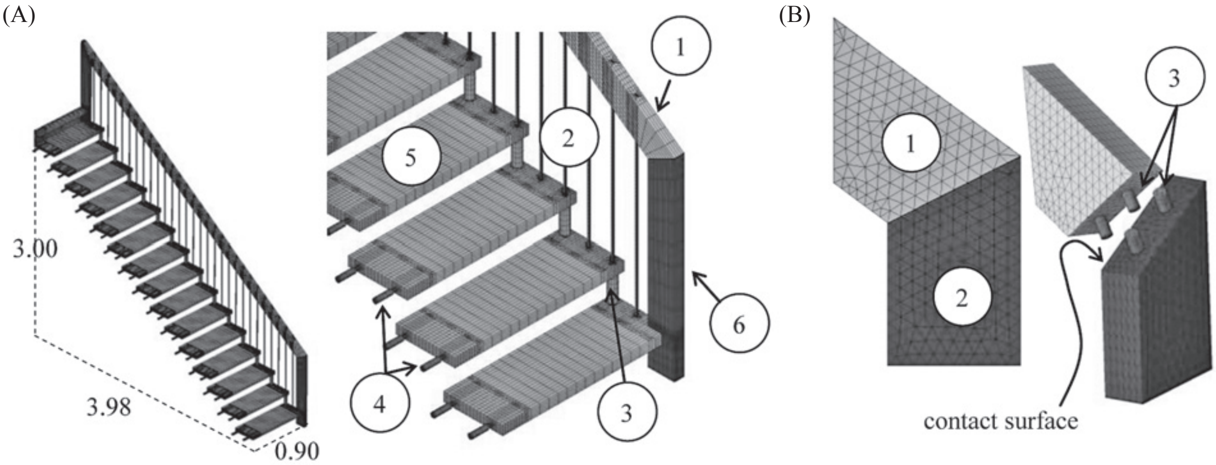


Figure 3 3D analysis model (A): 3D analysis model and its detail; dimension in m; (1 – massive handrail, 2 – system of bars, 3 – distance elements, 4 – rubber cases, 5 – stair, 6 – bottom newel) (B): Partial analysis models of massive handrail and bottom newel connections (1 – massive handrail, 2 – bottom newel, 3 – connection pin) with contact surface between 1, 2 and 3
Slika 3. 3D model analize (A): 3D model analize s detaljima (dimenzije u m) (1 - masivni rukohvat, 2 – sustav šipki, 3 – elementi kojima se određuje udaljenost stuba, 4 – gumeni dijelovi, 5 – stuba, 6 – donja ograda); (B) modeli djelomične analize spoja masivnog rukohvata i donje ograde (1 – masivni rukohvat, 2 – donja ograda, 3 – spoj između rukohvata i donje ograde) s kontaktnom površinom između 1, 2 i 3

open up, or a connection in the case of exceeded value of shear and normal stress, which equalled the value of glue strength of 10 MPa (Pěnčík and Lavický, 2006).

In the 3D analysis model and partial analysis models of details, the behaviour of wooden parts from Scotch pine (*Pinus sylvestris*) was described in the software ANSYS with the use of an orthotropic material model (Table 1). Material properties were taken from (Požgaj *et al.*, 1997; Matovič, 1993; 2004).

With the use of orthotropic material model, general anisotropic material properties of wood caused by different properties in different anatomic directions of wood were simplified, i.e. longitudinal direction *L*, tangent direction *T* and radial direction *R* (Požgaj *et al.*, 1997; Kretschmann, 2010; Mascia and Lahr, 2006; Bucur, 2006). The possibility of using an orthotropic material model is related to the method of producing laminated wooden profiles. When producing the laminated wooden profiles, it is possible to clearly define just the longitudinal direction *L*, which is identical to the direction of wood grains. The other anatomic directions of wood cannot be clearly determined due to the different orientation. This is the reason why the similar properties were considered for tangent *T* and radial *R* directions. Regarding the dimensions of the wooden elements, the material characteristics determined for the cylindrical system *LTR* were used for the Cartesian system *XYZ* (Danielsson and Gustafsson, 2013), where the material is considered to have similar properties in the direction *Y* and *Z*.

The behaviour of connecting elements and rubber cases was ideally modelled with the use of an isotropic material model. The steel elements were included in the analysis through material characteristics for steel S235. The isotropic material model of rubber cases was described by modulus of elasticity 10 MPa (2012), density 50 kg/m^3 and Poisson's ratio 0.475.

Boundary conditions concerning the 3D analysis model originated from the real support. The simple support was considered at the contact of the bottom newel to the bearing floor structure. The fixation of the staircase to the bearing ceiling structure was considered with the use of a board under the last stair anchored in the ceiling with three screws. Regarding the rubber cases, boundary conditions were defined to their cylindrical surface in the cylindrical coordinate system while preventing the case face movement out of the wall.

The analyses made with the use of the 3D analysis model and detailed analysis models were materially linear and geometrically nonlinear. The 3D analysis model was loaded in compliance with a Czech design standard ČSN EN 1991-1-1. Due to the use of the method of sub-modelling, the partial analysis models were only loaded by deformation load, which was determined with the use of an analysis of the 3D analysis model, i.e. the load of the partial analysis models was taken over from the output of the 3D analysis model.

After the solution of the 3D analysis model, as well as detailed analysis models, the evaluation of results was performed. The evaluation determined the field of displacement (U_Y, U_{SUM}) and field of stress (S_X, S_Y, S_Z, S_1, S_3). The vertical displacement U_Y and normal stress in the direction of grains for uniformly loaded

Table 1 Material properties of Scotch pine (*Pinus sylvestris*) in notation of ANSYS (ANSYS, 2012a)
Tablica 1. Obilježja borovine (*Pinus sylvestris*) zapisana u programu ANSYS

EX, MPa	14300	*GXY*, MPa	800	*NUXY*	0.04
EY, MPa	545	*GYZ*, MPa	500	*NUYZ*	0.38
EZ, MPa	700	*GXZ*, MPa	1230	*NUXZ*	0.03
DENS, kg/m^3	505				

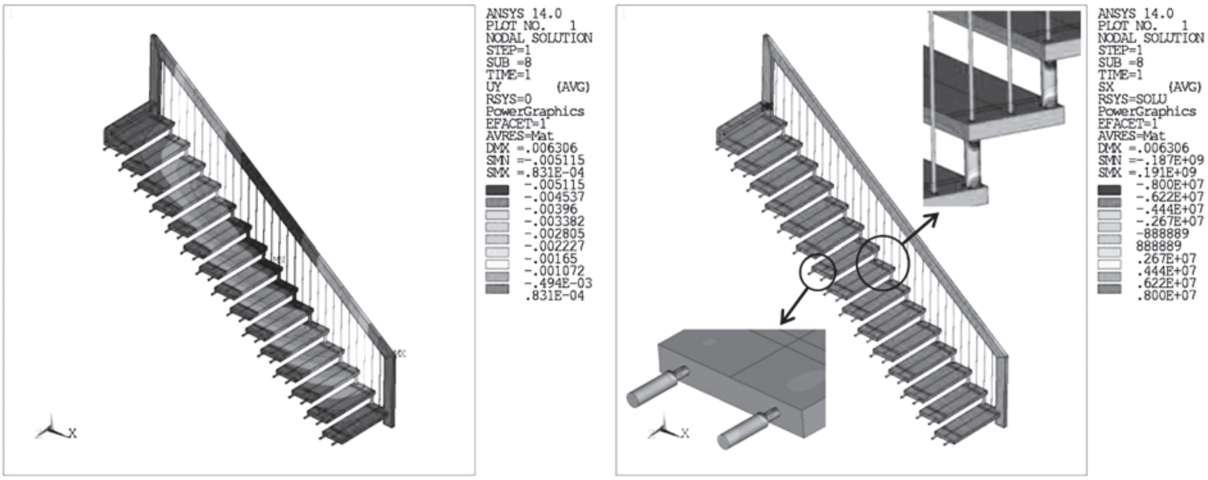


Figure 4 3D analysis model – results for uniformly loaded staircase in intensity of uniform serviceability load V = 3.0 kN/m^2 and self-weight (A): Vertical displacement U_Y (m) (B): Normal stress in the direction of grains (Pa) in the interval ⟨-8;+8⟩ MPa; examples of "critical" places

Slika 4. 3D model analize – rezultati za ravnomjerno opterećeno stubište pri opterećenju V = 3,0 kN/m^2 i uz vlastitu težinu: (A) vertikalni pomak U_Y (m); (B) normalno naprezanje u smjeru vlakanaca (Pa) u intervalu ⟨-8;+8⟩ MPa; primjeri kritičnih mjesta

staircase in intensity of uniform serviceability load V = 3.0 kN/m^2 (ČSN EN 1995-1-1, 2004) and self-weight is shown in Fig. 4. The average values of normal stress and principal stress in individual wooden construction parts of the staircase were in the range of the interval of the wood strength. The stress was distributed uniformly in the majority of construction parts of the staircase. Using interactive failure criteria Hoffman's criterion (Hoffman, 1967; Berthelot, 1998; Galicky and Czech, 2013) and Tsai-Wu criterion (Tsai and Wu, 1971; Danielsson and Gustafsson, 2013; Galicky and Czech, 2013) "critical" places of the staircase structure were identified (places of the contact of distance elements with stairs, at places of laying stairs on steel bars, at places of the suspension of stairs with the use of steel bars, and at places of the handrail contact with the top, or bottom, newel).

The "critical" places of the staircase structure were subsequently changed in order to reduce the concentration of stress at places of these details. The designed changes were numerically reanalysed. After their numerical verification, they were integrated in the prototype design of the prefabricated staircase with one-sided suspended stairs (Fig. 5).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Based on the results of numerical analyses from the 3D model, a prototype of a wooden straight prefabricated staircase was made from Scotch pine (*Pinus sylvestris*) with one-sided suspended stairs in two versions. The prototype design applied the proposed changes based on the numerical analyses. The changes included the reduction of the number of bars from 24 pieces for the whole staircase (Fig. 5) to 4 pcs, the reduction of the thickness of steps from 50 mm to 40 mm, the change of the anchoring of stairs in the bearing

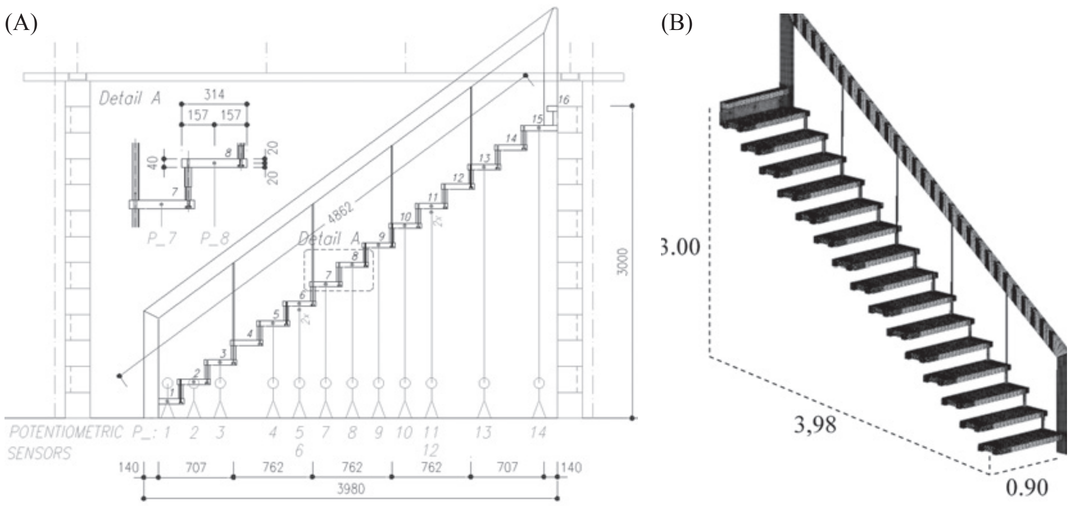


Figure 5 Prototype of a wooden straight prefabricated staircase: (A) Dimensions and measuring points with potentiometric sensors of the type MS04; (B) 3D analysis model

Slika 5. Prototip drvenoga ravnog montažnog stubišta: (A) dimenzije i mjerne točke s potenciometrijskim senzorima tipa MS04; (B) 3D model analize

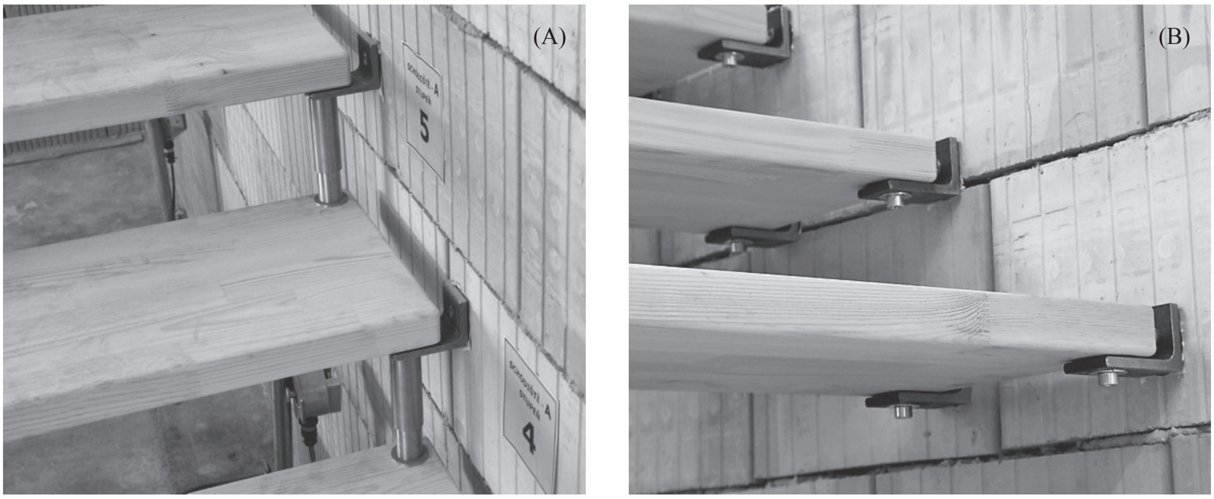


Figure 6 Different ways of fixing the stairs into the bearing wall: (A) Version A (the stairs supported by a steel profile and by a distance element); (B) Version B (the stairs supported by two steel profiles)
Slika 6. Različiti načini učvršćenja stubišta u nosivi zid: (A) verzija A (nosivi su elementi čelični profil i element koji određuje udaljenost između stuba); (B) verzija B (nosivi su elementi stuba dva čelična profila)

wall, the modification of solutions of distance elements through improved universality by height rectification, and the change of the contact of the top and bottom newel with the handrail was designed.

The two versions of the prototype of a wood straight prefabricated staircase differed in the way the stairs were fixed into the bearing wall. In the first version marked A, the stairs were supported at the entry edge by a steel profile L 80 × 60 × 8 mm and at the exit edge by a distance element made of stainless steel (Fig. 6a) without being fixed to the bearing wall. In the other version marked B, the stairs were supported at the entry and exit edge by a steel profile L 80 × 60 × 8 mm (Fig. 6b).

In accordance with the selected numerically analysed prefabricated staircase with one-sided suspended stairs, two prototypes of the staircase in versions A and B in the scale 1:1 were made in the testing laboratory of the Institute of Building Testing, Faculty of Civil Engineering, Brno University of Technology. The staircase prototypes consisted of 15 stairs of the length of 900 mm, width of 314 mm and thickness of 40 mm and an atypical exit stair (Fig. 3). The height of both staircases was 3.0 m, the handrail and the entry and exit newels were of a rectangular cross-section 50 × 140 mm. The position of the handrail was secured with the entry and exit newels. The handrail was connected to four stairs No. 4, 7, 10 and 13 with steel bars ⌀12/2 mm, which ran through a stainless steel newel and a height-rectifiable distance element ⌀32/1.85 mm made of stainless steel. The steel profiles L 80 × 60 × 8 mm were fixed to the wall with fixings Fischer FUR 10 × 115 T and screws ⌀7 mm.

The prototypes of staircases were experimentally tested in accordance with ETAG 008 – Guideline for European technical approval of prefabricated stair kits, edition January 2002. The results of tests were used for the verification of the precision and function of the designed modifications. The load tests monitored the response of the structures to the effect of a static load.

Within the experimental tests, the measured time data, i.e. the size of vertical displacement, were continuously recorded,. The loading scheme selected at the effect of the static load was chosen so as to model the effects of the uniform serviceability load (V = 3.0 kN/m^2) determined on the basis of Czech design standard ČSN EN 1991-1-1. The load was applied on the staircase with the use of loading boxes (Fig. 7). The boxes were placed on the staircase in such order, that the course of the bending moment drew as close to the course of the homogeneous distributed load, i.e. 2nd degree parabola. The reverse action was applied for the unloading.

