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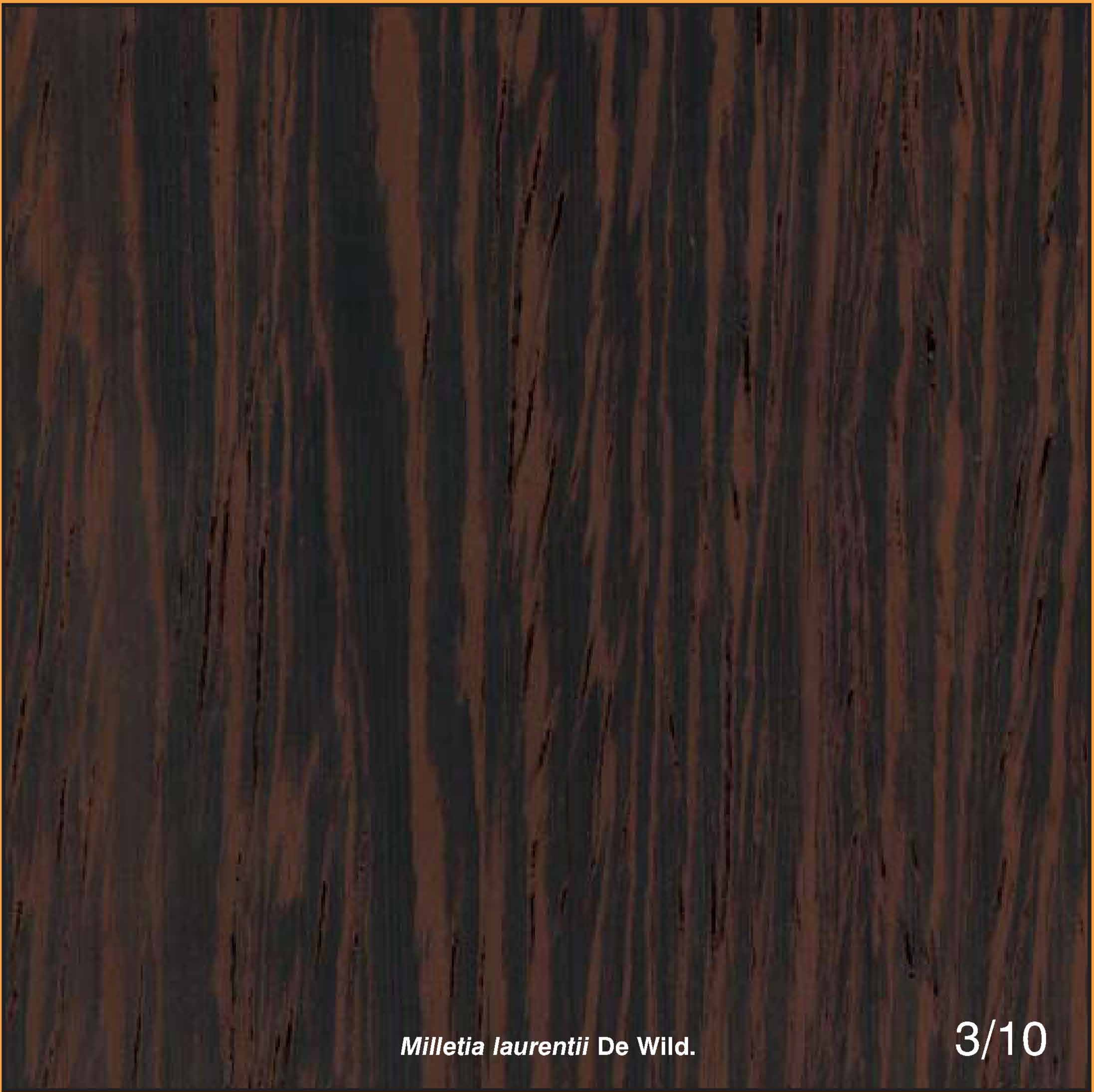

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Izet Horman, Seid Hajdarević, Sandra Martinović, Nikola Vukas[1]

Numerical Analysis of Stress and Strain in a Wooden Chair

Numerička analiza naprezanja i deformacija u drvenoj stolici

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ABSTRACT • *This paper presents numerical analysis of stress and strain conditions of a three-dimensional furniture skeleton construction and its joints. The finite volume method is used in the calculation. Orthotropy of the wood material is accounted for by approximating it with an isotropic material whose elastic modulus and Poisson's ratio are calculated by employing the least-square method. The displacement of the edge point for the loaded joint was also determined experimentally. The agreement of results of the calculation and experimental data can be considered satisfactory. The numerical results presented in this paper also provided an opportunity for identification of the region with the largest load and strain in the complex chair skeleton construction, which is one of the most complex pieces of furniture.*

Key words: *corner joint, chair, displacement, stress, wood, numerical analysis*

SAŽETAK • *U radu je prikazana numerička analiza naprezanja i deformacija prostorne okvirne konstrukcije namještaja i spojeva koji se u njoj pojavljuju. Za proračun je korištena metoda konačnih volumena. Zanemarena je ortotropija, a modul elastičnosti i Poissonov omjer za simulirani izotropni materijal aproksimirani su metodom najmanjih kvadrata. Za opterećeni kutnik pomak rubne točke i eksperimentalno je određen. Rezultati proračuna zadovoljavajuće se slažu s eksperimentalnim podacima, pa se predloženi numerički algoritam može primijeniti za analizu krutosti i čvrstoće spojeva. Numerički rezultati dani u ovom radu omogućili su identificiranje mjesta najvećeg opterećenja i deformacije u složenoj okvirnoj konstrukciji stolice kao jednome od najsloženijih komada namještaja.*

Ključne riječi: *kutni spoj, stolica, pomak, naprezanje, drvo, numerička analiza*

1 INTRODUCTION
1. UVOD

Development of new products in the wood industry in the past was mostly based on empiric information. The data about construction properties were usually obtained by testing prototypes of the final product. The development of computer technology and numerical methods have made the research much easier and enabled obtaining information of what is happening inside a loaded chair already at the design stage. Their use in the industry saves the time for the product development and improves its quality. For example, at the design stage of some pieces of furniture, their complex skeleton construction is subjected to stress and strain analysis. That allows them to satisfy all the functional demands

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(comfort), aesthetic demands, but also the strength and stiffness both by their shape and their dimensions. To achieve that, it is necessary to carry out a numerical simulation of the stress of a complex construction.

The study of the literature has established that the most frequent method applied in calculating the stress and strain in solid bodies was finite element method (Nicholls and Crisan, 2002; Smardzewski and Prekrat, 2002; Olsson P. and Olsson K., 2003; Pousette 2003; Smardzewski and Papuga, 2004; Pousette, 2006) and more recently the finite volume method (Demirdžić and Martinović, 1993; Demirdžić and Muzaferija, 1995; Demirdžić *et al.*, 2000; Martinović *et al.*, 2001; Horman *et al.*, 2008; Horman *et al.*, 2009). Calculations in this study are performed by employing the software package COMET (ICCM 2001) which applies the finite volume method for analysing stress in elastic, isotropic bodies of arbitrary shape. As wood is an orthotropic material, it is simulated by isotropic one and the mechanical properties are approximated by the least-square method (Heyden, 2000).

This paper first analyses the stress-strain state in a corner joint, and then in a complex, loaded chair skeleton, because the quality and durability of a complex skeleton construction primarily depends on the quality of its joints. The regions exposed to the largest strains and stresses are identified. The paper also presents the experimental determination of displacement of the targeted corner joint point, which serves to verify the numerical results.

2 MATHEMATICAL MODEL
2. MATEMATIČKI MODEL

2.1 Basic equations and constitutive relations
2.1. Osnovne jednadžbe i konstitutivne relacije

The equation of momentum balance, expressed in the Cartesian tensor notation (Slattery, 1981)

$$\int_S \sigma_{ij} n_j \, dS + \int_V f_i \, dV = 0 \tag{1}$$

and of the constitutive relation for the elastic material

$$\sigma_{ij} = C_{ijkl}\,\varepsilon_{kl} = \frac{1}{2} C_{ijkl}\left(\frac{\partial u_k}{\partial x_l} + \frac{\partial u_l}{\partial x_k}\right) \tag{2}$$

describe the stress and strain of a loaded solid body in the static equilibrium.

Equation (2) for the elastic, orthotropic material may be expressed in the following matrix form (Bodig and Jayne, 1993).

$$\begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & 0 & 0 & 0 \\ A_{21} & A_{22} & A_{23} & 0 & 0 & 0 \\ A_{31} & A_{32} & A_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & A_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & A_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & A_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \varepsilon_{12} \\ \varepsilon_{23} \\ \varepsilon_{31} \end{bmatrix} \tag{3}$$

In the equations above, x_j are the Cartesian spatial coordinates, V is the volume of the solution domain bounded by the surface S, σ_{ij} is the stress tensor, n_j is the out warded unit normal to the surface S, f_i the volume force, C_{ijkl} the elastic constant tensor components, ε_{kl} the strain tensor, and u_k the point displacement. Twelve non-zero orthotropic elastic constants A_{ij} are related to the Young's modulus E_i, the Poisson's ratio ν_{ij} and the shear modulus G_{ij} by the following relations:

$$A_{11} = \frac{E_1}{C}\left(1 - \nu_{23}\nu_{32}\right),\ A_{22} = \frac{E_2}{C}\left(1 - \nu_{31}\nu_{13}\right),$$

$$A_{33} = \frac{E_3}{C}\left(1 - \nu_{12}\nu_{21}\right),\ A_{12} = A_{21} = \frac{E_1}{C}\left(\nu_{21} + \nu_{31}\nu_{23}\right),$$

$$A_{13} = A_{31} = \frac{E_1}{C}\left(\nu_{31} + \nu_{21}\nu_{32}\right),$$

$$A_{23} = A_{32} = \frac{E_2}{C}\left(\nu_{32} + \nu_{12}\nu_{31}\right) \tag{4}$$

$$A_{44}=2G_{12},\ A_{55}=2G_{23},\ A_{66}=2G_{31}$$

$$C=1-\nu_{12}\nu_{21}-\nu_{23}\nu_{32}-\nu_{31}\nu_{13}-\nu_{12}\nu_{23}\nu_{31}-\nu_{21}\nu_{32}\nu_{13},$$

where

$$E_1\nu_{21}=E_2\nu_{12},\ E_1\nu_{31}=E_3\nu_{13},\ E_2\nu_{32}=E_3\nu_{23}. \tag{5}$$

To make the calculation of the stress and strain in complex shape bodies made of orthotropic material easier, the constitutive relation for the isotropic material

$$\sigma_{ij}=2\mu\varepsilon_{ij}+\lambda\delta_{ij}\varepsilon_{kk}, \tag{6}$$

is used, where δ_{ij} stands for Kronecker delta, and Lame's constants are given through the Young's modulus E and the Poisson's ratio ν in the following relations

$$\lambda = \frac{\nu E}{(1+\nu)(1-2\nu)},\ \mu = G = \frac{E}{2(1+\nu)}. \tag{7}$$

The Young's modulus and the Poisson's ratio for the orthotropic material, which is simulated by an isotropic material, are approximated by the least-square method (Heyden, 2000) as follows:

$$\nu = \frac{A_{11} + A_{22} + A_{33} + 4\left(A_{12} + A_{13} + A_{23}\right) - 2\left(A_{44} + A_{55} + A_{66}\right)}{2\left[2\left(A_{11} + A_{22} + A_{33}\right) + 3\left(A_{12} + A_{13} + A_{23}\right) + \left(A_{44} + A_{55} + A_{66}\right)\right]}$$

$$E = \frac{(1+\nu)(1-2\nu)}{15(1-\nu)}\left[3\left(A_{11} + A_{22} + A_{33}\right) + 2\left(A_{12} + A_{13} + A_{23}\right) + \right.$$
$$\left. + 4\left(A_{44} + A_{55} + A_{66}\right)\right] \tag{8}$$

where the coefficients A_{ij} are given by expressions (4).

Combining equations (1), (2) and (6), the following equations, expressed through unknown displacement, may be obtained:

$$\int_S \mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) n_j \, dS + \int_S \lambda \frac{\partial u_k}{\partial x_k} n_i \, dS + \int_V f_i \, dV = 0$$

$$(i=1,2,3) \tag{9}$$

2.2 Boundary conditions
2.2. Granični uvjeti

In order to complete the mathematical model (9), the boundary conditions have to be specified. The surface traction f_{si} and/or the displacement u_s at the domain boundaries are known, i.e.

$$\sigma_{ij}n_j=f_{si} \tag{10}$$

and/or

$$u_i=u_s. \tag{11}$$

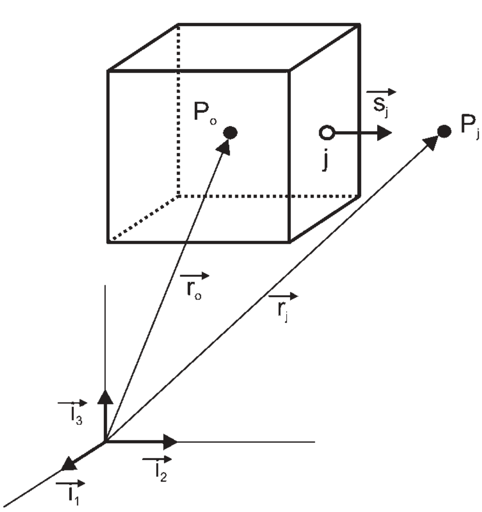

Figure 1 A typical control volume
Slika 1. Tipičan kontrolni obujam

3 NUMERICAL METHOD
3. NUMERIČKA METODA

The solution domain is discretized by a finite number of contiguous hexahedral control volumes (CV) or cells of the volume V which are bounded by six cell faces of the area S_j with calculation points P in the CV´s centres (Figure 1).

The equations of the mathematical model (9), expressed through unknown displacements, may be written for each control volume in the following form:

$$\sum_j \int_{S_j} \Gamma_{u_j} \frac{\partial u_j}{\partial x_j} dS_j + \int_V s_{u_i} dV = 0. \qquad (12)$$

Coefficients Γ_{u_j} and s_{u_i} are given in Table 1.

The integrals in equation (12) are approximated by employing the midpoint rule, whereas the gradients are calculated by assuming the linear variation of dependent variables between the computational points. The result is a non-linear algebraic equation for each control volume of the following form (Demirdžić and Martinović, 1993):

$$a_{P_o} u_{iP_o} - \sum_{j=1}^{n} a_{P_j} u_{iP_j} = b_{u_i}, \qquad (13)$$

where n stands for the number of internal faces of the observed control volume, and the coefficients are:

$$a_{P_j} = \Gamma_{u_j} \frac{S_j}{\delta x_j}, \; a_{P_O} = \sum_{j=1}^{n} a_{P_j}, \; b_{u_i} = s_{u_{iP_o}} V_{P_o} \qquad (14)$$

where $s_{u_{iP_o}}$ is the value of the source term given in Table 1 at the central point P_O, and δx_j is the distance between the points, P_O and P_j.

After employing the boundary conditions, the sets of equations (13) for each displacement component are lineralized and temporarily "decoupled", so that the coefficients a and source term b are calculated by using the values of displacements from the previous iteration. In such a manner a system of linear algebraic equations is obtained, which is solved by an iterative procedure. More details can be found in (Demirdžić and Muzaferija 1995).

4 NUMERICAL ANALYSIS
4. NUMERIČKA ANALIZA

Two examples are considered in this chapter. The first one analyses the stress and strain in the corner joint, and the second in the chair skeleton construction. More examples may be found in (Hajdarević, 2006).

Certain assumptions were provided in numerical modelling of stress and strain:
- the material is isotropic and the elastic modulus and Poisson's ratio for the simulated materials are calculated by the method of least squares,
- joint is without glue line,
- force is acting on the final small area.

4.1 Example 1 − Corner joint
4.1. Primjer 1. Ugaoni spoj

In this section the corner mortise and tenon joint presented in Figure 2 are analyzed.

The material used for the corner joint is spruce, whose mechanic properties at temperature of 20ºC and with the moisture content of 9.8 % are given in Table 2,

Table 1 The meaning of Γ_{u_j} and s_{u_i} in equation (12)
Tablica 1. Značenje Γ_{u_j} i s_{u_i} u jednadžbi (12)

u_i	Γ_{u_1}	Γ_{u_2}	Γ_{u_3}	s_{u_i}
u_1	$2\mu+\lambda$	μ	μ	$\frac{\partial}{\partial x_j}\left(\mu\frac{\partial u_j}{\partial x_1}\right)+\frac{\partial}{\partial x_1}\left(\lambda\frac{\partial u_k}{\partial x_k}\right)-\frac{\partial}{\partial x_1}\left[(\mu+\lambda)\frac{\partial u_1}{\partial x_1}\right]+f_1$
u_2	μ	$2\mu+\lambda$	μ	$\frac{\partial}{\partial x_j}\left(\mu\frac{\partial u_j}{\partial x_2}\right)+\frac{\partial}{\partial x_2}\left(\lambda\frac{\partial u_k}{\partial x_k}\right)-\frac{\partial}{\partial x_2}\left[(\mu+\lambda)\frac{\partial u_2}{\partial x_2}\right]+f_2$
u_3	μ	μ	$2\mu+\lambda$	$\frac{\partial}{\partial x_j}\left(\mu\frac{\partial u_j}{\partial x_3}\right)+\frac{\partial}{\partial x_3}\left(\lambda\frac{\partial u_k}{\partial x_k}\right)-\frac{\partial}{\partial x_3}\left[(\mu+\lambda)\frac{\partial u_3}{\partial x_3}\right]+f_3$

Table 2 Mechanic properties of wood (spruce) (Bodig and Jayne, 1993)
Tablica 2. Mehanička svojstva drva (smrekovine) (Bodig and Jayne, 1993)

E_t	E_r	E_l	G_{rt}	G_{lr}	G_{lt}	ν_{tr}	ν_{rt}	ν_{rl}	ν_{lr}	ν_{tl}	ν_{lt}
GPa	GPa	GPa	GPa	GPa	GPa	-	-	-	-	-	-
0.392	0.686	15.916	0.0392	0.618	0.765	0.24	0.42	0.019	0.43	0.013	0.53

E – elastic modulus *(modul elastičnosti); G* – shear modulus *(modul smicanja); ν* – Poisson's ratio *(Poissonov koeficijent); t* – tangential *(tangencijalni); r* – radial *(radijalni); l* – longitudinal *(longitudinalni)*

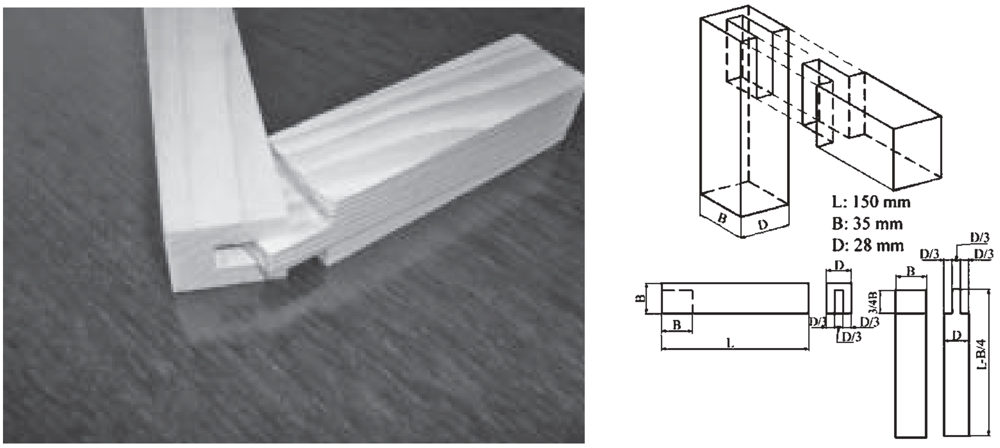

Figure 2 Corner mortise and tenon joint (left) and its dimensions (right)
Slika 2. Spoj sa skraćenim čepom: epruveta (lijevo), crtež (desno)

and according to (8) the corresponding Young's modulus is E = 3.98 GPa, while the Poisson's ratio is ν = 0.192.

Because of the symmetry, one half of the joint is taken for the solution domain. Two elements are joined only by vertical side of tenon (face). Figure 3 presents the solution domain and the numerical grid.

The 30 000 CV grid is used for calculations, as it had been established that the results obtained with this grid may be considered grid-independent (Hajdarević 2006, Martinović *et al.* 2008).

The following boundary conditions are used to calculate the stresses and strains in the loaded corner joint:

- the fixed support of the lower corner joint end: zero displacements,
- the loaded end: force of 200N, acting at an angle of 45° was replaced by the uniform load on two perpendicular surfaces whose length equals the thickness of the corner joint, and whose width equals the width of CV,
- other exterior surfaces: stress free,
- the clearance in the zone of joint (0.6 mm and 3 mm): the conditions taken are the same as for the free surface, i.e. the corresponding stress components equal zero.

The displacement field of the corner joint and the deformed joint are shown in Figure 4. The maximum displacement of 0.66 mm is at the free end of the joint.

The field of normal stresses σ_{xx} and σ_{yy} and the shear stresses τ_{xy} and τ_{xz} are shown in Figure 5.

The maximum compressive stresses (σ_{xx}= –9.3 MPa and σ_{yy}= – 6.6 MPa) occur on the inner surface of the corner joint, and the maximum tensile stress (σ_{xx}= 6.6 MPa and σ_{yy}= 2.2 MPa) on the outer surfaces. These values are smaller than the allowable compressive stress parallel to the grain of 11 MPa, i.e. the tensile stress of 10.5 MPa (Kollmann and Côté, 1968).

The extreme values of the shear stresses are τ_{xy} = 2.28 MPa and τ_{xz} = 2.43 MPa. It is extremely important for the corner joints that the shear stress is within the allowable values. Bearing that in mind, Figure 6 shows the distribution of the total shear stress on the reduced

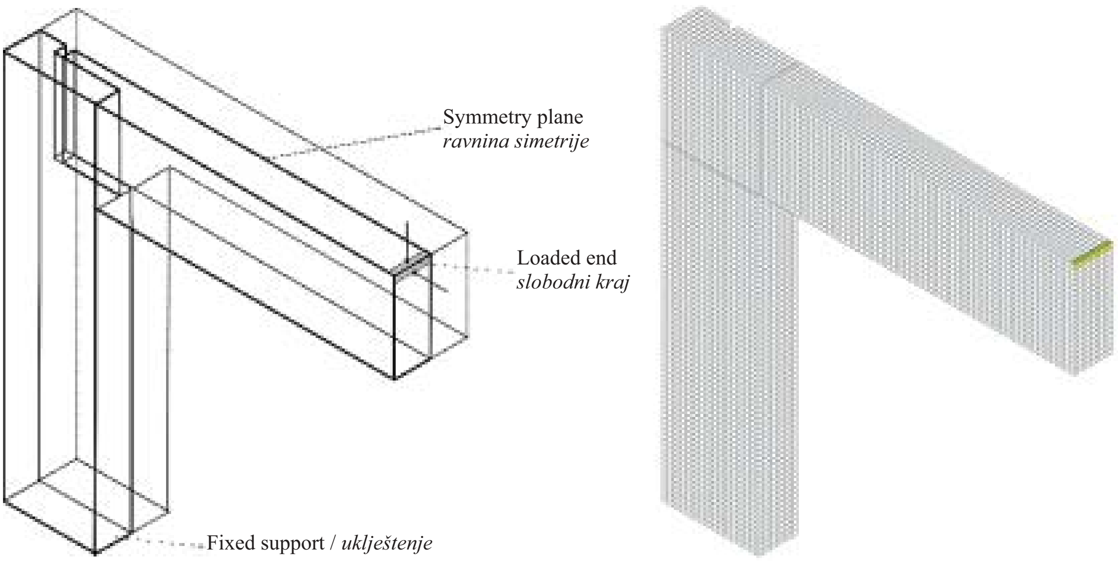

Figure 3 Corner joint: solution domain and boundary conditions (left), numerical grid (right)
Slika 3. Kutni spoj: područje rješavanja i rubni uvjeti (lijevo), numerička mreža (desno)

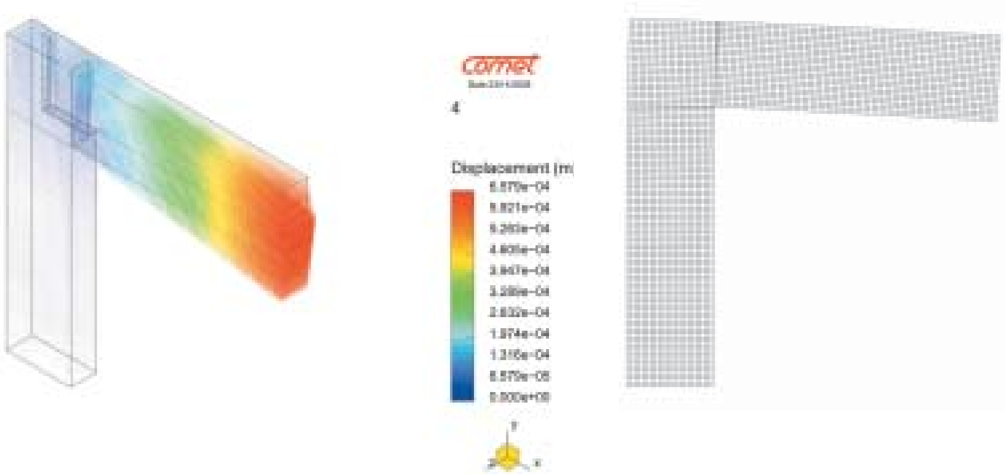

Figure 4 Total displacement field (left), deformed joint (right)
Slika 4. Područje ukupnog pomaka (lijevo), deformirani kutnik (desno)

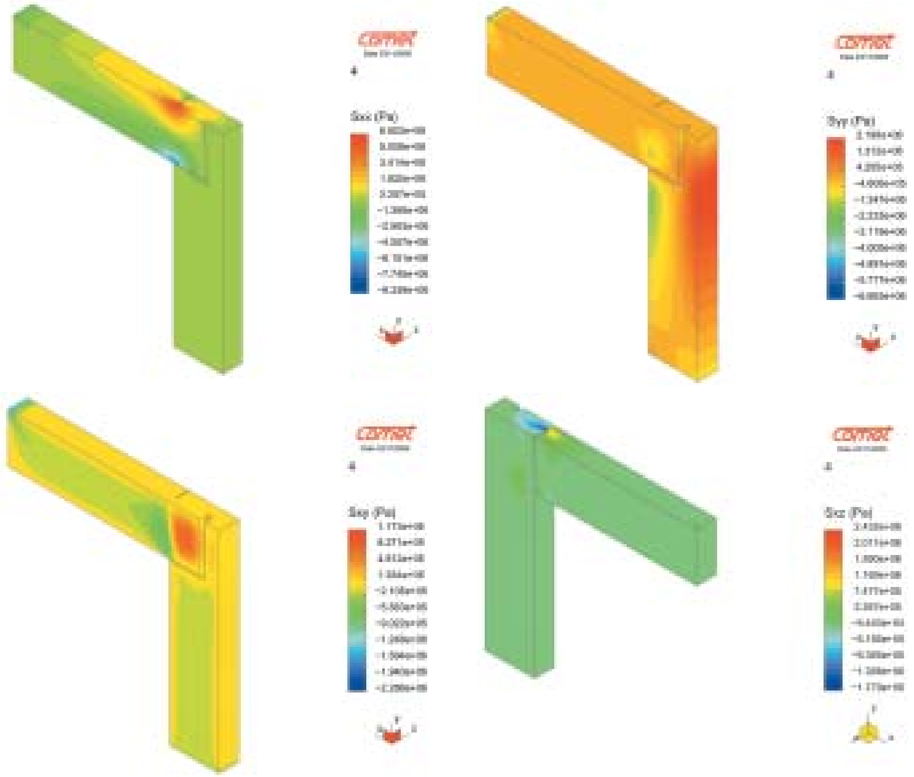

Figure 5 Distribution of normal stresses σ_{xx} and σ_{yy} (above) and of shear stresses τ_{xy} and τ_{xz} (below)
Slika 5. Raspodjela normalnih naprezanja σ_{xx} i σ_{yy} (gore) i raspodjela posmičnih naprezanja τ_{xy} i τ_{xz} (dolje)

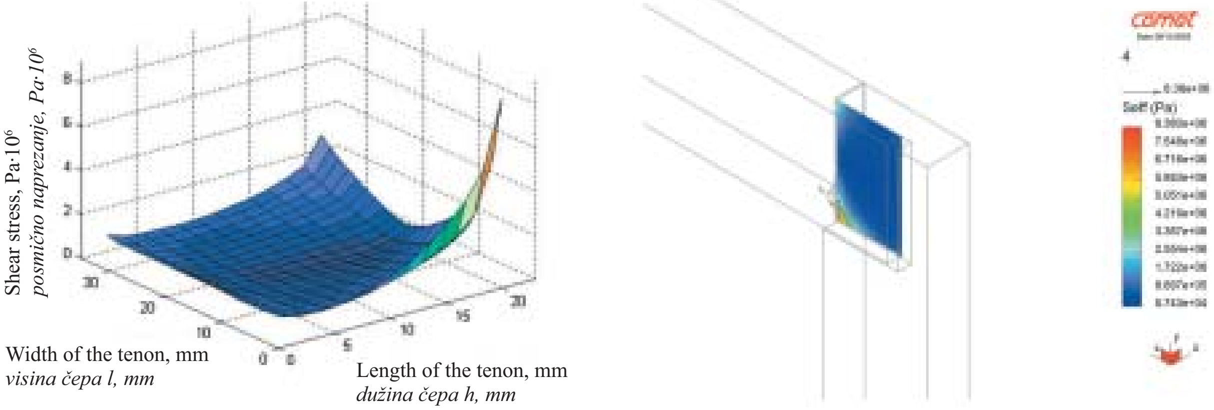

Figure 6 Distribution of shear stress on the contact surface of joint parts
Slika 6. Raspodjela ukupnoga posmičnog naprezanja na kontaktnoj površini dijelova spoja

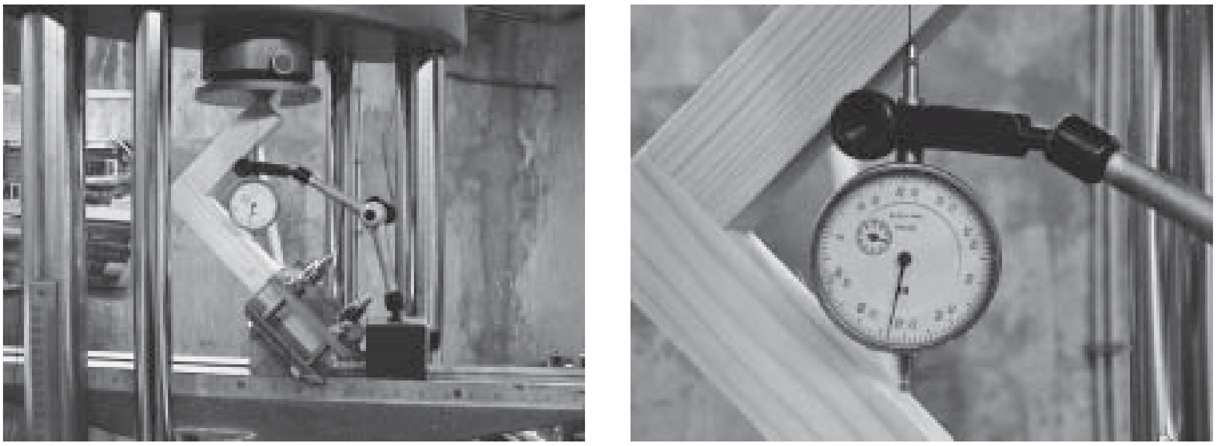

Figure 7 Laboratory measurement of the joint edge point displacement
Slika 7. Laboratorijsko određivanje pomaka rubne točke kutnika

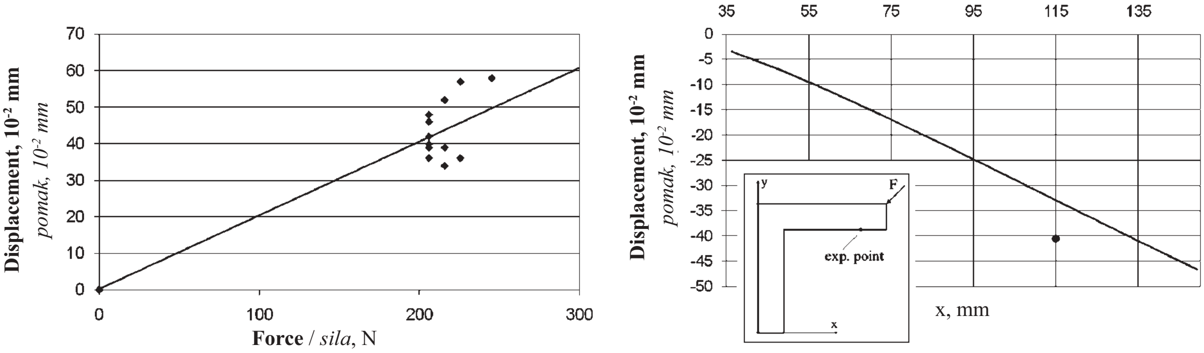

Figure 8 Experimentally determined displacement in the reference point (left) and distribution of displacement along the directions parallel to that of the load action at the intersection of planes y = 115.8 mm and z = 13.2 mm for the corner joint and the experimentally obtained displacement (right)
Slika 8. Eksperimentalno određen pomak u referentnoj točki (lijevo) i raspodjela pomaka duž pravaca paralelnih s pravcem djelovanja opterećenja u presjeku ravnina y = 115.8 mm i z = 13.2 mm za kutni spoj i eksperimentalno dobiven pomak (desno)

tenon, i.e. on the contact surface of the parts of the corner joint, which is at the distance of z = 4.6 mm from the symmetry plane.

