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Hiroshi Yoshihara, Hikaru Mizuno[1]

Mode I Critical Stress Intensity Factor of Medium-Density Fiberboard Obtained by Single-Edge-Notched Bending Test

Faktor kritičnog intenziteta naprezanja (I. mod) MDF ploča dobiven testom savijanja

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ABSTRACT • *The Mode I critical stress intensity factor (K_{Ic}) obtained by single-edge-notched bending (SENB) tests of medium-density fiberboard (MDF) was experimentally analyzed. In the SENB test, the critical load for crack propagation (P_c) was determined from the relationship between load/loading-line displacement and load/crack opening displacement (COD). A double cantilever beam (DCB) test was also conducted and the results were compared with those of SENB tests. The value of Mode I critical stress intensity factor was obtained by introducing an additional crack length, when the crack length ranged from 0.5 to 0.7 times the depth of the specimen. This range coincided well with that used to derive the appropriate K_{Ic} value in the single-edge-notched tension (SENT) test, which was conducted using the specimens with a similar configuration cut from the MDF panel used in this study.*

Key words: *additional crack length, Mode I critical stress intensity factor, medium-density fiberboard (MDF), western hemlock, single-edge-notched bending (SENB) test*

SAŽETAK • *U radu se eksperimentalno analizira faktor kritičnog intenziteta naprezanja (I. mod) (K_{Ic}) dobiven testom savijanja s jednim rubnim urezom (SENB) za ploče vlaknatice srednje gustoće (MDF ploče). U SENB testu kritično opterećenje za širenje pukotine (P_c) određeno je iz odnosa opterećenja i linije pomaka te iz odnosa opterećenja i širenja pukotine (COD). Proveden je i dvostruki konzolni test (DCB), a rezultati su uspoređeni s rezultatima SENB testova. Vrijednost faktora kritičnog intenziteta naprezanja (I. mod) dobiven je uvođenjem dodatne duljine pukotine kada je duljina pukotine u rasponu od 0,5 do 0,7 debljine uzorka. Taj se raspon podudario s rasponom koji se koristi za dobivanje odgovarajuće K_{1C} vrijednosti u tenzijskom testu s jednim rubnim urezom (SENT), a proveden je na uzorcima slične konfiguracije izrađenima od MDF ploče koja je upotrijebljena i u ovom istraživanju.*

Ključne riječi: *dodatna duljina pukotine, faktor kritičnog intenziteta naprezanja (I. mod), ploče vlaknatice srednje gustoće (MDF), test savijanja s jednim rubnim urezom (SENB test)*

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1 INTRODUCTION
1. UVOD

In analyzing the fracture behavior of material based on fracture mechanics theory, the value of critical stress intensity factor K_c is often measured because it can be regarded as a material constant. Of the three independent fracture modes, the crack opening mode (Mode I) is regarded as more important than the in-plane shear mode (Mode II) and out-of-plane shear mode (Mode III) because the Mode I critical stress intensity factor (K_{Ic}) is usually smaller than those of Mode II and Mode III, K_{IIc} and K_{IIIc}, respectively. To determine the K_{Ic} value, single-edge-notched bending (SENB), single-edge-notched tension (SENT), compact tension (CT), and double cantilever beam (DCB) tests, the diagrams of which are shown in Figures 1(a)-(d), respectively, are most frequently performed because the crack propagation under the opening mode can be easily induced by these tests.

In previous works, the K_{Ic} value of medium-density fiberboard (MDF) was examined by SENT and CT tests (Yoshihara, 2010b; Yoshihara and Usuki, 2011). In these tests, we found that the K_{Ic} value of MDF can be effectively measured when considering the additional crack length ahead of the crack tip and restricting the range of initial crack length with respect to the specimen geometry. Nevertheless, these tests require attachments to apply the tensile load, so the use of the attachments often restricts the specimen geometry. The SENB test is attractive because it can be conducted using specimens with various geometries more easily than the SENT and CT tests (Yoshihara, 2010a).

In this study, we examined the K_{Ic} value of MDF by the SENB test using two types of specimens with different dimensions. The results were compared with those obtained from the DCB tests, which can be determined based on energy consideration and are mathematically well defined (Adams *et al*., 2003).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

An MDF panel, which was used in previous works (Yoshihara, 2010b; Yoshihara and Usuki, 2011), was investigated. The density of the MDF at 12 % moisture content (*MC*) was 580 ± 10 kg/m^3. The panel was stored in a room at a constant 20 °C and 65 % relative humidity (*RH*) before the test, and the specimens were confirmed to be in an air-dried state. These conditions were maintained throughout the tests. Five specimens were tested for each test condition.