During the static loading tests, the values of vertical displacements at the stair faces at the selected 12 stairs (Fig. 5a) were continuously recorded with the MS04 with the accuracy of 0.05 mm and the measurement units HBM SPIDER 8 (2006). The measuring points were located in the middle of the width and thickness of the stairs. Two stairs No. 6 and 11 were also equipped with potentiometric trajectory sensors (Fig. 5a) in order to monitor vertical displacements at the bearing wall. The position of the measuring points was selected at the lower side of the stairs in the middle of the stairs 30 mm of the edge.

3.1 Staircase A
3.1. Stubište A

The staircase A was loaded in compliance with Czech design standard ČSN 73 2030 (1994) in two steps. In the first step, the staircase was loaded with uniform serviceability load (V = 3.0 kN/m^2), which was increased in the second step by the 0.3 multiple of the uniform serviceability load (Fig. 7). Under the effects of the increased load (1.3 multiple of uniform serviceability load), an extreme value of vertical displacement of 20.66 mm occurred at the stair No. 8, which is lower than the limit value according to (ETAG 008/2002, 2002; ČSN EN 1995-1-1, 2006) amounting to 29.797 mm ($(1/200)\times L_S/\cos\alpha$; L_S = 4.862 m (Fig. 5b); α = 35.3281°) (Table 2). The course of vertical displacements measured under gradual loading allows to clearly identify the course of loading and the moments, when the glued contact of the top (or bottom)

Figure 7 Prototypes of the staircase in version A during static load test - staircase loaded with uniform serviceability load (V = 3.0 kN/m²) increased by the 0.3 multiple
Slika 7. Prototip stubišta verzije A tijekom testa statičkog opterećenja – stubište je opterećeno ravnomjernim opterećenjem V = 3,0 kN/m² uvećanim za 0,3 puta

newel with the handrail was broken and opened. The values of vertical displacements in individual load steps are shown in Table 3. The graphical time record of vertical displacement of the static load test of the staircase A is shown in Fig. 8.

When relieving the load, there is a structure response and after the complete unloading, permanent irreversible deformations (notation PD in Table 3) appear amounting to 1.3 multiple of the uniform serviceability load of approx. 13.7 %. Under the loading, breaking occured as well as partial opening of the glued contact of the top (or bottom) newel with the handrail, while the screw contact showed no faults and the joint between the top and bottom newel and stairs was slightly opened and a distance element was partially displaced from the bottom washer. Some anchoring screws from the bearing wall were slightly pulled out at some stairs, which was manifested by the turning of the steel L 80 × 60 × 8 profile. After the load relief of the staircase A, the partially opened glued contact of the bottom and top newel, respectively, with the handrail was closed up.

3.2 Staircase B
3.2. Stubište B

The staircase B was loaded with the uniform serviceability load in three steps in compliance with standard ČSN 73 2030 (1994). In the first step, the staircase was loaded with uniform serviceability load (V = 3.0 kN/m²), which was increased in the second step by the 0.3

Table 2 Maximum measured vertical displacement U_Y (mm) for staircase A and B for uniform serviceability load with self-weight compared with theoretical values (ETAG 008/2002, 2002; ČSN EN 1995-1-1, 2006)
Tablica 2. Maksimalno izmjereni vertikalni pomak U_Y (mm) za stubište A i B pri ravnomjernom opterećenju korisnika i opterećenju težinom stubišta u usporedbi s teorijskim vrijednostima (ETAG 008/2002, 2002; ČSN EN 1995-1-1, 2006.)

Staircase A / *Stubište A*			**Staircase B** / *Stubište B*		
U_Y		$(1/200)\times L_S/\cos\alpha$	U_Y		$(1/200)\times L_S/\cos\alpha$
20.540	<	29.797	13.320	<	29.797
Condition is satisfied. / *Uvjet je zadovoljen.*			Condition is satisfied. / *Uvjet je zadovoljen.*		

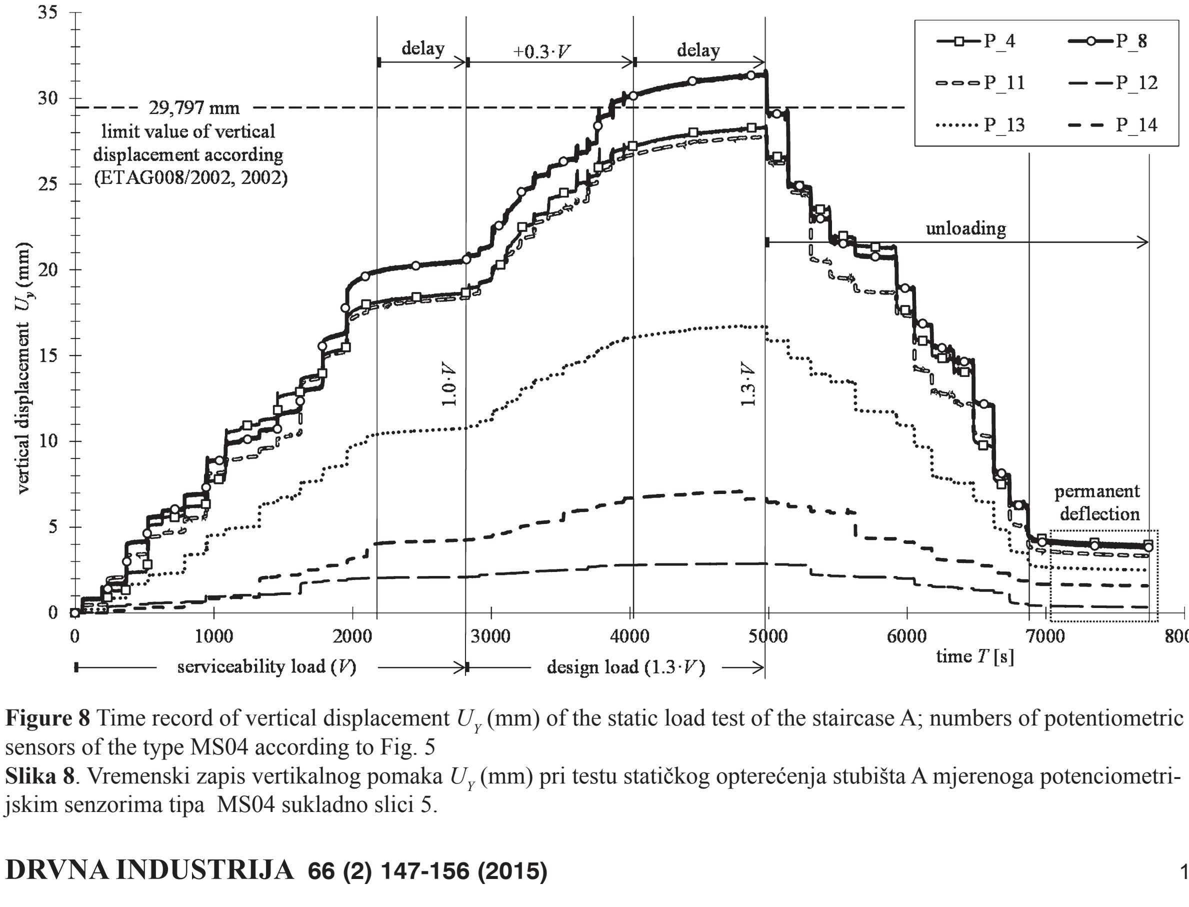


Figure 8 Time record of vertical displacement U_Y (mm) of the static load test of the staircase A; numbers of potentiometric sensors of the type MS04 according to Fig. 5
Slika 8. Vremenski zapis vertikalnog pomaka U_Y (mm) pri testu statičkog opterećenja stubišta A mjerenoga potenciometrijskim senzorima tipa MS04 sukladno slici 5.

Table 3 Measured vertical displacements in individual load steps U_Y (mm) for staircase A and B
Tablica 3. Izmjereni vertikalni pomak U_Y (mm) za različita opterećenja stubišta A i B

Stair / *stuba*	**Potentiometric sensor** *Potenciometrijski senzor*	**Staircase A** / *Stubište A* **Vertical displacement U_Y (mm)** *Vertikalni pomak, U_Y (mm)*				**Staircase B** / *Stubište B* **Vertical displacement U_Y (mm)** *Vertikalni pomak, U_Y (mm)*			
		$1.0 \cdot V$	$1.3 \cdot V$	PD	%	$1.0 \cdot V$	$1.5 \cdot V$	PD	%
			(a)	(b)	(a)/(b)		(c)	(d)	(c)/(d)
1	P_1	3.890	7.030	1.580	22.5	3.090	4.480	0.490	10.9
2	P_2	9.790	15.640	3.600	23.0	7.270	13.030	1.290	9.9
3	P_3	12.100	19.070	3.660	19.2	7.610	15.760	1.810	11.5
5	P_4	18.900	28.243	3.970	14.1	12.210	25.240	3.180	12.6
6	P_5	19.530	29.500	3.740	12.7	12.600	26.380	3.310	12.5
6	P_6 (wall)	1.890	2.420	0.160	6.6	1.070	1.891	0.190	10.0
7	P_7	19.760	30.270	3.870	12.8	12.950	27.480	3.290	12.0
8	P_8	20.660	31.050	3.870	12.5	13.480	28.750	3.480	12.1
9	P_9	19.177	28.954	3.593	12.4	12.772	27.457	3.697	13.5
10	P_10	18.705	28.107	3.491	12.4	12.644	26.594	3.844	14.5
11	P_11	18.546	27.680	3.324	12.0	12.461	25.724	4.047	15.7
11	P_12 (wall)	2.103	2.826	0.336	11.7	1.047	1.693	0.176	10.4
13	P_13	10.862	16.653	2.500	15.0	7.567	16.051	2.993	18.6
15	P_14	4.277	6.951	1.584	22.8	2.940	6.595	1.624	24.6

PD … permanent deflection / *trajni progib*

multiple and in the third step by 0.2 multiple of the uniform serviceability load. Under the effects of the increased load (1.5 multiple of uniform serviceability load), an extreme value of vertical displacement of 13.48 mm occurred at the stair No. 8, which is lower than the limit value according to (ETAG 008/2002, 2002; ČSN EN 1995-1-1, 2006) amounting to 29.797 mm (Table 2). The second part of the graph (Fig. 9) shows a noticeably sharp rise of vertical displacements caused by the broken contact of the bottom newel with the handrail. The values of vertical displacements in individual load steps are shown in Table 3.

When relieving the load, there is again a noticeable structure response and after the complete load relief, permanent deformations (PD in Table 3) appear amounting to 1.5 multiple of the uniform serviceability load of approx. 12.8 %. Similarly to the situation with staircase A, breaking and partial opening of the glued contact of the top newel with the handrail occurred under this load. In addition, a partial split of the handrail

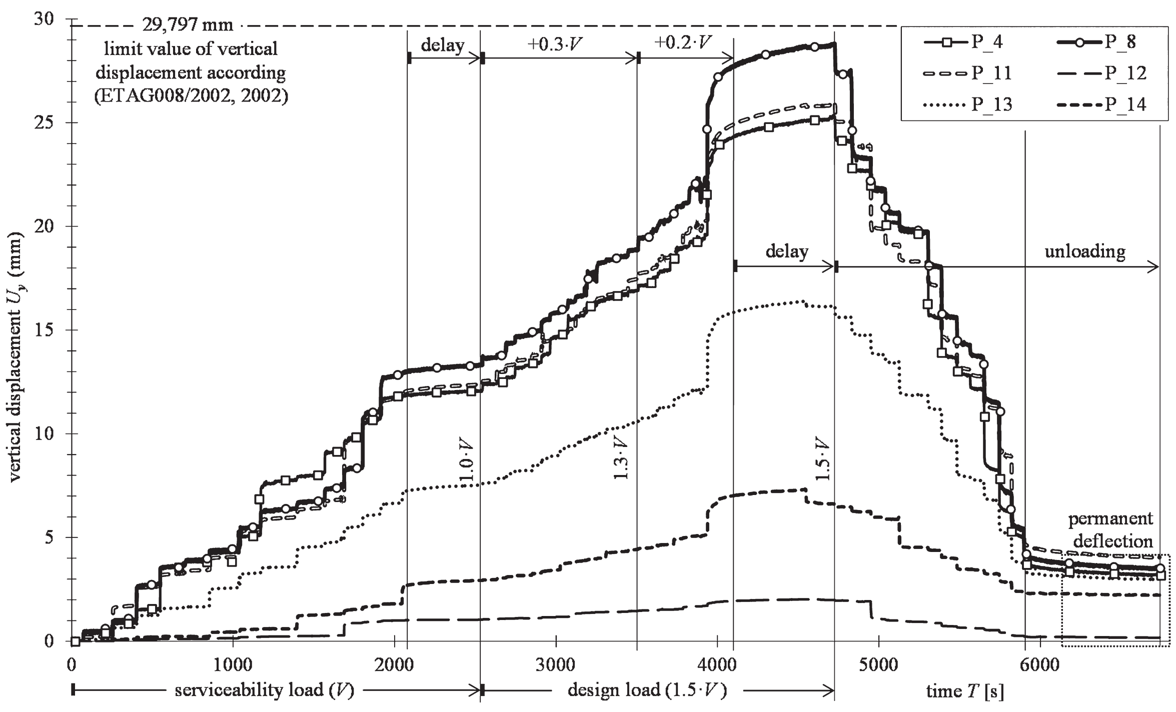


Figure 9 Time record of vertical displacement U_Y (mm) of the static load test of the staircase B; numbers of potentiometric sensors of the type MS04 according to Fig. 5
Slika 9. Vremenski zapis vertikalnog pomaka U_Y (mm) pri testu statičkog opterećenja stubišta B mjerenoga potenciometrijskim senzorima tipa MS04 sukladno slici 5.

appeared. The distance of the handrail and the newel reached approx. 3 mm. Some anchoring screws from the bearing wall were slightly pulled out at some stairs, which was manifested by the turning of the steel L 80 × 60 × 8 profile. After the load relief of the staircase A, the opened glued contact of the bottom newel with the handrail was not closed up.

3.3 Evaluation of static loading tests of staircase A and B
3.3. Ocjena testova statičkog opterećenja stubišta A i B

The evaluation of static loading tests of prefabricated staircases with one-sided suspended stairs in versions A and B was performed according to (ETAG 008/2002, 2002; ČSN EN 1995-1-1, 2006). This condition was met by both staircases. Staircase A was loaded by 1.3 multiple of the uniform serviceability load. After applying the same load, the staircase B continued to be loaded up to 1.5 multiple of the uniform serviceability load. The values of the ratio between the permanent and total deformation for staircases A and B are lower than the coefficient λ_1, which, according to Section D. 8 (ČSN 73 2030, 1994), amounts to 0.25 and 25 %, respectively, for glued structures. Both staircases met these criteria of reliability in terms of ultimate limit state.

The comparison of experimentally measured values of vertical displacements for comparable load shown in Table 3 for 1.0 multiple and 1.3 multiple of uniform serviceability load shows that staircase B is stiffer than staircase A.

4 CONCLUSION
4. ZAKLJUČAK

The comparison of the measured data showed that the prototype of staircase B is stiffer and more resistant to the applied load than the prototype of staircase A. Regarding statics, this finding indicates that supporting stairs with two steel profiles L 80 × 60× 8 mm is more advantageous than the combination of a steel profile and a rectifiable stainless steel distance element.

During a static loading test, staircases A and B were loaded by their own weight and then by uniform serviceability load of the intensity of V = 3.0 kN/m^2. Subsequently, the load of staircases A and B was increased up to 1.3 multiple for staircase A and up to 1.5 multiple of the load for staircase B. Even under the higher load, the vertical displacements of selected measuring points at staircase B were lower than those at staircase A. Under the effects of increased loading, which models the ultimate limit state, the staircase structure showed no serious faults and deficiencies. It should be emphasised that the pressing of newel washers into stairs occurred as well as opening of the contact between the bottom newel and handrail for staircases A and B, and opening of the contact between the top newel and handrail for staircase B. Despite these slight faults, the structures of staircases were reliable, which was documented by subsequently performed loading tests of broken and opened contacts.

Staircases A and B were evaluated in accordance with (ETAG 008/2002, 2002; ČSN EN 1995-1-1, 2006; ČSN 73 2030, 1994) in terms of ultimate and serviceability limit state. Both staircases A and B met the required criteria of the mentioned regulations.

Based on the behaviour of staircases in the course of loading tests, it was recommended to increase ultimate limit state of staircases structure and their general stiffness by changes in the detail of the contact of the top and bottom newel with handrail, and the detail of the passage of the exit stair through the top newel.