The maximum value of the shear stress is 8.3 MPa and it occurs at around 0.36% of the contact surface of the joint parts. Given that the shear strength parallel to the grain ranges between 4 and 20 MPa (Kollmann and Côté, 1968), the corner joint will support the applied load.

To verify the calculation results, the displacement of the edge point of the joint in the direction of the force action is measured, as shown in Figure 7.

The total of 15 corner joints, whose shape and dimensions are equal to those shown in Figure 2, were examined. The resulting dependence of the load of the joint edge point displacement is shown in Figure 8 (a). Figure 8 (b) shows the numerically obtained distribution of the displacement along the directions parallel to the direction of the load action at the intersection of planes y = 115.8 mm and z = 13.2 mm. Figure 8 also shows the displacement obtained experimentally, which is greater than the calculated one for about 18%.

4.2 Example 2 − Skeleton chair construction
4.2. Primjer 2. Okvirna konstrukcija stolice

Due to symmetry only a half of the chair presented in Figure 9 is analyzed. The dimensions of cross section of elements are 24x40 mm (p_1) and 16x24 mm (p_2). Tenon dimensions of the side rail and the back leg joint are: thickness 8mm, length 16 mm and width 40 mm. Chair elements are joined only by face of tenon. There are clearances (2 mm) between all other contact surfaces. The mass load of the horizontal lower skeleton of the entire chair is 100 kg. The vertical frame mass load is 22 kg. The others surfaces are unloaded. The chair is assumed to be fixed to the ground, i.e. the displacement in those points equals zero. The chair material is spruce, having the same properties as in the previous example. The calculation was done on the grid of 24329 CV (Figure 9).

The distribution of the dominant normal stress σ_{yy} on the chair skeleton surface and joints is shown in Figure 10. The maximum value of this stress is 10.7 MPa, both in the tensile and the compression zone and it occurs in the joint of the side rail and the back leg.

The maximum values of the shear stress occurs at the same place. The distribution of the stresses σ_{xz} and σ_{xy} and the total shear stress on the tenon surface i.e. in the surface x = 0.202 m is shown in Figure 11.

The maximum shear stress values τ_{xz} = 6 MPa and τ_{xy} =5.6 MPa and the value of total shear stress in that plane (x = 0.202 m) is about 8.2 MPa. The maximum shear stress occurs at about 2.5% of the total contact surface. The maximum values of both the normal and the shear stresses are within the allowable values (Kollmann and Côté, 1968).

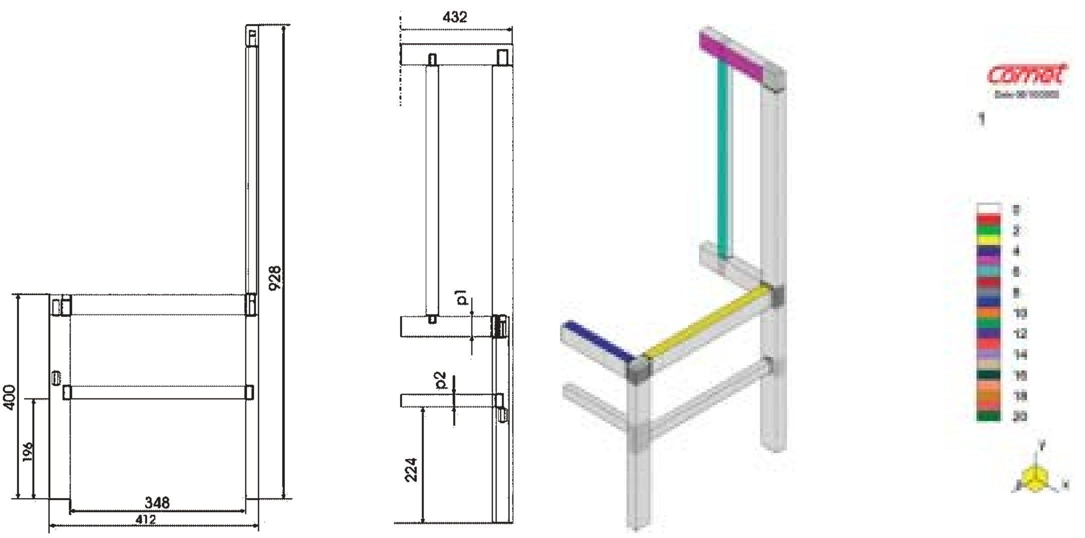

Figure 9 Chair skeleton construction (left), solution domain and numerical network (right)
Slika 9. Okvirna konstrukcija stolice (lijevo), područje rješavanja i numerička mreža (desno)

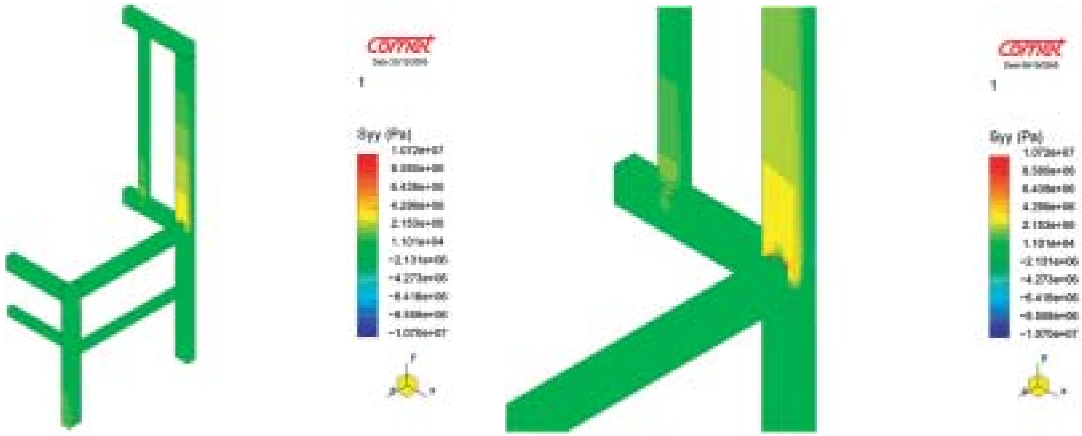

Figure 10 Distribution of stress σ_{yy} on the chair contour (left), and in the joint zone (right)
Slika 10. Raspodjela normalnog naprezanja σ_{yy} na nožištu stolice (lijevo) i u zoni spoja (desno)

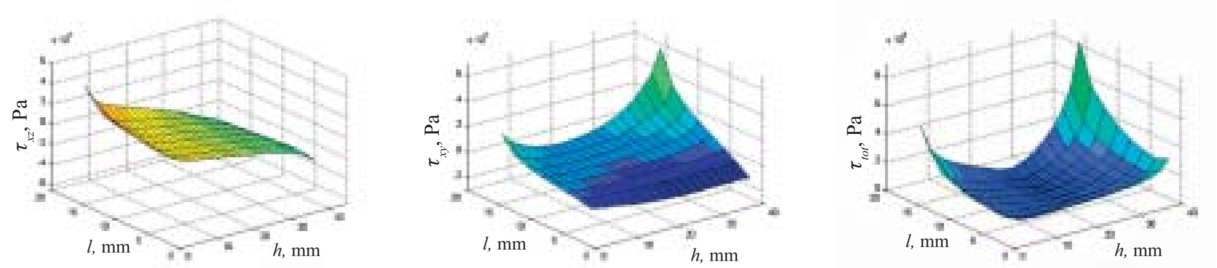

Figure 11 Distribution of shear stress in the contact pointing at the joint between the side rail and the back leg τ_{xz} (left), τ_{xy} (middle) and total shear stress τ_{tot} (right) (*l* – length of the tenon, mm; *h* – width of the tenon, mm)
Slika 11. Raspodjela posmičnog naprezanja u kontaktnoj površini spoja bočnog poveznika i stražnje noge, τ_{xz} (lijevo), τ_{xy} (u sredini), ukupno posmično naprezanje τ_{tot} (desno) (*l* – dužina čepa, mm; *h* – visina čepa, mm)

The chair deformation is shown in Figure 12. The largest displacement of around 13 mm occurs at the far end points of the chair back. That is an unusually large displacement, because the calculations are done for the chair made of soft wood, the material used in Example 1.

5 CONCLUSION
5. ZAKLJUČAK

This paper presents, for the first time, the development and the application of the finite volume method for predicting the distribution of displacements and stresses in the wooden corner joints and chair skeleton construction.

The numerical stimulation of stresses in a complex chair skeleton construction has shown that the construction strength depends on the stress values in the corner joints, primarily in the joint connecting the side rail and the chair back leg where both the maximum normal and shear stresses occur. Stiffness analysis has shown that the greatest deformation occurs in the points of the free end of the back of the chair. Thus,

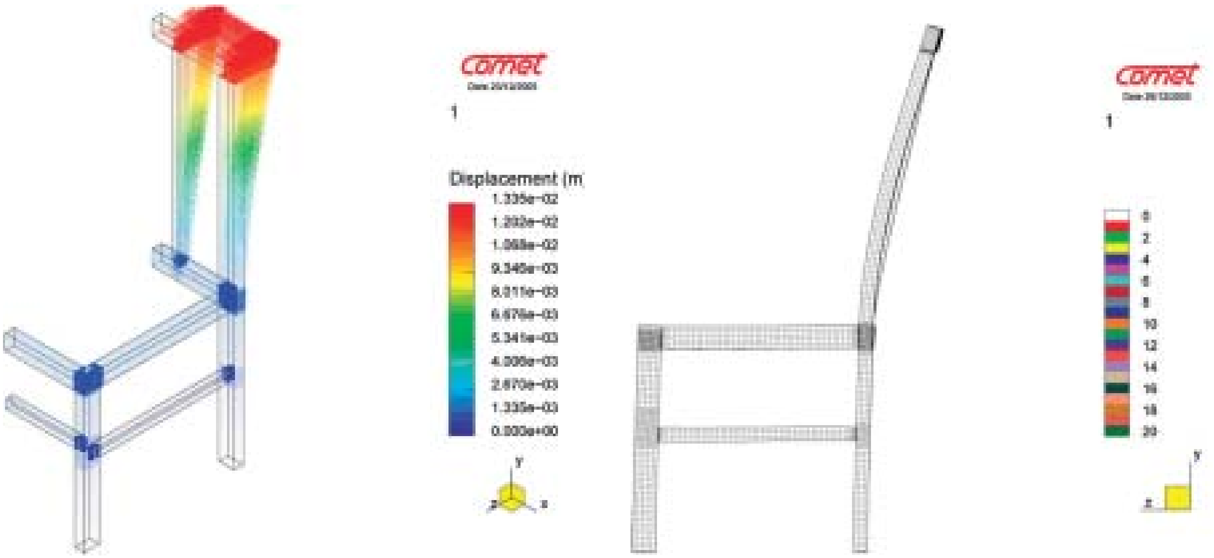

Figure 12 Distribution of the total displacement (left) and (right) the strained skeleton chair (10× increase)
Slika 12. Raspodjela ukupnog pomaka (lijevo) i deformirani okvir stolice (uvećanje10 puta, desno)

the mathematical model and the numerical calculation employing the finite volume method presented enable the design and the construction of a chair.

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Uredske radne stolice – istraživanje deformacija i indeksa udobnosti

Office Work Chairs – Research of Deformations and Comfort Index

Izvorni znanstveni rad • Original scientific paper
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*UDK: 630*836.1*

SAŽETAK • *Konstrukcije sjedala i naslona uredske stolice kao predmeta čovjekove radne okoline važni su u njezinom konačnom rješenju jer su to elementi koji su izravno i usko povezani s ljudskim tijelom. Sjedeći je položaj najčešći radni položaj modernog čovjeka u industrijski razvijenom svijetu. Neovisno o vrsti posla, pravilan i fiziološki ispravan sjedeći položaj smanjuje zamor pri radu i opterećenje kralješnice, a odgovarajući povoljan položaj pri sjedenju uvelike pridonosi povećanju koncentracije i radnog učinka. Sjedeći radni položaj moguće je razmatrati usklađivanjem antropometrijskih veličina s oblikom sjedala i naslona ili, mehaničkim pristupom, utvrđivanjem odnosa između korisnika i kvalitete sjedala, pri čemu velik utjecaj ima indeks udobnosti. Indeks udobnosti stolice kao jedan od pokazatelja udobnosti sjedenja proizlazi iz mehaničkih svojstava promatrane stolice.*
U radu su prikazani rezultati tzv. mehaničke udobnosti koju stolica može pružiti korisniku. Rezultati određivanja udobnosti sjedenja na uredskim radnim stolicama prikazani su indeksima udobnosti stolica dobivenih iz elastičnih svojstava materijala sjedala i stolice prema tehničkoj specifikaciji HRS ENV 14443.

Ključne riječi: *sjedenje, udobnost sjedenja, indeks udobnosti, uredska radna stolica, oblikovanje i konstrukcije sjedala*

ABSTRACT • *Construction of the seat and back of the office chair, as an actual object of the human working environment, is important in its final design since these are the elements that are in a direct and close contact with human body. The sitting position is the most frequent working position of the modern man in the developed world. Independently of the type of work, a sound and physiologically correct sitting position diminishes fatigue during work and strain of the spine, and suitable posture during sitting significantly contributes to the increase of concentration and efficiency. Sitting as a working position can be examined through coordination of anthropometric sizes and form of the seat and back, or mechanically, by determining the relation between the user and the seat quality, where the comfort index or support factor has a great influence. The comfort index as one of the factors of sitting comfort is the result of mechanical characteristics of the observed chair.*
This paper shows the results of ''mechanical comfort" that the chair can offer to the user. The results of determining the seat comfort on office chairs are featured through comfort index obtained from elastic characteristics of materials in the seat, but also of the chair itself according to Technical Specifications HRS ENV 14443.

Keywords: *sitting, sitting comfort, comfort index, support factor, office chair, seat design and seat construction*

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1 INTRODUCTION
1. UVOD

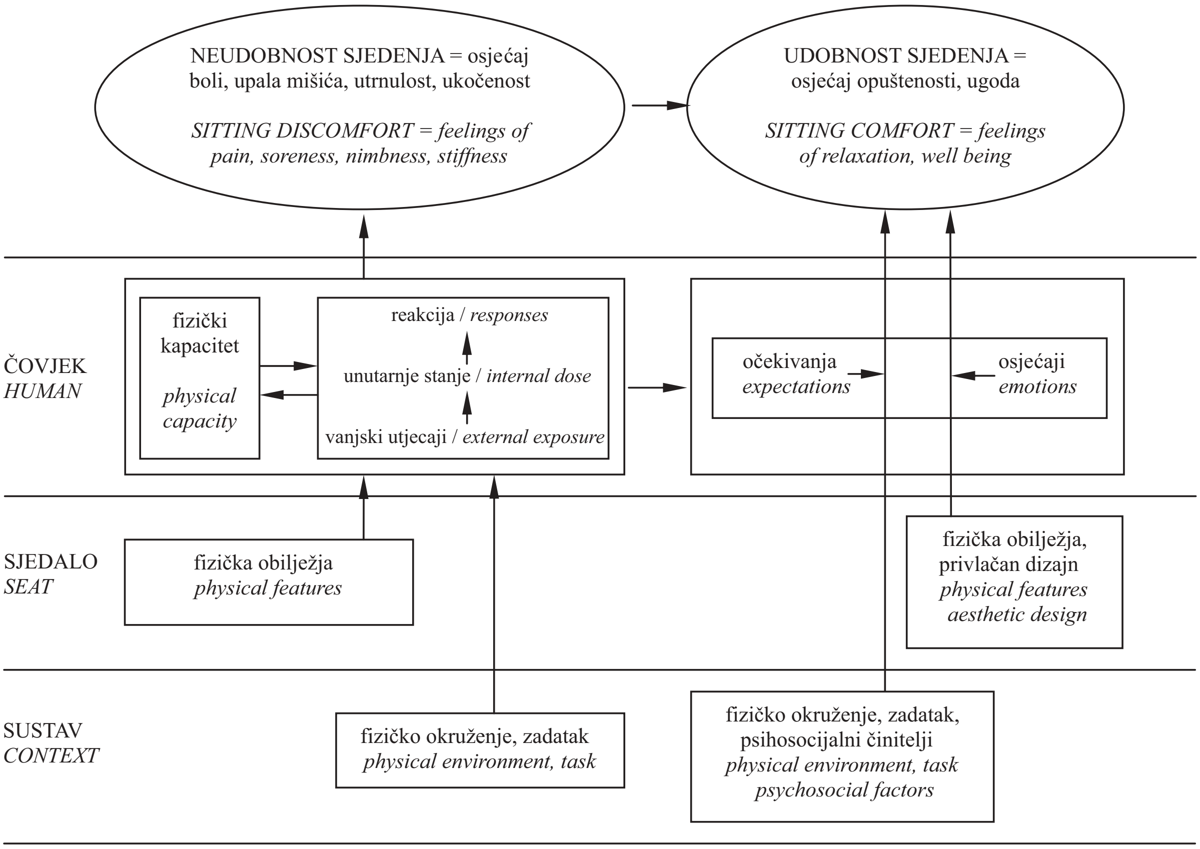
Problem odnosa čovjeka i namještaja s ergonomskog je stajališta najkritičniji upravo u vezi s pravilnim sjedenjem. Oblikovno rješenje uredske stolice kao predmeta čovjekove radne okoline važno je i zato što su sjedalo i naslon elementi koji su u izravnoj i uskoj vezi s ljudskim tijelom. To su osnovni razlozi zašto se pri dizajniranju namještaja osobita pozornost pridaje problemu sjedenja. Osim antropometrijskih zahtjeva i položaja pri radu, ergonomske usklađenosti uredskog namještaja za sjedenje i korisnika, važni su i ambijentalni čimbenici, koji određuju funkcionalna i namjenska određenja stolice (Lapaine, 1998; Grbac i Ivelić, 2005).

Sjedeći položaj najčešći je radni položaj koji čovjek zauzima i u moderno je vrijeme sve zastupljeniji. Neovisno o vrsti posla, pravilan i fiziološki ispravan sjedeći položaj smanjuje zamor pri radu i opterećenje kralješnice, a odgovarajući povoljan položaj pri sjedenju znatno pridonosi povećanju koncentracije i radnog učinka. Osim toga, sjedeći je položaj izuzetno važan za opuštanje tijela i odmor osim, naravno, potpune pasivne opuštenosti u ležećem položaju (Grbac, 2006; Vlaović i sur., 2006).

Za udobno sjedenje nisu bitna samo i isključivo svojstva sjedala ili naslona, već i drugi činitelji poput dojma, rasterećenosti i opće ugode i opuštenosti organizma, ali i zamora, biomehaničkih uvjeta, naprezanja i cirkulacije. Zbog metabolizma se npr. neprestano izlučuju toplina i vlaga i osjećaj udobnosti ovisi o ravnoteži primanja i otpuštanja topline i vlage na mjestu dodira tijela s podlogom (Hänel i sur., 1997; Horvat, 2008). Kao što je Zacharkow (1988) dokazao, otpor prema izmjenama snažno je povezan s veličinom dodirne površine i dodirnog tlaka (citirano u: Hänel i sur., 1997). Stoga je osjećaj udobnosti povezan s parametrima kao što su tlak, temperatura i relativna vlaga na mjestu dodira tijela s podlogom. “Mehanička udobnost” definirana je kao dio ukupne udobnosti koja ovisi o raspodjeli dodirnog tlaka po ljudskom tijelu u dodiru sa sjedalom. Dodirni tlak, njegova raspodjela i vrijeme djelovanja glavni su čimbenici mehaničke udobnosti.

Prema teorijskome modelu (De Looze i sur., 2003), različiti se čimbenici udobnosti i neudobnosti sjedenja mogu raščlaniti na tri osnovne razine: 1. sustav, 2. sjedalo i 3. čovjek (sl. 1).

Lijeva strana toga teorijskog modela odnosi se na neudobnost, koja se prema Zhangu i sur. (1996), temelji na fizičkim procesima. Slično prethodnim modelima o etiologiji fizičkih pritužbi povezanih s radom, Winkel i Westgaard (1992) te Armstrong i sur. (1993) u glavna pitanja ubrajaju “izloženost”, “stanje”, “reakciju” i “kapacitet” (citirano u: De Looze i sur., 2003). Prema Armstrongu, “izloženost” se odnosi na vanjske čimbenike koji uzrokuju smetnje “unutarnjeg stanja” pojedinca. Stanje može stvoriti niz mehaničkih, biomehaničkih ili fizioloških reakcija. Veličina kojom vanjski utjecaji vode unutarnjem stanju i reakcijama ovisi o fizičkom kapacitetu osobe. S obzirom na sjedenje, može se reći



Slika 1. Teorijski model udobnosti i neudobnosti i njihovi čimbenici na razini čovjeka, sjedala i sustava (De Looze i sur., 2003)

Figure 1 Theoretical model of comfort and discomfort and its underlying factors at the human, seat and context level (De Looze et al., 2003) da fizička obilježja uredskog sjedala, poput oblika i mekoće, okruženje, npr. visina stola i zadatak, rad s računalom, različitim silama i tlakovima opterećuju tijelo i zglobove osobe koja sjedi. Ta vanjska opterećenja remete unutarnje stanje u smislu smanjivanja mišićne aktivnosti, promjene unutarnjih sila, većeg tlaka na intervertebralne diskove, uključujući živce i cirkulaciju te povišenje tjelesne temperature, uzrokujući daljnje kemijske, fiziološke i biomehaničke reakcije. Desna strana modela odnosi se na udobnost, tj. osjećaj opuštenosti i ugode, za što su utjecajni čimbenici također svrstani na razinu čovjeka, sjedala i sustava. Na razini sustava važnu ulogu nemaju samo fizičke osobine, već i psihosocijalni čimbenici kao što su zadovoljstvo na poslu i društvena potpora. Na razini sjedala na osjećaj udobnosti mogu utjecati njegov privlačan dizajn uz fizička obilježja. Na razini čovjeka utjecajni čimbenici podrazumijevaju individualna očekivanja i druge individualne osjećaje ili emocije.

Općenito se može reći da su u tome modelu na jednoj strani živi činitelji - čovjek, sa svim svojim osobinama, a na drugoj strani neživi - stolica i materijali od kojih je napravljena te njihova svojstva. Materijali imaju svoja fizikalna svojstva poput gustoće, tvrdoće, mase i dr. Među polimernim materijalima, u koje ubrajamo spužve, najčešće se spominje gustoća materijala. Gustoća spužve sama po sebi nije važno svojstvo, ali sva ostala svojstva ovise o njezinoj gustoći (elastičnost, trajnost oblika...). Stoga se, kada se govori o gustoći spužve, zapravo misli na druga svojstva. Treba znati da ta svojstva nisu ovisna samo o gustoći, pa nam ona ne može uvijek biti pouzdan kriterij ocjene ostalih svojstava. Povećanjem gustoće povećava se tvrdoća, a smanjuje trajna deformacija. Zbog zaostajanja deformacija za opterećenjem, odnosno većeg utroška rada pri opterećenju nego u uvjetima rasterećenja dolazi do histereze (sl. 2). Histereza je mjera unutarnjeg prigušenja i izražava se odnosom površina pod krivuljama opterećenja i rasterećenja (Ljuljka, 1976; Ljuljka, 1977).

Dijagram elastičnosti pokazuje ovisnost tlačnog naprezanja i deformacije pri opterećenju i rasterećenju. Budući da je riječ o deformabilnome materijalu, krivulja opterećenja i krivulja rasterećenja razlikuju se i iz toga proizlaze i različitosti pojedinog materijala. Svojstva elastičnih spužvastih materijala ispituju se normiranim metodama, a to je učinjeno i u ovome radu.

U radu su istraživane deformacije sjedala i drugih konstrukcijskih dijelova stolice poput pneumatskog cilindra i kotačića te je određen indeks udobnosti stolice kao pokazatelja mehaničke udobnosti korisnika.

2. MATERIJAL I METODE
2 MATERIAL AND METHODS

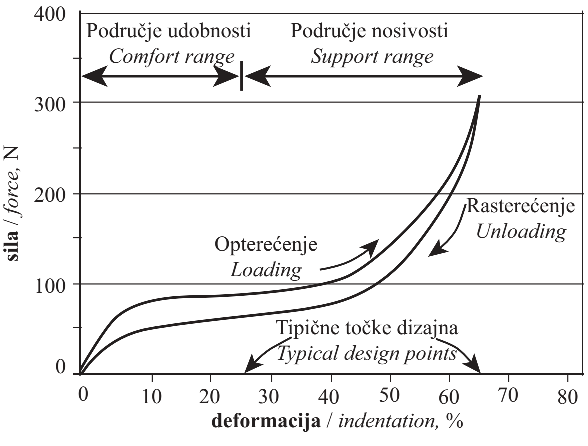
Dijagrami naprezanja/deformacije, tj. krivulje elastičnosti temelje se na prijedlogu europske norme *HRS ENV 14443:2004 – Kućni namještaj – Sjedenje – Metode ispitivanja za određivanje izdržljivosti ojastučenja,* koja specificira metode ispitivanja za određivanje izdržljivosti ojastučenja i sjedala, a jedan se njezin dio odnosi na ispitivanje i određivanje elastičnosti ojastučenja sjedala uredskih i drugih stolica.

Kružnica na slici 3. predočuje položaj aluminijskog podloška promjera 300 mm kojim je tlačena površina sjedala pri mjerenju odnosa naprezanje/deformacija. Točka 3 (središte podloška) namještena je iznad osi cilindra, tj. u točku A, kako upućuje norma *HRN EN 1335-1 Uredski namještaj – Uredske radne stolice – 1. dio: Dimenzije, određivanje dimenzija.*

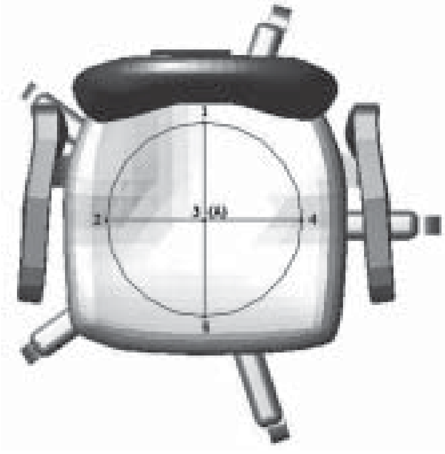
2.1. Uzorci
2.1 Samples

Uzorci uključeni u istraživanje bile su uredske radne stolice s peterokrakim postoljem i kotačićima za tvrde ili meke podloge, pneumatskim cilindrima i kvalitetnim mehanizmima za namještanje položaja i udobnosti te s naslonima za ruke. Sjedala su bila obložena dekorativnim tkaninama od poliestera (100-postotnog).

Za ovo istraživanje najvažnije su razlike bile one u konstrukciji sjedala: spužva, kombinacija spužve i opruga ili mreža. Nasloni za leđa u ovom istraživanju nisu bili važni, ali se može spomenuti da su, osim u jednom slučaju, bili od uokvirene mreže. Uzorci su imali oznake ST2, SA2, OA2, PT1, PA2, MA2 i MM2,



Slika 2. Tipični dijagrami naprezanja/deformacije za elastične spužve (Klempner i Sendijarevic, 2004)
Figure 2 Typical stress-strain curve for a flexible foam (Klempner and Sendijarevic, 2004)



Slika 3. Tlocrtni prikaz položaja podloška i rasporeda točaka za mjerenje debljine ojastučenja sjedala
Figure 3 Top view of seat loading pad and positions of measuring points for seat upholstery thickness

pri čemu prvo slovo označava konstrukciju sjedala, i to S – poliuretanska rezana spužva, O – džepićaste mikroopruge s poliuretanskom spužvom, P – poliuretanska hladno lijevana spužva i M – mreža, a ostale se oznake odnose na naziv i broj modela.

Poliuretanske spužve koje su se nalazile u pojedinim modelima sjedala bile su ovih gustoća: 32 kg/m^3 (ST2) i 40 kg/m^3 (SA2) za rezane PU spužve te 55 kg/m^3 (PT1) i 40 kg/m^3 (PA2) za hladno lijevane PU spužve. Sjedalo modela OA2 bilo je građeno od opruga promjera 45 mm i visine 40 mm (sa žicom promjera 1,60 mm) te s 15 mm debelim slojem PU hladno lijevane spužve gustoće 40 kg/m^3. Mreže napete u okvirnu konstrukciju sjedala bile su proizvođačkih naziva *Pellicle*™ (MA2) i *AirWeave*™ (MM2).

2.2. Metoda istraživanja
2.2 Research method

Elastičnost se dobiva iz omjera sile kojom djelujemo na površinu sjedala stolice i deformacije izazvane djelovanjem te sile (sl. 4.a). Sustav za mjerenje sastoji se od aluminijskog podloška kružnog oblika, promjera 300 mm, i ostalih dimenzija prema HRS ENV 14443, kojim se tlači sjedalo te mjernih uređaja (dinamometra i dubinomjera) kojima se mjere sila i deformacija (sl. 4.b).