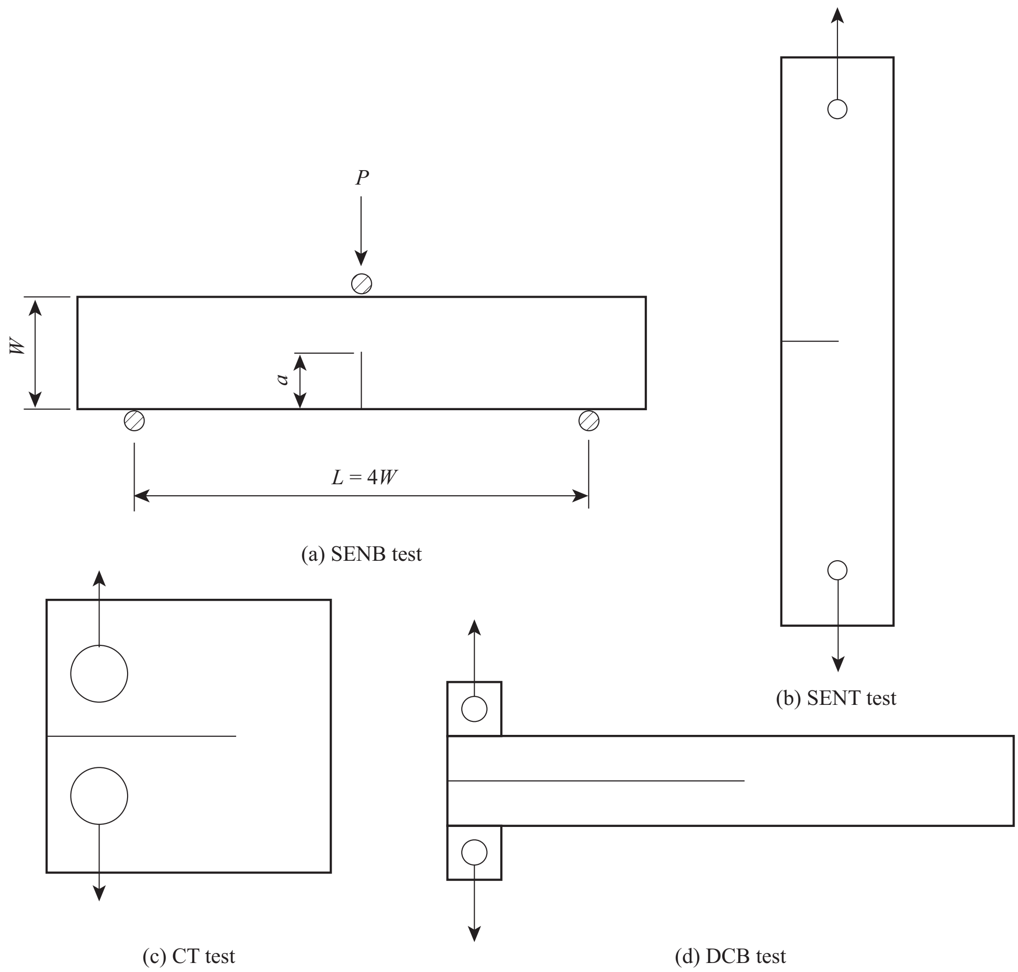

Figure 1 Typical Mode I fracture tests
Slika 1. Tipični testovi loma drva I. moda

2.2 SENB tests
2.2. SENB testovi

Figure 1(a) shows the diagram of the SENB test. Two kinds of specimens were tested. Specimen A had dimensions of 20 × 90 × 15 mm^3, while these dimensions were 40 × 180 × 15 mm^3 in specimen B. The specimen depth *W* was 20 and 40 mm in specimens A and B, respectively. The crack was first cut with a band saw (thickness = 1 mm) and then extended 1 mm ahead of the crack tip with a razor blade. The crack length *a* varied from 1 to 18 mm at intervals of 1 mm in specimen A, and from 2 to 36 mm at intervals of 2 mm in specimen B. Thus, the value of *a/W* varied from 0.1 to 0.9 at intervals of 0.1. The specimen configurations were similar with those of SENB tests for western hemlock (Yoshihara, 2010a).

In the SENB test of western hemlock, the nonlinearity in the relationship between the load (*P*) and loading-line deflection (*δ*) was not significant until the initiation of crack propagation, so the critical load for crack propagation was determined as the maximum load (Yoshihara, 2010a). From the results of the SENT and CT tests of MDF in which the crack opening displacement (*COD*) was measured, the nonlinearity was marked in the *P-COD* relationship (Yoshihara, 2010b; Yoshihara and Usuki, 2011). Although the loading-line displacement in the SENB test is significantly larger than that in the SENT and CT tests, we thought that the measurement of the *COD* was effective to detect the nonlinearity and *δ*. To measure the *COD*, a clip gauge extensometer (capacity = 5 mm; UB-5, Tokyo Sokki, Co., Tokyo, Japan) was used. The specimen was symmetrically supported and loaded at the mid-span. The span lengths (*L*) were 80 and 160 mm in specimens A and B, respectively, giving an *L/W* value of 4. A steel platen was placed between the specimen and the support to reduce indentation at the supporting point. The load *P* was applied at a crosshead speed of 0.5 mm/min[1] until the load markedly decreased. The total testing time was approximately 5 min.