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5 REFERENCES
5. LITERATURA

1. Berthelot, J. M., 1998: Composite Materials, Mechanical Behavior and Structural Analysis. Berlin: Springer.
2. Bucur, V., 2006: Acoustics of Wood. Berlin: Springer.
3. Danielsson, H.; Gustafsson, P. J., 2013: A three dimensional plasticity model for perpendicular to grain cohesive fracture in wood. Engineering Fracture mechanics, 98: 137-152. http://dx.doi.org/10.1016/j.engfracmech.2012.12.008
4. Fleischmann, M.; Müllner, H. W.; Krenn, H., Eberhardsteiner, J., 2005: Experimental and Numerical Investigation of Timber Structures for the Validation of an Orthotropic Plasticity Model. 22nd Danubia-Adria Symposium on Experimental Methods in Solid Mechanics (DAS-22), Monticelli Terme - Parma, Italy.
5. Franke, B.; Quenneville, P. J., 2011: Numerical Modelling of the Failure Behavior of Dowel Connections in Wood. Journal of Engineering Mechanics. 137(3): 186-195. http://dx.doi.org/10.1061/(ASCE)EM.1943-7889.0000217
6. Galicky, J.; Czech, M., 2013: A new approach to formulate the general strength theories for anisotropic discontinuous materials. Part A: The experimental base for a new approach to formulate the general strength theories for anisotropic materials on basis of wood. Applied Mathematical Modelling, 37(3): 815-827. http://dx.doi.org/10.1016/j.apm.2012.03.004
7. Habermann, K. J., 2002: Staircases: Design and Construction. Basel, Boston, Berlin: Birkhäuser.
8. Hoffman, O., 1967: The Brittle Strength of Orthotropic Materials. Journal of Composite Materials, 1: 200-206. http://dx.doi.org/10.1177/002199836700100210
9. Jiricna, E., 2001: Staircases. New York, NY: Watson-Guptill Publications.

10. Karre, A., 2005: Stairscaping: A Guide to Buying, Remodeling, and Decorating Interior and Exterior Staircases. Massachusetts: Quarry Books.
11. Kretschmann, D. E., 2010: Wood Handbook, Chapter 05: Mechanical Properties of Wood. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 5-1 - 5-46.
12. Labans, E.; Kalniņš, K., 2012: Numerical Modelling and Experimental Validation of Dendrolight Cellular Wood Material. In: The 8th Meeting "Northern European Network for Wood Science and Engineering (WSE)": Proceedings: The 8th Meeting of the Northern European Network for Wood Science and Engineering (WSE), Lithuania, Kaunas, 13-14 September, 2012. Kaunas: 2012, pp.177-184. (online: http://www.nordicforestresearch.org/wp-content/uploads/2011/03/26_Edgars_Labans.pdf)
13. Matovič, A., 1993: Fyzikální a mechanické vlastnosti dřeva a materiálů na bázi dřeva, Brno: Vysoká škola zemědělská.
14. Mascia, N. T.; Lahr, F. A. R., 2006: Remarks on orthotropic elastic models applied to wood. Materials Research, 9 (3): 301-310. http://dx.doi.org/10.1590/S1516-14392006000300010
15. Pěnčík, J.; Lavický, M., 2006: Možnosti modelování lepených dřevěných spojů pomocí prvků CONTA17x. (Modeling capabilities of glued wood joints with contact elements CONTA17x) 14. ANSYS Users Meeting pro Českou republiku a Slovensko 2006, Tábor. Tábor: SVS FEM s.r.o., pp. 1-9.
16. Pousette, A., 2003: Full-scale test and fi nite element analysis of a wooden spiral staircase. Holz als Roh-und Werkstoff, 61(1): 1-7. http://dx.doi.org/10.1007/s00107-002-0345-6
17. Pousette, A., 2006: Testing and modeling of the behavior of wooden stairs and stair joints. J Wood Sci, 52: 358-362. http://dx.doi.org/10.1007/s10086-005-0778-8
18. Požgaj, A.; Chovanec, D.; Kurjatko, S.; Babiak, M., 1997: Štruktura a vlastnosti dreva, Priroda, Bratislava.
19. Tankut, N.; Tankut, A. N.; Zor, M., 2014: Finite Element Analysis of Wood Materials. Drvna industrija, 65 (2): 159-171. http://dx.doi.org/10.5552/drind.2014.1254
20. ***2004: "Fyzikální a mechanické vlastnosti dřeva" (online), Mendel University in Brno, wood.mendelu.cz/cz/sections/Props/?q=node/56. First published 2004 (Accessed Aug. 1, 2013).
21. ***2006: "Spider8 from HBM" (online), HBM Inc. http://www.hbm.com/fileadmin/mediapool/hbmdoc/technical/b0409.pdf. First published 2006 (Accessed May 20, 2013).
22. ***2012: "Elastic Properties and Young Modulus for some Materials" (online), The Engineering Toolbox, www.engineeringtoolbox.com/young-modulus-d_417.html. First published 2012 (Accessed May 15, 2013).
23. *** ANSYS® Academic Research, Release 14.5, ANSYS, Inc., 2012a.
24. *** ANSYS® Academic Research, Release 14.5, Help System, Elements Reference, ANSYS, Inc., 2012b.
25. *** ANSYS® Academic Research, Release 14.0, Help System, Advanced Analysis Techniques Guide, ANSYS, Inc., 2012c.
26. *** ČSN 49 1531-1, 1998: Structural timber - Part 1: Visual strength grading.
27. *** ČSN 73 2030, 1994: Loading tests of building structures Common regulations.
28. *** ČSN 73 4130, 2010: Stairways and sliding ramps – Basic requirements.
29. *** ČSN EN 1990 (73 0002) Eurocode, 2004: Basis of structural design.
30. *** ČSN EN 1991-1-1 (73 0035) Eurocode 1, 2004: Action on Structures – Part 1-1: General actions – Densities, self-weight, imposed loads for buildings.
31. *** ČSN EN 1995-1-1 (73 1701), 2006: Design of timber structures, Part 1-1: General - Common rules and rules for buildings.
32. *** ETAG 008/2002, 2002: Guideline for European technical approval of prefabricated stair kits. Prefabricated stair kits in general.
33. *** IDA NEXIS 32, 2002: SCIA Group.
34. *** JEMA Svitavy a.s., 2006: Wooden staircase. Product catalog.

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Assessment of "Uso Fiume" Larch Beams Production in the Sawmilling Industry of Aosta Valley Region – Northwestern Italy

Procjena proizvodnje greda *Uso fiume* od arišovine u pilanskoj industriji regije Aosta Valley - Sjeverozapadna Italija

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ABSTRACT • *"Uso Fiume" (UF) beams are a traditional peculiarity of the Italian wooden carpentry. They are produced by parallel sawing of the log on four faces, which results in wanes on their whole length, while their cross section is constant from end to end.*
Structural timber is subjected to the dispositions of the European Construction Products Regulation (CPR) and since January 2012 it can be placed on the market only if CE marked; structural timber with irregular section, such as UF beams, shall be graded on the basis of a specific procedure named European Technical Assessment (ETA). In particular, UF beams made of larch (Larix decidua Mill.) wood can be CE marked according to ETA – 11/0219. This is a relevant factor for the enterprises of some Italian Regions, such as Aosta Valley, where larch is widespread and commonly used for producing structural assortments.
In this context the present work aims to assess the characteristics of UF larch beams production in the above geographical site. To this purpose a survey was addressed at regional sawmills producing these assortments. The inquiry was also designed in order to investigate different aspects such as enterprises dimensions, origin of round wood and production methods.
The survey gave a picture of this production reality and can provide useful considerations for similar cases in other Italian or European Regions.

Key words: *Structural timber, larch, CE marking, Uso Fiume beams, sawmills, Aosta Valley*

SAŽETAK • *Uso Fiume (UF) grede tradicionalna su posebnost talijanske drvene građe. Proizvode se paralelnim piljenjem trupca u četiri plohe, što rezultira nepravilnim rubovima cijelom duljinom dok im je presjek ujednačen.*

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Strukturna građa mora biti u skladu s Europskom uredbom o građevinskim proizvodima (CPR), a od siječnja 2012. može biti na tržištu samo ako ima oznaku CE. Strukturna građa nepravilnih dijelova kao što su UF grede mora se klasificirati na temelju određenog postupka koji se naziva europskom tehničkom procjenom (ETA). Konkretno, UF grede izrađene od drva ariša (Larix decidua Mill.) mogu biti označene CE oznakom u skladu s ETA - 11/0219. To je relevantan čimbenik za poduzeća u nekim talijanskim regijama kao što su Aosta Valley, gdje je ariš rasprostranjen i često se upotrebljava za izradu strukturnih proizvoda.
U tom kontekstu, cilj je ovog rada procijeniti obilježja proizvodnje UF greda od arišovine u regiji Aosta Valley. Za tu svrhu provedena je anketa u pilanama regije koje proizvode UF grede. Anketni je upitnik izrađen tako da bi se mogli istražiti različiti aspekti proizvodnje kao što su dimenzije pilane, podrijetlo trupaca te proizvodne metode. Istraživanje je omogućilo da se stvori slika stvarne produktivnosti, koja može dati korisne podatke i zaključke za slične primjere u drugim talijanskim ili europskim regijama.

Ključne riječi: *strukturna građa, ariš, oznaka CE, greda Uso Fiume, pilana, Aosta Valley*

1 INTRODUCTION
1. UVOD

The EU Regulation No. 305/2011 (CPR, acronym for Construction Products Regulation) lays down harmonized conditions for marketing of construction products within the European Union. Structural timber is subjected to CPR’s dispositions and since January 2012 it can be placed on the market only if it is CE marked (Negro *et al.,* 2013).

According to CPR, structural timber with rectangular cross section shall be classified in conformity with EN 14081-1 and assigned to a strength class included in the EN 338. Structural timber with irregular cross section is not considered neither by the EN 14081-1 nor by other harmonized standards. In this case the CPR envisages the possibility of placing the CE marking only if a European Technical Assessment (ETA) has been released for the specific product.

“Uso Fiume” (UF) beams belong to the category of structural timber with irregular section and represent a peculiarity of the Italian wooden carpentry (Figure 1). Uso Fiume larch beams are traditionally used by the Aosta Valley sawmilling industry for producing wooden carpentry). Their cost is lower compared to that of larch beams with regular sections, particularly due to higher transformation yields.

Figure 1 Uso Fiume larch beams are traditionally used by the Aosta Valley sawmilling industry for producing wooden carpentry
Slika 1. Grede *Uso Fiume* od drva ariša tradicionalno se upotrebljavaju u pilanskoj industriji regije Aosta Valley za proizvodnju drvne stolarije

Their cross section is constant from end to end and they are produced by parallel sawing of the log on four faces, which results in wanes on their whole length. Recently some Italian associations carried out, together with National Research Bodies, a wide sampling and testing on UF beams. As a result, the *Consortium Uso Fiume/Uso Trieste beams* obtained the ETA – 11/0219 that allows the enterprises part of the group to CE mark their UF beams made of spruce, silver fir or larch. Similarly, the *Consortium Wood Cork – Technical Committee Chestnut Uso Fiume* obtained the ETA 12/0540 for CE marking these assortments. Inclusion of larch wood in ETA – 11/0219 is a relevant factor for sawmills located in the Aosta Valley, where this wood species is widespread: larch stands cover 44.528 ha and constitute 45 % of the regional forest surface (INFC, 2005).

In this context the present work aims to analyze the characteristics of UF larch beams production in the above Region of Northwestern Italy. To this purpose, a survey was addressed to sawmills producing UF larch assortments. The inquiry was designed for investigating different aspects such as enterprises dimensions, origin of the round wood and production methods. Collected data were elaborated in order to obtain updated information on the examined sector and to understand the peculiarities and issues that characterize the regional production.

The survey gave a picture of this production reality; considerations for similar cases in other Italian or European Regions can also be drawn from the outcomes of the study.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

The Chamber of Commerce of Aosta Valley was contacted in order to individuate the regional sawmills that currently produce UF larch beams. In particular, the list of enterprises belonging to the following categories[1] was required:

[1] Derived from the statistical classification of economic activities in the European Communities (NACE) by the National Institute of Statistic (ISTAT, 2007).

- code 16.10: sawmilling and planning of wood;
- code 16.23: manufacture of other builders' carpentry and joinery.

The list included 238 regional enterprises and reported general descriptive information such as the number of employees or the main production activity for each of them. The latter parameter was used for shortening the list: for instance, all enterprises marked as "Production of furniture" were excluded. Through this selection, 56 enterprises were individuated as possible producers of UF larch beams in the area of study. Each of them was directly contacted, which enabled identifying the 9 enterprises that currently produce UF beams in the Region. The remaining 47 enterprises, instead, resulted to be mainly involved in timber commerce and in any case are not UF beams producers.

Taking as a reference other surveys describing the productive realities of sawmilling industries (Knowles *et al*., 2008; Crespell *et al*., 2006), a questionnaire addressed to the owners of the 9 shortlisted sawmills was formulated. Its development was aimed at assessing the main characteristics of UF larch beams production in Aosta Valley. The questionnaire was designed to be completed within 20 minutes and was structured in two segments: trade flows (1) and beams characteristics (2). Six questions were expressed; three in segment 1 (origin of round timber, annual production, selling destinations) and three in segment 2 (sections and lengths produced, production methods, grading procedures). A draft was submitted for revision to experts in structural timber both in academia and industry; limited changes were made according to comments received. The questionnaire was then subjected to sawmill owners by direct visiting *in loco*. Answers were registered in spreadsheets subsequently used for data elaboration and statistical analysis.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figure 2 shows the number of employees for each of the nine regional enterprises that currently produce UF larch beams.

All of them have less than 10 employees (while the activity of sawmills # 2 and 3 is entirely carried out by the owner) and fall into the category of Small Medium Enterprises, sub-category Microenterprises[2]. They are generally family owned, which indicates a sector still constituted by small productions fractioned in the regional area.

The above sawmills buy round wood and timber for producing UF larch beams from several provenances: Aosta Valley, Piedmont Region (still in Italy and close to the above), Austria, France, Germany and Switzerland. As shown in Figure 3, each sawmill counts on two or more provenances, with the exception of sawmill # 3 that satisfies its limited needs by buying round wood of local origin only.

Figure 4 reports the percentage distribution of logs provenances considering the collected data. The main part of round wood and timber comes from Aosta Valley (36 %) and France (28 %); relevant amounts are also imported from Switzerland (12 %), Austria (11 %) and Germany (10 %), while the remaining 3 % comes from Piedmont. From these data, it emerges that, despite the large presence of larch stands at local level, the main part of round wood (61 %) is imported from foreign countries. Sawmills owners indicated two main

[2] According to the Recommendation of the European Commission of May 6th 2003, a microenterprise is defined as "*an enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed 2 million €*".