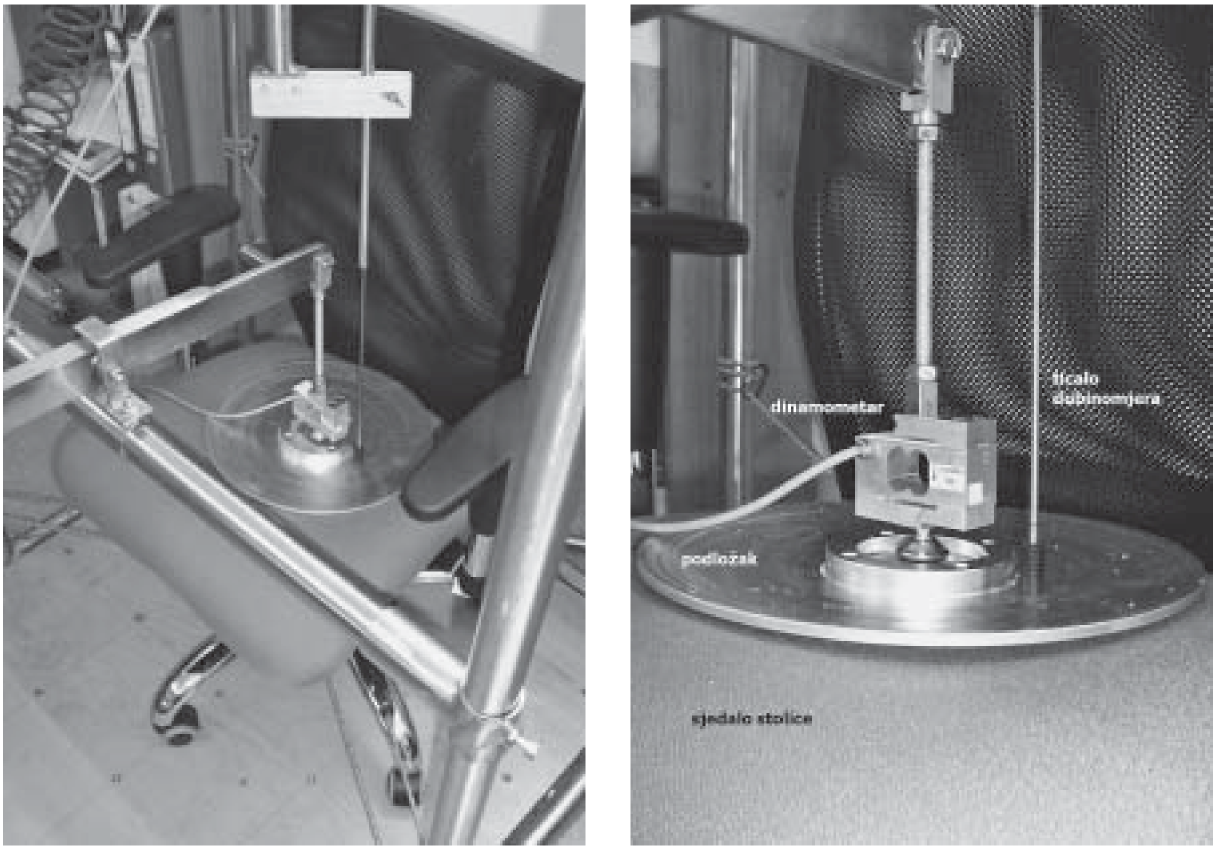
Na podložak se djelovalo silom od 0 do 1000 N brzinom 90±5 mm/min uz pomoć utega mase 27 kg i sustava s polugom u omjeru 1:4,75. Uteg i poluga povezani su čeličnim užetom, a sustav je potpomognut pneumatskim cilindrom za jednostavnije rukovanje. Cijeli je sustav povezan s računalom preko pojačala signala *Spider8* (HBM GmbH, SR Njemačka). Uz pomoć programskog paketa *Catman 4.0* očitane su vrijednosti sile i pomaka koje su kasnije obrađene programom *MS Excel*. Upravljanje pneumatskim cilindrom i vremenom djelovanja najveće sile obavljeno je ručno. Sam ciklus mjerenja elastičnosti stolica određen je i opisan u spomenutoj normi. Nakon obrade podataka kao rezultat su dobivene krivulje elastičnosti i progiba pri opterećenju.

Točke 1-5 na slici 3. mjesta su na kojima je izmjerena debljina ispune sjedala. Debljina je mjerena uz pomoć igle i digitalnog dubinomjera. Igla je zabodena u mjernoj točki do podloge sjedala, a zatim je debljina određena kao razlika između duljine igle i izmjerene visine igle do površine sjedala. Rezultati su prikazani u tablici 1.

3. REZULTATI I DISKUSIJA
3 RESULTS AND DISCUSSION

3.1. Elastičnost i deformacije stolica
3.1 Elasticity and deformations of chairs

Prikazani su dijagrami rezultati mjerenja i istraživanja elastičnih obilježja stolica (Vlaović, 2005). Za odabrane modele stolice prikazana su po dva dijagrama: prvi (lijevi) prikazuje odnos opterećenja, odnosno rasterećenja sjedala/stolice i deformacije koja se pojavljuje kao posljedica djelovanja sile, a drugi (desni) dijagram prikazuje ovisnost deformacije pri opterećenju stolice o sili koja na nju djeluje.



a) b)

Slika 4. Položaj ispitivanog uzorka, podloška, dinamometra i induktivnog dubinomjera
Figure 4 Position of the chair, seat loading pad with load-cell and inductive depth meter

Tablica 1. Debljina ojastučenja sjedala, najveća deformacija i udio s obzirom na debljinu sjedala
Table 1 Seat thickness, maximum deformation and deformation ratio to seat thickness

Model stolice *Chair model*	**Debljina sjedala** $\bar{x}_{2\text{-}3\text{-}4}$ *Seat thickness,* mm	**Najveća deformacija sjedala pri 1000 N** *Maximum seat deformation at 1000 N,* mm	**Najveća deformacija stolice s obzirom na debljinu sjedala** *Maximum chair deformation in relation to seat thickness*
ST2	48,8	37,47	77%
SA2	49,5	24,06	49%
OA2	56,2	31,75	56%
PT1	62,2	41,19	66%
PA2	49,1	39,56	81%

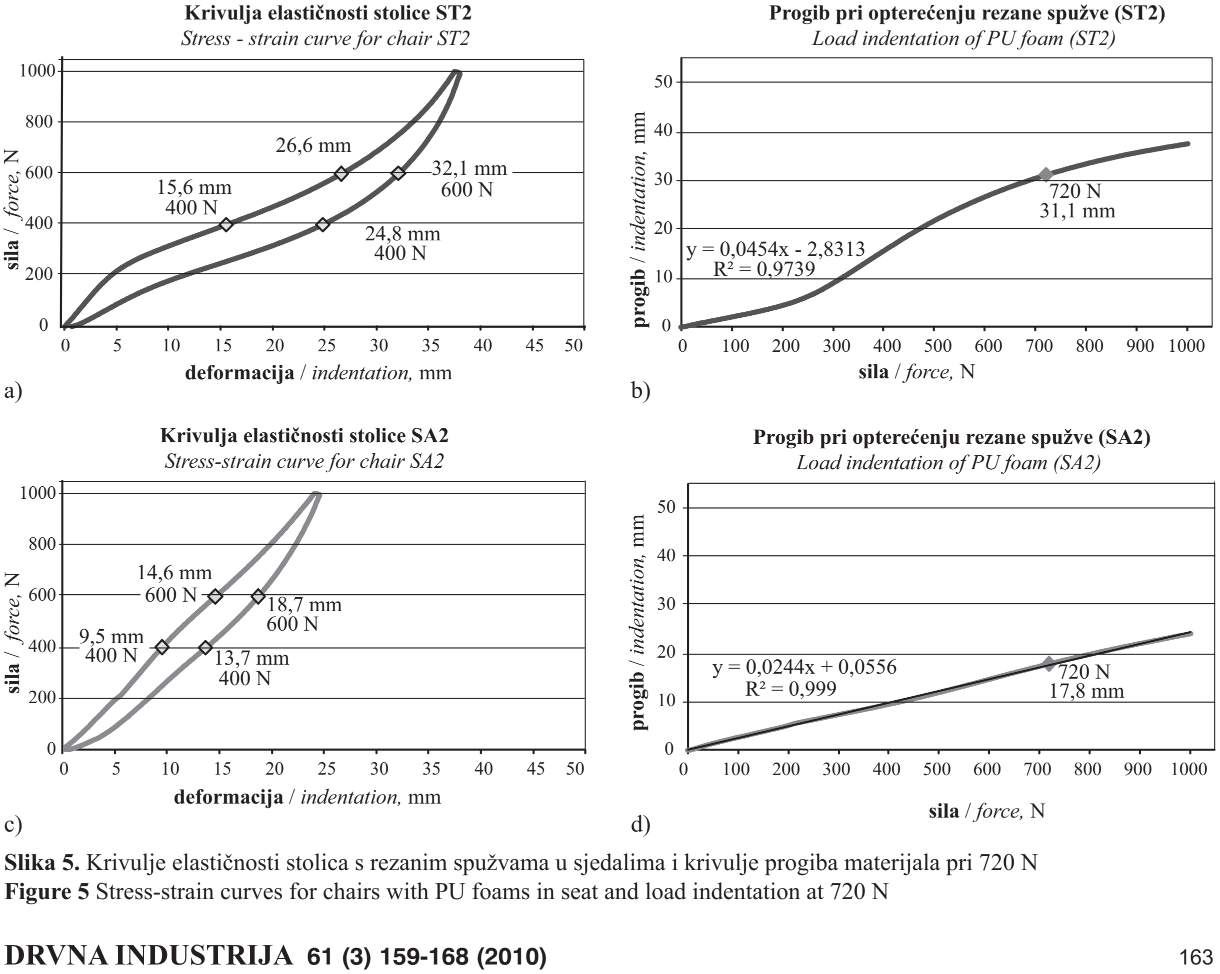
U tablici 1. prikazana su mjerenja, srednje vrijednosti debljina ojastučenja sjedala, najveća deformacija pri sili od 1000 N i udio najveće deformacije s obzirom na prosječnu debljinu sjedala.

Treba napomenuti da je prosječna debljina ojastučenja sjedala izračunana na temelju podataka mjernih točaka 2-3-4 jer na tom dijelu pri sjedenju leže sjedne kosti i najveći dio mase tijela. Točke 1. i 5. nalaze se na rubnim dijelovima sjedala i na tim se mjestima zbog zaobljenosti podloge i oblika ojastučenja vrijednosti debljine mogu bitno razlikovati s obzirom na središnju točku 3.

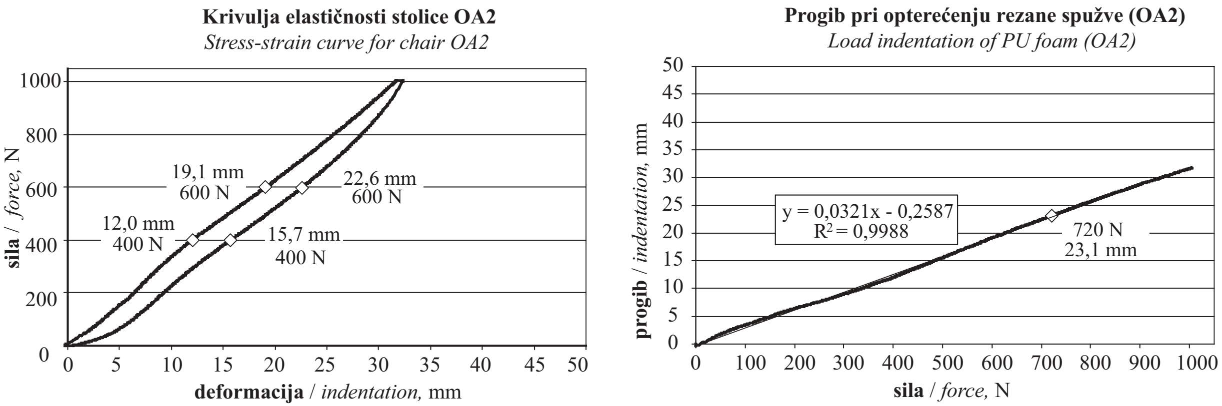
Iz lijevog se dijagrama može odčitati najveća sila kojom je stolica bila opterećena i najveća deformacija uzrokovana tom silom, koja je različita za svaku stolicu zbog različitih materijala ugrađenih u sjedalo. Usto, na svakom su grafikonu označene po četiri točke: dvije pri sili od 400 N na krivulji opterećenja i rasterećenja i dvije pri sili od 600 N. Te točke pokazuju zaostajanje pojedinih materijala pri rasterećenju. Budući da u cijelom sustavu sjedalo najviše utječe na izgled krivulje elastičnosti, s određenim oprezom možemo prihvatiti da je dobivena krivulja stvarna krivulja elastičnosti sjedala.

Rezana PU spužva (sl. 5) modela ST2 u početku je malo kruta, zatim popušta i omogućuje utonuće tijela pri silama od 250 do 600 N, a zatim ponovno pruža otpor, vjerojatno zbog blizine krute podloge i visokog stlačenja od 77 % (tabl. 1). Spužva SA2 nešto je drugačija, s prilično linearnom karakteristikom, bez većih područja tvrdoće ili mekoće. Vjerojatno su takva ujednačena krivulja i najveće stlačenje od 49% debljine spužve utjecali na bolji indeks udobnosti u usporedbi sa stolicom ST2, što je vidljivo i na slici 5.b.

Dijagram mikroopruga i PU hladno lijevane spužve modela OA2 također je linearan, što potpuno odgovara karakteristikama opruga pri takvim mjerenjima (sl. 6). U tom su sjedalu opruge vjerojatno preuzele najveće opterećenje, a sloj PU spužve preuzima samo početno opterećenje i daje osjećaj mekoće pri sjedanju. Težinu



Slika 5. Krivulje elastičnosti stolica s rezanim spužvama u sjedalima i krivulje progiba materijala pri 720 N
Figure 5 Stress-strain curves for chairs with PU foams in seat and load indentation at 720 N



a) b)

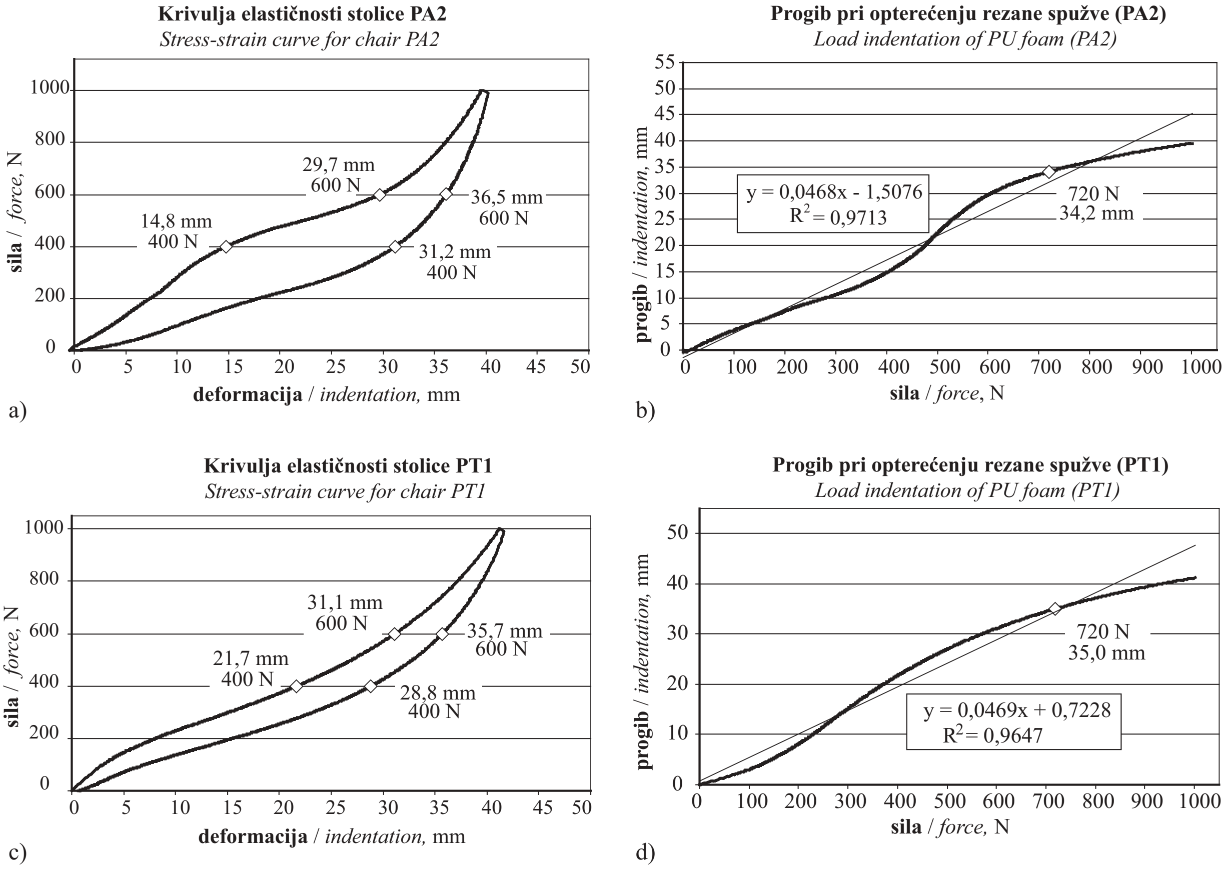
Slika 6. Krivulje elastičnosti stolice s oprugama u sjedalu i krivulje progiba materijala pri 720 N
Figure 6 Stress-strain curves for chairs with springs in seat and load indentation at 720 N

tijela preuzimaju opruge koje dopuštaju najviše 56-postotnu deformaciju u odnosu prema debljini sjedala.

Krivulje elastičnosti PU hladno lijevanih spužvi (PA2 i PT1) izgledaju vrlo slično, iako PA2 ima nešto veću razliku krivulja rasterećenja i krivulja opterećenja. Spužva PA2, kao i u drugim modelima tog proizvođača (SA2 i OA2), u početku se ponaša gotovo linearno i tvrdo, zatim dopušta nešto brži progib, veću mekoću. Što se sila povećava, spužva postaje sve tvrđom, a na kraju vjerojatno već i podloga utječe na najveću deformaciju, koja je iznosila čak 81 %. Spužva PT1 u početku je nešto tvrđa (sl. 7.c), a zatim sve do pret kraj opterećenja dopušta velik progib. Deformacija iznosi 66 % debljine sjedala.

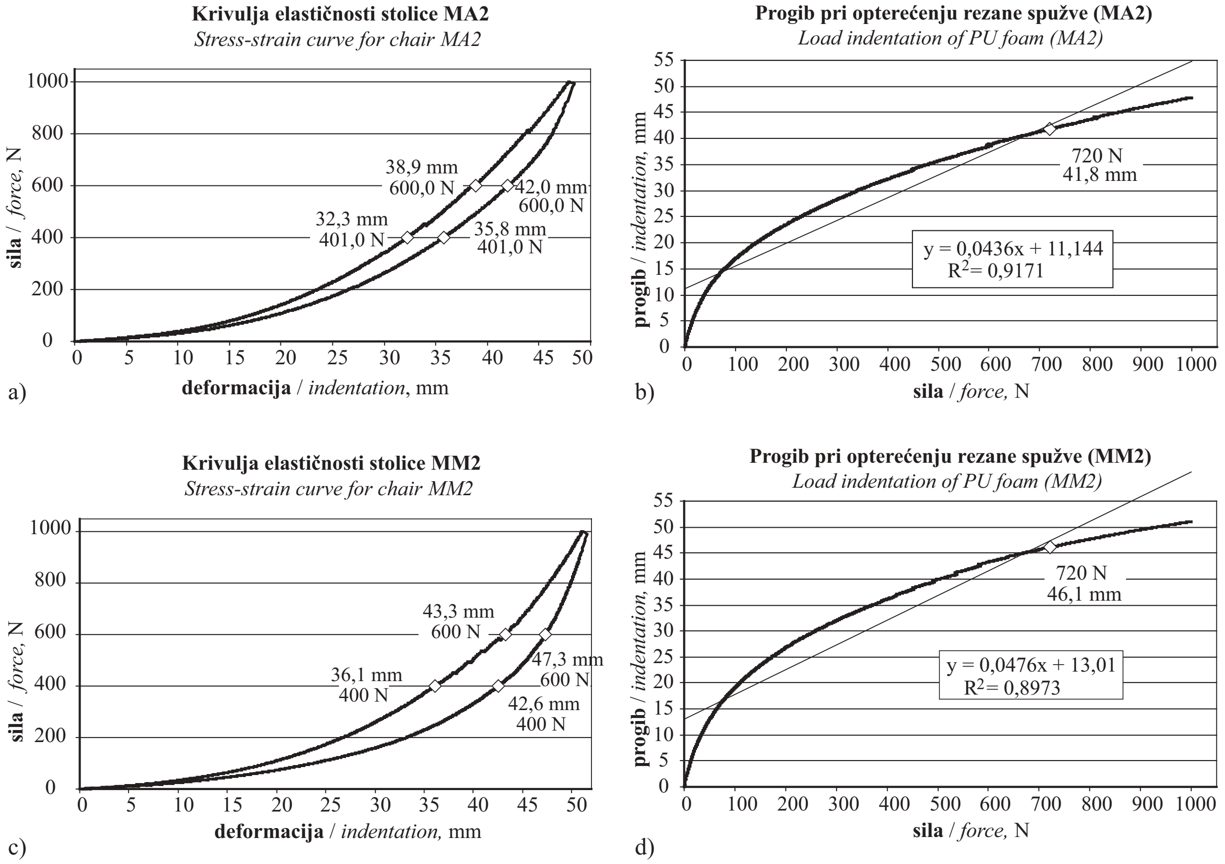
Krivulje poliuretanskih spužvi bitno su drugačije u usporedbi s krivuljama mreža. Iz dijagrama (sl. 8.a i 8.c) mogu se vidjeti vrlo dobre karakteristike mrežastih materijala koji u početku i još vrlo dugo imaju velik progib pri relativno maloj sili, a kasnije se do vrlo velikih sila ponašaju približno linearno omogućujući i dalje velik progib.

Desni dijagram detaljnije prikazuje krivulju opterećenja, trend i deformaciju ojastučenja pri sili od 720 N. Ta sila odgovara prosječnoj masi ispitanika (72 kg) koji su sudjelovali u paralelnom istraživanju udobnosti sjedenja na uredskim stolicama (Vlaović i sur., 2008), pa je ponašanje materijala provedeno upravo za tu masu ispitanika. Podaci su prikazani u sljedećoj tablici.



c) d)

Slika 7. Krivulje elastičnosti stolica s hladno lijevanim spužvama u sjedalima i krivulje progiba materijala pri 720 N
Figure 7 Stress-strain curves for chairs with cold-casted PU foams in seat and load indentation at 720 N



Slika 8. Krivulje elastičnosti stolica s mrežama u sjedalima i krivulja progiba materijala pri 720 N
Figure 8 Stress-strain curves for chairs with framed net in seat and load indentation at 720 N

Iz rezultata je vidljivo da je modelima s mrežom (MA2 i MM2) nakon deformacije prouzročene silom od 720 N preostalo mnogo manje (12,7 i 9,7 %) do maksimalne deformacije, negoli drugim modelima (26,0 % za SA2 i 27,2 % za OA2). Iz primjera stolica s mrežama može se pretpostaviti da su bedra i stražnjica dovoljno utonuli u površinu sjedala i time uspostavili veliku dodirnu površinu, što znači i ravnomjerniju raspodjelu tlakova. To je u konačnici stvorilo u korisnika osjećaj ugodnog sjedenja, što su ispitanici u spomenutom istraživanju svojim subjektivnim odgovorima i potvrdili. Konstrukcija stolice s mrežom nema krutu podlogu, pa nema reakcije podloge na proces sjedenja, a sama mreža dovoljno je elastična, čime omogućuje izvrsnu prilagodbu tijelu i držanje tijela u ravnoteži. Pri micanju stražnjice i bedara po sjedalu, mreža je stalno priljubljena uz tijelo, podržava ga i neprestano ostvaruje veliku dodirnu površinu.

Podloga ostalih stolica bila je kruta, od furnirskog otpreska. Stolicama SA2 i OA2 preostalo je više od četvrtine debljine sjedala “do dna”, što zapravo znači određenu pričuvu u smislu dubinske udobnosti. Iako su te vrijednosti malene, to se može primijetiti i na grafikonu indeksa udobnosti pojedinih modela (sl. 10), pa se upravo ta dva modela ističu među ostalima s PU spužvama.

Ostala tri modela - ST2, PT1 i PA2, pokazala su najslabije rezultate. Kruta podloga i mala preostala deformacija vjerojatno uzrokuju nizak indeks udobnosti u početnim trenucima sjedenja, no kasnije elastičnost ugrađenog materijala omogućuje relativno dobro utonuće tijela.

Stolice s PU spužvama, za razliku od konstrukcija s mrežom, pokazuju svojstvo kašnjenja materijala, odnosno pojavljuje se histereza. Kašnjenje se najviše primjećuje pri pomicanju tijela, kada spužva ne uspijeva jednakom brzinom mijenjati oblik i tijelo kratko

Tablica 2. Deformacija sjedala (stolice) pri prosječnoj sili od 720 N
Table 2 Seat (chair) deformation at average force of 720 N

Model stolice *Chair model*	**Deformacija** *Deformation,* mm	**Najveća deformacija** *Maximum deformation,* mm	**Deformacija u debljini sjedala** *Deformation in seat thickness*	**Preostalo** *Difference*
ST2	31,1	37,47	83 %	17 %
SA2	17,8	24,06	74 %	26 %
OA2	23,1	31,75	72,8 %	27,2 %
PT1	35,0	41,19	85 %	15 %
PA2	34,2	39,56	86,5 %	13,5 %
MA2	41,8	47,88	87,3 %	12,7 %
MM2	46,1	51,06	90,3 %	9,7 %

Tablica 3. Vrijednosti deformacija donjih dijelova stolica pri 1000 N
Table 3 Deformations of chair lower parts at 1000 N

Model stolice *Chair model*	**Prosječna deformacija donjeg dijela stolice** *Average lower part deformation of chair,* mm	**Deformacija donjeg dijela u ukupnoj deformaciji stolice** *Lower part deformation in total deformation of chair*	**Prosječna deformacija kotačića** *Average deformation of castors,* mm	**Deformacija kotačića u ukupnoj deformaciji stolice** *Castors deformation in total deformation of chair*
ST2[a]	8,56	22,8 %	1,39	3,7 %
SA2	7,45	31,0 %	1,61	6,7 %
OA2	6,96	21,9 %	1,50	4,7 %
PT1[a]	9,09	22,1 %	1,34	3,3 %
PA2	5,80	14,7 %	1,34	3,4 %
MM2	7,21	14,1 %	1,11	2,2 %

[a] stolice s kotačićima za tvrdu podlogu */chairs with castors for hard surface*

ostane nepodržano. To uzrokuje naglo koncentrirano tlačenje onog dijela tijela na strani na koju je prebačeno težište, a time i neujednačenu kratkoročnu raspodjelu tlakova sjedenja.

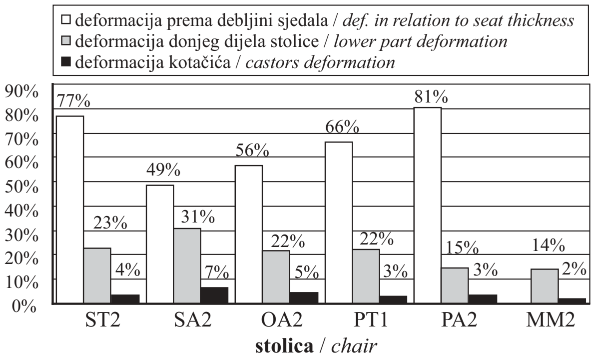
Važno je napomenuti da se prikazani dijagrami (sl. 5-8, desno) i veličine koje iz njih proizlaze, odnose na radnju opterećivanja stolice (sjedala) i da faktor vremena nije uključen u razmatranje. U početnome, kraćem vremenu sjedenja na stolici indeksi udobnosti relativno su visoki, ali s vremenom se udobnost može smanjiti.

3.2. Deformacije donjih dijelova stolica
3.2 Deformations of lower parts of chairs

Mjerenje elastičnosti napravljeno je na cijelom sustavu stolice zato što osoba sjedi neposredno na sjedalu, a posredno na mehanizmu, pneumatskom cilindru, postolju i kotačima. Svaki od tih elemenata stolice ima određene deformacije. Mjerenjem elastičnosti donjih dijelova stolice, odnosno mehanizma, cilindra, postolja i kotačića dobivene su vrijednosti prikazane u tablici 3.

Iz tablice 3. može se zaključiti da deformacija donjeg dijela stolice znatno utječe na ukupnu elastičnost sustava. Progibi od 6 do 9 mm nisu zanemarivi jer u ukupnoj deformaciji sudjeluju s 14 do 31 %. Kotačići namijenjeni tvrdoj podlozi (koji na gaznoj površini imaju sloj mekane plastike) nisu pokazali veću deformaciju od tvrdih kotačića, tj. onih za meku podlogu. Očekivano, veće se deformacije pojavljuju u modela stolica s tvrđim sjedalima: 31 i 6,7 % u modela SA2, čija je deformacija debljine sjedala samo 49 % ili 21,9 i 4,7 % u modela OA2, koji ima deformaciju sjedala 56 %. Na primjeru modela PA2 i ST2 uočeno je da je uz veću deformaciju sjedala (mekša sjedala), progib donjeg dijela manji: 14,7 i 3,4 % u PA2, dok je deformacija sjedala vrlo visokih 81 % te u ST2 iznosi 22,8 i 3,7 % za 77-postotnu deformaciju sjedala (sl. 9). Prema navedenome, može se zaključiti da donji dio stolice upotpunjuje njezinu elastičnost pri uporabi, što se možda najbolje očituje pri sjedanju osobe na stolicu, kad se početno udarno opterećenje na kralješnicu amortizira, ne samo sjedalom i njegovim elastičnim svojstvima, već cjelokupnim postoljem.

Na slici 9. uočava se obrnuta proporcionalnost u udjelima deformacija pojedinih dijelova stolica. Što je deformacija stolice u odnosu prema debljini sjedala veća, to su deformacije donjeg dijela stolice i kotačića manje, i obratno - što su deformacije donjeg dijela stolice veće, to je maksimalna deformacija sjedala manja.

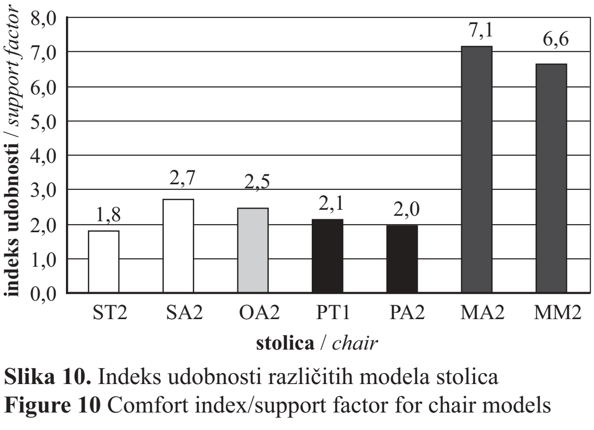


Slika 9. Prikaz trendova kod deformacija
Figure 9 Deformation trend overview

3.3. Indeks udobnosti
3.3 Comfort Index or Support Factor

Indeks udobnosti, ili engl. *support factor,* mjera je udobnosti. Korisnik stolice želi imati osjećaj mekoće pri visokom i pri niskom opterećenju, što je vrlo zanimljivo kad je riječ o primjeni jednakog materijala za sjedala i naslone, posebno u naslonjača i višesjeda. Pri usporedbi različitih materijala koristi se odnos iznosa opterećenja pri 65-postotnoj deformaciji (a) s iznosom opterećenja pri 25-postotnoj deformaciji (b) provedenih IFD testom (engl. *Indentation Force Deflection).* Veći su iznosi poželjniji jer veće vrijednosti indeksa udobnosti odgovaraju većoj općoj udobnosti ojastučenja (Klempner i Sendijarevic, 2004). Vrijednosti u sljedećoj tablici dobivene su iz podataka krivulje elastičnosti koji se mogu naći u izvornom radu autora.