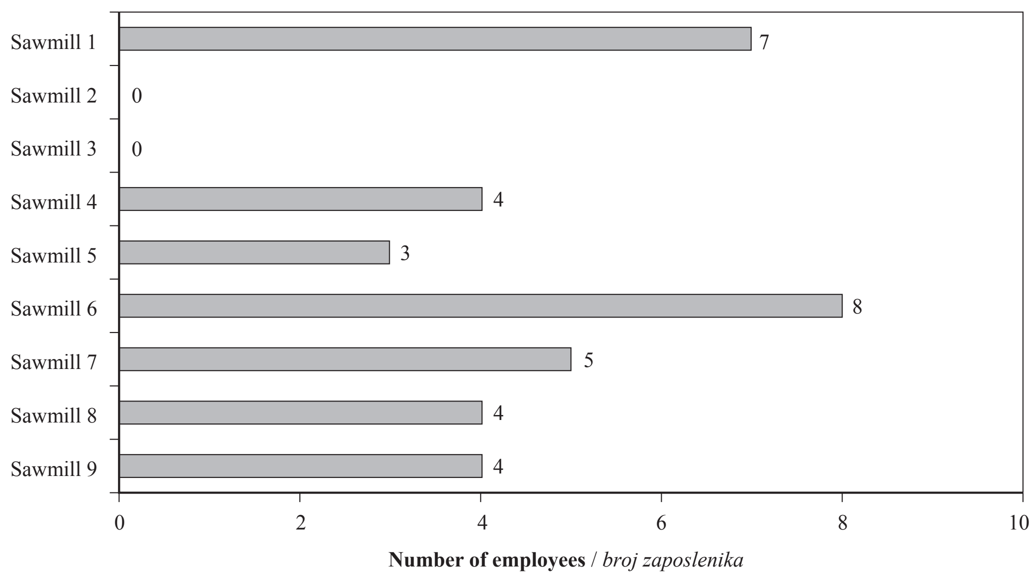

Figure 2 Number of employees for each inquired enterprise
Slika 2. Broj zaposlenika u ispitivanim pilanama

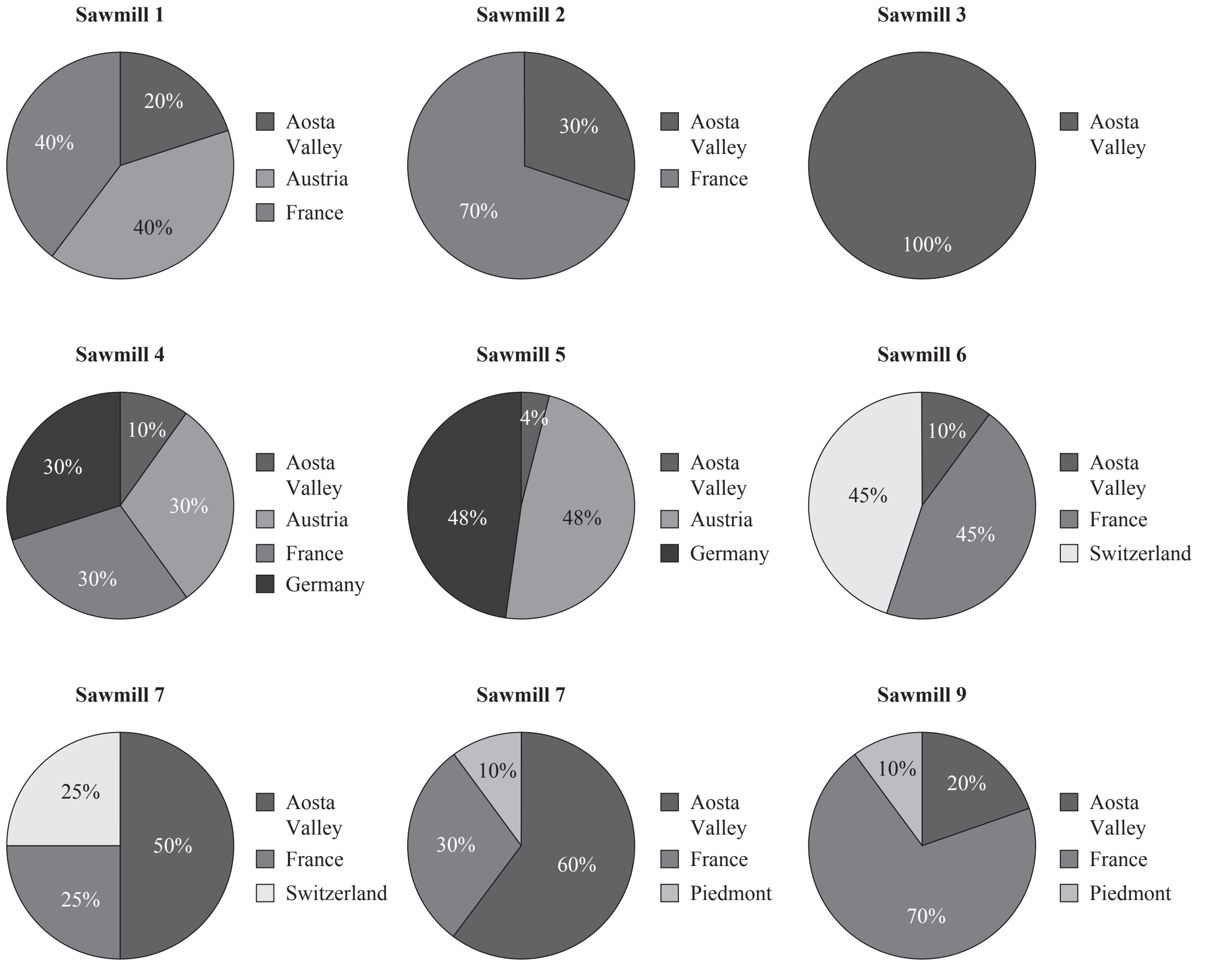

Figure 3 Provenance of round wood and timber used for producing UF beams
Slika 3. Podrijetlo oblovine za proizvodnju UF greda

reasons for that: firstly, in their opinion the regional harvesting polices are too restrictive and not enough oriented to the productive function, and secondly the quality of regional round wood is not always able to satisfy the market requirements.

As for dimensions of UF larch beams, their most common sections range from 18x18 cm and 20x25 cm, used for producing rafters, and from 30x30 cm to 35x35 cm, used for ridgepoles. Most frequent lengths vary within a broad range from 400 to 13.000 cm. On the whole, the main combinations are 20x20 cm x 6-10 m, 20x25 cm x 6-8 m, 30x30 cm x 6-8 m.

From the analysis of the annual production of UF larch beams per sawmill, it emerges that volumes are generally limited (Figure 5).

Grouping the above data in volume classes shows that five sawmills out of nine have a production equal or minor to 100 m^3 per year, while the others reach a larger productions, which in any case is not higher than 200 m^3 per year (Figure 6).

This distribution indicates that production of UF beams represents a niche market and constitutes a marginal part of the whole activity of the inquired enterprises, as also stated by their owners.

Figure 7 reports the modalities used by enterprises for producing UF beams. According to the standard UNI 11035-3[3] Uso Fiume beams shall be "*obtained from a trunk by mechanical sawing, continuously and parallel from end to end on four faces with constant thickness*". Four sawmills declared to produce UF beams using the above method, while one sawmill de-

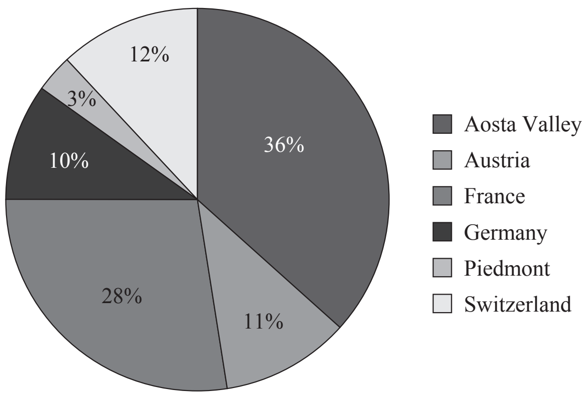

Figure 4 Provenance of round wood and timber considering the grouped data
Slika 4. Podrijetlo oblovine prema podacima za sve ispitivane pilane

[3] This standard regards UF beams made of spruce and silver fire but can be taken as a valid guide for many aspects of UF larch beam production.

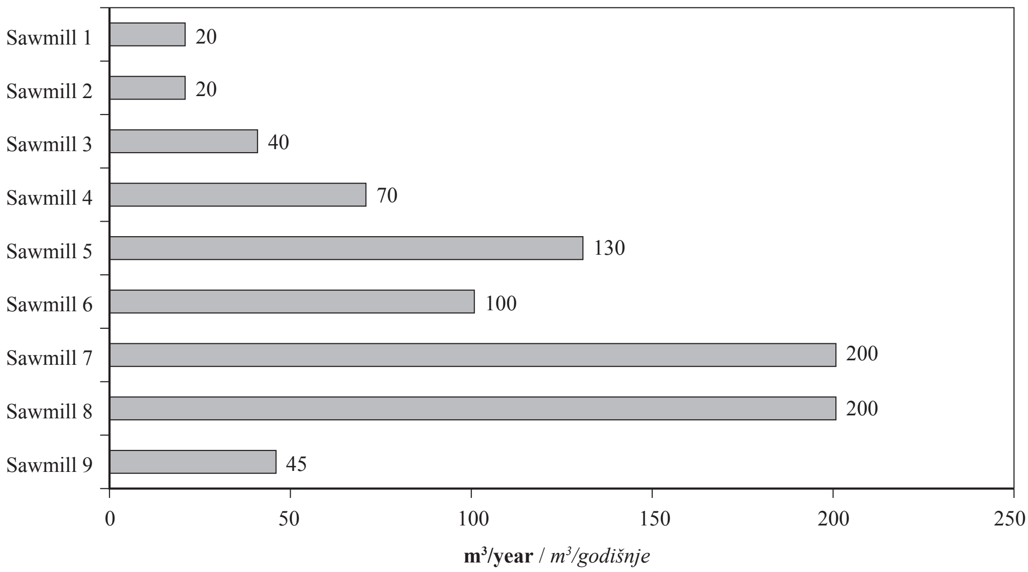

Figure 5 Annual production of UF beams for each sawmill
Slika 5. Godišnja proizvodnja UF greda za svaku ispitivanu pilanu

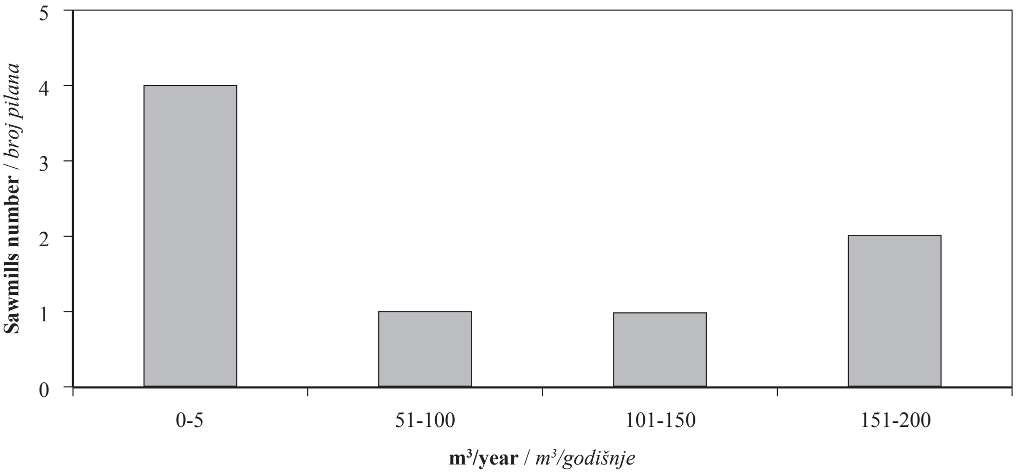

Figure 6 Annual production per volume classes
Slika 6. Godišnja proizvodnja prema volumnim klasama

clared to produce these assortments by milling the edges of rectangular beams, therefore artificially obtaining the wanes along the beam. The remaining four declared to use both methods.

The difference between these methods is not only formal: beams milled along edges do not present, in correspondence of their wanes, the continuity of wooden tissues that is an added value of UF assortments.

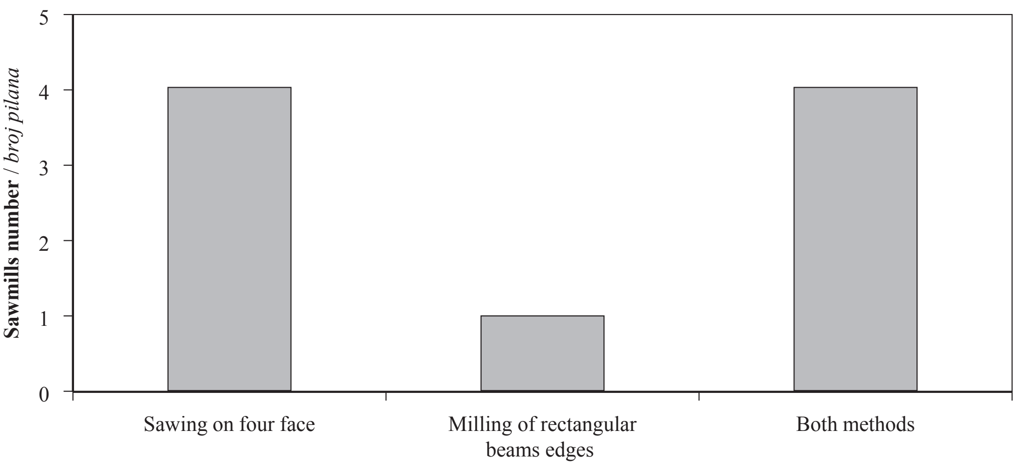

Figure 7 Methods used for producing UF assortments
Slika 7. Metode proizvodnje UF greda

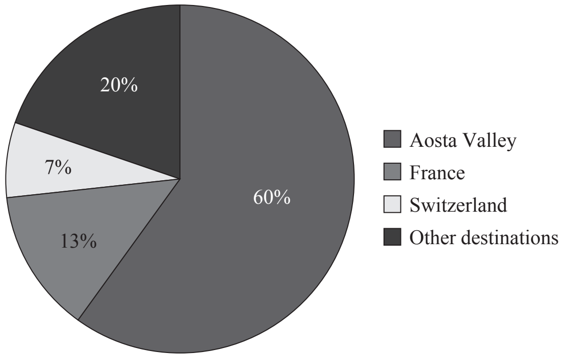

Figure 8 Selling destinations of UF larch beams
Slika 8. Destinacije prodaje UF greda

Therefore, it is recommendable for producers to exclusively use the mechanical squaring.

Finally, Figure 8 shows destinations towards which enterprises sale their UF larch beams. The higher amount (60 %) is sold within Aosta Valley, confirming that this reality is limited but relevant at local level.

Volumes sold to different destinations, mainly other Italian Regions and in particular the near Piedmont and Lombardia, are 20 % of the total. The remaining part is exported to France (13 %) and Switzerland (7 %).

4 CONCLUSIONS
4. ZAKLJUČCI

Introduction of CE marking obligation for construction products is a demanding challenge for enterprises of Aosta Valley that produce UF larch beams. These are, in fact, microenterprises often family owned and their organization is not always properly structured. On the other side, the new standard requirements offer the opportunity for valorizing the regional structural timber. This can determine positive effects both on sawmills and local wood sector. This aspect is particularly relevant since in the last years the entire forest-wood-chain has been weakened at regional and national level by several factors, namely the competition of engineered wood-based products such as glue laminated wood, the adverse economic period and the delocalization of production processes.

The survey showed how, today, the production of Uso Fiume larch beams in Aosta Valley is a niche reality characterized by small volumes. Still, this is a heritage of the Italian wooden carpentry that should be valorized and, where possible, supported in increasing the productive and commercial potential. The use of larch wood for structural timber is, in fact, a valid alternative to spruce and silver fir, in particular when the purpose is to exploit and valorize the durability, the major mechanical properties and the aesthetic appearance of larch wood or to promote the use of a local timber. It is, therefore, worth considering further research aimed at investigating the technical and economical performance of sawmills producing these assortments.

In any case, the essential pre-requisite for valorizing the available wooden resources is to be able to guarantee a full compliance of products and processes to the in-force technical and legislative dispositions. Therefore, sawmills should make an effort, also supported by associations, to fully comply with the current normative framework. In this context, CE marking of UF larch beams, together with an adequate promotion on the market, can give a relevant impulse to the sector. This can help the regional enterprises to acquire more updated, modern and efficient production methods.

Acknowledgements - Zahvala

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5 REFERENCES
5. LITERATURA

1. EU Commission Recommendation 2003/361/EC of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises.
2. Crespell, P.; Knowles, C.; Hansen, E., 2006: Innovativeness in the North American softwood sawmilling industry. Forest Science 52 (5): 568-578.
3. EN 338:2009 Structural timber - Strength classes.
4. EN 14081-1:2005+A1:2011 Timber structures - Strength graded structural timber with rectangular cross section - Part 1: General requirements.
5. Knowles, C.; Hansen, E.; Shook, S. R., 2008: Assessing innovativeness in the North American softwood sawmilling industry using three methods. Canadian Journal of Forest Research 38 (2): 363-375. http://dx.doi.org/10.1139/X07-140
6. Negro, F.; Cremonini, C.; Zanuttini, R., 2013: CE marking of structural timber: the European standardization framework and its effects on Italian manufacturers. Drvna industrija 64 (1): 55-62. http://dx.doi.org/10.5552/drind.2013.1214
7. Regulation (EU) No 305/2011 of 9 March 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.
8. UNI 11035-3:2010 Legno strutturale - Classificazione a vista dei legnami secondo la resistenza meccanica – Parte 3: Travi Uso Fiume e Uso Trieste.
9. *** 2007: National Forest and Carbon Sink Inventory (in Italian). http://www.sian.it/inventarioforestale/ (Accessed Dec. 3, 2014).
10. *** 2007: ISTAT, ATECO 2007 – Classification of economic activities (in Italian). http://www.istat.it/it/archivio/17888 (Accessed Dec. 3, 2014)

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Study on Energy Requirement of Wood Chip Compaction

Analiza energije potrebne za prešanje peleta

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ABSTRACT • *In order to utilize waste products such as sawdust and chips in the wood industry, pellets are made using compaction pressures in the range of 100 MPa or higher. During the compaction process, the density and the modulus of elasticity of the material rapidly increase. Wood materials generally show non-linear viscoelastic-plastic behavior and, therefore, the pressure-deformation relationship is dependent on the loading velocity and on the time during which the material is subjected to constant deformation or load. The energy requirement of pellet production depends on many influencing factors and in such cases the use of dimensionless numbers in the form of similarity equation facilitates the processing of experimental results and the obtained similarity relationship has a more general validity for the users. Various fractions of different wood species were used in these experiments, and the pressure, pellet diameter, temperature were also varied. The proposed similarity equation shows a good correlation with the experimental results.*

Key words*: *chip fraction, compaction, pellet diameter, temperature effect, compaction work, dimensionless numbers

SAŽETAK • *U praksi se često od poljoprivrednih ili drvnih materijala prešanjem usitnjenog materijala pod visokim tlakom proizvode pelete pri čemu je tlak često jednak ili veći od 100 MPa. Tijekom prešanja gustoća peleta brzo raste, a zajedno s njom povećava se i modul elastičnosti. Drvo i od njega proizvedeni peleti ponašaju se viskoelastično, tj. njihova tlačna deformacija ovisi o vremenu odnosno brzini opterećenja. Prijašnja istraživanja prešanja usitnjenoga drvnog ostatka pokazala su da cjelovito drvo ni tijekom prilično male kompresije ne pokazuje obilježja elastičnosti prema Hookeovu zakonu. Na kraju ciklusa opterećenja uvijek se zadrži određeni stupanj deformacije, a postupkom rasterećenja velik je dio deformacije nepovratan. Osim vremenom, odnos naprezanja i deformacije određen je i veličinom naprezanja tako da se ne može govoriti o linearnoj viskoelastičnosti. Na temelju rezultata provedenih istraživanja nastala je jednadžba prema kriteriju bezdimenzionalnosti koja univerzalno (neovisno o vrsti drva) karakterizira promjenu gustoće i pritiska s obzirom na prešanje i temperaturu prešanja usitnjenoga drvnog ostatka i dobivenog peleta različitog promjera. Osim toga, istom se jednadžbom može utvrditi karakteristična energija pri izradi peleta ovisno o pritisku prešanja.*

Ključne riječi: *prešanje, viskoelastičnost, specifični rad, bezdimenzionalni brojevi*

1 INTRODUCTION
1. UVOD

A rational utilization of waste products in the wood industry is to make them into pellets. The pelleting reduces the volume of the bulk chip considerably and facilitates its handling (transport, storage, feeding into boiler) fundamentally. At the same time, energy and suitable equipment are needed to perform the pelleting process. The most commonly used pelleting machines use a rotating die ring and the material is pressed into the boreholes of the ring by rollers. The first comprehensive

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analysis of the pelleting process is given by Schwanghart, (1969). Focus was placed on measuring and analyzing the working principle of the press rollers and the effect of their operational parameters on the throughput. For describing the compaction process, a relatively simple empirical relationship was used. Using non-linear rheological models, a more generally valid description of the compaction process was developed and used for sawdust and chips (Sitkei, 1994; Sitkei, 1997) and, furthermore, the non-linear viscoelastic behavior of the material was experimentally mapped in the entire loading velocity range. Some experimental results on the energy requirement of the pelleting process for fodder flours were already summarized by (Schwanghart, 1969) without specifying the measurement conditions and material properties. Later experiments also failed to give generally valid relationships for the energy requirement of the pelleting process (Carlos *et al*., 2010).

The aim of the present work is to develop and validate a relationship which takes into account the pressure, the final density of the pellet, pellet diameter, the effect of temperature and material properties. For this purpose, the application of similarity equation seems to be the most promising method, similarly to those successfully applied in the last hundred years in the field of heat transfer and fluid flow problems.

2 THEORETICAL CONSIDERATIONS
2. TEORIJSKA OSNOVA

Biological materials have very complicated material laws and, in the case of higher volume changes as is the pelleting process, the stress-strain relationship is always highly non-linear. Therefore, pure mathematical methods for describing the compaction process in all its details are today hardly available. A more practical and reliable approach is to perform carefully designed experimental measurements and to process these results in such a way that the obtained relationship would be valid with as few constraints as possible. In order to extend the validity of a relationship for different materials, it is necessary to include the proper material properties.

The particles in the ring die channels are loaded by compressive forces and, therefore, the material property may be characterized, as a first approximation, by the compressive strength of the material in question. Concerning the compaction process of wood chips, the following main influencing factors should be treated: material property of wood species, average particle diameter, compaction pressure, temperature of the material, diameter of the pellet, and final density of the pellet and the total specific work of compaction. There are further influencing factors with limited variability range due to the process itself. For instance, the loading speed has always a definite influence on the compaction process, but in real pelleting machines the loading speed can not be varied as a process parameter. The moisture content is also an important process parameter, but its range is also limited due to the durability requirement of the pellet.

Keeping in mind the above statements, the following formal functional relationship with seven variables may be written:

$$W = f(p, y, d, \sigma_C, \vartheta, \vartheta_0) \qquad (1)$$

where:
p – pressure, N/m^2
W – total specific energy of compaction, Nm/m^3
γ – final specific weight of the pellet, N/m^3
d – diameter of the pellet, m
σ_c – compressive strength of the wood, N/m^2
ϑ, ϑ_0 – the pellet temperature and a reference temperature, here taken as ϑ_0 =25 °C (room temperature)

In order to derive the proper functional form of Eq. (1), the standard dimensional analysis method was used (Buckingham, 1914; Langhaar, 1951). It yields the following dimensionless numbers

$$\pi_1 = \frac{W}{p}; \quad \pi_2 = \frac{\gamma \cdot d}{\sigma_C}; \quad \pi_3 = \frac{\vartheta}{\vartheta_0}$$

and according to Buckingham's theorem, we may further write

$$\frac{W}{p} = f\left(\frac{\gamma \cdot d}{\sigma_C}, \frac{\vartheta}{\vartheta_0}\right)$$

or

$$\frac{W}{p} = const \cdot \left(\frac{\gamma \cdot d}{\sigma_C}\right)^n \cdot \left(\frac{\vartheta}{\vartheta_0}\right)^m \qquad (2)$$

where the constant and the exponents n and m should be determined experimentally.

In the above equation, the dependent variable is the specific energy consumption W, therefore, the dimensionless number π_1 containing the specific energy is placed on the left side of Eq. (2). The other two numbers containing only independent variables are on the right side of Eq. (2). The total work of compaction is determined by the pure compression work and by the work done during pushing out the pellet from the boreholes.

The pure compression work is given by integration of the pressure along the displacement. The pressure–strain relationship is strongly non-linear and can be given in the following form (Sitkei, 1994; Pronk, 2005):

$$p = A \cdot \left(\frac{\varepsilon}{1-\varepsilon}\right)^n \qquad (3)$$

where:
A – material dependent constant
n – exponent
ε – strain.

The exponent n depends on the size and strength of particles and on the pressure range. Its value varies between 1.5 and 2.5 for various wood chips (Sitkei, 1994; Hofko, 2008). The strength of chips especially influences the course of compaction curve as a function of displacement. Soft particles can be compacted at relatively low pressures and, increasing further the pressure, the curve ascends steep giving a higher exponent. On the contrary, particles of hardwood species with higher individual strength will be compacted more

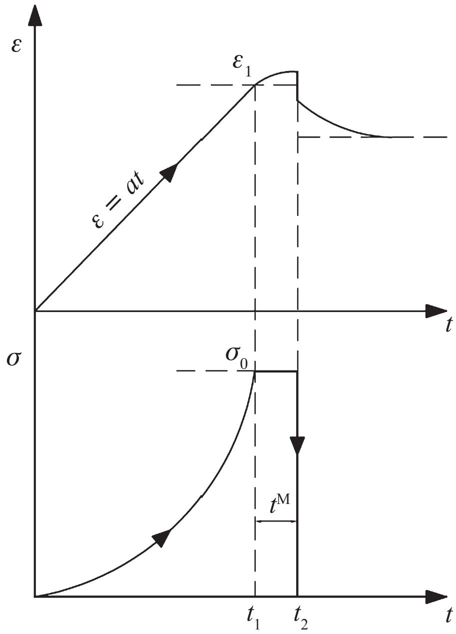

Figure 1 Time course of the compression process (Sitkei, 1994)
Slika 1. Vremenski tijek procesa kompresije (Sitkei, 1994.)

uniformly as a function of displacement resulting in lower exponent *n*. Due to the anatomical structure of wood, the individual strength of particles depends not only on wood species but also on the size of particles. With decreasing particle size, the surface–volume ratio increases (Csanády *et al*., 2013; R.C. Akdeniz *et al*., 2013). The surface of a particle is created by fracture with highly uneven surface and the load-bearing capacity of this near-surface layer is less compared to that of the sound inner part. As a consequence, a smaller particle may behave similarly as if it originated from a softer wood species. The effect of size on the compaction process can only be determined experimentally.

The second main part of the total compaction work is the work done during the push-out of the pellet from the boreholes. This work depends on the friction coefficient between the pellet and channel wall, the length of the channel and the elastic-plastic behavior of the material at the given pressure. This work should also be determined experimentally.

Concerning constant deformation velocity, the particular phases of a compaction process is illustrated in Fig. 1. Due to the constant deformation rate, the pressure increases progressively. During constant load or stress, the deformation and compaction continues to grow (creep). After unloading the elastic part of the deformation, it recovers suddenly followed by a retarded rebound. Much of the deformation is retained as permanent deformation ensuring the required pellet density.

3 MATERIALS AND METHODS
3. MATERIJAL I METODE

In order to get industrial sized pellets (20-30 mm in length), the design of the experimental equipment should fulfill some basic requirements (Carlos *et al*., 2010). A plunger type, cylinder and ram, compaction unit was chosen with three diameters of 6, 8 and 16 mm. Its length was 150 mm enabling to use the required volume of loose material to get 20-30 mm pellet length (Fig. 2a). The outer face of the cylinder could have been heated to a given temperature, using proper thermo-regulating equipment (Fig. 2b). An Instron universal testing machine served as a loading device. The loading velocity was generally 1 cm/min, which more or less corresponds to the real industrial condition.

Chips of softwood (spruce – *Picea abies*) and hard wood (Black locust – *Robinia pseudoacacia*), having different strength properties, were used in these experiments. In order to get a more uniform chip size distribution, a chipper was used and thereafter the samples were sieved into fractions. In these experiments, fractions of 0.063 to 0.2 mm, 0.2 to 0.5 mm and 0.8 to 1.0 mm were used. For sieving, an electromagnetic sieve shaker was used with 10 minutes shaking duration at 1.5 mm amplitudes.

The moisture content of chips was between 10 and 12 % corresponding to the air-dried condition and also to the requirement of getting durable pellets.

Completing the compaction process, the bottom of the cylinder is removed and the pellet is pushed out from the cylinder measuring the required force as a function of displacement. The integral of this force along the displacement gives the work done during the push-out cycle of the pellet.

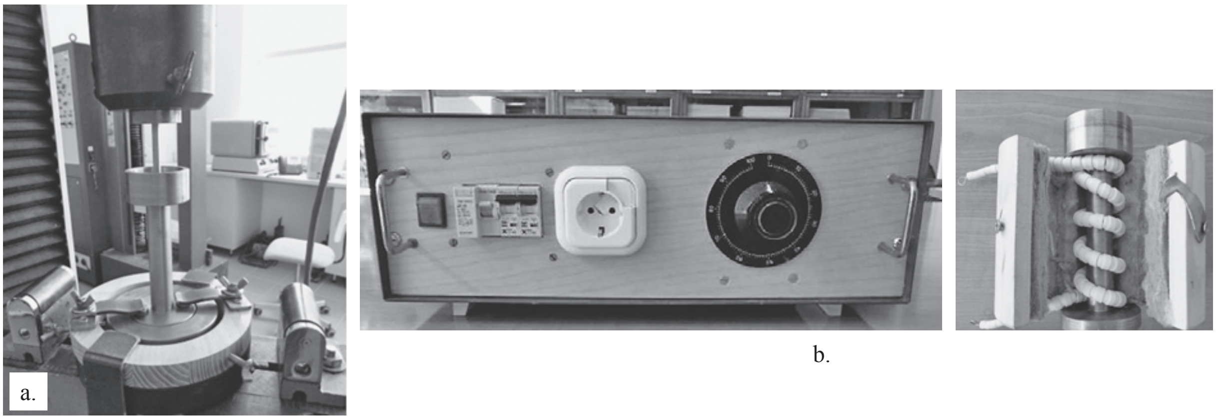

Figure 2 Punch and temperature control and measurement system
Slika 2. Uređaj za peletiranje te sustav za kontrolu i mjerenje temperature

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

Figure 3 shows the total specific work for spruce chips for different pellet diameters using 140 MPa pressure. With increasing diameters, the relative contribution of wall friction decreases and therefore the energy requirement also decreases.

Using pellet heating with different temperatures, the viscoelastic properties of wood materials change considerably. Figure 4 shows the effect of pellet temperature on the total specific compaction energy.

The beneficial effect of heating is more efficient, however, only up to 100-110 °C, while further increase of temperature reduces the energy requirement in a lesser extent. A possible explanation for this may be the

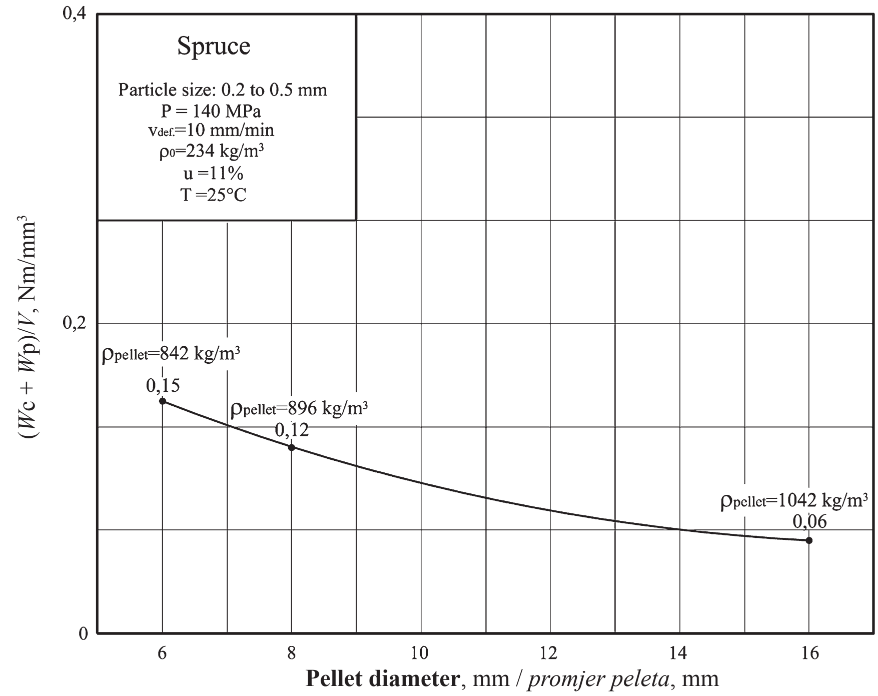

Figure 3 The change in specific work depending on the diameter of spruce pellets at ambient temperature
Slika 3. Promjena specifičnog rada u ovisnosti o promjeru peleta od smrekovine pri ambijentalnoj temperaturi

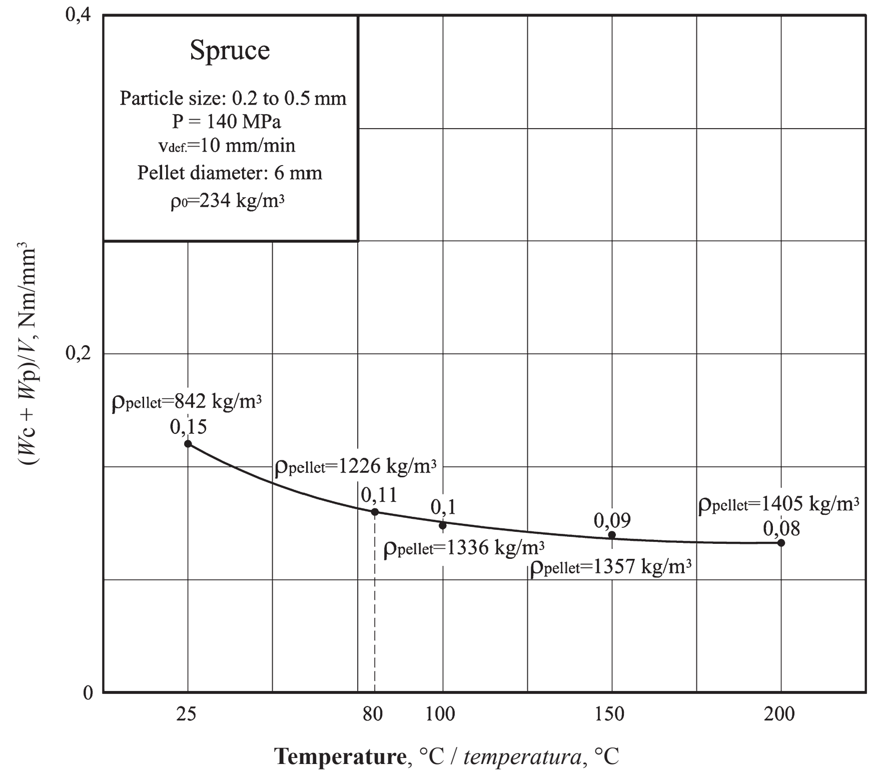

Figure 4 The change of total specific work depending on pellet temperature using spruce chips
Slika 4. Promjena ukupnoga specifičnog rada u ovisnosti o temperaturi peleta izrađenoga od smrekova iverja