Iz tablice 4. i slike 10. zamjetno je da su u stolica MA2 i MM2 zabilježeni nedvojbeno najviši iznosi indeksa udobnosti, što upućuje na njihovu opću udobnost



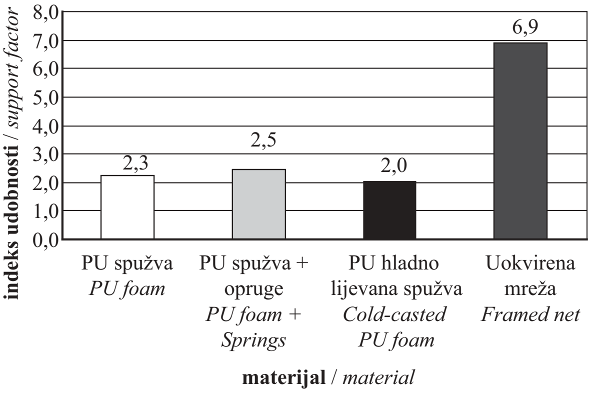
Slika 10. Indeks udobnosti različitih modela stolica
Figure 10 Comfort index/support factor for chair models

Tablica 4. Indeks udobnosti stolice
Table 4 Comfort Index/Support Factor of chairs

Model stolice *Chair model*	**Deformacija pri 1000 N (100 %)** *Seat deformation at 1000 N (100 %),* mm	**Deformacije od 65 %** *Indentation at 65 % of deformation,* mm	**Sila pri 65 % (a)** *Force at 65 % of deformation,* N	**Deformacije od 25 %** *Indentation at 25 % of deformation,* mm	**Sila pri 25 % (b)** *Force at 25 % of deformation,* N	**Indeks udobnosti a/b** *Comfort index*
ST2	37,47	24,36	550,62	9,37	306,30	1,8
SA2	24,06	15,64	636,24	6,02	235,30	2,7
OA2	31,75	20,64	645,50	7,94	262,00	2,5
PT1	41,19	26,77	496,56	10,30	233,60	2,1
PA2	39,56	25,71	540,00	9,89	276,50	2,0
MA2	47,88	31,12	369,18	11,97	51,70	7,1
MM2	51,06	33,19	326,82	12,77	49,30	6,6

i kvalitetu sjedala, ali svakako treba podsjetiti da nije riječ o poliuretanskome materijalu u sjedalima.

Zbog postojanja učinka udobnosti i neudobnosti, o kojima govore Helander i Zhang (1997), pojavljuju se situacije prikazane na slici 11, na kojoj se uočava veći indeks udobnosti stolice s oprugama nego stolica s rezanim i hladno lijevanim spužvama. Zbog malog broja uzoraka značajnost tih odstupanja nije ispitivana, ali je uočena mala razlika. Ono što je najvažnije jest značajna razlika u ocjeni stolica s mrežama čije su vrijednosti oko tri puta veće.



Slika 11. Indeks udobnosti materijala ojastučenja sjedala
Figure 11 Comfort index of seat upholstery material

4. ZAKLJUČAK
4 CONCLUSION

Na osnovi provedenih istraživanja i mjerenja deformacija sjedala i ostalih konstrukcijskih dijelova uredskih radnih stolica te određivanja indeksa udobnosti, mogu se donijeti sljedeći zaključci.

- Postoje bitne razlike među materijalima ojastučenja sjedala i njihovim konstrukcijama. Stoga je velika različitost ponude izbora za krajnje korisnike poželjna.
- Konstrukcija sjedala utječe na izgled krivulje elastičnosti, što se vidi na grafikonima, iako je u tome imao udjela i utjecaj postolja.
- U modela s tvrđim sjedalima više dolazi do izražaja elastičnost sustava stolice. Deformacija donjeg dijela stolice znatno utječe na ukupnu elastičnost sustava.
- Kotačići namijenjeni tvrdoj podlozi nisu pokazali veću deformaciju od onih za meku podlogu, tj. od tvrdih kotačića.
- Budući da faktor vremena nije razmatran, kratkoročno, u prvim trenucima sjedenja na stolici, indeksi udobnosti su visoki, ali kasnije, tijekom dnevne uporabe, mogu se smanjivati.
- Najveći indeks udobnosti pokazala su sjedala s mrežom. Utjecaj tvrde podloge na sjedenje primaran je, iz čega proizlazi da je okvirna konstrukcija sjedala s mrežom najprilagodljivija tijelu.
- Razmak krivulja rasterećenja i opterećenja, odnosno svojstava materijala koja uzrokuju te razlike moraju biti takva da su one manje jer je tada premještanje na sjedalu lakše, a potpora bolja.
- Među rezultatima ispitivanja "mehaničke udobnosti" stolica s PU spužvom uočava se veći indeks udobnosti stolica koje su subjektivnim testom bile ocijenjene kao neudobne. Najvjerojatniji je razlog tome postojanje osjećaja udobnosti i neudobnosti.

U svim provedenim usporedbama i analizama (osim za indeks udobnosti), konstrukcija sjedala s oprugama pokazala je niske rezultate. Debljina sjedala bila je oko 56 mm, visina opruga 40 mm (oko 70 % debljine sjedala), a iznos najveće deformacije bio je oko 32 mm ili 56 % debljine sjedala. Budući da je riječ o konstrukciji složenoj od opruga i spužve, valjalo bi izmjeriti koliki je progib opruga u cijelom sustavu. Sumnja se da se opruge vrlo brzo dokraja stlače i ponašaju se kao tvrda podloga, a spužva tada postaje pretanka za sjedenje, što rezultira većom neudobnosti pri dugotrajnom sjedenju.

Na točnost navedenih mjerenja donekle je utjecala ograničena krutost uređaja i ograničenja u postizanju visokih tlakova u cilindru. Rekonstrukcijom uređaja mogli bi se postići pouzdaniji rezultati.

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Dimensional Stability of Olive (*Olea europaea* L.) and Teak (*Tectona grandis* L.)

Postojanost protega maslinovine (*Olea europaea* L.) i tikovine (*Tectona grandis* L.)

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ABSTRACT • *Olive, as a wood species, can be compared by its dimensional stability with teak wood, which is mainly used for products exposed to external conditions. Mean density in absolutely dry condition of researched olive wood is 0.810 g/cm^3 while the average value of teak wood is 0.610 g/cm^3. Regardless of higher density, the mean value of total tangential shrinkage for olive wood is only by 3.6 % higher than the one for teak wood, so the value for olive wood is 5.6 % and for teak wood 5.4 %. Based on this research of density in absolutely dry condition and total shrinkage, olive wood can be considered as a possible alternative indigenous species for use in products that are daily exposed to external conditions.*

Keywords: *dimensional stability, olive wood, teak wood, physical properties*

SAŽETAK • *Utezanje je fizikalno svojstvo drva koje bitno utječe na njegovu upotrebljivost u proizvodima. Male vrijednosti utezanja daju nekim vrstama drva prednosti pri upotrebi (Ugrenović, 1950), posebno pri izradi proizvoda koji su svakodnevno izloženi vanjskim vremenskim uvjetima (Giordano, 1976). Maslinovina se kao vrsta drva po postojanosti protega može usporediti s tikovinom, koja se najčešće rabi za proizvode svakodnevno izložene vremenskim uvjetima. Srednja vrijednost gustoće u apsolutno suhom stanju istraživane maslinovine iznosila je 0,810 g/cm^3, za razliku od tikovine, čija je srednja vrijednost iznosila 0,610 g/cm^3. Usprkos većoj gustoći, srednja vrijednost maksimalnoga tangencijalnog utezanja maslinovine samo je 3,6 % veća od srednje vrijednosti maksimalnoga tangencijalnog utezanja tikovine, te za maslinovinu iznosi 5,6 %, a za tikovinu 5,4 %. Na temelju ovog istraživanja gustoće u apsolutno suhom stanju i maksimalnih utezanja, može se zaključiti da se maslinovina pokazala kao moguća zamjenska domaća vrsta za upotrebu u proizvodima koji su svakodnevno izloženi vanjskim vremenskim uvjetima.*

Ključne riječi: *postojanost protega, maslinovina, tikovina, fizikalna svojstva*

1 INTRODUCTION
1. UVOD

Shrinkage is a physical property of wood that significantly affects its usability in products. Small shrinkage values are an advantage in use for some wood species (Ugrenović, 1950), especially in products that are daily exposed to external conditions (Giordano, 1976). The aim of this research was to compare some physical properties of olive and teak wood. In this research the following physical properties of wood

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were studied: density in absolutely dry condition, density in raw condition, nominal density, water content, longitudinal, radial, tangential and volumetric shrinkage. Based on variations of the shrinkage value, it is possible to compare dimensional stability (Horvat and Krpan, 1967) of the two wood species, as one of the key factors in selecting wood for products daily exposed to external conditions. Olive, as a wood species, was chosen for comparison because of its appearance on wood market, and it is considered to be a substitute for teak.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Olive
2.1 Maslinovina

Olive (*Olea europaea* L.) is classified in botanical genus *Olea* and family *Oleaceae*. It is reported to be indigenous to the Mediterranean, including Southern Europe, the Middle East and North Africa. Also, it has been extensively planted in areas of California, Arizona and Florida. For olive, sub tropical or Mediterranean climate is preferable, especially hot, dry regions under irrigation (Arno, 1988).

Olive trees are extremely long lived, up to 1 500 years. They grow to heights that rarely exceed 8 m and diameters of 30 cm. Trunk is fluted and knotted. Sapwood is narrow, gold or yellow in color, and often striped. On the other hand, heartwood varies from golden-brown to dark brown (Horvat, 1983).

It is reported to dry very slowly, with very mild drying schedules recommended. The wood is moderately durable and somewhat resistant to fungi attack.

Olive fruits are rich in oil that is both used in nutrition and for medical purpose. In flooring industry olive is, together with teak, most valued wood. It is frequently used in production of expensive furniture.

2.2 Teak
2.2. Tikovina

Teak (*Tectona grandis* L.) is a tropical hardwood in genus *Tectona* and family *Verbenaceae*. It is native to the regions of Africa, Central and South America, Southeast Asia and Indonesia. As olive, it has been extensively planted in Europe (France) and North America (Florida) (Kaiser, 1992).

Teak trees are reported to attain heights of 39-45 m and diameters of 90-150 cm, while plantation trees grow to 45 m and can be ready for harvesting after 60 years. Trunk is irregular and narrow. The clearly demarcated sapwood is white to pale yellow in color, while heartwood varies in color from golden-brown to dark brown (Kline, 1976).

Teak wood dries very well, but slowly. Its natural durability and resistance to fungi attack is reported to be very high.

The wood is especially valued in carpentry (Ugrenović, 1948), production of expensive furniture, and it is used for floor coverings, stairs, windows, doors, etc. Considering its outstanding stability in external conditions it is suitable for external use, e.g. in horticulture and landscape tending, while in shipbuilding it is almost irreplaceable.

Olive (*Olea europea* L.) used in this research originates from the Island of Silba, region of North Dalmatia in Croatia, while teak (*Tectona grandis* L.) comes from the state of Sierra Leone, West Africa Region.

Sharp-edged samples for the determination of physical properties were made from heart boards. Physical properties of olive and teak wood were determined according to standards applicable Croatia. Maximum number of sharp-edged samples was made from heart boards. Dimensions of samples were 20x20x25 mm (*R*x*T*x*L*). The samples were then soaked in water for the time they required to achieve water content higher than the fiber saturation point. After reaching the specified water content, the samples were dried at the

Figure 1 Olive tree (*Olea europea* L.)
Slika 1. Stablo masline (*Olea europea* L.)

Figure 2 Teak tree (*Tectona grandis* L.)
Slika 2. Stablo tika (*Tectona grandis* L.)

Table 1 Survey of statistical values of researched olive and teak wood
Tablica 1. Pregled statističkih vrijednosti rezultata istraživanja maslinovine i tikovine

Olive wood - *Maslinovina*							**Teak wood** - *Tikovina*					
ρ_w	ρ_0	w	β_{rmax}	β_{tmax}	β_{vmax}		β_{vmax}	β_{tmax}	β_{rmax}	w	ρ_0	ρ_w
g/cm^3	g/cm^3	%	%	%	%		%	%	%	%	g/cm^3	g/cm^3
62	62	62	62	62	62	N	16	16	16	16	16	16
1.0160	0.7498	42	2.5	0.0	6.9	MIN	6.6	4.4	1.5	44	0.5663	0.7498
1.0974	0.8047	51	4.5	5.6	10.9	AVE	7.9	5.4	2.2	48	0.6089	0.8276
1.1897	0.8899	69	10.0	9.0	15.8	MAX	10.0	8.2	3.7	52	0.6494	0.8840
0.0508	0.0370	7.9	1.56	2.11	2.54	SD	1.06	1.02	0.64	2.7	0.0242	0.0355
0.0026	0.0014	62.4	2.44	4.47	6.43	VAR	1.13	1.05	0.40	7.2	0.0006	0.0013

ρ_w – density in raw condition (*gustoća u sirovom stanju*), ρ_0 – density in absolutely dry condition (*gustoća u apsolutno suhom stanju*), w – water content (*sadržaj vode*), β_{rmax} – total radial shrinkage (*maksimalno radijalno utezanje*), β_{tmax} – total tangential shrinkage (*maksimalno tangencijalno utezanje*), β_{vmax} – total volumetric shrinkage (*maksimalno volumno utezanje*)

temperature of 103±2 ºC until they reached constant mass. After obtaining an absolutely dry condition, the measurements were repeated and data were processed, all according to applicable standards.

The evaluation of the basic statistical data was made using statistical software Statistica 7.1, together with the comparison of researched mean property values in the same software using Mann-Whitney test.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

Statistical values of researched physical properties of olive and teak wood are shown in Table 1.

Mean values of researched physical properties of olive wood are higher in all segments than the ones of teak wood, as shown in Table 1. The mean value of water content after water soaking of olive wood is higher by 5.9 % than the mean value of water content after water soaking of teak wood. The mean value of density in raw condition after water soaking of olive wood is higher by 24.6 % than the same value of density in raw condition of teak wood. The mean value of density in absolutely dry condition of olive wood is higher by an almost identical percentage than the same value of density in absolutely dry condition of teak wood, and the mentioned value is 24.3 %. Mean values of total shrinkage in radial direction and volumetric shrinkage differ significantly from mean values of total shrinkage in tangential direction. The mean value of total radial shrinkage of olive wood is higher by 51.1 % than the mean value of teak wood, and with total volumetric shrinkage by 27.5 %. The mean value of total tangential shrinkage of olive wood is only by 3.6 % higher than the same value of teak wood.

Graphical view shown in Figure 3 was formed based on mean, maximum and minimum statistical values of shrinkage.

Figure 3 clearly shows the range of researched shrinkages. Figure 4 shows the relation between density in absolutely dry condition and tangential shrinkage. This view was given because such pieces of information are not available in literature and few researches of this kind were carried out.

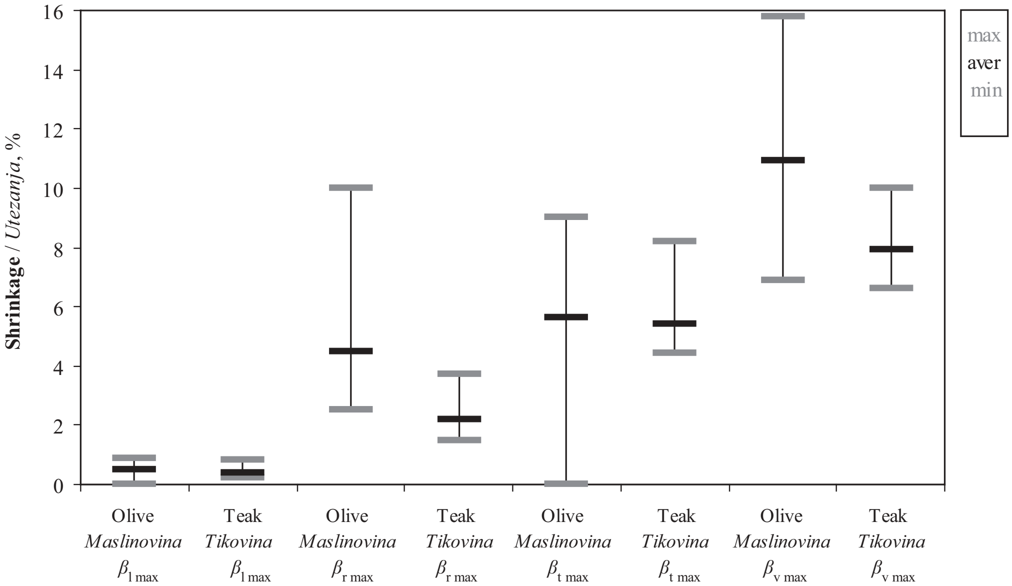

Figure 3 Comparison of maximum, minimum and mean values of total longitudinal, radial, tangential and volumetric shrinkage of olive and teak wood
Slika 3. Usporedba maksimalnih, minimalnih i srednjih vrijednosti maksimalnoga longitudinalnog, radijalnog, tangencijalnog i volumnog utezanja masline i tika

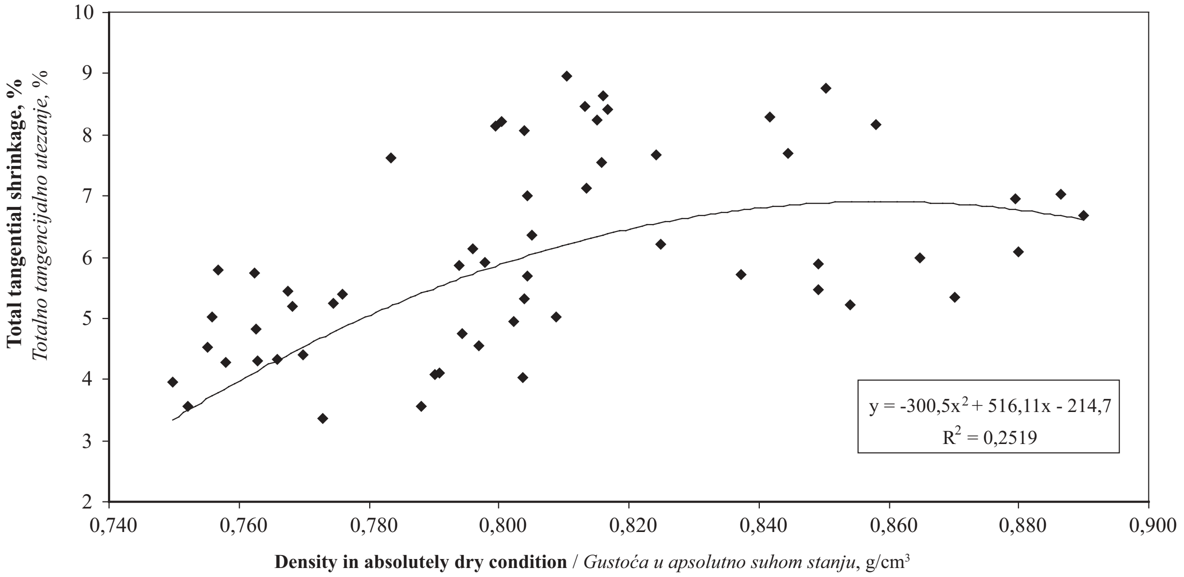

Figure 4 Relation between total tangential shrinkage and density in absolutely dry condition for olive wood
Slika4. Odnos maksimalnog tangencijalnog utezanja i gustoće u apsolutno suhom stanju za maslinu

Figure 4 shows the growth trend of total tangential shrinkage with the increase in density in absolutely dry condition for olive wood. Figure 5 shows the relation between density in absolutely dry condition and total volumetric shrinkage for olive wood.

The results obtained by comparison of mean values of researched physical properties show that mean values are significantly different.

This is because structural elements of teak wood are evenly arranged in the ring width compared to olive wood. Macroscopic structure of teak wood, with respect to its structural elements, is uniform, while this is not the case with olive wood. Disparity in structure and structural elements affects greater variability in properties for olive wood. The cause of such discrepancies also results from the fact that teak grows in relatively constant climatic conditions, while olive grows in highly variable climatic conditions.

4 CONCLUSIONS
4. ZAKLJUČCI

This research of density in absolutely dry condition, density in raw condition, nominal density and total values of longitudinal, radial, tangential and volumetric shrinkage shows that all mean values of the above mentioned properties are significantly different between olive and teak wood. After observing the mean values of researched properties, it is evident that they are higher for olive than for teak wood. Also, by observing variations between mean values of researched properties in percentages, it can be concluded that they are relatively small, apart from total radial shrinkage. All the above shown property values, their arrangement and relations show that olive wood can be substituted with teak wood, from the aspect of total shrinkage. As far as density is concerned, olive wood has

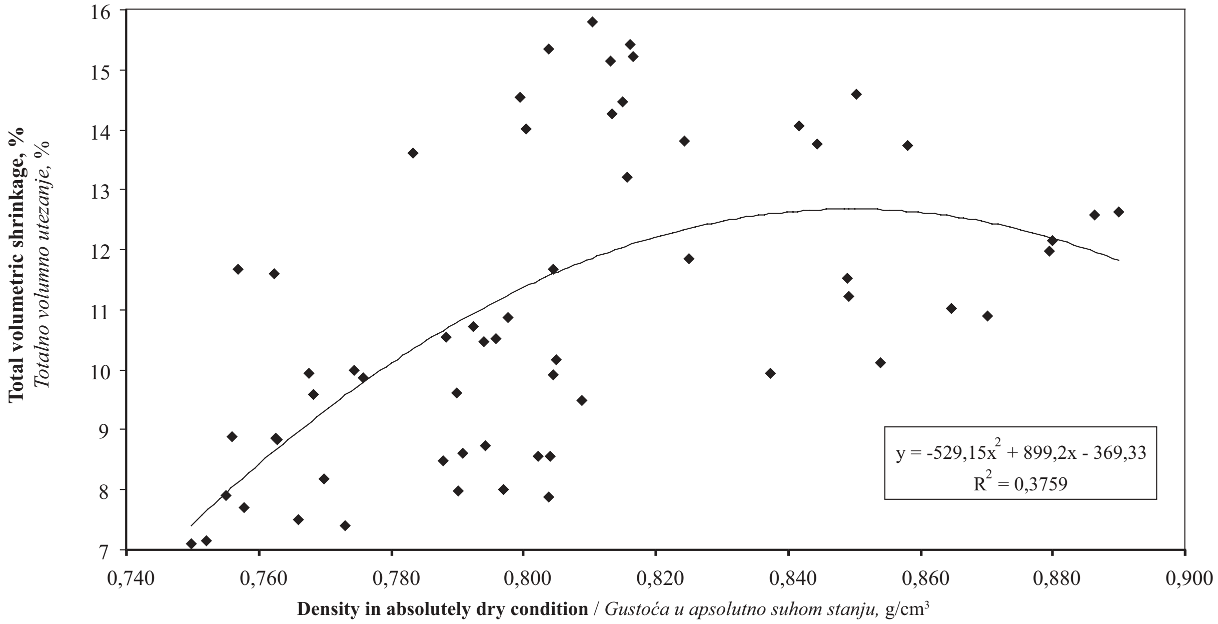

Figure 5 Relation between total volumetric shrinkage and density in absolutely dry condition for olive wood
Slika 5. Odnos maksimalnog volumnog utezanja i gustoće u apsolutno suhom stanju za maslinovinu

somewhat higher density in absolutely dry condition than teak wood.

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IZ SADRŽAJA
DRVO &
NAMJEŠTAJ
Drvo se sve više istiskuje!
Dominiraju PVC i umjetni materijali

Nadir Ayrilmis, Zeki Candan, Turgay Akbulut[1]*, Ozgur D. Balkiz*[2]

Effect of Sanding on Surface Properties of Medium Density Fiberboard

Utjecaj brušenja na svojstva površine MDF ploče

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ABSTRACT • *The objective of this research was to investigate the effects of sanding on the surface properties of the medium density fiberboard (MDF) panels made from* Rhododendron ponticum *L. wood. The MDF panels were sanded with different sizes of the sand paper grit: 60-, 60+80- or 60+80+120-grit. Surface absorption and surface roughness of the MDF panels were determined based on EN 382-1 standard and ISO 4287 by using a fine stylus profilometer, respectively. Sessile water drop technique was used to determine contact angle values of the panel surface. The results indicated that sanding process improved the surface smoothness of the panels. However, the wettability and surface absorption of the panels were negatively affected by increasing grit size. The MDF surface sanded with 60-grit size had a lower contact angle, more wettable surface, compared to those that were sanded with 60+80+120-grit size. For example, the average contact angle value of the panels sanded with 60-grit sandpaper was 43.3° as compared to the panels sanded with 60+80+120-grit sand paper which was 76.1°. The rougher surface was more wettable and absorbent compared to smoother surface. Based on the findings obtained from the present study, sanding has a significant effect on the wettability, surface roughness, and surface absorption of the MDF panels, which could provide useful information on the bonding and finishing of the MDF panels.*

Key words: *contact angle, medium density fiberboard (MDF),* rhododendron *(R.)* ponticum *L., sanding, surface absorption, surface roughness, wettability*

SAŽETAK • *Cilj je istraživanja bio ispitati utjecaj brušenja na svojstva površine srednje gustih ploča vlaknatica (MDF ploča) proizvedenih od drva rododendrona (*Rhododendron ponticum *L.) MDF ploče brušene su brusnim papirima različitih granulacija: 60, 60+80 ili 60+80+120. Određena su apsorptivna svojstva prema normi EN 382-1 i hrapavost površine MDF ploča prema normi ISO 4287 uz pomoć finog profilometra. Za određivanje kontaktnog kuta površine ploča primijenjena je metoda ispitivanja s kapljicom vode. Rezultati istraživanja pokazuju da brušenje pozitivno utječe na glatkoću površine ploča. Međutim, povećanje granulacije brusnog papira negativno utječe na kvašenje i apsorpciju površine ploča. Površina MDF ploča brušenih brusnim papirom granulacije 60 imala je manji kontaktni kut i bolje kvašenje u usporedbi s površinom koja je brušena brusnim papirima granulacije 60+80+120. Na primjer, srednja vrijednost kontaktnog kuta ploča brušenih brusnim papirom granulacije 60 bila je 43,3°, a ploča brušenih papirom granulacija 60+80+120 bila je 76,1°. Hrapavija površina imala je bolje kvašenje i apsorpciju nego glatkije površine. Na temelju rezultata dobivenih istraživanjem može se zaključiti da proces brušenja ima znatan utjecaj na kvašenje i hrapavost te na apsorptivna svojstva površine MDF ploča, što je osobito važno za proces lijepljenja i površinske obrade brušenih površina.*

Ključne riječi: *kontaktni kut, MDF ploče,* Rhododendron *(R.)* ponticum *L., brušenje, apsorpcija površine, hrapavost površine, kvašenje*

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1 INTRODUCTION
1. UVOD

Rhododendron ponticum L. of the Ericaceae is one of the largest genera of dicotyledons. There are about 700 species in the area of China, Tibet, Burma, Assam and Nepal; almost 300 species in New Guinea; many in Japan, tropical Asia from Indochina to Indonesia and the Philippines; while a small number occur in Europe and North America (Terzioglu, 2000). The habitats of *Rhododendron* species also show a wide range, from low-mountain forests to alpine regions more than 4000 m high. The species are usually shrubs of low to medium height, sometimes dwarfed with creeping fine stems in alpine regions, while certain members in low mountain regions grow into fairly tall trees of about 30 m in height and 100 cm in diameter. *R. ponticum* has flowers of different colors. Spots of corolla changing from deep purplish-pink to pure white are arranged regularly (Terzioglu, 2000). Turkish *Rhododendron* species grow naturally from sea level to altitudes of 2500 (3100) m. They take the form of shrubs (*R. luteum* Sweet), dwarf shrubs (*R. caucasicum* Pallas) and large shrubs (*R. ponticum* L., *R. ungernii* Trautv., *R. smirnovii* Trautv.). *Rhododendron* wood is diffuse-porous, growth ring boundaries distinct or indistinct. Some anatomical properties of *R. ponticum* wood used in this study are shown in Table 1 (Balkiz, 2006).

R. ponticum having a density of 0.671±0.018 g/cm^3 is a raw material used for manufacturing of wood-based panels such as particleboard and MDF in Turkey (Balkiz, 2006; Oktem, 1982). Quality of furniture products made from MDF depends on finishing quality of MDF. The finishing quality depends on the quality of surface prior to applying the finishing materials. When the panels are used as substrate for thin overlays and liquid surface coatings their surface characteristics such as roughness and wettability play an important role in determining the quality of the final product. Most MDF panels are used as a substrate for thin overlays such as melamine-impregnated papers in the furniture industry. In addition, various types of finishes such as paint and lacquer are directly applied to the sanded panel surface to be used as furniture panels. In both applications, surface characteristics of the substrate panel, including absorption ability, wettability, and roughness properties, are important factors affecting better use of the panel products. For example, surface roughness of MDF prior to finishing is very important in determining the quality of the finished product. Any irregularity on the surface may show through thin layer of the finishing materials. Standard contact measuring devices employing a stylus tracer, such as used in the metal and plastic industry, were successfully used to evaluate roughness characteristics of various wood composites (Hiziroglu, 1996). One of the main advantages of the stylus method is to have an actual profile of the surface and standard numerical roughness parameters that can be calculated from the profile. Any kind of irregularities and magnitude of show-trough on the overlaid substrate can be objectively quantified. Therefore, it is important to quantify surface roughness of the panel to have a better overlaying of the substrate.

Rough wood surface could limit surface contact and result in weak glue or poor finishing quality (Sulaiman *et al.*, 2009). According to Petri (1987) surface roughness affects adhesion of two surfaces because it increases the total contact area between adhesive and substrate. It could also provide mechanical interlocking effect that could trap the adhesive in the cavities and act like an anchor to each other. Roughness of wood based panels could be decreased to a certain extent by sanding. Besides the measurement of the surface roughness, it could also be estimated from wettability of the surface (Akbulut *et al.*, 2000). Wettability is defined as a surface condition that determines how good wetting and spreading on the surface of a liquid will be or whether it will be repelled and not spread on the surface. Wettability is crucial for good adhesion in wood bonding and it is important to determine the adhesive and coating properties of wood and wood-based composite surfaces (Ayrilmis and Winandy, 2009; Petrissans *et al.*, 2003). Wettability of the wood can be characterized by various methods (Gray, 1962; Casilla *et al.*, 1981; Gardner *et al.*, 1991). Recently, contact angle method has been commonly used to determine surface characteristics of wood and wood based composites (Petrissans *et al.*, 2003; Ayrilmis and Winandy, 2009; Ayrilmis *et al.*, 2009). Contact angle is the angle at the three-point contact between solid-liquid-gas interface and this gives a degree of wettability of solid by liquid. A smaller contact angle means that the surface is more wettable and if contact angle is measured with water more hydrophilic (Fig. 1). Contact angle is directly influenced by the comparable surface roughness and also indicates an average wettability of the surface.

Table 1 Some anatomical properties of *Rhododendron ponticum* wood
Tablica 1. Neka anatomska svojstva drva rododendrona (*Rhododendron ponticum*)

Anatomical properties /*Anatomska svojstva*	***Rhododendron ponticum* wood** / *Drvo rododendrona*
Fiber length /*duljina vlakanaca*	0.92 mm
Cell-wall thickness / *debljina stijenke*	2 μm
Lumen diameter / *promjer lumena*	6 μm
Trache diameter / *promjer traheje*	30 μm
Trache numbers per mm² / *broj traheja po mm²*	491
Trache content in wood / *udio traheja u drvu*	26 %
Fiber content in wood / *udio vlakanaca u drvu*	34 %
Parenchyma content in wood / *udio parenhima*	24 %
Runkel ratio / *Runkelov omjer*	0.7

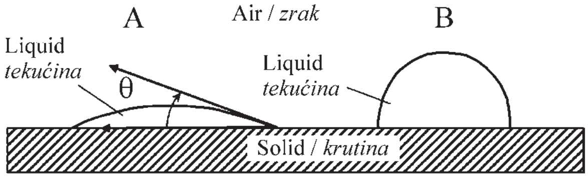

Figure 1 Apparent contact angle (θ) of a sessile drop resting on a MDF surface, showing a high degree of wetting (A) and a low degree of wetting (B)
Slika 1. Kontaktni kut (θ) kapljice tekućine na površini MDF ploče koji pokazuje velik stupanj kvašenja (A) i mali stupanj kvašenja (B)

Wood species has long been recognized as a major variable in the manufacture of MDF. Although previous studies reported that R. *ponticum* wood could be utilized in manufacture of wet and dry-process fiberboard, there is no information about the surface characteristics of the panels (Taskin, 1977; Balkiz, 2006). The objective of this study was to evaluate the surface characteristics of the panels such as surface roughness, surface absorption, and wettability in terms of overlaying of the panels made from R. *ponticum* wood. Secondary objective was to investigate the effect of the sanding treatment at various grit sizes of sand paper on the surface properties of the panels.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Materials
2.1. Materijali

R. ponticum woods (purplish-pink flowered *R. ponticum*) with a top end diameter of more than 5 cm were obtained from the Black Sea region in Turkey. The chips produced from *R. ponticum* woods were converted into fibers in a defibrator at SFC Integrated Wood Company located in Kastamonu, Turkey. The wood fibers were produced using a thermo-mechanical refining process without any chemical and resin. The moisture content of the fibers, as determined by oven-dry weight, was 8 % prior to treatment. A commercial liquid urea-formaldehyde (UF) resin with 50 % solid content was used as an adhesive in the manufacture of the experimental MDF panels.

2.2 MDF panel preparation
2.2. Priprema MDF ploče

Three experimental MDF panels (2800 mm x 2100 mm x 18 mm) were manufactured at SFC Integrated Wood Company located in Kastamonu, Turkey from round wood. After the chips were converted to fibers, the following was added to the fibers: 1 % hydrophobic paraffin, 1 % NH_4Cl (30 % solid content) as hardener, and 11 % UF resin. The mats with average moisture content of 10 % were pressed at temperature of 200 °C for 240 s at a pressure of 4 N/mm^2. The panels were sanded with different types of abrasive grit sizes: 60-, 60+80- or 60+80+120-grit following the cooling process.

A total of three MDF panels were tested, one panel for each level of sanding. The resulting MDF panels had 7-8 % moisture content based on the weight of oven dry fibers. The average density values of the panels varied from 0.781 to 0.790 g/cm^3. Before the surface roughness, contact angle, and surface absorption measurements, the samples were conditioned in a climate chamber having 65 % relative humidity and 20 °C until no changes in the weights were detected.

2.3 Determination of surface roughness
2.3. Određivanje hrapavosti površine

Fifteen samples with dimensions of 50 mm × 50 mm × 18 mm were used from each type of sanding treatment for surface roughness measurements. A total of thirty roughness measurements (two from each of fifteen samples: one measurement parallel to the sand mark and one measurement perpendicular to the sand mark from each of the samples) were taken from each type of sanding treatment. A Mitutoyo SJ-301 surface roughness tester, stylus type profilometer, was used for the surface roughness tests (Fig. 2). Three roughness parameters characterized by ISO 4287: 1997, respectively, average roughness (R_a), mean peak-to-valley height (R_z), and maximum peak-to-valley height (R_y) were considered to evaluate the surface characteristics of the panels. The surface roughness parameters can be calculated from the profiles. R_a is the arithmetic mean of the absolute values of the profile deviations from the mean line and is by far the most commonly used parameter in surface finish measurement. Specification of this parameter is described in previous studies (Hiziroglu, 1996; Hiziroglu and Graham, 1998; Mummery, 1993). Roughness values were measured with a sensitivity of 0.5 μm. Measuring speed, pin diameter and pin top angle of the tool were 10 mm/min, 4 μm and 90°, respectively. The length of tracing line (L_t) was 12.5 mm and the cut-off was λ = 2.5 mm. Measuring force of the scanning arm on the samples was 4 mN (0.4 gf). Measurements were done at room temperature and pin was calibrated before the tests.

2.4 Determination of surface absorption
2.4. Određivanje apsorpcije površine

Surface absorption tests were carried out based on the EN 382-1:1993 standard, which uses toluene as a surface liquid. Twenty surface absorption test specimens (300 mm x 100 mm x 18 mm) were cut from each type of sanding treatment. Each individual sample was put on the test apparatus with a 60° angle and 1 mL toluene is dropped from 1 cm above the surface at a 90° angle to the panel surface according to EN 382-1 standard. The maximum distance in which the toluene drop spread on the panel surface was measured from the starting point, and this value was used as a measure of absorption ability of the samples. The shorter the spreading distance, the greater the absorption of the panels. The minimum spread of toluene drops on the panel surface should be 150 mm based on **Euro MDF Board** (EMB:1993) industrial standard. A total of twenty measurements, one from each of twenty samples, were performed for each type of sanding treatment.

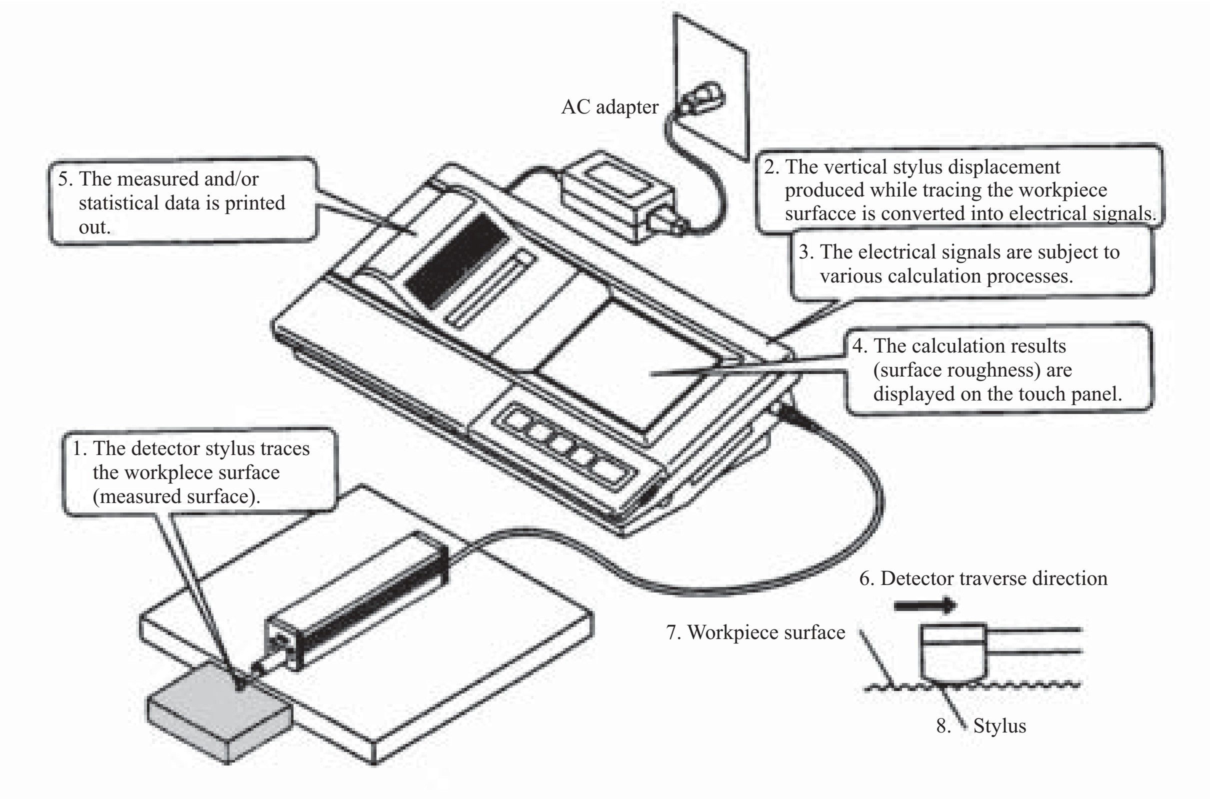

Figure 2 Outline of the stylus type profilometer (Model: Mitutoyo Surftest SJ-301)
Slika 2. Mjerni sustav s profilometrom za mjerenje hrapavosti površine (model Mitutoyo Surftest SJ-301)

2.5 Determination of wettability
2.5. Određivanje kvašenja

The contact angle was defined as the angle through the liquid phase formed between the surface of a solid and the line tangent to the droplet radius from the point of contact with the solid. The contact angles were obtained using a KSV Cam-101 Scientific Instrument (Helsinki, Finland). A sessile drop method was used to measure the contact angle (θ) of a 5-µL distilled water drop that was applied to the surface by means of a pipette (Fig. 3). An image analyze software was used to measure contact angle and shape and size of water droplets for the tested surfaces of MDF samples.

The contact angle measurements were obtained by using a goniometer system connected with a digital camera and computer system. The contact angle measurements were done from one point of view (one-camera device) since MDF surface was isotropic (random orientation of the fibers on the surface). The liquid used for the measurements was distilled water at 20°C with a surface tension of 72.80 mN/m. After the 5-µL droplet of distilled water was placed on the sample surface, the contact angles from the images were measured at 1 sec time intervals up to 60 sec total. Twenty samples with a size of 50 mm x 50 mm x 18 mm were taken used from each type of the treatment for contact angle measurements.

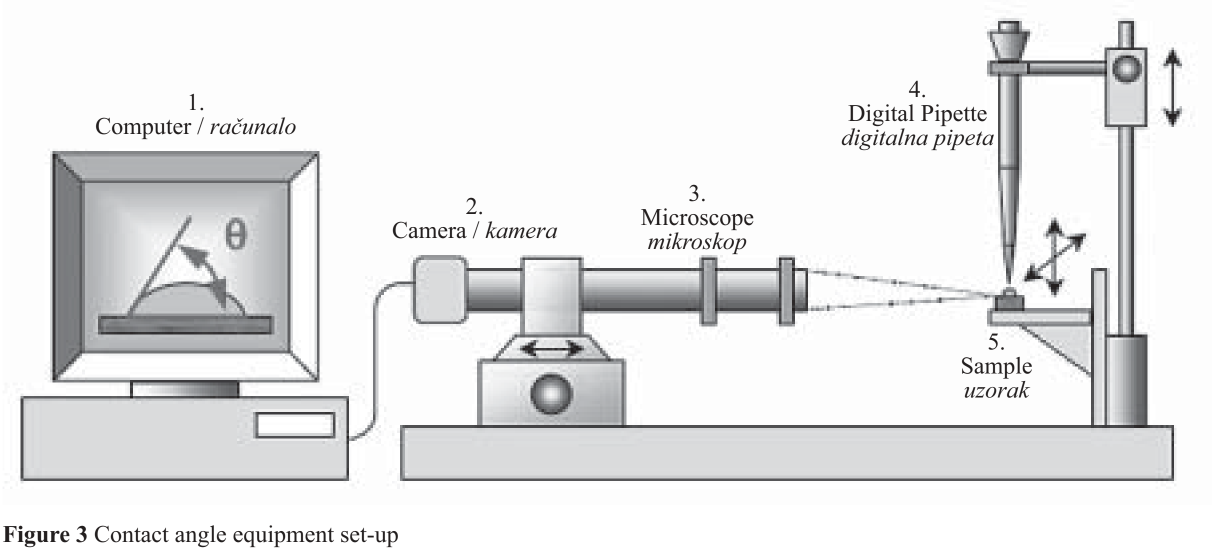

Figure 3 Contact angle equipment set-up
Slika 3. Oprema za mjerenje kontaktnog kuta

2.6 Statistical analysis
2.6. Statistička analiza

For the surface roughness and surface absorption tests, all multiple comparisons were first subjected to an analysis of variance (ANOVA) at $p<0.01$ and significant differences between mean values of the control and treated MDF test samples were determined using Duncan's multiple range test.

3 RESULTS AND DISCUSSION
3. REZULTATI I DUSKUSIJA

3.1 Surface roughness and surface absorption
3.1. Hrapavost i apsorpcija površine

Table 2 shows the results of surface roughness parameters of the MDF samples. The surface smoothness of the MDF panels significantly improved with increasing grit size of sand paper. This was in agreement with the results reported by de Moura and Hernández (2006) and Sulaiman et al. (2009). Statistical analysis showed some significant differences ($p<0.01$) between the average roughness values of the samples. The differences between the sanding treatment groups are given in Table 2 as letters. The R_a, R_z and R_y showed a significant reduction as the sanding grit became higher. The panels sanded with 60-grit sand paper had the roughest surface with an R_a value of 7.01 μm while the smoothest surface was found for the panels sanded with 60+80+120-grit sand paper having an R_a value of 4.15 μm. The R_y and R_z values of the panels also decreased with increasing sand paper grit size. This can be clearly observed by inspection of raw data from the surface roughness profilometer that recorded noticeably shallower ridges and valleys when compared to control panels as it traversed the MDF surface at a constant speed. With the increase of grit size, the size of the aluminum oxide on sand paper gets smaller. The size of the aluminum oxide affects the smoothness of the panel surface. It is obviously clear that application of higher grit of sanding reduced the surface roughness of MDF panels made from *R. ponticum* wood fibers. Sanding process smoothens the panel surface, because small particles (dust) from broken cells fill up the pore area on the surface.

Anatomical structure of wood, determined by elements such as fiber length, width and wall thickness, vessel element length and diameter, and pore density (pore number/1mm^2 in cross section), is one of the important factors affecting surface roughness and surface absorption of wood-based panels. For example, the porous anatomical structure of wood (i.e. oak) is a prime factor influencing its higher surface roughness (Akbulut *et al.*, 2000). In a previous study, average surface roughness of commercial MDF panels (sanded 150+180+200) made from oak, beech, or pine were found as 4.1μm, 3.6 μm, and 3.8 μm, respectively (Akbulut *et al.*, 2000).

The surface absorption values showed trends similar to the results of the surface roughness measurements (Table 2). The surface absorptivity decreased with increasing grit size of the sand paper. This was clearly observed for the MDF samples sanded with 60+80+120-grit sand paper having the average surface absorption value of 255.2 mm, while it was found as 166.4 mm for the samples sanded with a 60-grit size sand paper. Akbulut et al. (2000) reported that the average surface absorption values of MDF panels made from oak and beech wood fibers were 179.1 mm and 197.4 mm, respectively. The MDF panels (sanded with 60-grit size sand paper) made from *R. ponticum* wood had higher absorptivity as compared to the panels made from beech and oak wood fibers. In general, surface absorption of the MDF can be related to raw material characteristics. For example, the porous anatomical structure of oak is a prime factor influencing its surface absorptivity, which is higher than surface absorptivity of beech and *R. ponticum* woods.

3.2 Wettability
3.2. Kvašenje

The surface with lower grit sanding size had a lower contact angle value. Typical contact angle values of the MDF samples sanded with different sizes of sand paper grit are shown in Fig. 4. A smaller contact angle means that the surface is more wettable and more hydrophilic. Contact angle is directly influenced by the comparable surface roughness and also indicates an average wettability of the surface. For example, the MDF samples sanded with 60-grit size have 43.3° contact an-

Table 2 Variations in average surface roughness and surface absorption values of the MDF panels as a function of the grit size of sand paper
Tablica 2. Promjene srednje hrapavosti površine i vrijednosti apsorpcije površine MDF ploča ovisno o granulaciji brusnog papira

Sanding treatment level *Granulacije brusnog papira*	**Panel density** *Gustoća ploče*	**Surface roughness parameters** *Parameter hrapavosti površine*			**Surface absorption** *Apsorpcija površine*
		R_a	R_y	R_z	
	g/cm³	μm	μm	μm	mm
60-grit	0.785 (0.03)	7.01 A[a] (1.68)	56.64 A (5.08)	45.99 A (4.15)	166.4 (9.0) A
60+80-grit	0.790 (0.04)	5.10 B (0.92)	43.99 B (7.10)	35.60 B (4.98)	201.7 (10.6) B
60+80+120-grit	0.781 (0.02)	4.15 C (0.57)	38.60 C (5.17)	30.76 C (3.53)	255.2 (14.4) C

[a] Groups with the same letters in the column indicate that there was no statistical difference ($p<0.01$) between the samples according Duncan's multiple range test. Values in parentheses are standard deviations.

[a] *Grupe s istim slovom u koloni pokazuju da ne postoji statistički značajna razlika (p<0,01) između uzoraka prema Duncanovu testu. Vrijednosi u zagradama standardne su devijacije.*

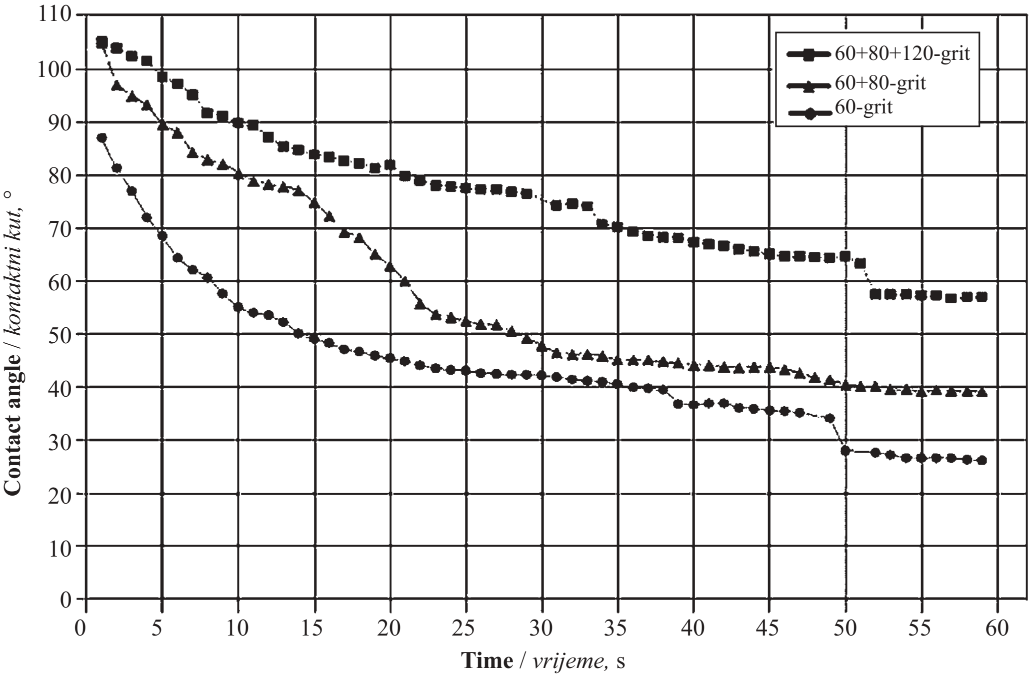

Figure 4 Typical time-dependent contact angles of the MDF samples sanded with different sizes of sand paper grit
Slika 4. Tipična krivulja ovisnosti kontaktnog kuta MDF ploča brušenih brusnim papirom različitih granulacija

gles after 29 s while the surface that was sanded with 60+80+120-grit size showed a contact angle of 76.1°. The MDF surface that was sanded with 60-grit size was certainly more wettable compared to those that were sanded with 60+80+120-grit size. The contact angle of water decreased significantly over time on surface of different grit size.

With increasing surface roughness, the surface absorption of the MDF samples increased (Table 2). This will increase the tendency of water to be captured by capillary forces emerging from greater surface area exposed on the rough wood surface. It should be noted that the higher wettability of rough surfaces may be due to the higher amount of peaks and valley points on the surface where liquid can be captured by capillary force. Surface roughness was proposed to enhance intrinsic adhesion by providing greater interfacial area and some mechanical interlocking mechanism. A low contact angle is very important to capillary flow into the complex porous structure of wood to achieve a strong bond between adhesive and material surface. Therefore, the lower contact angle on the surface should be analyzed as a function of surface roughness.

4 CONCLUSIONS
4. ZAKLJUČCI

The following general conclusions were drawn from the study provided in the paper:

1. Sanding with higher grit size increases the surface smoothness. The average roughness values of the MDF samples decreased by 41 % when comparing 60-grit and 60+80+120-grit sand papers.
2. The MDF surface that was sanded with lower grit size was more wettable compared to those sanded with higher grit size. This means that rougher surface is more wettable compared to smoother surface.
3. The surface absorption showed a similar trend to the results of the surface roughness measurements. The surface absorption values of the MDF panels sanded with lower grit size (60) were 53% lower than higher grit size (60+80+120).
4. The surface properties have a significant impact on bonding and finishing of the MDF panels.

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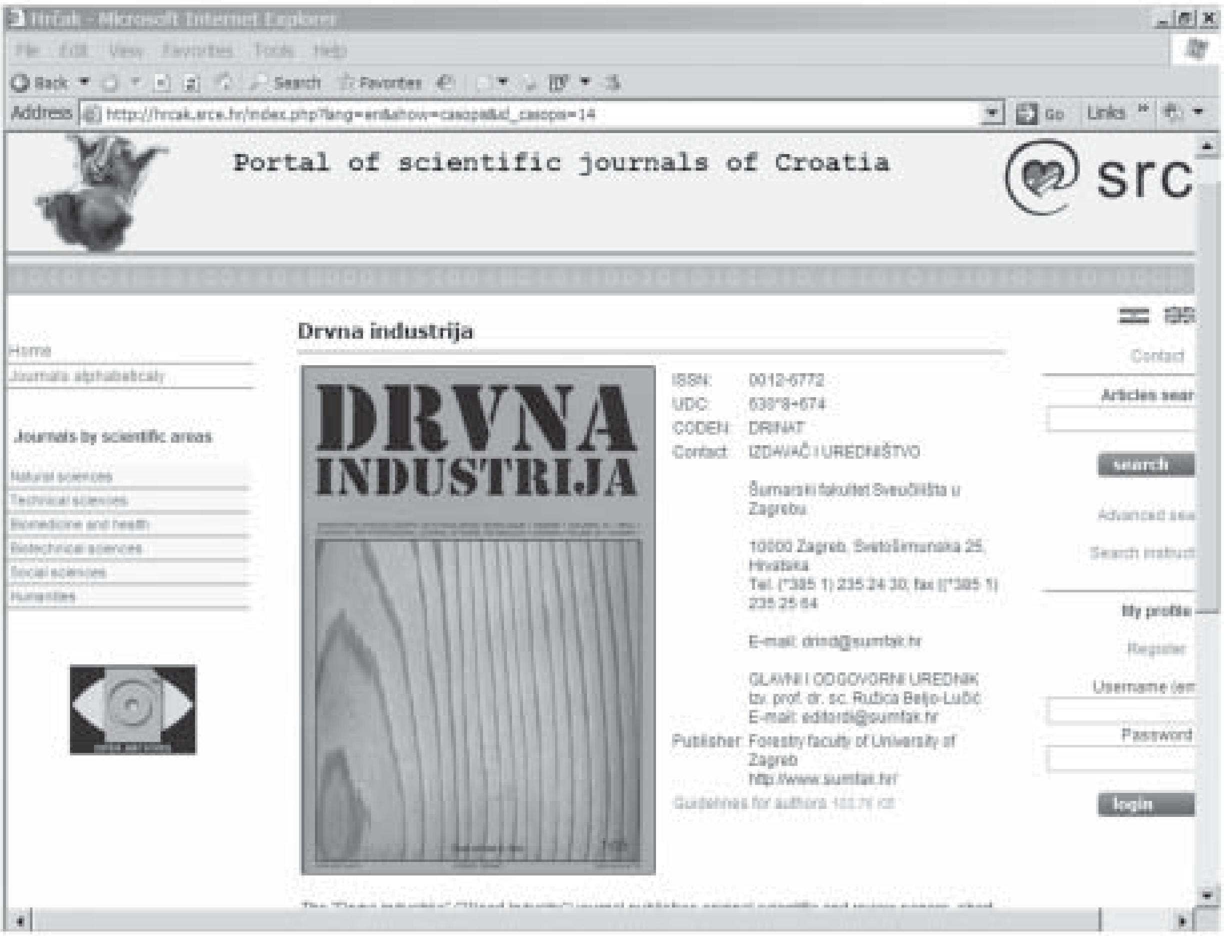

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MDF/HDF Production from Plantation Wood Species

Proizvodnja MDF/HDF ploča od plantažnih vrsta drva

Original scientific paper • Izvorni znanstveni rad
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*UDK: 630*863.312; 630*863.313*

ABSTRACT • *The purpose of this research was to establish the raw material base for the newly built MDF/HDF production line in Mohács, Hungary. The desired raw material for the factory is 80 % poplar and 20 % other species (conifers and broad leaved species). These raw materials should be obtained from wood plantations.*
*Laboratory experiments were done in production of MDF and HDF boards with the following raw materials: 5 and 10 year old Pannonia poplar (*Populus x euramericana Pannónia*), I214 poplar (*Populus x euramericana 'I214'*), black locust (*Robinia pseudoacacia*) and Austrian pine (*Pinus nigra*). The selected trees were evaluated based on the following parameters: diameter, bark volume, ability for barking, ability for chipping, fiber yield, fiber quality, energy consumption of defibrating, chemical analysis of waste water after defibrating. MDF and HDF boards were made in laboratory from clear poplar species, and from a mixture of poplar and Austrian pine and poplar and black locust. In both cases of mixing, the ratio of poplar and other wood species was 80:20. Urea-formaldehyde adhesive and ammonium-sulphate hardener were used during board production. Also some paraffin was added to increase the moisture resistance. The following board characteristics were tested: bending strength, internal bond, modulus of elasticity, thickness swelling, density, moisture content, formaldehyde content. Except the values of internal bond, the results were very satisfactory, highly above the standard requirements. The reason for the low internal bond values is as follows:*
- in the laboratory we could not apply a proper blending of fibers and additives,
- mat forming by hand.
In spite of this, we are sure that an actual technological test production will give good results.

***Key words:** MDF, HDF, wood plantation, Pannonia poplar, I214 poplar, black locust, Austrian pine, fiberboard production, physical aspects of MDF/HDF boards*

SAŽETAK • *Cilj je rada bio ustanoviti sirovinsku bazu za novu proizvodnu liniju ploča srednje i velike gustoće (MDF/HDF ploče). Predviđeni materijal za proizvodnju ploča činilo je 80 % topolovine i 20 % ostalih vrsta drva (četinjača i listača). Za proizvodnju ploča upotrijebljeno je drvo dobiveno plantažnim uzgojem.*
*Laboratorijski eksperiment započeo je proizvodnjom MDF i HDF ploča od ovih materijala: 5 i 10 godina starih stabala panonske topole (*Populus x euramericana Pannónia*), klona topole I214 (*Populus x euramericana 'I214'*), crnog bagrema (*Robinia pseudoacacia*) i austrijskog bora (*Pinus nigra*). Izabrana stabla procijenjena su uzimanjem u obzir ovih parametara: promjera, obujma kore, mogućnosti otkoravanja, mogućnosti usitnjavanja, količine proizvedenih vlakanaca, kvalitete vlakanaca, potrošnje energije za razvlaknjivanje i kemijske analize otpadne vode nakon razvlaknjivanja.*

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U laboratoriju su napravljene MDF i HDF ploče samo od topolovine, od mješavine topolovine i drva austrijskog bora te od topolovine i drva crnog bagrema. U oba slučaja miješanja topolovine s drugom vrstom drva omjer miješanja bio je 80:20. Za proizvodnju ploča upotrijebljeni su urea-formaldehidno ljepilo i amonij-sulfatni učvršćivač. Također je dodano nešto parafina radi povećanja vodootpornosti ploča. Ispitana su ova svojstva ploča: savojna čvrstoća, čvrstoća raslojavanja ploča, modul elastičnosti, debljinsko bubrenje, gustoća, sadržaj vode, sadržaj formaldehida. Osim čvrstoće raslojavanja ploča, druga su svojstva ploča bila vrlo zadovoljavajuća, daleko veća od zahtjeva odgovarajućih normi. Loša vrijednost čvrstoće raslojavanja ploča bila je posljedica toga što u laboratorijskim uvjetima nije bilo moguće ostvariti dobro miješanje vlakana i ljepila, a tepih ploče oblikovan je rukama. Može se pretpostaviti da bi ploče proizvedene u uvjetima stvarne proizvodne tehnologije imale bolja svojstva.

Ključne riječi: *MDF i HDF ploče, plantažno drvo, panonska topolovina, klon topole I214, crni bagrem, austrijski bor, proizvodnja ploča vlaknatica, svojstva MDF/HDF ploča*

1. UVOD
1 INTRODUCTION

Only a small part of Hungary area is forest: ~ 20 000 km^2 (20 %) (Molnár, 2000). The industrial utilization of wood is getting harder because of the recent energy price supporting system of the government. A good solution for both the wood processing industry and the energy sector could be the wood plantations, where improved and selected clones could ensure a higher yield of biomass with improved properties at a more reasonable price. These might relieve traditional forests regarding energy use in power stations (Mőcsényi, 2003).

In Hungary the total forest area is handled by forestry plans, but in the European Union only 60 % of the total area is handled in this way. The governmental forest property in Hungary is 59 %, and in the EU it is only around 21 % on average. In practice, harvesting of forests are only the 80 % of the possible total, which means that the renewable resources are partly unused (National Development Plan).

Recently, there have been only ~ 15 km^2 of plantation forests in Hungary, while 30 km^2 are allowed. The intent of the energy sector is to utilize this surplus. The distribution of plantation species are: 9 % black locust, 22 % willow, 69 % poplar (Szajkó, 2009). It could be a solution to increase suitable plantation forests to balance the demand of both energy sector and wood based panel industry.

This research was done within the scope of NKFP4-0011/2005 FAFORRÁS project's sub-project: „1.5. Scientific establishing of new wood working technologies by laboratory experiments“. The task was to investigate whether the raw material base of MDF/HDF production can be widened to species of plantation forests in domestic relations (Alpár *et al*, 2006).

Common species for MDF production in Europe are spruce (*Picea abies*) and beech (*Fagus sylvatica*) but it largely depends on local market supply as Deppe *et al*. (1996) outlines in his book. Traditionally, in Hungary different species are used at the same time with specific mixing ratios. It is because Hungary's forests are very mixed, so for panel board production several species must be harvested. A typical set up of species is: Scots pine (*Pinus sylvestris*), fir (*Abies alba*), spruce (*Picea abies*), beech (*Fagus sylvatica*), oak (*Quercus robur*) and different poplar clones (*Populus spp.* - eg. *alba* and *nigra* and *cv. euramericana*). There is another reason for different recipes: the required density and quality of the desired board. Higher density boards (eg. HDF) contain more high density broad leaved species like beech or oak (Winkler, 1999). Traditionally, these species come from natural forests but in this research we used only timber from plantation forests.

The main questions of this research were connected to the dry process technology of fiberboard production:

- find suitable plantations – procurement of suitable row material,
- examination of row material,
- chipping – examination of wood chips,
- defibrating – examination of defibrating parameters and the fibers themselves,
- experimental laboratory board production,
- examination of board properties,
- evaluation of examinations.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Procurement and examination of wood from plantations
2.1. Nabava i analiza plantažnog drva

In this research the following species, which might be grown in plantations, were examined:

- poplar clones (*Populus spp*): Pannonia and I214,
- black locust (*Robinia pseudoacacia*),
- black pine (*Pinus nigra*).

First, forest plantations were sought, which were considered suitable for the aims of the research.

The woodlands of two forestry units were visited, the plantations of VIRÁGH Producer, Commercial and Service Deposit Company (*VIRÁGH Termelő, Kereskedelmi és Szolgáltató Bt.*) at Csemő, where the plantations of 4 years old Pannonia poplar, 6 years old black locust, 3 years old black locust, 5 years old I214 poplar, and 5 years old black locust were evaluated, and the plantations of Forestry of North Kiskunság (*Észak Kiskunsági Erdészet*) at Kerekegyháza, where the plantations of 9 year old black locust, 10 year old black pine, 9 year old black locust and 4-5 year old black pine were evaluated.

The evaluation of these plantations showed that the 5 year old timber is not suitable for fiberboard (MDF/HDF) production, because the diameter of this timber is below the required 4 cm in the largest part of

Table 1 Mixing ratio and marking of the produced boards
Tablica 1. Omjer miješanja različitih vrsta drva i oznake proizvedenih ploča

Mark *Oznaka*	**I-214** *klon topole I-214* %	**Pannonia** *panonska topola* %	**Black pine** *crni bor* %	**Black locust** *crni bagrem* %	**Age** *years*
I10_10	100	0	0	0	10
P10_10	0	100	0	0	10
PI55_10	50	50	0	0	10
IF82_10	80	0	20	0	10
PF82_10	0	80	20	0	10
IA82_10	80	0	0	20	10
PA82_10	0	80	0	20	10

the logs (in case of smaller diameter the size of chips is unsuitable). In spite of this the main characteristics of this timber were also examined.