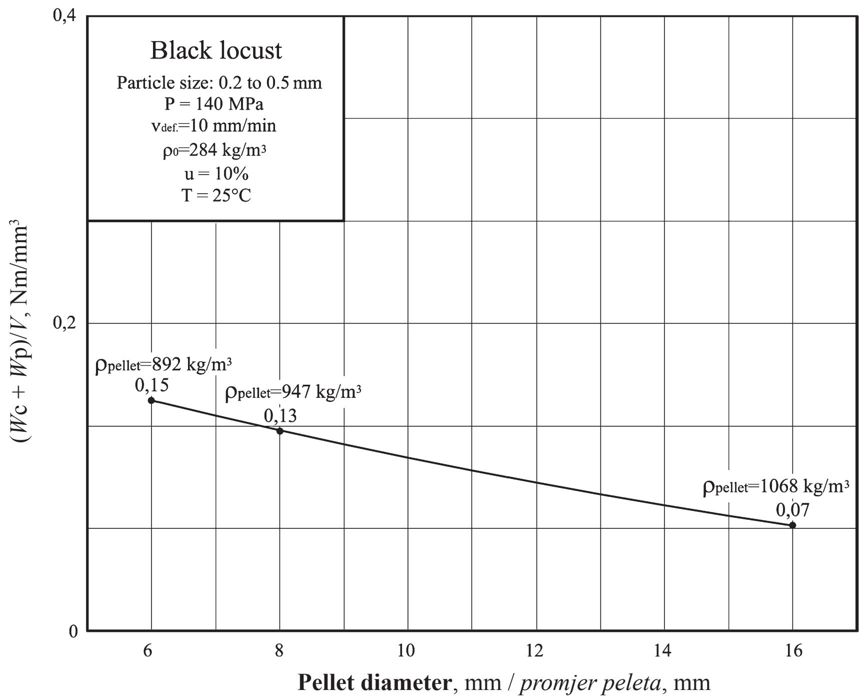

Figure 5 The change in specific work as a function of the punch diameter using black locust samples
Slika 5. Promjena specifičnog rada u ovisnosti o promjeru peleta izrađenoga od drva običnog bagrema

reduction in friction coefficient between particles and in the virtual viscosity of the material as the temperature increases. Due to the limiting effect of solid wood density on the compaction process, however, the compaction is an asymptotic phenomenon with decreasing effectivity toward high densities. An inspection of Fig. 4 and Fig. 6 clearly shows that the pellet density over 100 °C is not far from the solid wood density. It should also be remembered that the pellet density, due to the rebound, is always less than the compaction density at maximum pressure.

Similar measurement results are depicted in Figure 5 and 6 for black locust.

It is interesting to note that the total energy values of compaction for black locust differ only slightly from those of spruce, although the components are not the

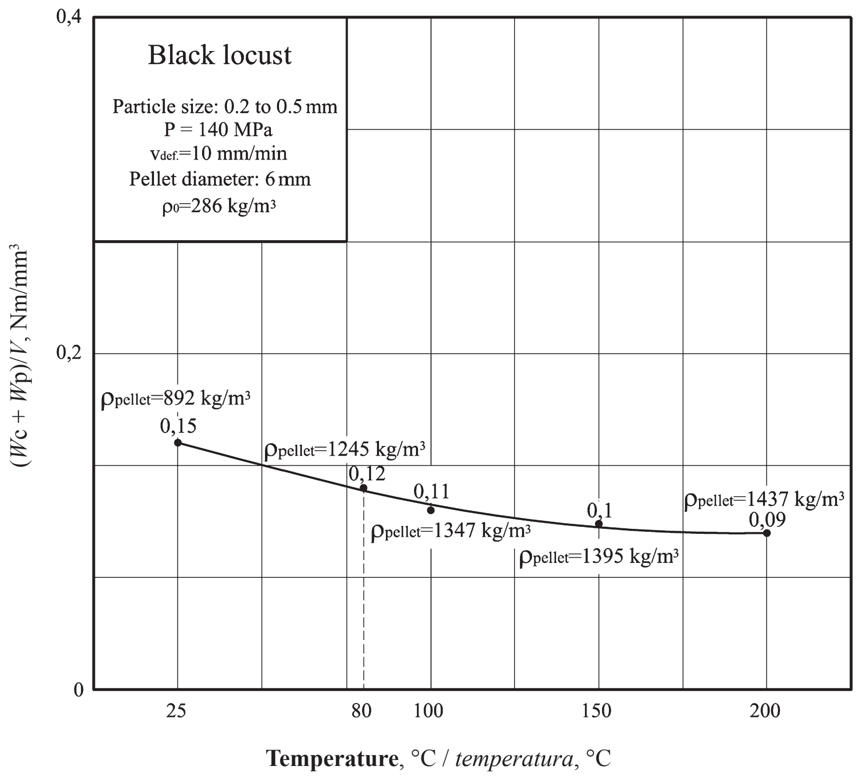

Figure 6 The change in the specific work as a function of temperature using black locust chips
Slika 6. Promjena specifičnog rada u ovisnosti o temperaturi peleta izrađenoga od drva običnog bagrema

Table 1 Summary of research findings in the 100 and 140 MPa pressure range with 0.2 to 0.5 mm particle sized pellets at 25 °C
Tablica 1. Sažetak rezultata istraživanja pri tlaku prešanja 100 i 140 MPa i za pelete izrađene od drvnih čestica veličine 0,2 – 0,5 mm pri 25 °C

Species *Vrsta drva*	**Pressure** *Tlak* *p*	**Specific energy** *Specifični rad* *W*	**Specific energy** *Specifični rad* *W*	***W*/*p***	**Pellet specific gravity** *Specifična težina peleta* γ	**Pellet diameter** *Promjer peleta* *d*	σ_C	$\gamma \cdot d/\sigma_C$
	N/m^2	Nm/mm^3	Nm/m^3		N/m^3	m	N/m^2	
black locust *obični bagrem*	$1.4\cdot10^8$	0.15	$1.5\cdot10^8$	1.07	8920	0.006	$65\cdot10^6$	$8.93\cdot10^{-7}$
	$1.4\cdot10^8$	0.13	$1.3\cdot10^8$	0.93	9470	0.008	$65\cdot10^6$	$11.65\cdot10^{-7}$
	$1.4\cdot10^8$	0.07	$0.7\cdot10^8$	0.50	10680	0.016	$65\cdot10^6$	$26.28\cdot10^{-7}$
	$1.0\cdot10^8$	0.12	$1.2\cdot10^8$	1.20	8130	0.006	$65\cdot10^6$	$7.50\cdot10^{-7}$
	$1.0\cdot10^8$	0.10	$1.0\cdot10^8$	1.00	8340	0.008	$65\cdot10^6$	$10.26\cdot10^{-7}$
	$1.0\cdot10^8$	0.05	$0.5\cdot10^8$	0.50	9720	0.016	$65\cdot10^6$	$23.92\cdot10^{-7}$
spruce *smreka*	$1.4\cdot10^8$	0.15	$1.5\cdot10^8$	1.07	8420	0.006	$55\cdot10^6$	$9.18\cdot10^{-7}$
	$1.4\cdot10^8$	0.12	$1.2\cdot10^8$	0.86	8960	0.008	$55\cdot10^6$	$13.03\cdot10^{-7}$
	$1.4\cdot10^8$	0.06	$0.6\cdot10^8$	0.43	10420	0.016	$55\cdot10^6$	$30.31\cdot10^{-7}$
	$1.0\cdot10^8$	0.12	$1.2\cdot10^8$	1.20	7030	0.006	$55\cdot10^6$	$7.67\cdot10^{-7}$
	$1.0\cdot10^8$	0.09	$0.9\cdot10^8$	0.90	7500	0.008	$55\cdot10^6$	$10.90\cdot10^{-7}$
	$1.0\cdot10^8$	0.05	$0.5\cdot10^8$	0.50	8450	0.016	$55\cdot10^6$	$24.58\cdot10^{-7}$

same. In order to calculate the dimensionless numbers, the compressive strength of the wood species used are needed. In general, this value varies for spruce in the range of 45 to 55 N/mm^2 and for black locust in the range of 60 to 65 N/mm^2 (Molnár, 1999). It should be noted, however, that the strength ratio for small particles is not exactly the same as for the solid wood. Therefore, a slight correction might be required. The measured and calculated values for spruce and black locust are summarized in Table 1.

Plotting the dimensionless numbers has revealed that in our case the selection of compressive strength values of 55 and 65 N/mm^2 for spruce and black locust, respectively, is appropriate and all measurement points are on the same line as shown in Figure 7.

The next step was to include the measurement results for different temperatures. The summary of measured and calculated data is given in Table 2.

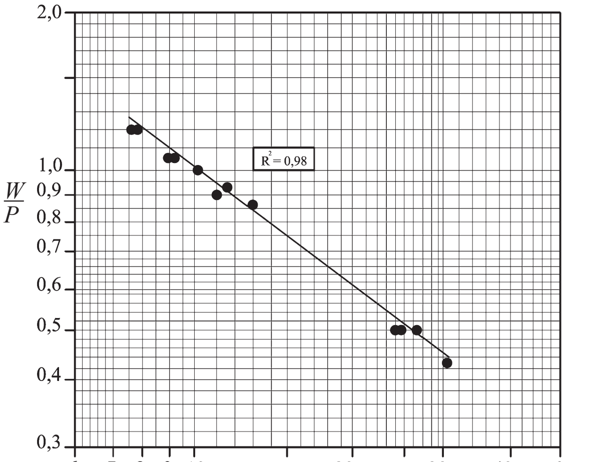

Figure 7 Dimensionless plot of experimental results for ambient temperature
Slika 7. Bezdimenzionalni graf eksperimentalnih rezultata pri ambijentalnoj temperaturi

The exponent m in Eq. (1) should be determined such that the measured points for different pellet temperatures fit the same line properly as given in Figure 7. Taking m = 0.15, all measurement points including also those for heated pellets fit the straight line as shown in Figure 8.

The scattering zone of measurement points is fully acceptable and it corresponds to a good engineering accuracy. The calculated correlation coefficient is around 0.97.

In the following, the effect of particle size on the compression work was examined. For these experiments, three fractions of chips were used for both spruce and black locust. The fractions had the following particle ranges: 0.063 to 0.2 mm, 0.2 to 0.5 mm and 0.8 to 1.0 mm. The measurement and calculated results are plotted in Figure 9 and 10. It is clearly seen that in both cases the energy requirement changes in a very low extent, although the slight decrease for both wood

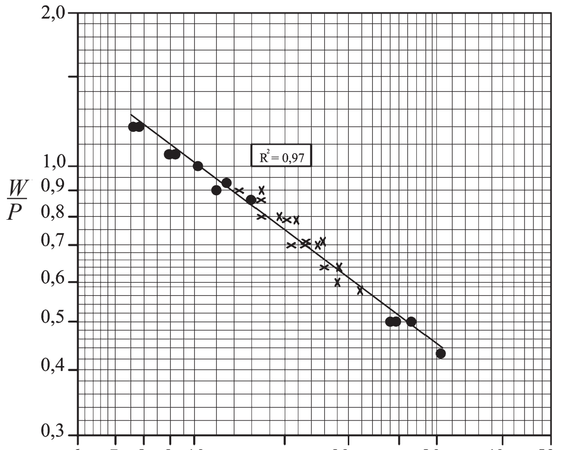

Figure 8 Measurement points including also those for heated pellets
Slika 8. Mjerne točke uključujući i one za grijane pelete

Table 2 Summary of measured and calculated results at 100 and 140 MPa, 0.2 to 0.5 mm size particles with the effect of the temperature
Tablica 2. Sažetak izmjerenih i izračunanih rezultata istraživanja pri tlaku prešanja 100 i 140 MPa i za pelete izrađene od drvnih čestica veličine 0,2 – 0,5 mm uz učinak temperature

Species *Vrsta drva*	**Pressure** *Tlak* p N/m²	**Specific energy** *Specifični rad* W Nm/mm³	**Specific energy** *Specifični rad* W Nm/m³	***W/p***	**Pellet specific gravity** *Specifična težina peleta* γ N/m³	**Pellet diameter** *Promjer peleta* d m	σ_C N/m²	$\left(\frac{\gamma \cdot d}{\sigma_C}\right)\cdot\left(\frac{\vartheta}{\vartheta_0}\right)^{0,15}$
black locust *obični bagrem*	$1.4\cdot10^8$	0.12	$1.2\cdot10^8$	0.86	12450	0.006	$65\cdot10^6$	$13.67\cdot10^{-7}$
	$1.4\cdot10^8$	0.11	$1.1\cdot10^8$	0.79	13470	0.006	$65\cdot10^6$	$15.29\cdot10^{-7}$
	$1.4\cdot10^8$	0.10	$1.0\cdot10^8$	0.71	13950	0.006	$65\cdot10^6$	$16.74\cdot10^{-7}$
	$1.4\cdot10^8$	0.09	$0.9\cdot10^8$	0.64	14370	0.006	$65\cdot10^6$	$18.04\cdot10^{-7}$
	$1.0\cdot10^8$	0.09	$0.9\cdot10^8$	0.90	11200	0.006	$65\cdot10^6$	$12.30\cdot10^{-7}$
	$1.0\cdot10^8$	0.08	$0.8\cdot10^8$	0.80	11960	0.006	$65\cdot10^6$	$13.58\cdot10^{-7}$
	$1.0\cdot10^8$	0.07	$0.7\cdot10^8$	0.70	12870	0.006	$65\cdot10^6$	$15.44\cdot10^{-7}$
	$1.0\cdot10^8$	0.07	$0.7\cdot10^8$	0.70	13110	0.006	$65\cdot10^6$	$16.46\cdot10^{-7}$
spruce *smreka*	$1.4\cdot10^8$	0.11	$1.1\cdot10^8$	0.79	12260	0.006	$55\cdot10^6$	$15.91\cdot10^{-7}$
	$1.4\cdot10^8$	0.10	$1.0\cdot10^8$	0.71	13360	0.006	$55\cdot10^6$	$17.92\cdot10^{-7}$
	$1.4\cdot10^8$	0.09	$0.9\cdot10^8$	0.64	13570	0.006	$55\cdot10^6$	$19.24\cdot10^{-7}$
	$1.4\cdot10^8$	0.08	$0.8\cdot10^8$	0.57	14050	0.006	$55\cdot10^6$	$20.84\cdot10^{-7}$
	$1.0\cdot10^8$	0.09	$0.9\cdot10^8$	0.90	10520	0.006	$55\cdot10^6$	$13.65\cdot10^{-7}$
	$1.0\cdot10^8$	0.08	$0.8\cdot10^8$	0.80	11100	0.006	$55\cdot10^6$	$14.89\cdot10^{-7}$
	$1.0\cdot10^8$	0.07	$0.7\cdot10^8$	0.70	12360	0.006	$55\cdot10^6$	$17.53\cdot10^{-7}$
	$1.0\cdot10^8$	0.06	$0.6\cdot10^8$	0.60	12860	0.006	$55\cdot10^6$	$19.08\cdot10^{-7}$

species has the same tendency. If these additional data are used in the similarity equation without any correction and plotted quite similarly to Figure 7 and 8, Figure 11 is obtained including all measurement points.

The scattering of data points is not much higher and in this case the correlation coefficient is also as high as 0.96. This is also due to the fact that for the construction of Figure 7 and 8, the middle fraction of the three fractions was used and therefore, the points of the other two fractions are placed on the opposite sides of the resultant straight line. The final similarity equation is given in the following form:

$$\frac{W}{p} = C \cdot \left(\frac{\gamma \cdot d}{\sigma_C}\right)^{-0,75} \cdot \left(\frac{\vartheta}{\vartheta_0}\right)^{0,15} \tag{4}$$

where the constant C has the value of $3.12 \cdot 10^{-5}$

It should finally be noted that in these experiments a plunger with bottom face was used. In practice, however, due to the continuous operation requirements, the chip material is pressed into the boreholes of a die ring and the counter-force is assured by friction forces. Therefore, the push-out force is more or less the same as the maximum compression force. This means that under real conditions somewhat higher specific energy is required.