2.2 Preparation and examination of raw materials
2.2. Priprema i analiza sirovine za izradu ploča

The preparation of raw material was made at MOFA Zrt. in industrial conditions: chipping was done by a Ferrari drum chipper and the chips were defibrated by an industrial Defibrator.

The moisture content and the size distribution of the chips were examined in the laboratory of the Institute of Wood and Paper Technology at the University of West Hungary. In case of the latter a Retsch Plan vibrating classifier was used. The sieves and the requirements of different size ranges are as follows (opening of the sieves in mm): 31.5 – max. 20 %; 20.0 – min. 50 %; 10.0 mm – max. 20 %; bottom tray – max. 10 %. To determine the bark content, the fractions were completely sorted out. Maximum bark content is 20 %.

All the four species were defibrated with the same parameters. In the pre-heater, the steam pressure was 7.8 bar, the temperature was 173 °C, and the filling level was set to 45 %. The fibers (moisture content of about 50 %) were dried in laboratory drier with daily air mixing for 8 hours during 20 days at 70 °C.

Regarding the fiber production the following examinations were done:

1. size distribution analysis:
   This was made by a vertical Defibrator fiber separator in wet condition; the mounted sieve hole sizes were 1.0, 0.3, 0.15, 0.08 mm.
2. amount of produced fiber:
   This gives the fiber capacity per hour.
   amount of produced fiber = (*volume of fiberboard* x *density*) / *production hours*
3. energy need for fiber production:
   The electric energy consumption, production time and steam consumption were measured.

2.3 Laboratory board production
2.3. Proizvodnja ploča u laboratoriju

Table 1 shows the mixing ratio and the marking of the produced boards.

General parameters of board production are shown in table 2. In every case urea-formaldehyde adhesive (UF) was used with ammonium-sulphate as a hardener. Also, 1.5 % of paraffin dispersion was added.

The thickness of 4 mm was chosen, because the successor of MOFA Zrt., the Kronospan-MOFA Kft. plans to produce mainly 3-4 mm fiberboards.

The boards were pressed in a laboratory size Siempelkamp hot press at 180 ^{o}C. The prevailing initial pressure was decreased in two steps during the 68 sec press time. The average initial specific pressure was 7 MPa. The required 4 mm thickness was ensured by steel bard.

2.4 Board tests
2.4. Ispitivanje ploča

The following tests were made on the laboratory fiberboards:

- Density (EN 323) - ρ
- Bending strength (EN 310) - f_m
- Modulus of elasticity (EN 310) - E_m
- Internal bond (EN 319) - f_{ti}
- Thickness swelling (EN 317) - G_t
- Formaldehyde content (EN 120) - P_e

During the evaluation of test results EN 622-5 was considered, (Table 3), which specifies the requirements of fiberboards produced by dry process (MDF).

Table 2 General parameters of MDF/HDF boards
Tablica 2. Parametri MDF/HDF ploča

Length / *duljina*, m	0.40
Width / *širina*, m	0.40
Thickness / *debljina*, mm	4.0
Planned density oven dry /*gustoća u suhom stanju*, kg/m^3	800
Solid resin content, % (oven dry wood) / *sadržaj smole, % (suho drvo)*	12
$(NH_4)_2SO_4$, %	1.0
MC_{board}	8 %
Solid content of resin / *sadržaj smole*, %	66.0
Solution of $(NH_4)_2SO_4$ / *otopina* $(NH_4)_2SO_4$, %	35.0

Table 3 Standard requirements for MDF of 4 mm thickness
Tablica 3. Zahtjevi normi za MDF ploče debljine 4 mm

Properties / *Svojstvo*	**Test method** *Ispitna metoda*	**Unit** *Jedinica*	**Nominal thickness** *Nominalna debljina,* >2,5-4,0
Thickness swelling – 24 h / *debljinsko bubrenje – 24 h*	EN 317	%	35
Internal bond / *čvrstoća raslojavanja*	EN 319	MPa	0,65
Bending strength / *savojna čvrstoća*	EN 310	MPa	23
Modulus of elasticity / *modul elastičnosti*	EN 310	MPa	-

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

3.1 Examination of plantation woods
3.1. Analiza plantažnog drva

Diameters on both ends of logs of purchased species were measured with and without bark by a caliper. From these data the portion of bark was determined (Table 4 and Figure 1).

In case of the investigated poplars and pine, the bark volume is in inverse relation to the age of the tree. The reason for this is that these species create an initially thick bark, which grows significantly slower than wood.

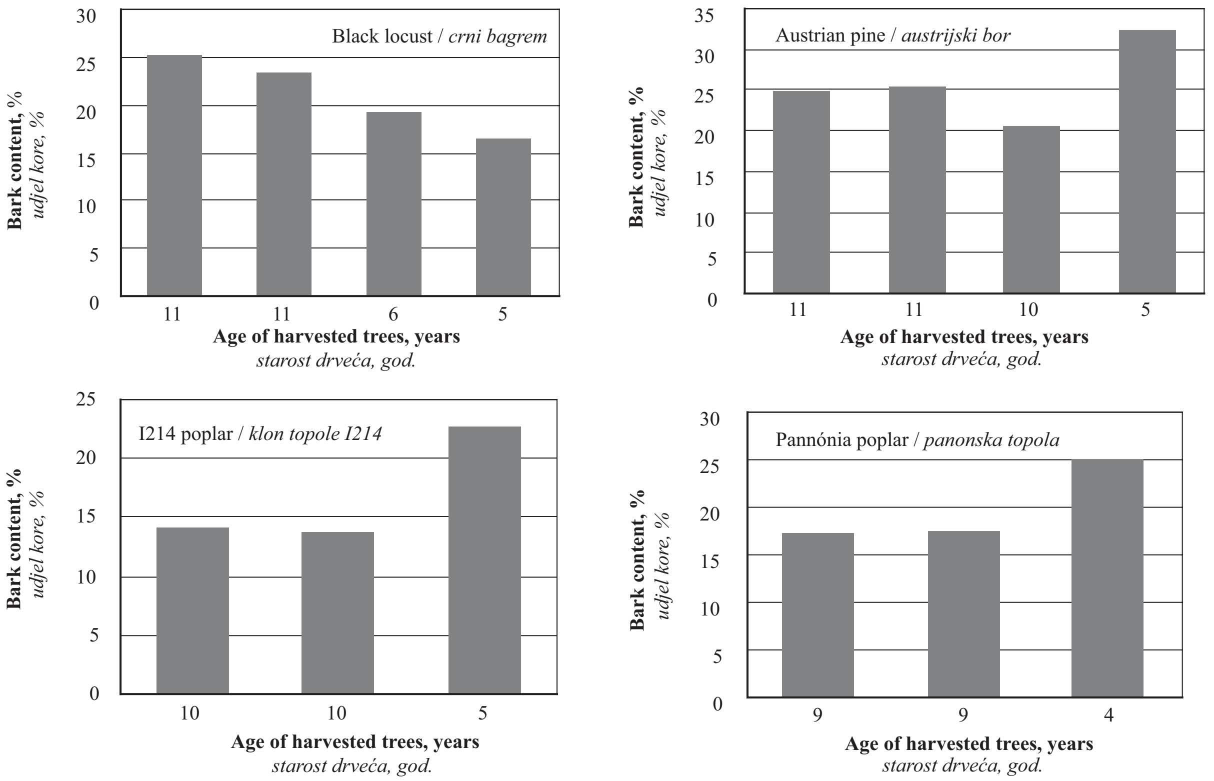

Figure 1 Bark content of different species
Slika 1. Sadržaj kore različitih vrsta drva

Table 4 Portion of bark of species of different age
Tablica 4. Udjel kore u drvu različitih vrsta i starosti

Species / *Vrsta*	**Age,** years / *Starost*, god.	**Share of bark** / *Udjel kore,* %
Black locust / *crni bagrem*	11	25.2
Black locust / *crni bagrem*	11	23.3
Black locust / *crni bagrem*	6	19.3
Black locust / *crni bagrem*	5	16.5
Black pine / *crni bor*	11	24.8
Black pine / *crni bor*	11	25.3
Black pine / *crni bor*	10	20.5
Black pine / *crni bor*	5	32.2
I214 poplar / *klon topole I214*	10	14.1
I214 poplar / *klon topole I214*	10	13.7
I214 poplar / *klon topole I214*	5	22.7
Pannonia poplar / *panonska topola*	9	17.2
Pannonia poplar / *panonska topola*	9	17.6
Pannonia poplar / *panonska topola*	4	25.1

In case of poplar and pine species the bark volume decreases with time. In case of the examined poplars the decrease of bark volume was 7-8% during 5 years. In case of pine the decrease was 12% during the same period.

Regarding black locust, the slow growth of the wooden part also results in a small diameter of 4 cm even at age of 11. Also the bark grows faster (gets thicker) than the wooden part in the investigated period of their life. Therefore, the wood of young black locust is not adequate to produce fiberboards; it would be unprofitable.

On the other hand, the volume of the wooden part is a more important factor in fiberboard production. A smaller amount of fiber can be obtained from pine than from poplar at the same age.

None of the examined species were found suitable for fiberboard production at the age of 5. The bark volume of such timber is too large and timber is too thin, so it is hard to debark them, and the fiber yield is too low.

3.2 Examination of wood chips
3.2. Analiza drvnog iverja

The following diagrams (Figures 2 to 5) show the examination results of chip size distribution and bark content of chipped material.

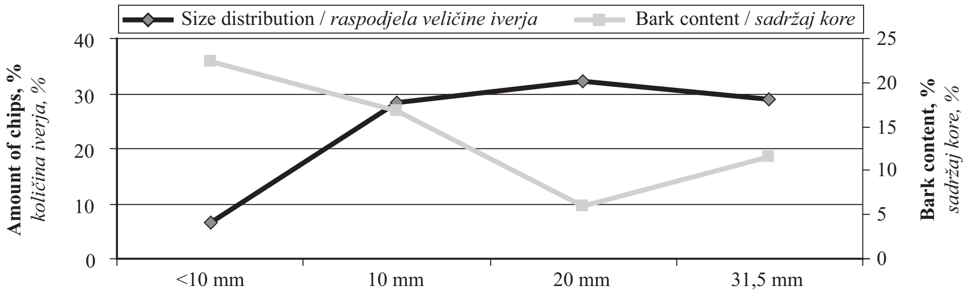

Figure 2 Size distribution and bark content of I214 poplar
Slika 2. Raspodjela veličine iverja i udjel kore za drvo klona topole I214

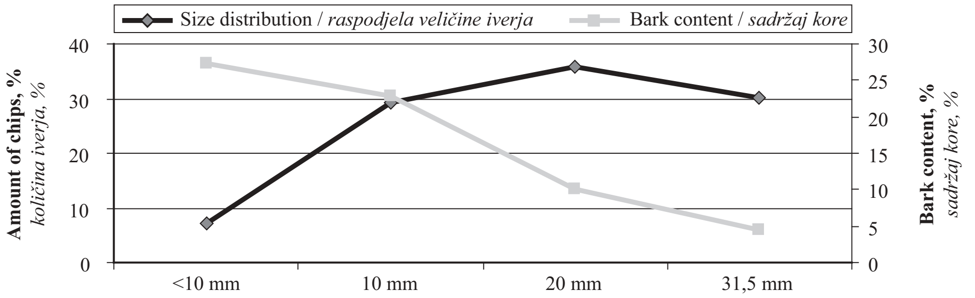

Figure 3 Size distribution and bark content of Pannonia poplar
Slika 3. Raspodjela veličina iverja i udjel kore za drvo panonske topole

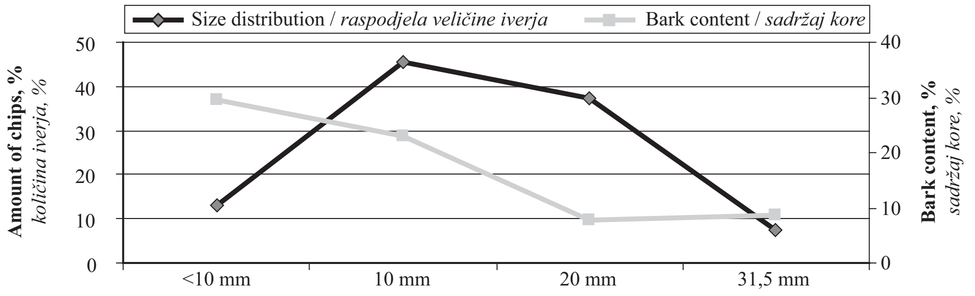

Figure 4 Size distribution and bark content of black locust
Slika 4. Raspodjela veličine iverja i udjel kore za drvo crnog bagrema

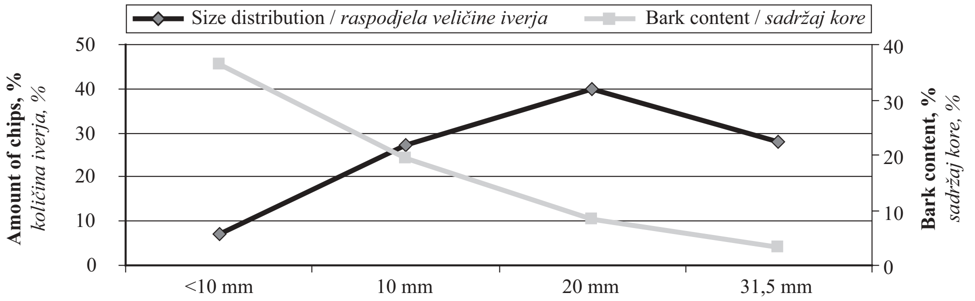

Figure 5 Size distribution and bark content of black pine
Slika 5. Raspodjela veličine iverja i udjel kore za drvo crnog bora

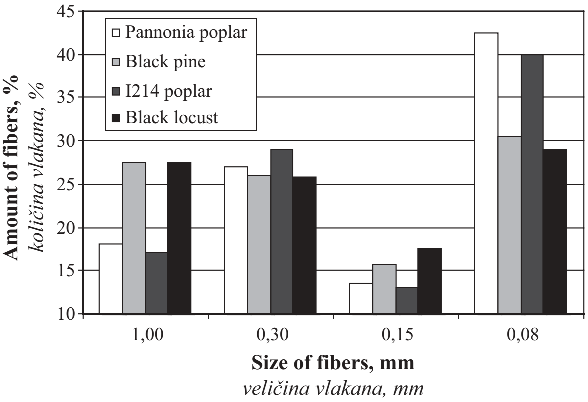

Figure 6 Fiber size distribution
Slika 6. Raspodjela veličine vlakanaca

In case of all four species only the size range below 10 mm met the length requirements of chips, as described in the "Technical Documentation" of the company MOFA Zrt.. At the same time the size distribution curves were adequate, except in case of black locust.

The reason for the differences regarding black locust as compared to poplar and pine is a more dense structure and higher stiffness of fibers. Therefore black locust has to be rechipped in some cases.

Regarding bark content, the amount was found below the limit of 20 % in every case.

3.3 Examination of fibers
3.3. Analiza vlakanaca

3.3.1 Fiber size distribution
3.3.1. Raspodjela veličine vlakanaca

Figure 6 shows the size distribution of produced fibers.

The best fibers for dry process fiberboard production are the ones that remain on the 0.15 mm hole size sieve. At this size almost the same amount of fibers were measured in case of both poplar species.

However, in case of black pine and black locust more fibers were found at 1 mm level. In the case of the poplars a small amount of fibers at 0.08 mm level is favorable.

Comparing the results of black locust and black pine to poplars, it was established that the amounts at the levels of 0.08 mm and 1.0 mm are almost the same. This means that it is more difficult to defibrate pine and black locust than the poplars, and hence smaller amount of fine fibers can be produced from them. This also means that these two species can be defibrated better together than together with other species. Species should be defibrated separately with specifically defined defibratig parameters to achieve the same fiber quality in case of different species.

Based on fiber size distribution diagrams all the four examined species (these are 10 year old trees!) are suitable for dry process fiberboard production, but if the finest and the roughest fraction could be decreased more technical fibers could be obtained.

3.3.2 Obtained fibers and power consumption
3.3.2. Količina proizvedenog iverja i potrošnja energije

Table 5 shows economical parameters of fiber production.

Based on our previous experiences the harder wood species can be defibrated at a lower energy consumption. In this experiment while defibrating the black locust the feeding snail of the Defibrator was jammed several times so this species resulted in the highest energy consumption. This result should be discarded.

The highest steam consumption was found in the case of black pine, but its electric power consumption was not so high.

In case of Pannonia poplar the electric power consumption was lower and the steam consumption higher, but in case of I214 poplar it was quite the opposite.

3.4 Examination of board properties
3.4. Analiza svojstava ploča

In the following chapter, the results of tested parameters are introduced. Only tests based on EN standards were made as described above.

3.4.1 Density (EN 323)
3.4.1. Gustoća (EN 323)

In the research plan, the production of two types of fiberboard was planned: 800 kg/m^3 (MDF) and 950 kg/m^3 (HDF).

The measured density of the produced experimental MDF boards was 801±15kg/m^3.

The measured density of the produced experimental HDF boards was 915±15kg/m^3.

3.4.2 Bending strength (EN 310)
3.4.2. Savojna čvrstoća (EN 310)

As shown in Figure 7 the bending strength exceeded the standard requirement (23 MPa). In case of fiber boards with lower density (800 kg/m^3) the requirements

Table 5 Obtained fibers and power consumption
Tablica 5. Količina proizvedenih vlakanaca i potrošnja energije

Wood species *Vrsta drva*	**Obtained fibers** *Proizvodnja vlakanaca* t/h	**Specific electric power consumption** *Specifična potrošnja električne energije* kWh/m^3	**Specific steam consumption** *Specifična potročnja pare* t/m^3
Pannonia poplar *panonska topola*	1.90	99.51	0.806
I214 poplar *klon topole I214*	1.76	107.27	0.746
Black locust *crni bagrem*	0.94	144.80	0.883
Black pine *crni bor*	1.98	96.80	0.892

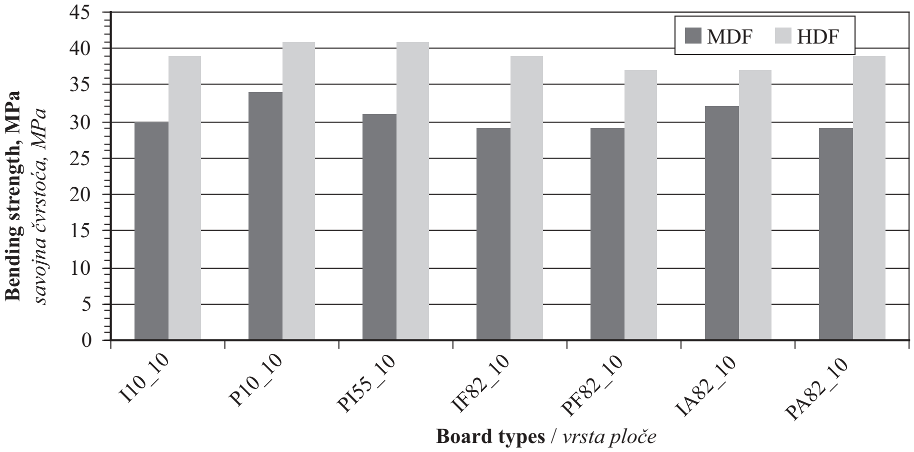

Figure 7 Bending strength of MDF and HDF
Slika 7. Savojna čvrstoća MDF i HDF ploča

(27 MPa) for MDF.H type board (use in wet condition for general purposes) were fulfilled, and in case of higher density boards the requirements (30 MPa) of MDF.HLS type (use in wet condition for load bearing purposes) were fulfilled.

Regarding the poplars, Pannonia clone showed slightly better values than I214. When other species (black pine or black locust) were mixed with poplar in a 20% ratio, a small decrease of bending strength was measured.

In case of MDF boards, testing was carried out of a control board made of special fibers from a dry process line. Its bending strength was the highest, because these fibers were shorter and smoother than the fibers from MOFA's wet process line.

3.4.3 Modulus of elasticity (EN 310)
3.4.3. Modul elastičnosti (EN 310)

The EN 622-5 standard has no requirements for MOE in case of board thickness below 4 mm for MDF of general use type. At the same time it should be mentioned that all of the HDF experimental boards have fulfilled the minimum requirements even of MDF.HLS type panels (3000 MPa)!

Regarding MDF boards of lower density, only in case of boards made 100 % of poplar was the MOE higher than the requirement (2700 MPa) for MDF.H type panels (Fig. 8).

3.4.4 Internal bond (EN 319)
3.4.4. Unutrašnje raslojavanje (EN 319)

The internal bond values of both MDF and HDF boards were above the standard requirements. There is no significant effect of the species on the internal bond values (Fig. 9).

3.4.5 Thickness swelling (EN 317)
3.4.5. Debljinsko bubrenje (EN 317)

The values of thickness swelling were much better than the standard requirements in every case (Fig. 10).

Regarding water adsorption, higher values were measured in case of lower density MDF boards (average 75 %) than in case of denser HDF boards (average 56 %).

3.4.6 Formaldehyde content (EN 120)
3.4.6. Sadržaj formaldehida (EN 120)

Hence the content of adhesive was the same (12 %) in case of each board type and the free formaldehyde content was measured only on one board: No. P10 10M MDF.

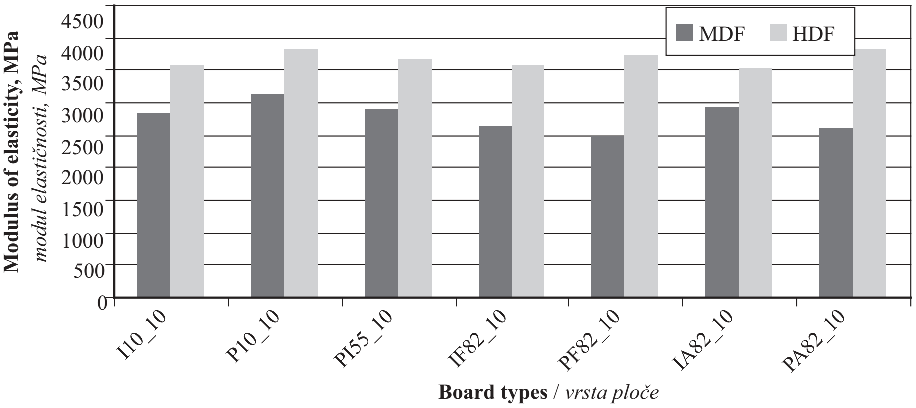

Figure 8 MOE of MDF and HDF boards
Slika 8. Modul elastičnosti MDF i HDF ploča

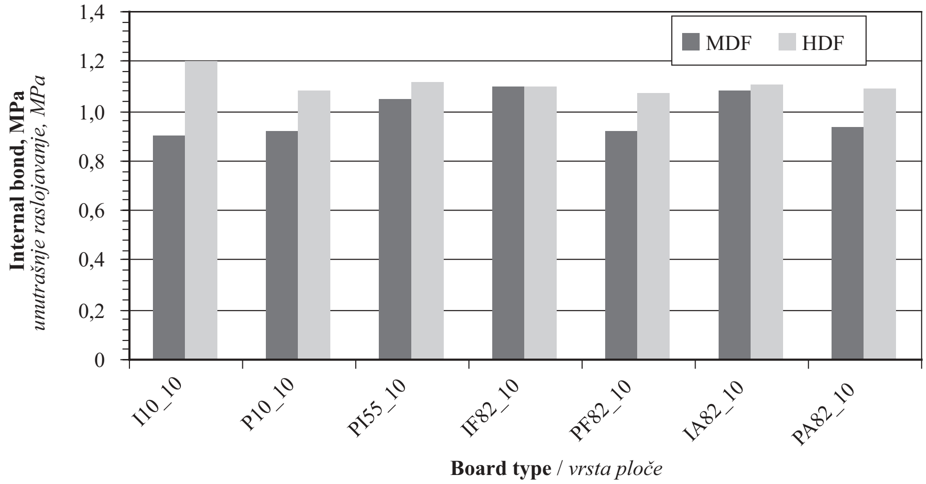

Figure 9 Internal bond of MDF and HDF boards
Slika 9. Čvrstoća raslojavanja MDF i HDF ploča

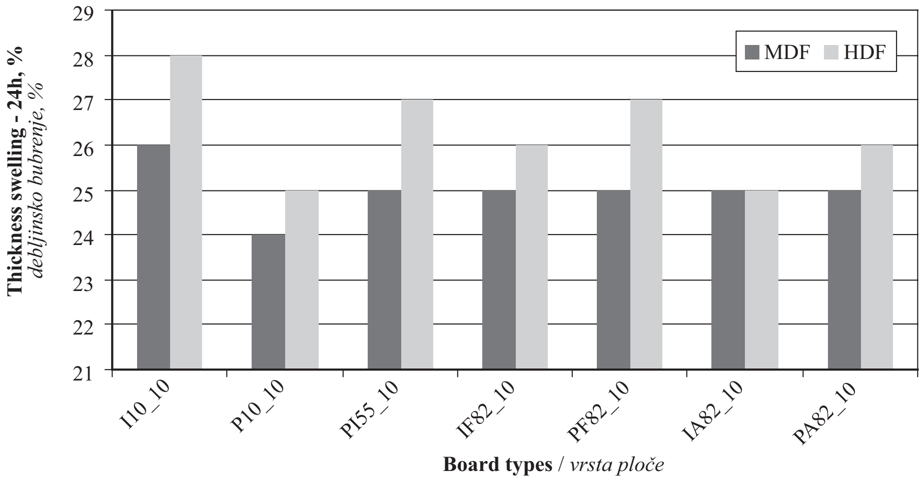

Figure 10 Thickness swelling (24h) of MDF and HDF boards
Slika 10. Debljinsko bubrenje (24 h) MDF i HDF ploča

The result was 6.5 mg/100g, which is below the standard requirement of a maximum 8 mg/100g. So these boards are considered as E1.

4 CONCLUSIONS
4. ZAKLJUČCI

The aim of this project was to examine whether the raw material basis of dry process MDF/HDF production can be widened by species from domestic wood plantations. In this project in 2006 the following 5 and 10 year old species were examined: Pannonia poplar, I214 poplar, black pine and black locust.

Based on previous examinations, the 5 year old timber was discarded for laboratory board production. It could be established during visiting the plantations that the 5 year old trees are not suitable to produce MDF/HDF boards, because the diameter of their log is below the required 4 cm. Also these young trees have larger bark volume, and debarking is difficult.

In case of plantation wood, regarding the diameter, a drum debarker is recommended. Regarding the amount of obtained technical fibers in case of black pine and the poplars no significant differences could be observed. The measured values of defibrating of black locust are not usable because of the jam of the feeding snail.

Regarding energy consumption, Pannonia poplar needed lower use of electric energy but higher use of steam. In case of I214 poplar it was quite the opposite.

Boards were made 100% from both poplar species, from mixtures of poplars at a 50%-50% ratio and from mixtures with both other species at an 80%-20% ratio. All standard physical and mechanical properties were tested.

All the standard requirements were fulfilled.

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“DRVO JE PRVO – PRIJENOS ZNANJA U PRAKSU KAO PUT IZLASKA IZ KRIZE”

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Agnieszka Kurowska, Piotr Borysiuk, Mariusz Mamiński, Marcin Zbieć[1]

Veneer Densification as a Tool for Shortening of Plywood Pressing Time

Stlačivanje furnira kao metoda skraćenja vremena prešanja furnirskih ploča

Preliminary paper • Prethodno priopćenje
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ABSTRACT • *Veneer densification was performed at 105±3 ºC under pressure of 1,8 N/mm² for 30 s. The approach allowed to reduce 20-mm thick plywood pressing time by 12-25 % when compared to the non-densified controls. It was found that densification did not affect shear strength of the plywood which met the requirements of the respective standards.*

Key words: *plywood, veneer densification, pressing time, shear strengths*

SAŽETAK • *Stlačivanje furnira provedeno je pri temperaturi 105±3 ºC i tlaku 1.8 N/mm² tijekom 30 s. Na taj je način omogućeno skraćenje vremena prešanja furnirske ploče debljine 20 mm za 12-25 % u usporedbi s kontrolnim uzorcima od nestlačenih furnira. Istraživanje je pokazalo da stlačivanje furnira ne utječe na čvrstoću smicanja furnirske ploče koja zadovoljava zahtjeve odgovarajućih normi.*

Ključne riječi: *furnirska ploča, stlačivanje furnira, vrijeme prešanja, čvrstoća smicanja*

1 INTRODUCTION
1. UVOD

The pressing time is a crucial parameter of plywood processing, since it strongly affects total number of cycles during a single shift and, in consequence, the total capacity of a production line. On one hand, in order to maximize the efficacy of the process, pressing time should be as short as possible. On the other hand, it should be long enough to allow the adhesive to be cured.

Wood, as a porous body, is good insulator and therefore weak heat conductor (heat conductivity coefficient ranges from 0.12 up to 0.35 W/mK). Heat conductivity of wood is dependent mainly on the species, density, grain direction, moisture content and temperature. Dependence of heat conductivity and density of wood is practically linear (Kollmann, 1955). Increase of density causes proportional gain of wood heat transfer. Heat conductivity along the wood grain is around 2 times higher than in perpendicular direction.

Low cross the grain heat conductivity is especially visible during overheating veneer loads for thick board production. As a result, long heating (pre-pressing) times and in effect long total pressing times are needed for proper plywood production.

As it is reported in literature, the shortening of plywood pressing time can be realized by steam injection (Jokerst and Geimer, 1994) or by combining steam injection and veneer incising. Veneer incising followed by steam injection provided reduction of pressing time by 27% for 21-mm thick 7-ply plywood and by 32%

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for 40-mm thick 13-ply LVL when compared to standard technology (Troughton and Lum, 2000). Dai et al (2003) stated that veneer incisions in 13-ply LVL manufacturing did not significantly affect either pressing times or mechanical performance of the product.

Other approach to shortening of the overheating time and total pressing time is preliminary veneer densification. Bekhta and Marutzky (2007) stated that veneer densification increases the possibilities of design and control of physical and mechanical properties of the material. Densified beech veneers allow production of plywood with better shear strength properties with lowered glue consumption by 25 % and with pressure limited by 22 %. Densification process includes veneer pre-pressing by 33 % and final manufactured plywood by 0.1 %. Plywood properties are mainly dependent on the stage of the technological process and conditions in which the source material undergoes densification process (Bekhta and Marutzky, 2007; Bekhta *et al*, 2009). In contemporary plywood technologies this processing is not used at all.

The objective of the study was to investigate the possibility of shortening the overheating time and total pressing time of plywood by preliminary veneer densification.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

Pine (*Pinus sylvestris*) veneers of dimensions 350 x 350 x 1.4 mm^3 and 4 % moisture content were used in the experiments. The densification was performed at 105±3 ºC in a laboratory press under pressure of 1.2, 1.5 or 1.8 N/mm^2 for 15 or 30 s. The most effective plasticization of wood, densification and retention of the reduced thickness was obtained at 1.8 N/mm^2 pressure and 30 s pressing time. 20-mm thick, 15-ply plywood was made using densified or non-densified veneers. A urea-formaldehyde adhesive (UF - 100 p. b.w., filler - 16 p.b.w., hardener – 16 p.b.w., water – 23 p.b.w.) was used for bonding. Gelling time was measured according to the following procedure: a glass test tube with 10 g of glue was immersed in boiling water. The glue was mixed with a glass stick until gelation occurred. Measurement was made in triplicate.

Total pressing time (t_p) was calculated from the relation (1):

$$t_p = t_g + t_0 \tag{1}$$

where: t_g - gelling time at a given temperature, t_o - time of heating the most internal glueline (stack core) to a given temperature. Three temperatures were examined: 80 ºC, 90 ºC and 100 ºC.

Plywood with glue loads 160 g/m^2 and 120 g/m^2 were pressed under pressure of 1.2 N/mm^2 and at 130±2 ºC. Plywood variants and results are tabulated in Table 2.

For the plywood prepared at the shortest pressing times, the shear strength of the glue lines and wood failure percentage were determined according to EN 314-1 and EN 314-2. Twenty specimens were tested in each batch. Both the veneers prior to densification and resultant plywood were conditioned at 20±2 ºC and 65±5 % relative humidity for 7 days.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

The applied densification conditions allowed for sufficient plasticizing of the veneers and retention of their reduced thickness. Due to the process, the initial 1.45-1.55-mm thickness of the veneers (4 % moisture content) was reduced to 1.35-1.40 mm (2 % moisture content). The average densification ratio was 8 %. Gelation time (t_g) of the glue is presented in Table 1.

Veneer densification clearly reduces overheating time in comparison to unprocessed samples (Fig. 1). The shortest heating time was obtained with 120 g/m^2 glue load variant. This phenomenon is caused by lower total moisture content in the veneer stack. Furthermore, faster stack internal temperature gain is caused by more dense wood substance.

Data presented in Table 2 clearly show that 20 mm plywood made of densified veneers had 24-54 % shorter overheating time (t_o) in comparison to control sample (heating up to 100 °C). Again, taking into account glue gelation times (t_g), it was concluded that veneer densification shortened total pressing time (t_p) by 12-25 % in

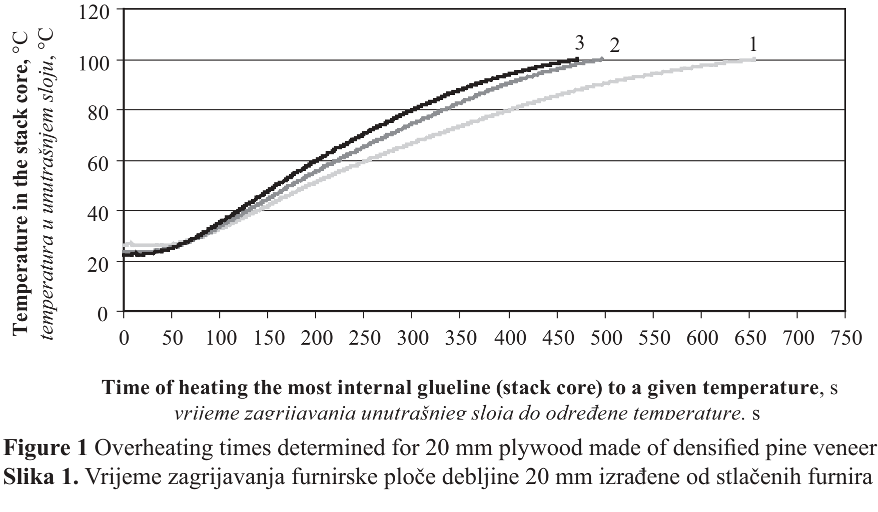

Figure 1 Overheating times determined for 20 mm plywood made of densified pine veneers
Slika 1. Vrijeme zagrijavanja furnirske ploče debljine 20 mm izrađene od stlačenih furnira

Table 1 Glue gelation time of urea-formaldehyde adhesive at different temperatures
Tablica 1. Vrijeme stvrdnjavanja urea-formaldehidnog ljepila pri različitim temperaturama

Stack core temperature, °C *Temperatura u središtu,* °C	**Gelation time (t_g)**, s *Vrijeme stvrdnjavanja,* s
80	315
90	186
100	80

comparison to control samples (total pressing time is a sum of gelation and overheating times).

It was found that (Table 3) modification of veneers by densification showed no significant effect on plywood shear strength in dry and wet state. Wood shear percentage ranged from 60 up to 100 % for dry samples, and after soaking in water it dropped to 30 – 60 %. The percentage of shear in wood in dry state is significantly higher for plywood made of densified veneers than in control samples (ranging between 60 and 70 %). Strength properties characterized by lower glue bonds (in dry and wet state) of plywood made of densified veneers are caused by lower glue saturation possibilities in modified veneers. This result confirms literature results. Pocius (2002) concludes that one of the conditions of good glue bond formation is solubility of glue in the base (or intrinsic wettability) and surface development, substantially lower in densified veneers. The shear strength values as well as the percentage of wood failure met the requirements of the EN 314-2 standard. Basing on the obtained results it may be concluded that veneer densification may allow glue load reduction without negative impact on the bond strength properties. This is also confirmed by other researchers (Bekhta and Marutzky, 2007).

4 CONCLUSIONS
4. ZAKLJUČCI

This paper deals with the approach to shortening of the total possible plywood pressing time with veneer densification. The obtained results show overheating time shortening possibilities, and thus final total pressing time shortening of the 20 mm pine plywood with strength properties conforming to PN-EN 314-2:2001 standard.

The shortest total pressing time of densified veneer plywood reached 551s (variant with 120 g/m^2 glue load). Veneer densification allows shortening of overheating time by 24-54 % and pressing time by 12-25 %, at 80-100 °C while upkeeping internal stack temperature.

Densified veneers, except 25 % pressing time shortening, allow 25 % glue load reduction without affecting glue bonds strength properties.

Table 2 Pressing conditions and reduction of pressing time
Tablica 2. Uvjeti prešanja i smanjenje vremena prešanja

Variant *Varijanta*	**Glue loads** *Količina ljepila* g/m^2	**Stack core temperature** *Temperatura u središnjem sloju* °C	**Overheating time (t_o)** *Vrijeme zagrijavanja* s	**Shortening of lay up overheating time** *Skraćenje vremena zagrijavanja* %	**Pressing time (t_g+t_o)** *Vrijeme prešanja* s	**Shortening of pressing time** *Skraćenje vremena prešanja* %
control plywood *kontrolni uzorak furnirske ploče*	160	100	656	0	736	0
plywood from densified veneers *furnirska ploča od stlačenih furnira*	160	100	497	24	577	22
		90	396	40	582	21
		80	333	49	648	12
	120	100	472	28	552	25
		90	365	44	551	25
		80	301	54	616	16

Table 3 Shear strengths and wood failure percentage of plywood pressed at the shortest pressing times (values in parentheses are standard deviations)
Tablica 3. Čvrstoća smicanja i postotak loma po drvu furnirske ploče prešane pri najkraćem vremenu (vrijednosti u zagradama standarne su devijacije)

Variant *Varijanta*	**Glue loads** *Količina ljepila* g/m^2	**Glue line number** *Linija ljepila*	**Dry shear strength** *Suha smicajna čvrstoća* N/mm^2	**Percentage of wood failure** *Postotak loma po drvu* %	**Wet shear strength** *Vlažna smicajna čvrstoća* N/mm^2	**Percentage of wood failure** *Postotak loma po drvu* %
control plywood *kontrolna furnirska ploča*	160	1	3.44 (0.27)	60	2.73 (0.18)	40
		7	3.59 (0.50)	70	2.81 (0.30)	50
plywood from densified veneers *furnirska ploča od stlačenih furnira*	160	1	2.69 (0.19)	60	2.01 (0.19)	40
		7	3.11 (0.39)	70	1.92 (0.15)	30
	120	1	2.59 (0.31)	90	1.88 (0.20)	30
		7	3.63 (0.35)	100	2.52 (0.19)	60

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Glued Laminated Timber in Architecture

Lamelirano lijepljeno drvo u arhitekturi

Professional paper • Stručni rad
Received – prispjelo: 17. 2. 2010.
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ABSTRACT • *Structural glued laminated timber (glulam) is an engineered, stress-rated product that consists of two or more layers of lumber (i.e., laminations) glued together with the grain running lengthwise. This article discusses typical shapes and sizes of glulam construction elements and static systems.*
This paper presents special stress conditions in the apex area of double-tapered beams with varying cross-section, curved and pitched-cambered beams. The results (tensile stresses perpendicular to the grain) obtained by the SAP2000 computer program are shown. In many cases these stresses are the crucial parameter that determines the size of the beam in the apex area.
The article discusses the most typical application of glulam elements and analyses its production and use in Slovenia and other EU member states. The study seeks to identify opportunities for increased use of glulam construction in Slovenia.

Key words: *wood structure, glued laminated timber (glulam), structural elements, composite*

SAŽETAK • *Lamelirano lijepljeno drvo moderni je kompozitni materijal koji se sastoji od tankih lamela uglavnom paralelnih vlakanaca. U radu se opisuje tipični oblik i veličina lameliranih lijepljenih nosača i statičkih sustava. Prikazane su posebnosti pri napregnutom stanju nosača od lijepljenog drva promjenjivog presjeka (osobito u sljemenoj zoni). Napravljena je analiza naprezanja računalnim programom SAP2000. Grafički su prikazana vlačna naprezanja okomito na vlakanca drva, koja su obično odlučujuća za određivanje dimenzija u sljemenoj zoni nosača. U članku se opisuje najčešća uporaba lameliranoga lijepljenog drva i analiziraju proizvodnja i uporaba u Sloveniji i drugim zemljama EU. Upozoreno je na mogućnost povećane upotrebe konstrukcija od lameliranoga lijepljenog drva u našem okruženju.*

Ključne riječi: *drvena konstrukcija, lamelirano lijepljeno drvo, konstrukcijski element, kompozit*

1 INTRODUCTION
1. UVOD

1.1 Glulam production
1.1. Proizvodnja lameliranoga lijepljenog drva

Glulam (also known as glued laminated timber, laminated wood, glulam beam, or classic glulam) is a composite material with more uniform distribution and higher values of mechanical characteristics than wood. Thin laminates are arranged so that the grain is generally parallel; they are glued together with structural adhesives that are rigid and durable, water resistant, and resistant to humidity, temperature, and biological factors.

Laminated construction elements are industrial construction elements characterized by a high degree of prefabrication. Glulam is one of the lightest construction materials. Moreover, due to its outstanding

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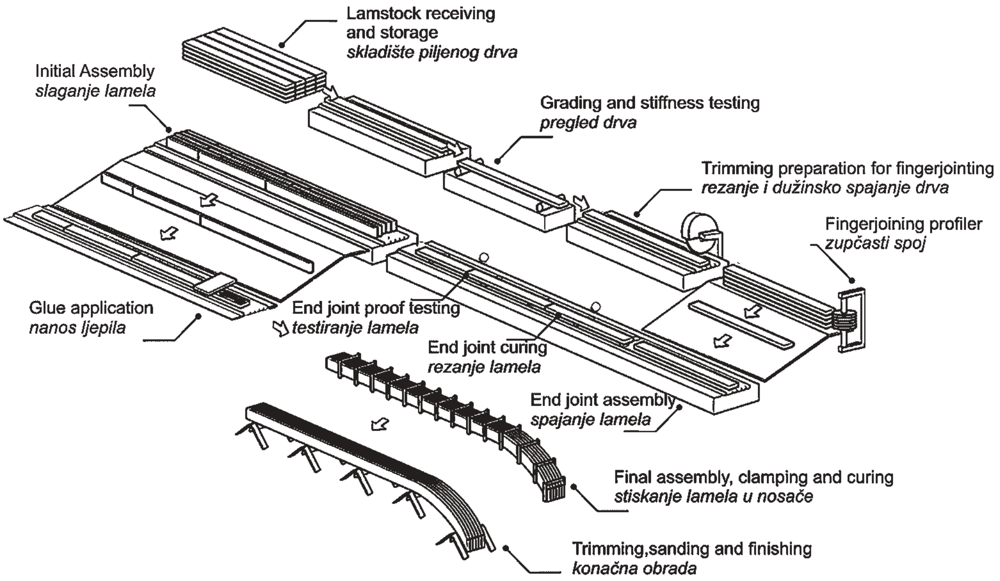

Figure 1 Manufacture of Glulam. Manuel de la construction en Bois (www.cwc.ca)
Slika 1. Shematski prikaz proizvodnje lameliranoga lijepljenog drva kontinuiranim postupkom. Manuel de la construction en Bois (www.cwc.ca).

elastic and mechanical characteristics it can be used for production of individual beams and columns as well as for large-span planar and spatial construction.

1.2 Laminates
1.2. Lamele

Although almost all types of wood can be used for glulam construction, the most common are top-grade spruce, fir, larch, and poplar. The wood has to be sound, suitably dry (maximum 18 (15±3) % moisture), and without great imperfections. Solid wood is first sawed into pieces and naturally dried, followed by kiln drying in order to achieve the desired degree of moisture content (Figure 1). Prior to use, the boards are stored in a temperature- and moisture-controlled warehouse. The moisture of the boards must be 1 to 2 % lower than the degree of moisture content upon later use. The difference in moisture content between individual laminates in one glulam element should not exceed 4 % (HRN EN 386).

Maximum thickness of laminates depends on the type of wood and service class. The maximum thickness for service class 1 and 2 conifer wood is 45 mm. The maximum thickness of laminates in curved elements depends on the curve radius and the characteristic bending strength of the wood. The net width of the laminates should not exceed 20 cm, and the gross width should be 21 cm or less. The width of the elements can be increased up to a maximum of 30 cm. With this width, two laminates form one row. Alongside transverse and horizontal lamination, edge-bonding is necessary as well.

In order to prevent bending, it is important to choose appropriate boards for producing the laminates because the correct positioning of laminates for adhesion can reduce unwanted tension on the gluing surface. Laminates must be properly oriented according to the growth rings – when two laminates are used, the gluing surface is the convex part of the growth rings.

Laminates must be joined lengthwise together in order to achieve the necessary length of beams. The most common is the wedged finger joint. The execution and minimum production standards are defined in the HRN EN 385 standard. The standard defines the finger joint as a self-centering tapered joint, shaped with machine milling of equal symmetrical tapering wedges, which are later glued together (Figure 2).

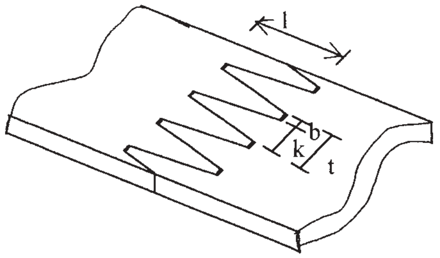

Figure 2 A finger joint (Müller, 2000)
Slika 2. Zupčasti spoj (Müller, 2000)

1.3 Adhesives
1.3. Ljepila

The development of synthetic adhesives has enabled versatile use of glulam construction. The requirements for structural adhesives are set forth in the HRN EN 301 standard. In some cases, using adhesives characterized by resistance to temperature, climate changes, chemicals, and microorganisms can give glulam construction an advantage over reinforced concrete and steel structures. The adhesive bonds wood into a new material. The adhesive must have mechanical characteristics such that the joint is practically non-deformable (Šernek *et al*, 1999).

Not all types of wood are suitable for gluing; the wood has to be porous enough in order for the adhesive to penetrate its cells. Improper adhesion can cause the joint to break. Fractures are often sudden (e.g., the collapse of the Ig Primary School gymnasium in 1980). The preparation of wood is an important factor for adhesion because it can entail significant changes in the wood characteristics. Wood drying can affect mechanical processing, wood stability, the interaction between the adhesive and wood during adhesive bonding, and the creation of internal stresses resulting from wood activity after adhesive bonding.

Phenolic and aminoplastic structural adhesives – urea formaldehyde (UF), melamine formaldehyde (MF), and melamine urea formaldehyde (MUF) adhesives – fall into two groups: Type I and Type II. This categorization takes into account the shear strength of joints, the resistance of the adhesive to delamination, cyclical strain of temperature and humidity, and strains caused due to wood shrinkage. The factors that influence the formation of the adhesive joint are application of the adhesive, application technique, assembly time, clamping pressure, curving time, temperature during bonding, and the conditioning of glulam. The color of the adhesive layer depends on the type of the adhesive.

2 CONSTRUCTION SYSTEMS AND STRESS IN TYPICAL ELEMENTS
2. KONSTRUKCIJSKI SUSTAVI I NAPREZANJA U TIPIČNIM ELEMENTIMA

2.1 Construction systems
2.1. Konstrukcijski sustavi

The use of glulam in modern construction depends on the successful cooperation of various specialists, especially the architect and building contractor. Usually, interior architecture depends on the choice of construction system. Today, there is a variety of different construction systems that enable top construction projects for different purposes. Load-bearing glulam systems can be categorized into the following groups: beams, three-hinged arches, frames, curved beams, consoles, and suspended structures (Figure 3).

Structures are categorized according to the predominant load (e.g., truss and axial load, beams and bending load) and the predominant load distribution (planar and spatial construction: cupolas, spatial frame constructions, spatial trusses, grids, and domes). Glulam systems allow practically unlimited choice in the dimensions of cross-section elements, they can cover extensive surfaces with large spans, and can easily adapt to modern architectural demands. The dimension of the load-bearing element depends on the static construction system, the load capacity of the material, production and installation technology, and the expected effect of the architectural composition of the construction.

2.2. Glulam beam and column cross-sections
2.2. Poprečni presjeci nosača i stupova od lijepljenog drva

Cross-sections are composed of laminates that are glued together. The choice among various types of cross-sections has increased with the development of increasingly stable and fire-resistant adhesives. This allows for various cross-sections (Figure 4). The most typical are the perpendicular, I-shaped, and composite box cross-sections.

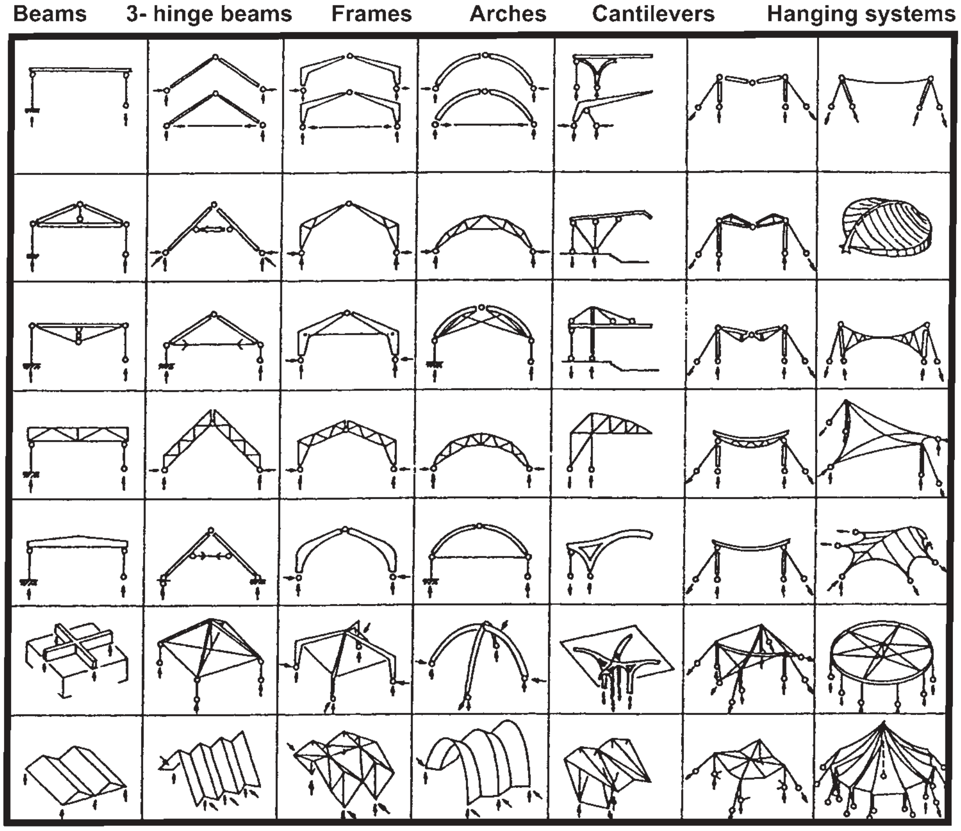

Figure 3 Wood structural systems: Beams – 3-hinge beams – Frames – Arches – Cantilevers – Hanging systems (Winter, 2004)
Slika 3. Grupe nosivih sustava: nosači – trozglobni nosači – okviri – zakrivljeni nosači – konzole – viseći sustavi (Winter, 2004)

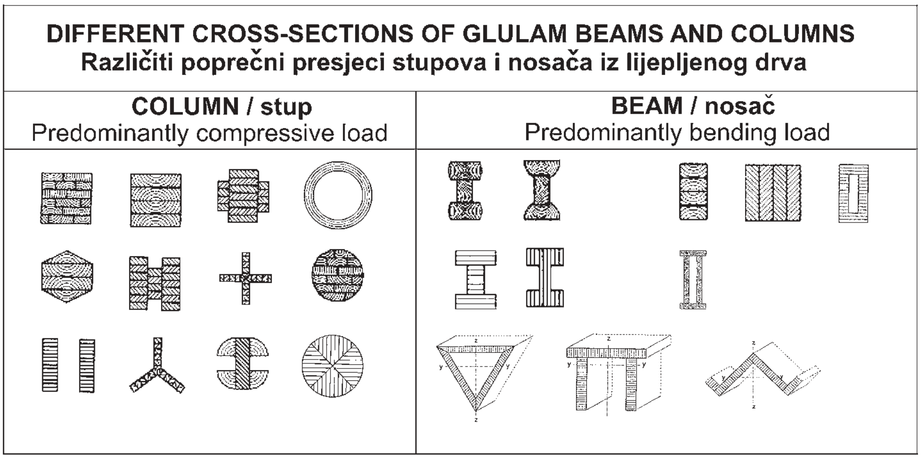

Figure 4 Glued members are available in a wide range of section sizes to suit every application
Slika 4. Različiti poprečni presjeci stupova i nosača od lijepljenog drva

The adaptation of the cross-section geometry to the direction of stress is based on this principle: as much material as possible must be positioned where it contributes most to the load capacity (i.e. to the edges, which bear the most stress).

2.3 Mechanical properties
2.3. Mehanička svojstva

The general requirements for glulam are defined in the HRN EN 14080 standard. Mechanical properties are established or experimentally defined with procedures prescribed in the HRN EN 408 standard.

Glulam strength classes are described in HRN EN 1194 (*Wood Constructions – Glued Laminated Timber – Strength Classes and Determination of Characteristic Values*). The standard categorizes and defines the use of two types of glulam: homogenous glulam (i.e., GL 24h, GL 28h, GL 32h, and GL 36h) and combined glulam (i.e., GL 24c, GL 28c, GL 32c, and GL 36c). The number following the label GL (glued laminated) is the characteristic bending strength in MPa (N/mm^2). The inner part of the cross-section of combined wood is made from lower-strength wood. The minimum thickness of the outer part is one-sixth of the height of the element or two laminates.

The strength-class categorization can be based on test results of glulam patterns in line with the HRN EN 408 standard or following the calculation of glulam properties depending on the properties of laminated wood. Formulas for this calculation are cited in the HRN EN 1194 standard (Annex A).

2.4 Stress state in typical glulam beam shapes
2.4. Naprezanja u tipičnim oblicima nosača od lameliranoga lijepljenog drva

Successful introduction and widespread use of glulam requires standardization of the production process, quality control, production technique/technology, computer-analysis processes, and construction safety documentation. Extensive work is being conducted in the European Union in order to harmonize the European standards for structural load-bearing design from various materials (known as the Eurocodes). The regulations for wood construction (HRN EN 1995-1-1, 2005; Bjelanović and Rajčić, 2005) include procedures for designing or dimensioning various glulam beams. In addition to straight beams with a constant height, they address three other typical beam shapes (Figure 5):

- Single- or double-tapered straight beams (a),
- Curved beams (b) and,
- Pitched cambered beams (c).

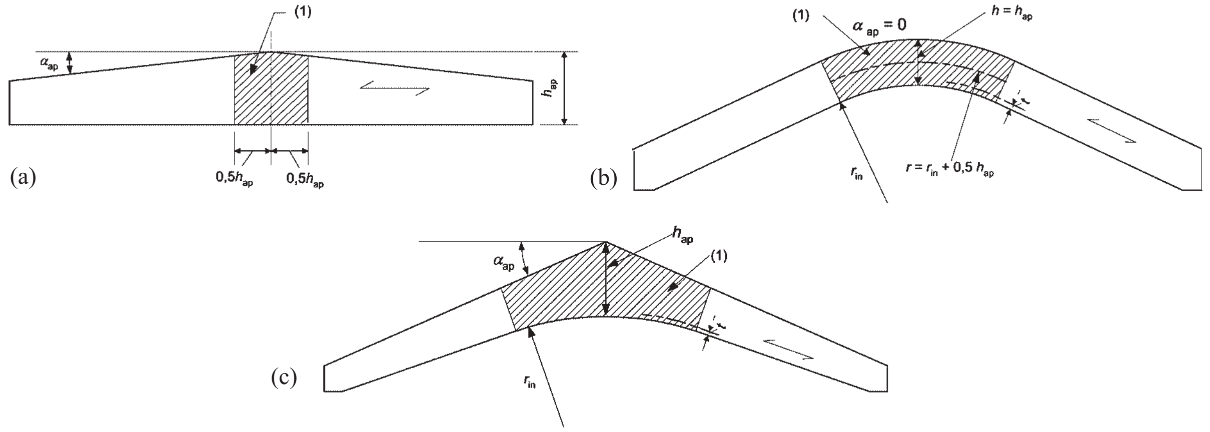

Figure 5 Typical glued laminated beams: (a) double-tapered beam, (b) curved beam and (c) pitched cambered beam; (1) apex area (HRN EN 1995-1-1, 2005)
Slika 5. Tipični oblici lameliranih lijepljenih nosača: (a) dvostrešni trapezni nosač, (b) zakrivljeni nosač, (c) sedlasti nosač; (1) – sljemena zona (HRN EN 1995-1-1, 2005)

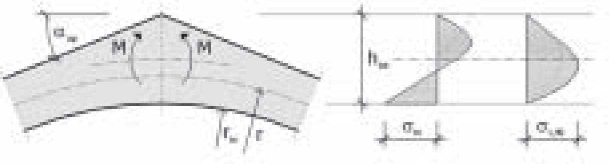

Figure 6 Special stress conditions in the apex area of a pitched-cambered beam. (σ_m – bending stresses, $\sigma_{t,90}$ – radial stresses; tension perpendicular to grain direction)
Slika 6. Naprezanja zbog savijanja σ_m i vlačna naprezanja okomito na vlakna drveta $\sigma_{t,90}$ u sljemenu sedlastog nosača

Shapes a and c have a variable cross-section height; curved beams can have a constant or variable height. Glulam technology enables the production of elements of different heights and shapes. By varying the height of the beams, it is possible to follow the flow of bending moments, which allows for greater use of cross-sections according to normal bending stresses. With the correct choice of construction shape and geometry, increasingly larger spans can be achieved. Glulam constructions have surpassed 100 m in span (Iimura *et al*, 2006).

The calculation of stresses for elements made of glued laminated timber is usually more complicated than for the elements made of other materials (Natterer *et al*, 1996; Žagar, 2002). The main reason is the variable geometry of the cross sections, inclinations of element edge regarding the grain direction in laminations and the curvature of element axis. For double-tapered beams with varying cross-section, curved and pitched-cambered beams, we should account for special stress conditions in the apex area (Figure 6). In addition to normal bending stresses σ_m, we should also expect tensile stresses perpendicular to the grain $\sigma_{t,90}$. These stresses are in many cases the crucial parameters that determine the size of the beam in the apex area, because the design tensile strength perpendicular to the grain is much lower than along the grain.

There is another solution for the beams with high tensile stresses perpendicular to the grain: special reinforcing devices can be used, which prevents the splitting of lamellas in radial directions. These can be made of wood, metal or even of carbon fiber reinforcement (Haiman and Rak, 2003; Johnsson et al, 2007). Wooden reinforcing devices are usually made of harder wood plates, which can be glued on both sides of the beam. The metal devices are usually internal steel screws for wood or threaded glued-in rods. Epoxy or PU resin should be poured in pre-drilled holes before mounting the transversal screws.

Different researchers, especially Möhler & Blumer (1978), have performed elaborate analyses of such beams and studied the effects of the afore-mentioned parameters on beam stress conditions. They have also proposed some expressions which enable the simplified analytical calculation of such beams, which were later included in many national codes and standards (also in HRN EN 1995-1-1, Chapter 4.2). With the rapid development of information technology, it is possible to analyze in more detail the stress state of such elements with suitable software based on the finite elements method (e.g., Sofistik, SAP2000, Tower, etc.). Glulam elements can be modeled as orthotropic walls with the correct direction of wood characteristics in given edge conditions. The software can take into account the different type of wood used in beams (with bottom and top parts made of better-quality wood). A comprehensive bibliographical review of the finite element methods (FEMs) applied in the analysis of wood products and structures can be for example found in the recent paper by Mackerle (2005).

A case in point is the stress state in the apex area of the pitched cambered beam. Alongside normal bending stress σ_m there are also tensile stresses perpendicular to the grain $\sigma_{t,90}$ (Figure 7).

Design and production should consider various construction demands in the HRN EN 386 standard regarding cross-section dimensions and individual laminates.

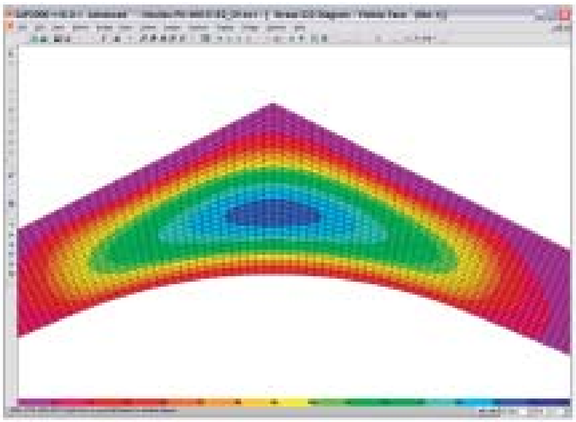

Figure 7 Part of the pitched-cambered (saddled) beam – tensional radial stresses in the apex area. (Analysis with computer program SAP2000; timber GL28h [E_1 = 1260 kN/cm^2, E_2 = 42 kN/cm^2, G = 78 kN/cm^2]; L = 16 m, b/h_{ap} = 20/171 cm, q_d = 21 kN/m; α_{ap} = 26.5°, r_{in} = 5.13 m; max. stresses $\sigma_{t,90}$ = 0.097 kN/cm^2.)
Slika 7. Dio sedlastog nosača – vlačna naprezanja okomito na drvna vlakanca (izračun u programu SAP2000; drvo GL28h [E_1 = 1260 kN/cm^2, E_2 = 42 kN/cm^2, G = 78 kN/cm^2]; L = 16 m, b/h_{ap} = 20/171 cm, q_d = 21 kN/m; α_{ap} = 26,5°, r_{in} = 5,13 m; najveće naprezanje $\sigma_{t,90}$ = 0,097 kN/cm^2.)

3 STRENGTHS AND WEAKNESSES OF GLULAM CONSTRUCTION ELEMENTS
3. PREDNOSTI I NEDOSTACI KONSTRUKCIJSKIH ELEMENATA OD LAMELIRANOG DRVA

3.1 Architecture and construction aspects
3.1. Arhitekturno i konstrukcijsko gledište

With regard to architecture, the main advantage of glulam elements is their versatility in form, which makes possible various shapes and dimensions (Figure 8). They have an aesthetic appeal and preserve elegance even with large spans.

As regards construction, one of the main advantages of wood constructions is their high loading capacity in relation to their own weight (e.g., 20% of the

Figure 8 Timber glulam construction (Hoja d.d., Škofljica, Slovenia)
Slika 8. Drvene lamelirane lijepljene konstrukcije (Hoja d.d., Škofljica, Slovenija)

weight of reinforced concrete). Glulam has several advantages over solid wood: better strength and rigidity, dimensional stability, various cross-sections possibilities, and the possibility of shaping the longitudinal axis of the beam. The comparison of waste produced between solid wood and glulam shows that the quantity of waste depends on the construction; the wider the beam, the better the utilization. The approximate estimate of utilization is ca. 1.5 m³ of wood mass for 1 m³ net of glulam beam.

3.2 Ecology
3.2. Ekološko gledište

Although aesthetic and economic considerations are usually the major factors influencing material selection, the environmental advantages of using wood may have an increasingly important effect on material selection. From the environmental viewpoint, wood biodegradability and the possibility of recycling are important factors. The production of glulam elements requires approximately twice the energy (1,218 KWh/m³) as a comparable solid wood construction element (688 KWh/m³) (Frühwald, 2005).