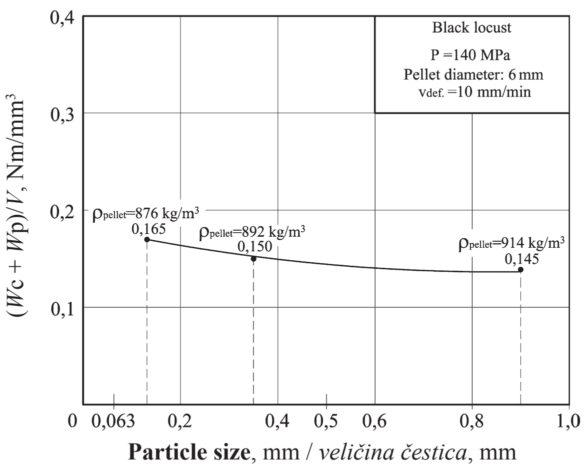

Figure 9 The change in the specific work as a function of particle size using black locust
Slika 9. Promjene specifičnog rada u ovisnosti o veličini čestica usitnjenog drva bagrema

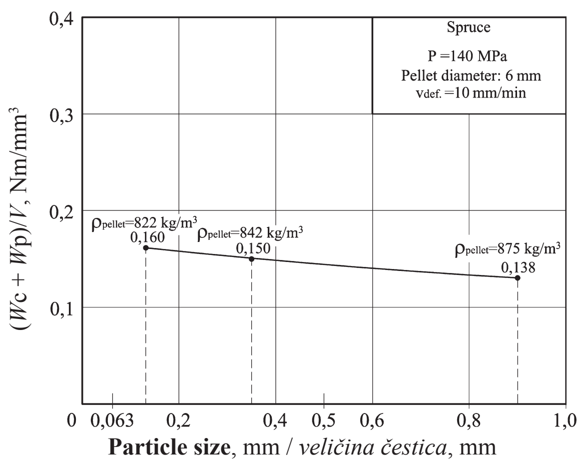

Figure 10 The change in the specific work as a function of particle size using spruce samples
Slika 10. Promjene specifičnog rada u ovisnosti o veličini čestica usitnjenog drva smreke

Table 3 Summary of measurement results at 140 MPa pressure and with three different particle fractions: 0.063 to 0.2 mm, 0.2 to 0.5 mm and 0.8 to 1.0 mm
Tablica 3. Sažetak mjernih rezultata pri tlaku 140 MPa i za tri različite frakcije veličine čestica: 0,063 – 0,2 mm, 0,2 – 0,5 mm i 0,8 – 1,0 mm

Species *Vrsta drva*	**Pressure** *Tlak* p	**Specific energy** *Specifični rad* W	**Specific energy** *Specifični rad* W	W/p	**Pellet specific gravity** *Specifična težina peleta* γ	**Pellet diameter** *Promjer peleta* d	σ_C	$\gamma \cdot d/\sigma_C$
	N/m²	Nm/mm³	Nm/m³		N/m³	m	N/m²	
black locust *obični bagrem*	$1.4 \cdot 10^8$	0.165	$1.65 \cdot 10^8$	1.18	8760	0.006	$65 \cdot 10^6$	$8.08 \cdot 10^{-7}$
	$1.4 \cdot 10^8$	0.150	$1.5 \cdot 10^8$	1.07	8920	0.006	$65 \cdot 10^6$	$8.93 \cdot 10^{-7}$
	$1.4 \cdot 10^8$	0.145	$1.45 \cdot 10^8$	1.04	9140	0.006	$65 \cdot 10^6$	$8.74 \cdot 10^{-7}$
spruce *smreka*	$1.4 \cdot 10^8$	0.160	$1.6 \cdot 10^8$	1.14	8220	0.006	$55 \cdot 10^6$	$8.96 \cdot 10^{-7}$
	$1.4 \cdot 10^8$	0.150	$1.5 \cdot 10^8$	1.07	8420	0.006	$55 \cdot 10^6$	$9.18 \cdot 10^{-7}$
	$1.4 \cdot 10^8$	0.138	$1.38 \cdot 10^8$	0.99	8750	0.006	$55 \cdot 10^6$	$9.54 \cdot 10^{-7}$

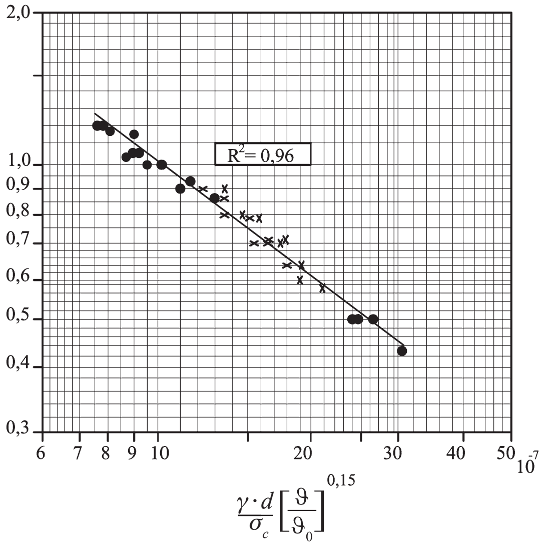

Figure 11 The final similarity plot of all measurement results
Slika 11. Konačni graf sličnosti za sve mjerne rezultate

5 CONCLUSIONS
5. ZAKLJUČAK

Based on theoretical and experimental investigations, the following main conclusions may be drawn:

- The main influencing factor is the pellet diameter, which fundamentally determines the role of wall friction forces in the total energy requirement;
- The heating of chips during pellet formation seems to be advisable up to 100 °C. Above this temperature limit, its effect continuously decreases;
- The chip size distribution has some effects on the energy requirement but, disregarding its effect, it does not cause significant error;
- Using similarity equation is a powerful method to generalize experimental results also for compaction processes. In this way a simple and quick estimation of energy requirement is possible.

6 REFERENCES
6. LITERATURA

1. Akdeniz, R. C.; Haghighat, S., 2013: The effect of die dimensions, raw material moisture content and particle size on pelletizing characteristics of olive cake. Department of Agricultural Machinery, International Conferences Engineering, Agriculture, Waste Management and Green Industry Innovation. Gödöllő, Hungary, 13-19. October, p. 33-41.
2. Buckingham, E., 1914: On the physically similar systems. Physical Review (4), p. 345. http://dx.doi.org/10.1103/PhysRev.4.345
3. Carlos, S.; Tore, F.; Geir, S.; Odd-Ivar, L.; Olav, H.; Reidar, B., 2010: Compression rheology and physical quality of wood pellets pre-handled with four different conditions. Annual Transactions of the Nordic Rheology Society, Norwegian, 14: 152-168.
4. Csanády, E.; Magoss, E., 2013: Mechanics of Wood Machining. Springer-Verlag Berlin Heidelberg 2013, p. 25-30. http://dx.doi.org/10.1007/978-3-642-29955-1
5. Hofko, B., 2008: Rheologische Modelle zur Beschreibung des Verformungsverhaltens von Asphalten. p. 98-112.
6. Langhaar, H., 1951: Dimensional analysis and theory of models. John Wiley London. p. 25-34.
7. Molnár, S., 1999: Faanyagismerettan [Wood material science]. Mezőgazdasági Szaktudás Kiadó, Budapest. p. 292. (in Hungarian).
8. Pronk, C., 2005: The Huet-Sayegh Model; a Simple and Excellent rheological Modell for Master Curve of Asphaltic Mixes. Geotechnical Special Publication No. 146. Asphalt Concrete. p. 115-185.
9. Sitkei, Gy., 1994: Non-linear rheological method describing compaction processes. Int. Agrophysics, pp.137-142.
10. Sitkei, Gy., 1997: A non-linear viscoelastic-plastic model describing compaction processes. Proc. of the 2nd Int. Conf. of IMACS/IFAC Budapest, pp.105-112.
11. Schwanghart, H., 1969: Messung und Berechnung von Druckverhältnissen und Durchsatz in einer Ringkoller-Strangpresse. Aufbereitungs-Technik, p. 713-722.

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ADRIATIC WOOD DAYS 2015

Središnji događaj za područje prerade drva i proizvodnje namještaja europskog jugoistoka

ADRIATIC WOOD DAYS 2015 (AWD) krovni je naziv koji obuhvaća šest različitih znanstvenih i stručnih konferencija koje zajednički organiziraju WoodEMA, i. a., Hrvatski drvni klaster i Forest Products Society. Konferencije će se održavati istodobno u tjednu od 5. do 10. listopada 2015. u Mlinima pokraj Dubrovnika. Šest konferencija nose naslove: *RIM 2015 – Razvoj i modernizacija proizvodnje*; *Marketing u drvnom sektoru*; *Trgovina u drvnom sektoru*; *Energija na bazi drva poprima globalne razmjere*; *WoodEMA 2015 – Izazovi pred preradom drva i proizvodnjom namještaja na svjetskom tržištu* i *Dizajn u proizvodnji namještaja*. ADRIATIC WOOD DAYS 2015 zamišljen je kao središnje događanje posvećeno preradi drva i proizvodnji namještaja u Srednjoj i Jugoistočnoj Europi, s ciljem da preraste u jedno od najvećih okupljanja subjekata i stručnjaka drvoprerađivačkog sektora u Europi.

Zašto sudjelovati

Tijekom AWD tjedna očekuje se oko 500 znanstvenika, stručnjaka, menadžera, šumara, šumovlasnika, predstavnika poduzeća, predstavnika ministarstava zemalja regije, članova Europskog parlamenta i drugih sudionika iz Europe i ostalih svjetskih regija.

1. Dvije konferencije: Poziv za slanje sažetaka/prezentacija/prijava za sudjelovanje

a) Jednodnevnu konferenciju **Energija na bazi drva poprima globalne razmjere** (*Wood-based Energy Goes Global*), koja će se održati 7. listopada kao dio ADRIATIC WOOD DAYS 2015 (AWD), organiziraju Forest Products Society (FPS), Louisiana Forest Products Development Center, Louisiana State University Agricultural Center, Hrvatski drvni klaster i WoodEMA, i. a. – međunarodna asocijacija za ekonomiku i menadžment u preradi drva i proizvodnji namještaja. Glavne teme bit će vezane za energiju na bazi drva, tj. za stanje na svjetskom tržištu vezano za pelete, brikete i druge izvore energije na bazi drva. Glavni predavači bit će dr. Richard Vlosky, potpredsjednik Forest Products Society i direktor Louisiana Forest Products Development Center, Crosby Land & Resources, profesor na Forest Sector Business Development, Louisiana State University Agricultural Center, Baton Rouge, Louisiana, SAD, te dr. Marius C. Barbu, voditelj Europske sekcije Forest Products Society i profesor na Fakultetu za drvno inženjerstvo Sveučilišta Transilvania, Brasov, Rumunjska. Savjetovanje će se održati 7. listopada 2015. *Formulari za slanje sažetaka i registraciju mogu se naći na web stranici WoodEMA, i.a. www.woodema.org.*

b) WoodEMA 2015 – Izazovi pred preradom drva i proizvodnjom namještaja na svjetskom tržištu (*Wood Processing and Furniture Manufacturing Challenges on the World Market*) osma je po redu godišnja konferencija međunarodng udruženja za ekonomiku i menadžment u preradi drva i proizvodnji namještaja WoodEma, i. a. Glavne teme savjetovanja bit će organizacija proizvodnje, ekonomika poduzeća i poslovanja, trgovina drvom i drvnim proizvodima, upravljanje proizvodnjom, upravljanje kadrovima, upravljanje kvalitetom i osiguranje kvalitete, inovacije i informacijski sustavi. Jedan od glavnih predavača bit će prof. Mikulaš Šupin, predsjednik WoodEMA, i. a. i predstojnik Katedre za marketing, trgovinu i svjetsko šumarstvo na Tehničkom sveučilištu u Zvolenu. Savjetovanje će se održati 8. i 9. listopada 2015. *Formulari za slanje sažetaka i registraciju mogu se naći na web stranici WoodEMA, i .a. www.woodema.org.*

2. Druge konferencije i događanja tijekom ADRIATIC WOOD DAYS 2015

RIM 2015 – Razvoj i modernizacija proizvodnje **(Development and Modernisation of Production)**

Ovogodišnju, desetu konferenciju organizira **Tehnički fakultet iz Bihaća** (Bosna i Hercegovina). Glavne su teme konferencije *Istraživanje i razvoj u mehaničkim proizvodnim sustavima i tehnologijama*; *Istraživanje i razvoj u preradi drva*; *Tehnologije i tehnike u elektrotehnici, elektronici i informacijskoj tehnologiji*; *Inženjerstvo u graditeljstvu*; *Moderne tehnike i tehnologije u tekstilnoj industriji*; *Nove tehnologije*; *Menadžment, poduzetništvo i gospodarski razvoj*; *Upravljanje kvalitetom, upravljanje ljudskim resursima i upravljanje prirodnim resursima*; *Studentska sekcija*.

Konferencija će se održati 5. i 6. listopada 2015.

Marketing u drvnom sektoru (Marketing in the Forest-based Industry)

U organizaciji **Hrvatskoga drvnog klastera**, ta će konferencija predstaviti znanstveni i stručni pristup marketingu i promociji poduzeća za preradu drva i proizvodnju namještaja. Drvni sektor u Hrvatskoj, kao i u zemljama regije, ostvaruje rezultate koji su među najboljima u sektoru tijekom povijesti, no medijsko praćenje tih rezultata nije ni približno na toj razini. Konferencija će sudionicima dati uvid u znanstvena dostignuća i prezentirati najbolje primjere iz prakse na tom području. Savjetovanje će se održati 5. i 6. listopada 2015.

Trgovina u drvnom sektoru (Trade in the Wood Sector)

Hrvatski drvni klaster organiziranjem te konferencije želi predstaviti najbolje primjere iz prakse i prenijeti posjetiteljima znanstvena dostignuća s područja trgovine drvom i drvnim proizvodima u regiji i svijetu. Sudionici će dobiti informacije o mogućnostima trgovanja na različitim tržištima u području šumarstva, prerade drva i proizvodnje namještaja. Savjetovanje će se održati 7. i 8. listopada 2015.

Dizajn u proizvodnji namještaja (Design in Furniture Manufacturing)

Tu konferenciju organizira Hrvatski drvni klaster s ciljem prezentacije najboljih primjera iz prakse u proizvodnji namještaja u Republici Hrvatskoj i u regiji. Bit će riječi o europskim i svjetskim sajmovima na kojima predstavnici hrvatskog dizajna ostvaruju odlične rezultate i dobivaju vrijedne nagrade za dizajn namještaja. Hrvatska udruga dizajnera predstavit će svoje ideje s područja dizajna namještaja. Savjetovanje će se održati 9. i 10. listopada 2015.

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PEROBA ROSA / CRVENA PEROBA

UDK: 674.031.937.32

NAZIVI

Peroba rosa trgovački je naziv drva skupine vrsta botaničkog roda *Aspidosperma* Mart. & Zucc. iz porodice *Apocynaceae*. U toj se skupini najčešće nalazi vrsta *Aspidosperma polyneuron* Muell. Arg.

Boja peroba drva često služi kao lokalni trgovački naziv drva. Na primjer, peroba reta ima uočljive crne pruge; peroba miuda je crvena, s tamnijim mrljama; peroba peca je bijelo drvo; peroba rajada je svjetlocrvene boje, sa svijetlim, gotovo zlatnim mrljama, a peroba revesa ima teksturu sličnu ptičjem javoru.

Trgovački naziv vrste *Aspidosperma polyneuron* jest peroba rosa (Brazil, Njemačka, Velika Britanija); peroba rose (Francuska); palo rosa (Argentina); amarello, armogoso, buchiero, muirajussara, peroba grauda rosa (Brazil); red peroba (Velika Britanija).

NALAZIŠTE

Stabla crvene perobe rastu u Južnoj Americi te u istočnom i južnom Brazilu, a rasprostranjene su i dalje, do Paragvaja i Sjeverne Argentine. Nalazimo je u tropskim nizinskim kišnim šumama, na nižoj razini elevacije, do 1400 metara nadmorske visine, gdje se pojavljuje u zajednici s cedrom (*Cedrus* Trew), palisandrom (*Dalbergia nigra* (Vell.) Benth.) i ostalim vrstama roda *Aspidosperma* Mart. & Zucc.

STABLO

Crvena peroba u svojoj domovini naraste od 30 do 35 metara, dužina njezina čistog debla doseže od 15 do 20 metara, a prsni joj je promjer (0,8)1,3 do 1,5 metara. Deblo je pravilnoga, cilindričnog oblika.

DRVO

Makroskopska obilježja

Drvo crvene perobe jedričavo je. Srž mu je žućkastosmeđa, narančasta do ružičastocrvena, često nejednolično crvenkasta do ljubičastosmeđa. Stajanjem potamni. Bjeljika je uska, žućkasta do žućkastobijela. Drvo je rastresito porozno. Granica goda jasno je vidljiva. Pore i drvni traci uočljivi su pod povećalom. Drvo je fine strukture i pretežito pravilnog toka vlakanaca.

Mikroskopska obilježja

Traheje su pojedinačno raspoređene, rjeđe se pojavljuju u parovima ili u malim skupinama. Promjer traheja iznosi 12...30...50 mikrometara, a gustoća im je 80...100...115 na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi oko 24 %. Traheje su često ispunjene tilama.

Aksijalni parenhim perobe je apotrahealan, tangentnog rasporeda. Volumni je udio aksijalnog parenhima oko 1 %.

Drvni su traci perobe homocelularni, visine 70...270...500 mikrometara, odnosno do 10 stanica visoki, a širina im je 32...42...49 mikrometara, odnosno od 1 do 2 – 3 stanice. Gustoća drvnih trakova je 8...10...11 na 1 mm. Volumni udio drvnih trakova iznosi oko 17 %. U drvnim tracima i aksijalnom parenhimu ima kristala. Drvna su vlakanca perobe libriformska, odnosno vlaknaste traheide. Dugačka su 700...1000...1250 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 1,75...3,2...4,2 mikrometara, a promjer lumena 1,5...3,7...8,4 mikrometara. Volumni je udio vlakanaca oko 58 %.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	700...740 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	750...800 kg/m^3
Gustoća sirovog drva, ρ_s	900...1100 kg/m^3
Poroznost	Oko 55 %
Radijalno utezanje, β_r	3,8...5,0 %
Tangentno utezanje, β_t	7,2...9,0 %
Volumno utezanje, β_v	11,2...14,2 %

Mehanička svojstva

Čvrstoća na tlak	oko 56 MPa
Čvrstoća na savijanje	oko 86 MPa
Čvrstoća na smik	oko 17,5 MPa
Tvrdoća (prema Janki), paralelno s vlakancima	oko 93 MPa
Tvrdoća (prema Janki), okomito na vlakanca	oko 78 MPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro strojno i ručno obrađuje. Dobro se blanja i tokari. Blanjane su površine vrlo glatke. Dobro se lijepi i politira. Bruševina nastala obradom drva perobe, prema navodima iz literature, karakterizirana je kao nadražujuća. Najčešće su pojave iritacija očiju, kože i dišnih organa te nazalni i astmatični simptomi. Svježe drvo uzrokuje znatno jače reakcije, dok prosušeno drvo ima bitno smanjenu toksičnost.

Sušenje

Građa se sporo suši. Sušenje treba provoditi pažljivo kako ne bi došlo do njegova vitoperenja, iskrivljavanja i kolapsa.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva vrlo je otporna na gljive truležnice (razred otpornosti 1) i srednje otporna na termite (razred otpornosti M). Srž je slabo permeabilna (razred 3).

Prema normama, može se upotrebljavati i bez kemijske zaštite u razredu opasnosti 4 (u dodiru sa zemljom ili vodom).

Uporaba

Od drva crvene perobe izrađuju se furnir, namještaj i dijelovi namještaja, parket, drvne intarzije, stolarsko drvo, a upotrebljava se i za izradu skulptura i noževa od drva te za građevinske drvene konstrukcije na otvorenome.

Sirovina

Drvo na tržište dolazi u obliku trupaca i piljenica različitih dimenzija.

Napomena

Drvo crvene perobe ne nalazi se na popisu ugroženih vrsta međunarodne organizacije CITES. No međunarodna organizacija IUCN Red List crvenu je perobu uvrstila na popis ugroženih vrsta zato što se populacija tog drveća zbog izumiranja i pretjerane eksploatacije u posljednje tri generacije smanjila za više od 50 %.

Drvo ostalih vrsta roda *Aspidosperma* sličnih je svojstava, a tih vrsta ima oko 70.

Literatura

1. Richter, H. G.; Dallwitz, M. J. (2000 onwards): „Commercial timbers: descriptions, illustrations, identification, and information retrieval“. In English, French, German, and Spanish. Version: 4th May 2000. http://biodiversity.uno.edu/delta/
2. Wagenführ, R.; Scheiber, C., 1974: HOLZATLAS, VEB Fachbuchverlag, Leipzig, 261-262.
3. ***1964: Wood dictionary, Elsevier publishing company, Amsterdam.
4. ***http://tropix.cirad.fr/FichiersComplementaires/EN/America/ARARACANGA.pdf (preuzeto 7. lipnja 2015.).

prof. dr. sc. Jelena Trajković
doc. dr. sc. Bogoslav Šefc

Upute autorima

Opće odredbe

Časopis *Drvna industrija* objavljuje znanstvene radove (izvorne znanstvene radove, pregledne radove, prethodna priopćenja), stručne radove, izlaganja sa savjetovanja, stručne obavijesti, bibliografske radove, preglede te ostale priloge s područja biologije, kemije, fizike i tehnologije drva, pulpe i papira te drvnih proizvoda, uključujući i proizvodnu, upravljačku i tržišnu problematiku u drvnoj industriji.

Predaja rukopisa podrazumijeva uvjet da rad nije već predan negdje drugdje radi objavljivanja ili da nije već objavljen (osim sažetka, dijelova objavljenih predavanja ili magistarskih radova odnosno disertacija, što mora biti navedeno u napomeni) te da su objavljivanje odobrili svi suautori (ako rad ima više autora) i ovlaštene osobe ustanove u kojoj je istraživanje provedeno. Kad je rad prihvaćen za objavljivanje, autori pristaju na automatsko prenošenje izdavačkih prava na izdavača te na zabranu da rad bude objavljen bilo gdje drugdje ili na drugom jeziku bez odobrenja nositelja izdavačkih prava.

Znanstveni i stručni radovi objavljuju se na hrvatskome, uz sažetak na engleskome, ili se pak rad objavljuje na engleskome, sa sažetkom na hrvatskom jeziku. Naslov, podnaslovi i svi važni rezultati trebaju biti napisani dvojezično. Ostali se članci uglavnom objavljuju na hrvatskome. Uredništvo osigurava inozemnim autorima prijevod na hrvatski. Znanstveni i stručni radovi podliježu temeljitoj recenziji najmanje dvaju recenzenata. Izbor recenzenata i odluku o klasifikaciji i prihvaćanju članka (prema preporukama recenzenata) donosi Urednički odbor.

Svi prilozi podvrgavaju se jezičnoj obradi. Urednici će od autora zahtijevati da tekst prilagode preporukama recenzenata i lektora, te zadržavaju i pravo da predlože skraćivanje ili poboljšanje teksta. Autori su potpuno odgovorni za svoje priloge. Podrazumijeva se da je autor pribavio dozvolu za objavljivanje dijelova teksta što su već negdje objavljeni te da objavljivanje članka ne ugrožava prava pojedinca ili pravne osobe. Radovi moraju izvještavati o istinitim znanstvenim ili tehničkim postignućima. Autori su odgovorni za terminološku i metrološku usklađenost svojih priloga. Radovi se šalju elektroničkom poštom na adresu:

drind@sumfak.hr ili techdi@sumfak.hr

Upute

Predani radovi smiju sadržavati najviše 15 jednostrano pisanih A4 listova s dvostrukim proredom (30 redaka na stranici), uključujući i tablice, slike te popis literature, dodatke i ostale priloge. Dulje je članke preporučljivo podijeliti na dva ili više nastavaka. Tekst treba biti u *doc formatu*, u potpunosti napisan fontom *Times New Roman* (tekst, grafikoni i slike), normalnim stilom, bez dodatnog uređenja teksta.

Prva stranica poslanog rada treba sadržavati puni naslov, ime(na) i prezime(na) autora, podatke o zaposlenju autora (ustanova, grad i država) te sažetak s ključnim riječima (duljina sažetka približno 1/2 stranice A4).

Posljednja stranica treba sadržavati titule, zanimanje, zvanje i adresu (svakog) autora, s naznakom osobe s kojom će Uredništvo biti u vezi.

Znanstveni i stručni radovi moraju biti sažeti i precizni. Osnovna poglavlja trebaju biti označena odgovarajućim podnaslovima. Napomene se ispisuju na dnu pripadajuće stranice, a obrojčavaju se susljedno. One koje se odnose na naslov označuju se zvjezdicom, a ostale uzdignutim arapskim brojkama. Napomene koje se odnose na tablice pišu se ispod tablica, a označavaju se uzdignutim malim pisanim slovima, abecednim redom.

Latinska imena trebaju biti pisana kosim slovima (italicom), a ako je cijeli tekst pisan kosim slovima, latinska imena trebaju biti podcrtana.

U uvodu treba definirati problem i, koliko je moguće, predočiti granice postojećih spoznaja, tako da se čitateljima koji se ne bave područjem o kojemu je riječ omogući razumijevanje ciljeva rada.

Materijal i metode trebaju biti što preciznije opisane da omoguće drugim znanstvenicima ponavljanje pokusa. Glavni eksperimentalni podaci trebaju biti dvojezično navedeni.

Rezultati trebaju obuhvatiti samo materijal koji se izravno odnosi na predmet. Obvezatna je primjena metričkog sustava. Preporučuje se upotreba SI jedinica. Rjeđe rabljene fizikalne vrijednosti, simboli i jedinice trebaju biti objašnjeni pri njihovu prvom spominjanju u tekstu. Za pisanje formula valja se koristiti Equation Editorom (programom za pisanje formula u MS Wordu). Jedinice se pišu normalnim (uspravnim) slovima, a fizikalni simboli i faktori kosima (italicom). Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.

Broj slika mora biti ograničen samo na one koje su prijeko potrebne za objašnjenje teksta. Isti podaci ne smiju biti navedeni i u tablici i na slici. Slike i tablice trebaju biti zasebno obrojčane, arapskim brojkama, a u tekstu se na njih upućuje jasnim naznakama ("tablica 1" ili "slika 1"). Naslovi, zaglavlja, legende i sav ostali tekst u slikama i tablicama treba biti napisan hrvatskim i engleskim jezikom.

Slike je potrebno rasporediti na odgovarajuća mjesta u tekstu, trebaju biti izrađene u rezoluciji 600 dpi, crno-bijele (objavljivanje slika u koloru moguće je na zahtjev autora i uz posebno plaćanje), formata jpg ili tiff, potpune i jasno razumljive bez pozivanja na tekst priloga.

Svi grafikoni i tablice izrađuju se kao crno-bijeli prilozi (osim na zahtjev, uz plaćanje). Tablice i grafikoni trebaju biti na svojim mjestima u tekstu te originalnog formata u kojemu su izrađeni radi naknadnog ubacivanja hrvatskog prijevoda. Ako ne postoji mogućnost za to, potrebno je poslati originalne dokumente u formatu u kojemu su napravljeni (*excel* ili *statistica* format).

Naslovi slika i crteža ne pišu se velikim tiskanim slovima. Crteži i grafikoni trebaju odgovarati stilu časopisa (fontovima i izgledu). Slova i brojke moraju biti dovoljno veliki da budu lako čitljivi nakon smanjenja širine slike ili tablice. Fotomikrografije moraju imati naznaku uvećanja, poželjno u mikrometrima. Uvećanje može biti dodatno naznačeno na kraju naslova slike, npr. "uvećanje 7500 : l".

Diskusija i zaključak mogu, ako autori žele, biti spojeni u jedan odjeljak. U tom tekstu treba objasniti rezultate s obzirom na problem postavljen u uvodu i u odnosu prema odgovarajućim zapažanjima autora ili drugih istraživača. Valja izbjegavati ponavljanje podataka već iznesenih u odjeljku *Rezultati*. Mogu se razmotriti naznake za daljnja istraživanja ili primjenu. Ako su rezultati i diskusija spojeni u isti odjeljak, zaključke je nužno napisati izdvojeno. Zahvale se navode na kraju rukopisa. Odgovarajuću literaturu treba citirati u tekstu, i to prema harvardskom sustavu (*ime – godina*), npr. (Bađun, 1965). Nadalje, bibliografija mora biti navedena na kraju teksta, i to abecednim redom prezimena autora, s naslovima i potpunim navodima bibliografskih referenci. Popis literature mora biti selektivan, a svaka referenca na kraju mora imati naveden DOI broj, ako ga posjeduje (http://www.doi.org) (provjeriti na http://www.crossref.org).

Primjeri navođenja literature

Članci u časopisima: Prezime autora, inicijal(i) osobnog imena, godina: Naslov. Naziv časopisa, godište (ev. broj): stranice (od – do). Doi broj.

Primjer

Kärki, T., 2001: Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, 59: 79-84. http://dx.doi.org/10.1007/s001070050479.

Knjige: Prezime autora, inicijal(i) osobnog imena, godina: Naslov. (ev. izdavač/editor): izdanje (ev. svezak). Mjesto izdanja, izdavač (ev. stranice od – do).

Primjeri

Krpan, J., 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb, Tehnička knjiga.

Wilson, J. W.; Wellwood, R. W., 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A. Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551- 559.

Ostale publikacije (brošure, studije itd.)

Müller, D., 1977: Beitrag zür Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanstalt für Forstund Holzvvirt schaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

Web stranice

***1997: "Guide to Punctuation" (online), University of Sussex, www.informatics.sussex.ac.uk/department/docs/punctuation/node00.html. First published 1997 (pristupljeno 27. siječnja 2010).

Autoru se prije konačnog tiska šalje pdf rada. Rad je potrebno pažljivo pročitati, ispraviti te vratiti Uredništvu s listom ispravaka te s formularom za prijenos autorskih prava na izdavača. Ispravci su ograničeni samo na tiskarske pogreške: dodaci ili znatnije promjene u radu naplaćuju se. Autori znanstvenih i stručnih radova besplatno dobivaju po jedan primjerak časopisa. Autoru svakog priloga također se dostavlja besplatan primjerak časopisa.

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Papers submitted shall consist of no more than 15 single-sided DIN A-4 sheets of 30 double-spaced lines, including tables, figures and references, appendices and other supplements. Longer papers should be divided into two or more continuing series. The text should be written in doc format, fully written using Times New Roman font (text, graphs and figures), in normal style without additional text editing.

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The last page should provide the full titles, posts and address(es) of each author with indication of the contact person for the Editor's Office.

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Latin names shall be printed in italics and underlined.

Introduction should define the problem and if possible the framework of existing knowledge, to ensure that readers not working in that particular field are able to understand author's intentions.

Materials and methods should be as precise as possible to enable other scientists to repeat the experiment. The main experimental data should be presented bilingually.

The results should involve only material pertinent to the subject. The metric system shall be used. SI units are recommended. Rarely used physical values, symbols and units should be explained at their first appearance in the text. Formulas should be written by using Equation Editor (program for writing formulas in MS Word). Units shall be written in normal (upright) letters, physical symbols and factors in italics. Formulas shall be consecutively numbered with Arabic numerals in parenthesis (e.g. (1)) at the end of the line.

The number of figures shall be limited to those absolutely necessary for clarification of the text. The same information must not be presented in both a table and a figure. Figures and tables should be numbered separately with Arabic numerals, and should be referred to in the text with clear remarks ("Table 1" or "Figure 1"). Titles, headings, legends and all the other text in figures and tables should be written in both Croatian and English.

Figures should be inserted into the text. They should be of 600 dpi resolution, black and white (color photographs only on request and extra charged), in jpg or tiff format, completely clear and understandable without reference to the text of the contribution.

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Example of references

Journal articles: Author's second name, initial(s) of the first name, year: Title. Journal name, volume (ev. issue): pages (from - to). DOI number.

Example:
Kärki, T., 2001: Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, 59: 79-84. http://dx.doi.org/10.1007/s001070050479.

Books:
Author's second name, initial(s) of the first name, year: Title. (ev. Publisher/editor): edition, (ev. volume). Place of publishing, publisher (ev. pages from - to).

Examples:
Krpan, J. 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb: Tehnička knjiga.
Wilson, J.W.; Wellwood, R.W. 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A. Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551-559.

Other publications (brochures, studies, etc.):
Müller, D. 1977: Beitrag zur Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanslalt für Forst- und Holzwirtschaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

Websites:
***1997: "Guide to Punctuation" (online), University of Sussex, www.informatics.sussex.ac.uk/department/docs/punctuation/node00.html. First published 1997 (Accessed Jan. 27, 2010).

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