Adhesives are essential for the load-bearing durability of glulam elements. Many adhesives contain formaldehyde, which is harmful for health and is a burden on the environment. However, adhesive accounts for only approximately 1 % (Burgbacher, 1991) of the entire volume of the construction. As a result, the ecological advantages of glulam constructions are not significantly lower than those of solid wood constructions, especially when considering the almost inevitable use of metal connectors.

3.3 Fire resistance
3.3. Otpornost prema požaru

Glulam elements have significantly better fire resistance than is generally attributed to them, surpassing the fire resistance of steel and reinforced concrete beam structure. The capacity of wood to conduct heat is insignificant because it conducts heat 300 to 400 times more slowly than steel. The elements char slowly from the surface towards the inner parts. Charring reduces heat conduction and prevents oxygen from reaching the wood. In the non-charred cross-section the beams preserve full load capacity. In a normal fire, solid spruce wood burns at a speed of 0.6 to 1.1 mm/min and glulam at 0.1 mm/min. Glulam elements do not change shape during combustion. As a result, the beams do not exert pressure on peripheral walls and do not cause them to collapse.

Fire resistance of wood construction can be achieved if (1) the product is suitably dimensioned (HRN EN 1995-1-2, 2005), (2) it can be covered with fire insulation, or (3) it can be protected with chemical products, bearing in mind the actual purpose of the protection and choosing a suitable preparation.

4 USE OF GLUED LUMBER CONSTRUCTIONS IN ARCHITECTURE
4. UPORABA LAMELIRANIH DRVENIH KONSTRUKCIJA U ARHITEKTURI

Glulam is indispensable with constructions that require great strength, dimensional stability, and suitable aesthetic quality of the wood product (Stungo, 2001). In the EU, the largest share of glulam is used for non-residential buildings (commercial, sports and leisure, industrial, and cultural structures) (Figure 9). The share of residential buildings is 11 %.

There are various glulam elements with the possibility of combining different materials. These combined products include composite wood and polystyrene I-joists. Glulam elements can also have improved properties (curve, shear) due to pre-bending. There are also glulam beams with cross-sections that have laminates installed vertically in the stress zone or vertical laminates along the entire cross-section, glulam beams fitted with bands (steel, carbon laminates, or fiberglass

Figure 9 Modern timber construction Expo Roof - Hannover exhibition grounds
Slika 9. Suvremena drvena konstrukcija (Expo 2000, Hannover)

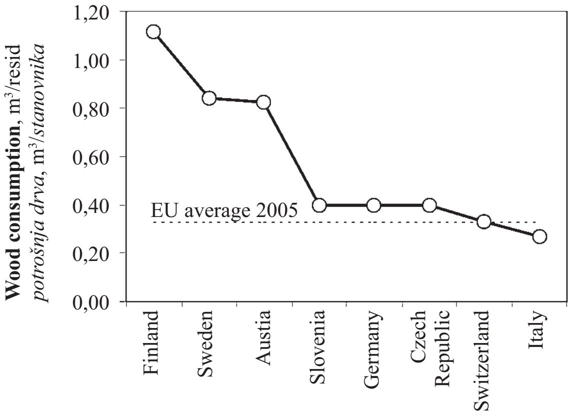

Figure 10 Wood products per capita consumption in selected EU countries, 2005 (Source: UNECE - analysed by M. Piskur, Slovenian Forestry Institute)
Slika 10. Potrošnja proizvoda od drva po stanovniku u nekim zemljama EU, 2005. (izvor: UNECE – analiza: M. Piskur, Slovenski šumarski institut)

laminates) (Natterer *et al*, 1996), reinforced pre-stressed beams, beams with epoxied threaded steel rods (Möhler and Hemmer, 1981), pre-stressed beams with external plastic cables, or elements reinforced with carbon-fibers, known as Carboglulam®, wood joints and laminated wood beams assembled by mechanically-welded wood dowels (Bocquet *et al*, 2007). Lately, there has been an increase in the use of wood and concrete composite constructions, especially in ceiling constructions.

Slovenian wood consumption is, according to official input raw data, relatively low compared to available wood resources, but nevertheless higher than the European average. Analysis done by SFI indicates that the actual consumption may be in the range 0.60-0.70 m³/capita (Figure 10).

The use of wood in Slovenia in construction and engineering primarily focuses on wood in its natural shape and pays too little attention to designed products with higher added value. The sale of round timber is becoming increasingly difficult due to ever smaller capacities in primary wood processing (sawmilling and production of particle boards and panels) and chemical wood processing (cellulose production). High processing costs, a consequence of significantly smaller processing capacities in comparison with those abroad, and increasingly poorer quality of processed wood have caused Slovenia to lose its competitive edge in the glulam market.

According to CEI-Bois the production of glulam beams would be more than triple in the period between 1990 and 2010, primarily due to heavy exports to the Japanese market. It is expected that better use of existing and new capacities will also create growth in glued-wood production in Eastern Europe. Lately, Europe has been seeing a significant increase in the use of glued wood. It is expected that Asian countries, including Russia, will increase their supply. In Europe, the Mediterranean countries are prime importers; this trend is expected to continue in the coming years.

Slovenia significantly lags behind geographically comparable Austria in the production and use of glued wood; both countries have a similar share of forests. There are several reasons for this, but the primary ones are uncompetitive production and insignificant demand for glued wood. The annual use of wood and wood composites in various areas of construction is about 400,000 m³; some 800,000 m³ is used for furniture. The leading Slovenian manufacturer of glulam wood is the Hoja company, producing 3,750 m³ net of straight and curved beams per year. The Svea and Legoles companies also produce glued wood. The Legoles production program includes cross-laminated timber (referred to as *KLH* '*Kreuzlagenholz*') as 50 % of production, two-layer (*DUO*) and three-layer (*TRIO*) glued construction timber as 20 %, glued laminated timber (*BSH* '*Brettschichtholz*') as 30 %, ceiling elements, and glued timber, adding up to 2,950 m³ net per year. The Svea company has an annual production of 4,000 m³ net.

According to some estimates, glued wood accounts for more than 50 % of the processed wood in Slovenia. In addition to glulam elements, glued wood includes wood-based panels (i.e., particle boards, oriented strand boards, fiberboards, and composite panels) and composite wood for construction: laminated veneer lumber (LVL), parallel strand lumber (PSL), and laminated strand lumber (LSL).

5 CONCLUSION
5. ZAKLJUČAK

Ecological concerns give glued wood a competitive edge over other materials; moreover, its outstanding physical, mechanical, and technological properties make it indispensable in construction. Its aesthetic value is highly appreciated because it enables the formation of demanding architectural shapes, the realization of new spatial concepts, and various construction shapes.

Optimization, milling, and gluing can improve glulam elements and make use of weaker wood, and even recycled wood. The production and use of laminated wood elements has increased all over the world. With new technologies that will enable improved accuracy in production and design, their use will only increase further in the future. The current state of production and low use of glulam elements in Slovenia is cause for concern. Nonetheless, promoting and raising awareness about the advantages of such construction can contribute to promoting laminated wood constructions.

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IN MEMORIAM

Prof. dr. sc. Zdenko Pavlin

Nakon duge i teške bolesti u subotu 10. srpnja 2010. godine zatekla nas je tužna vijest o završetku životnog puta našega dragog profesora Zdenka Pavlina. Prisjetimo se njegovih djela koja su oplemenila njegov životni put.

Zdenko Pavlin rođen je 16. veljače 1929. godine u Sisku. Od 1930. godine živi u Zagrebu, gdje je završio osnovnu školu i gimnaziju. Potom se upisao na Poljoprivredno-šumarski fakultet, Tehnički smjer, na kojemu diplomira u srpnju 1954. godine. Nakon diplomiranja prva praktična iskustva stječe kao projektant u Projektnom birou šumarstva i drvne industrije u Zagrebu. Ubrzo prelazi u Institut za drvno-industrijska istraživanja u Zagrebu, gdje počinje njegov intenzivan razvoj kao specijalista za sušenje i parenje drva. Kao vrlo talentirani mladi stručnjak 1. listopada 1958. godine zasniva stalni radni odnos na Šumarskom fakultetu u Zagrebu, u Zavodu za tehnologiju drva, kao asistent za predmet Sušenje i parenje drva. Dolaskom na Šumarski fakultet počinje intenzivno usavršavati engleski i njemački jezik u Centru za učenje stranih jezika.

Poslijediplomski studij s područja hidrotermičke obrade drva na Šumarskom fakultetu u Zagrebu započeo je 1963. godine, a završio 1967. godine obranom magistarskog rada. Iste godine stječe zvanje znanstvenog asistenta. Doktorsku disertaciju s područja hidrotermičke obrade drva obranio je u rujnu 1975. godine. Potom biva izabran za višeg predavača za područje hidrotermičke obrade drva, a 1976. godine postao je docent za isti predmet. Savjet Šumarskog fakulteta 1981. godine izabire ga u znanstveno-nastavno zvanje izvanrednog profesora. U znanstveno-nastavno zvanje redovitog profesora izabran je 1985. godine.

Osim redovitih obveza vezanih za predmet Sušenje i parenje drva, vodi i vježbe predmeta Industrija furnira i ploča te nastavu predmeta Specijalni proizvodi iz drva. Godine 1969. povjerena mu je nastava predmeta Hidrotermička obrada drva na dodiplomskom studiju, a 1971. godine i na poslijediplomskom studiju. Od 1973. godine održava nastavu predmeta Sušenje, parenje i kondicioniranje drva. Bio je i voditelj posebne nastave područja Proizvodnja namještaja. Od akad. god. 1978/79. do 1992/93. na Biotehničkom fakultetu u Ljubljani održava i redovitu nastavu predmeta Sušenje i modifikacija drva.

Bio je vrsni voditelj brojnih diplomskih i magistarskih radova te doktorskih disertacija.

U znanstvenoistraživačkom radu bavio se istraživanjem mehanizma kretanja vode u drvu, parametara sušenja drva, furnira i iverja, energetskim parametrima, mjernom i regulacijskom tehnikom, istraživanjem procesa prirodnog sušenja drva te primjenom Sunčeve energije u sušenju drva. Bio je voditelj i suradnik u više znanstvenoistraživačkih projekata. Autor je brojnih projekata za izgradnju i rekonstrukciju sušionica te niza ekspertiza vezanih za sudske sporove. Niz objavljenih znanstvenih, stručnih i drugih popularnih radova prof. Pavlina otvorili su nove znanstvenoistraživačke horizonte, osjetno unaprijedili primjenu znanosti u praksi te znatno pridonijeli popularizaciji područja drvne tehnologije.

Prof. Pavlin bio je sudionik, predavač i član organizacijskih odbora brojnih domaćih i inozemnih savjetovanja i seminara. Bio je predsjednik Organizacionog odbora Međunarodno-naučno-tehničkog savjetovanja o sušenju i predsušenju drva. Bio je član Radne grupe IUFRO-a za područje hidrotermičke obrade drva, član izaslanstva na zasjedanju Savjeta opunomoćenih i Naučno-tehničkog savjeta SEV-a, predsjednik izaslanstva na Savjetovanju specijalista članova SEV-a te koordinator suradnje na SEV-ovu projektu sušenja drva. Od 1972. do 1996. godine sudjelovao je na sastancima IUFRO-a i sastancima Radne grupe za sušenje drva (Working party for wood drying). Tijekom 1977. prisustvovao je sastanku Radne grupe IUFRO-a za sušenje drva u Nacionalnom institutu za šumske proizvode u Meridi, u Venezueli, te održao zapaženi referat s naslovom *Sušenje tvrdog drva u našim uvjetima*. S navedenim institutom ostvario je trajnu suradnju. Sudionik je zasjedanja Savjeta opunomoćenih u Varni (Bugarska) i Ljubljani (Slovenija). Surađivao je i više puta posjećivao Sveučilišta u Krakowu, Poznanu i Waršavi te Visoku šumarsku i drvarsku školu u Zvolenu.

Bio je član Odbora Sveučilišne skupštine za statutarna pitanja i propise, član Odbora za nastavu, predsjednik Povjerenstva za izradu prijedloga obrazovnih profila visokog obrazovanja u grani drvne industrije, tajnik Sindikalne podružnice Instituta za drvo, tajnik Sindikalne podružnice Šumarskog fakulteta te aktivni član brojnih drugih domaćih i stranih stručnih, znanstvenih i društvenih udruga, odbora i povjerenstava.

Prof. dr. sc. Zdenko Pavlin postao je u prosincu 1975. godine predstojnik Katedre za mehaničku preradu drva, a tu je dužnost obnašao punih 15 godina. Prodekan Drvnotehnološkog odsjeka Šumarskog fakulteta postao je 1976. godine te na toj dužnosti ostao dva mandata. Godine 1988. izabran je za dekana Šumarskog fakulteta Sveučilišta u Zagrebu.

U siječnju 1999. godine uvršten je na popis Outstanding people of the 20th century, Who´s Who in the World.

Svijetli lik i djela prof. dr. sc. Zdenka Pavlina ostat će trajno u našim mislima i našim srcima, a brojni naraštaji studenata još će se dugo sjećati jednoga od najvećih doajena drvno-tehnoloških znanosti.

Neka mu je vječna slava i hvala za sve što je učinio!

izv. prof. dr. sc. Vladimir Jambreković

Nova knjiga *Tehnologija obrade drva vodenom parom*

U nakladi Šumarskog fakulteta u Zagrebu iz tiska je izašao sveučilišni udžbenik autora izv. prof. dr. sc. Stjepana Pervana pod naslovom *Tehnologija obrade drva vodenom parom.*

Recenzenti udžbenika su izv. prof. dr. sc. Željko Gorišek s Oddelka za lesarstvo Biotehniške fakultete iz Ljubljane, izv. prof. dr. sc. Vladimir Jambreković i izv. prof. dr. sc. Mladen Brezović sa Šumarskog fakulteta Sveučilišta u Zagrebu.

Opseg knjige je 166 stranica, a tekst je podijeljen na 15 poglavlja s 131 slikom, 21 tablicom i 92 navoda literature.

Tehnologija obrade drva vodenom parom važno je djelo s područja hidrotermičke obrade drva, koje je manje istraživano i za koje već dugo ne postoji značajnija literatura.

Ovo je djelo zasigurno dobra osnova za korištenje u znanosti, struci i nastavi, a daje usustavljeni pregled stanja tehnologije toplinskih obrada vodenom parom na području proizvodnje i prerade drva u Republici Hrvatskoj. Autor djela ukomponirao je u rad teorijske i praktične spoznaje te bogata iskustva stečena tijekom znanstvenoga i praktičnog laboratorijskoga i terenskog rada u matičnoj ustanovi i u pogonima za preradu drva. Osnovna značajka djela je velik udio vlastitih slikovnih, grafičkih i tabličnih podataka te iskustvenih spoznaja, detaljno razrađenih i opisanih rječnikom prihvatljivim svakomu korisniku djela.

Bogatstvo novih informacija i spoznaja, originalan i prepoznatljiv pristup, razumljivost i najsloženijih elemenata obrađene problematike učinit će to djelo izuzetno korisnim i traženim.

Posebna vrijednost knjige jest specifičan pristup u sklopu kojega autor ne daje samo bogate informacije statične prirode, već i usmjerava istraživanja problematike različitih metoda termičke obrade drva primjenjivih u gospodarstvu.

S obzirom na to da na spomenutom području u novije vrijeme nije objavljeno djelo koje bi ovako široko i sustavno obradilo tu materiju, autor je zaista sadržajno, kvalitetno i aktualizirano obradio tematiku navedenog područja, dajući stručnoj javnosti djelo koje će korisno poslužiti studentima i stručnjacima u praksi.

Knjiga je podjeljena na 15 poglavlja:

1. *Parenje drva – uvod*,
2. *Zagrijavanje drva vodenom parom*,
3. *Promjene svojstva drva u postupku parenja*,
4. *Karakteristike vodene pare*,
5. *Tehnologija obrade drva vodenom parom*,
6. *Parionice za drvo*,
7. *Karakteristike materijala za izradu postrojenja za hidrotermičku obradu drva*,
8. *Postupak parenja*,
9. *Omekšavanje trupaca i polovnjaka*,
10. *Održavanje parionice*,
11. *Troškovi postupka parenja drva*,
12. *Ekološka problematika nusprodukata hidrotermičkih procesa obrade drva*,
13. *Istraživanja problematike promjene boje u postupku obrade vodenom parom*,
14. *Kazalo pojmova u hidrotermičkoj obradi drva*,
15. *Literatura.*

Sveučilišni udžbenik *Tehnologija obrade drva vodenom parom* sveobuhvatno se bavi posebnim područjem postupaka hidrotermičke obrade drva, a oni se temelje na osnovnim načelima prolaska topline kroz porozni drvni materijal u postupku parenja i sušenja drva.

Ta se načela odnose i na mnoga druga područja prerade drva, što može izuzetno pridonijeti lošim ili dobrim svojstvima drva u primjeni. Knjiga je sadržajem na adekvatan način prilagođena nastavi i praksi te daje teorijske i praktične osnove industrijskih postupaka obrade vodenom parom, kao i pregled najnovijih istraživanja na tom području, uključujući i istraživanja samog autora.

Poglavlja od 1. do 10. daju osnovne teorijske i praktične spoznaje postupka obrade vodenom parom, a u poglavljima 11. i 12. obrađuje se uvijek aktualna tema visokih troškova procesa, kao i vrlo bitni ekološki kriteriji i problemi takvih postupaka.

Poglavlje 13. iznimno je važno jer daje poveznicu između svih teorijskih, praktičnih i znanstvenih spoznaja o problematici promjene boje drva tijekom postupaka obrade drva vodenom parom i sušenja. To je poglavlje napisano na strogim načelima znanstvenog djela te korisnike upoznaje sa sustavom znanstvenog pristupa određenoj problematici.

Knjiga sadržava izuzetno mnogo dijagrama, slika i autorskih fotografija te na taj način čvrsto potkrepljuje tekstualna objašnjenja postupaka obrade drva vodenom parom.

S obzirom na ciljanu skupinu korisnika korištena je literatura odgovarajuća i osim podataka o tiskanim izdanjima daje i informacije o toj tematici koja je dostupna na internetu.

Ovaj se sveučilišni udžbenik može nabaviti na Šumarskom fakultetu u Zagrebu ili u tvrtki Sand, d.o.o. Cijena knjige bez dostave je 200 kn za tuzemstvo i 30 eura za inozemstvo. Kontakt osobe su izv. prof. dr. sc. Stjepan Pervan (tel. 01/2352 509, faks 01 2352-2544, e-mail: pervan@sumfak.hr) ili Andrija Lovrec (tel. 01/3640-248, faks 3664-177, e-mail: andrija@sand.hr).

izv.prof.dr.sc. Vladimir Jambreković
izv.prof.dr.sc. Mladen Brezović

WENGE (*Milletia laurentii* De Wild.)

NAZIVI

Drvo wenge (*Milletia laurentii* De Wild.) pripada botaničkoj porodici *Leguminosae*. Strani nazivi su Wengé (Njemačka, Velika Britanija, Francuska, Italija, Nizozemska, Belgija), Awong (Njemačka, Nizozemska, Francuska, Kamerun), palisandro del Congo (Španjolska).

NALAZIŠTE

Wenge je prirodno rasprostranjen u zapadnoj ekvatorskoj Africi (od Kameruna do Zaira). U istočnoj Africi raste i vrsta drva panga-panga (*Milletia stuhlmanii* Taub.), čiji izgled i karakteristike podsjećaju na drvo wenge i teško ih je razlikovati. Wenge raste u močvarnim područjima Zaira, Kameruna i Gabona. Panga-panga raste u otvorenim šumama Mozambika i Tanzanije.

STABLO

Stablo doseže do 20 m (25 m) visine, a promjer je od 0,6 do 1,2 m. Deblo je dugo od 8 do 12 m (15 m), cilindrično je, ali rijetko ravno. Kora je gotovo glatka, siva do sivoružičasta, tanka i otrovna.

DRVO

Makroskopska obilježja

Drvo je jedričavo, bjeljika je bjelkasta do sivobijela. Srž je u sirovom stanju svjetlosmeđa, kasnije tamnosmeđa do crnoljubičasta i prošarana crnkastim prugama.

Pravilne je žice i grube teksture. Tekstura je dekorativna zbog kombinacije crnih vlakanca i bijelih pruga aksijalnog parenhima. Granica goda je uočljiva. Drvo je difuzno porozno. Traheje i vrpčasti aksijalni parenhim vidljivi su golim okom, a drvni su traci vidljivi pod povećalom.

Mikroskopska obilježja

Promjer traheja iznosi 80..235..380 µm, gustoće 1..2..3 na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi 1,1..6,3..11,5 %.

Aksijalni parenhim je paratrahealno vrpčast i širok do 18 stanica. Volumni udio aksijalnog parenhima je 23,6..31,3..38,0 %.

Drvni traci su homogeni, visoki 175..210..235 µm, odnosno do 12 stanica, a široki 20..39..58 µm. Gustoća drvnih trakova je 6..7..8 na 1 mm. Volumni udio drvnih trakova iznosi 17,0..19,1..21,8 %.

Drvna su vlakanca libriformska, duga 1540..1760..2060 µm. Dvostruka debljina staničnih stijenki vlakanaca iznosi 4,8..9,7..14,5 µm, a promjer lumena 1,3..4,4..7,0 µm. Volumni udio vlakanaca kreće se od 35,6..43,3..55,1 %.

Fizikalna svojstva

Gustoća standardno suhog drva (ρ_o)	oko 750 kg/m^3
Gustoća prosušenog drva (ρ_{12-15})	750..800..950 kg/m^3
Gustoća sirovog drva (ρ_s)	1100..1125..1200 kg/m^3
Poroznost	oko 50 %
Radijalno utezanje (β_r)	4,5..5,8 %
Tangentno utezanje (β_t)	8,6..9,4 %
Volumno utezanje (β_v)	13,3..15,4 %

Mehanička svojstva

Čvrstoća na tlak	70,0..85,0 MPa
Čvrstoća na vlak, okomito na vlakanca	2,5..2,8 MPa
Čvrstoća na savijanje	125,0..180,0 MPa
Čvrstoća na smik	oko 11,3 MPa
Tvrdoća (prema Brinellu),	
paralelno s vlakancima	oko 51 MPa
okomito na vlakanca	jako tvrdo
Modul elastičnosti	16,8..18,0 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Zbog svoje tvrdoće wenge se teže pili, reže i ljušti. Ljuštenje zahtijeva obvezno parenje drva. Pri obradi jače se zatupljuje oštrica alata. Drvo dobro prihvaća vijke i čavle, no zbog tvrdoće ga je potrebno predhodno izbušiti. Pjeskarenjem drva stvara se fina prašina koja može biti izuzetno iritantna za kožu, oči i pluća. Teško se lijepi i površinski obrađuje zbog gumoznih tvari u trahejama.

Sušenje

Drvo se suši polako jer je sklono raspucavanju i vitoperenju.

Trajnost i zaštita

Drvo je trajno, otporno na gljive i insekte te neotporno na štetnike pod vodom. Vrlo ga je teško impregnirati.

Uporaba

Zbog vrlo atraktivne prošarane teksture upotrebljava se za proizvodnju visoko-kvalitetnog namještaja, izradu dekorativnih furnira, za unutarnje uređenje te za tokarene proizvode, ukrasne predmete, kundake za puške, športske rekvizite, a u novije vrijeme zbog svoje prirodne otpornosti na habanje i teksture od njega se sve češće izrađuju drveni podovi (u javnim zgradama, hotelima itd.).

Wenge je posebno drvo. U Africi od davnina služi za izradu drvenih maski i kipova.

Literatura

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

Upute autorima

Sve autore molimo da prije predaje rukopisa pažljivo prouče sljedeća pravila. To će poboljšati suradnju urednika i autora te pridonijeti skraćenju razdoblja od predaje do objavljivanja radova. Rukopisi koji budu odstupali od ovih odredbi i ne budu udovoljavali formalnim zahtjevima bit će vraćeni autorima radi ispravaka, i to prije razmatranja i recenzije.

Opće odredbe

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

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

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

Svi prilozi podvrgavaju se jezičnoj obradi. Urednici će zahtijevati od autora da prilagode tekst preporukama recenzenata i lektora, a urednici zadržavaju i pravo da predlože skraćivanje i poboljšanje teksta.

Autori su potpuno odgovorni za svoje priloge. Podrazumijeva se da je autor pribavio dozvolu za objavljivanje dijelova teksta što je već negdje drugdje objavljen, 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, u dva tiskana primjerka i u elektronskom zapisu, šalju na adresu:

Uredništvo časopisa "Drvna industrija"
Šumarski fakultet Sveučilišta u Zagrebu
Svetošimunska 25, HR - 10000 Zagreb
E-mail: drind@sumfak.hr

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Predani rukopisi smiju sadržavati najviše 15 jednostrano pisanih DIN A4 listova s dvostrukim proredom (30 redaka na stranici), uključivši i tablice, slike i popis literature, dodatke i ostale priloge. Dulje članke je preporučljivo podijeliti u dva ili više nastavaka.

Tekst treba biti napisan u MS Wordu, u normalnom stilu bez dodatnog uređenja teksta. Uredništvo prihvaća elektronski zapis na disketi, CD-u ili putem elektronske pošte.

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

Znanstveni i stručni radovi na sljedećim stranicama trebaju imati i naslov, prošireni sažetak i ključne riječi na jeziku različitom od onoga na kojem je pisan tekst članka (npr. za članak pisan na engleskome ili njemačkome naslov, prošireni sažetak i ključne riječi trebaju biti na hrvatskome, i obratno). Prošireni sažetak (približno 1 1/2 stranice DIN A4), uz rezultate, trebao bi omogućiti čitatelju koji se ne služi jezikom kojim je pisan članak potpuno razumijevanje cilja rada, osnovnih odrednica pokusa, rezultata s bitnim obrazloženjima te autorovih zaključaka.

Posljednja stranica sadrži 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, uz izbjegavanje dugačkih uvoda. Osnovna poglavlja trebaju biti označena odgovarajućim podnaslovima. Napomene se ispisuju na dnu pripadajuće stranice, a obrojčuju se susljedno. One koje se odnose na naslov označuju se zvjezdicom, a ostale natpisnim (uzdignutim) arapskim brojkama. Napomene koje se odnose na tablice pišu se ispod tablice, a označavaju se uzdignutim malim pisanim slovima abecednim redom.

Latinska imena pisana kosim slovima 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 namjera autora.

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

Rezultati trebaju obuhvatiti samo materijal koji se izravno odnosi na predmet. Obvezatna je primjena metričkog sustava. Preporučuju se SI jedinice. Rjeđe rabljene fizikalne vrijednosti, simboli i jedinice trebaju biti objašnjeni pri prvom spominjanju u tekstu. Za pisanje formula koristiti Equation Editor (program za pisanje formula unutar MS Worda). Jedinice se pišu normalnim (uspravnim) slovima, a fizikalni simboli i faktori kosim slovima. Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.

Broj slika mora biti ograničen na samo one koje su prijeko potrebne za pojašnjenje teksta. Isti podaci ne smiju biti navedeni u tablici i na slici. Slike i tablice trebaju biti zasebno obrojčene arapskim brojkama, a u tekstu se na njih upućuje jasnim naznakama ("tablica 1" ili "slika 1"). Naznaka željenog položaja tablice ili slike u tekstu treba biti navedena na margini. Svaka tablica i slika treba biti prikazana na zasebnom listu, a njihovi naslovi moraju biti tiskani na posebnim listovima, i to redoslijedom. Naslovi, zaglavlja, legende i sav ostali tekst u slikama i tablicama treba biti pisan hrvatskim i engleskim ili hrvatskim i njemačkim jezikom.

Slike i tablice trebaju biti potpune i jasno razumljive bez pozivanja na tekst priloga. Naslove slika i crteža ne pisati velikim tiskanim slovima. Uputno je da crteži odgovaraju stilu časopisa i da budu tiskani na laserskom printeru. Tekstu treba priložiti izvorne crteže ili fotografske kopije. Slova i brojke moraju biti dovoljno veliki da budu lako čitljivi nakon smanjenja širine slike ili tablice na 160 ili 75 mm. Fotografije trebaju biti crno-bijele; one u boji tiskaju se samo na poseban zahtjev, a trošak tiskanja u boji podmiruje autor. Fotografije i fotomikrografije moraju biti izvedene na sjajnom papiru s jakim kontrastom. Fotomikrografije trebaju imati naznaku uvećanja, poželjno u mikrometrima. Uvećanje može biti dodatno naznačeno na kraju naslova slike, npr. "uvećanje 7500 : l".

Svaka ilustracija na poleđini treba imati svoj broj i naznaku orijentacije te ime (prvog) autora i skraćeni naslov članka. Originalne se ilustracije ne vraćaju autorima.

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Zahvale se navode na kraju rukopisa.

Odgovarajuću **literaturu** treba citirati u tekstu i to prema harvardskom ("ime - godina") sustavu, npr. (Bađun, 1965). Nadalje, bibliografija mora biti navedena na kraju teksta, i to abecednim redom prezimena autora, s naslovima i potpunim navodima bibliografskih referenci. Nazive časopisa treba skratiti prema publikacijama Biological Abstracts, Chemical Abstracts, Forestry Abstracts ili Forestry Products Abstracts. Popis literature mora biti selektivan, osim u preglednim radovima. Primjeri navođenja:

Članci u časopisima: Prezime autora, inicijal(i) osobnog imena, godina: naslov. Skraćeni naziv časopisa, godište (ev. broj): stranice (od - do).

Primjer: *Bađun, S. 1965: Fizička i mehanička svojstva hrastovine iz šumskih predjela Ludbrenik, Lipovljani. Drvna ind. 16 (1/2): 2 - 8.*

Knjige: Prezime autora, inicijal(i) osobnog imena, godina: naslov. (ev. izdavačeditor): izdanje (ev. tom). Mjesto izdavanja, 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.

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Müller, D. 1977: Beitrag zür Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanstalt für Forst- und Holzvvirtschaft 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).*

Tiskani slog i primjerci

Autoru se prije konačnog tiska šalju po dva primjerka tiskanog sloga. Jedan primjerak treba pažljivo ispraviti upotrebom međunarodno prihvaćenih oznaka. Ispravci su ograničeni samo na tiskarske greške: dodaci ili promjene teksta posebno se naplaćuju. Autori znanstvenih i stručnih radova primaju besplatno po pet primjeraka časopisa. Autoru svakog priloga dostavlja se po jedan primjerak časopisa.

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Manuscripts should be written in MS Word, in normal style. Electronic version on diskettes, CD or sent by e-mail will be accepted with the printout.

The first page of the typescript should present full title, name(s) of author(s) with professional affiliation (institution, city and state), abstract with keywords in the main language of the paper (approx. 1/2 sheet DIN A4, concise in abstract form).

The succeeding pages of scientific and professional papers should present a title and extended summary with keywords in a language other than the main language of the paper (e.g. for a paper written in English or German, the title, extended summary and keywords should be presented in Croatian, and vice versa). The extended summary (approx. 1 1/2 sheet DIN A4), along with the results, should enable the reader who is unfamiliar with the language of the main text, to completely understand the intentions, basic experimental procedure, results with essential interpretation and conclusions of the author.

The last page should provide the full titles, posts and address(es) of (all) the author(s) with indication as to whom of the authors are editors to contact. Scientific and professional papers must be precise and concise and avoid lengthy introductions. The main chapters should be characterised by appropriate headings.

Footnotes should be placed at the bottom of the same page and consecutively numbered. Those relating to the title should be marked by an asterix, others by superscript arabic numerals. Footnotes relating to the tables should be printed below the table and marked by small letters in alphabetical order. Latin names to be printed in italic should be underlined.

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

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

Other publications (brochures, reports etc.):

Müller, D. 1977: Beitrag zur Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanslalt für Forst- und Holzwirtschaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

Web pages:

****1997: "Guide to Punctuation" (online), University of Sussex, www.informatics.sussex.ac.uk/department/docs/punctuation/node 00.html. First published 1997 (Accessed 27th January 2010).*

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