Figure 2 shows typical *P-δ* and *P-COD* relationships obtained by the SENB tests. In the results for western hemlock, the crack often propagates unstably when the initial crack length is less than 0.3 times the depth of the specimen, whereas it propagates stably when the initial crack is longer than 0.4 times the depth (Yoshihara, 2010a). In the results of MDF, however, the crack always propagates stably all over the range of the initial crack length. In addition, the *P-δ* and *P-COD* relationships were significantly nonlinear before the load reached its maximum. Therefore, the critical load for crack propagation P_c was provisionally determined to be the load at the onset of nonlinearity. This was determined in the same manner as that used for the SENT and CT tests (Yoshihara, 2010b; Yoshihara and Usuki, 2011) and for the DCB tests described below.

Similar to the previous investigation (Yoshihara 2010a), the K_{Ic} value was initially evaluated using the following two equations, which were originally proposed by Gross and Srawley (1965) and Srawley (1976):

$$K_{Ic} = \frac{3 \cdot P_c \cdot L}{2 \cdot B \cdot W^2} \cdot \sqrt{\pi \cdot a} \cdot \left[1.09 - 1.735 \cdot \left(\frac{a}{W}\right) + 8.20 \cdot \left(\frac{a}{W}\right)^2 - 14.18 \cdot \left(\frac{a}{W}\right)^3 + 14.57 \cdot \left(\frac{a}{W}\right)^4 \right] \quad (1)$$

$$K_{Ic} = \frac{3 \cdot P_c \cdot L}{2 \cdot B \cdot W^2} \cdot \sqrt{\pi \cdot a} \cdot \left[\frac{1.99 - \left(\frac{a}{W}\right) \cdot \left(1 - \frac{a}{W}\right) \cdot \left[2.15 - 3.93 \cdot \left(\frac{a}{W}\right) + 2.7 \cdot \left(\frac{a}{W}\right)^2 \right]}{\sqrt{\pi} \cdot \left[1 + 2 \cdot \left(\frac{a}{W}\right) \right] \cdot \left[1 - \frac{a}{W} \right]^{\frac{3}{2}}} \right] \quad (2)$$

where *B* is the beam width.

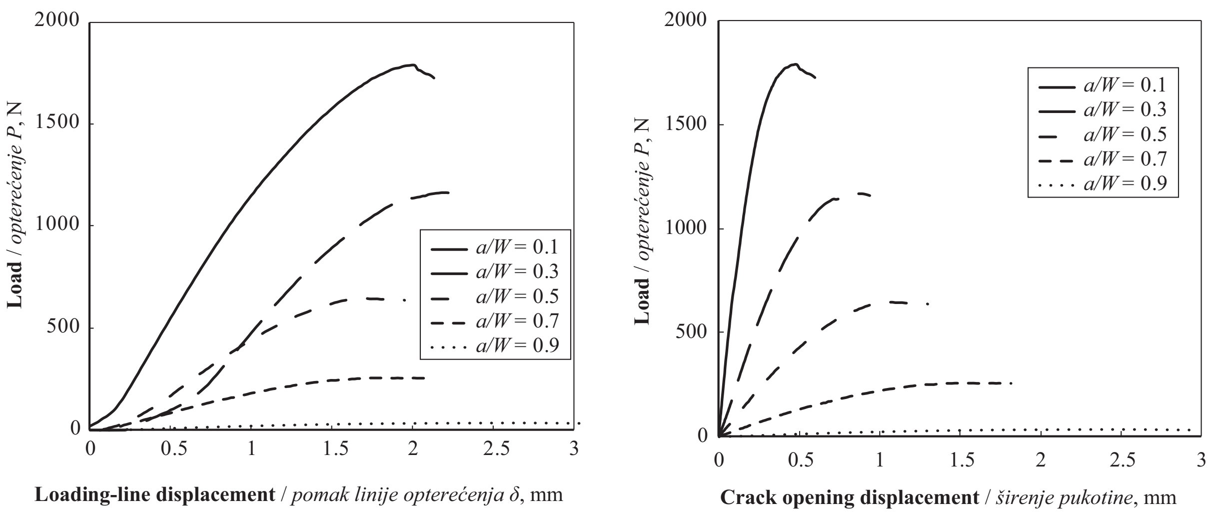

Figure 2 Typical example of the relationship between load *P* and loading-line displacement δ and that between *P* and the crack opening displacement *COD* for various crack lengths *a* in SENB test. Depth of the specimen *W* = 40 mm
Slika 2. Tipičan primjer odnosa između opterećenja *P* i pomaka linije opterećenja δ te između opterećenja *P* i širenja pukotine *COD* za različite duljine pukotine *a* u SENB testu; debljina uzorka *W* = 40 mm

2.3 DCB tests
2.3. DCB test

The K_{Ic} value was measured by the DCB test using a side-grooved specimen independent of the SENB test, and it was compared with those obtained from the SENB test. The details of the DCB test were similar to those previously conducted (Yoshihara, 2010a, b).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figure 3 shows the K_{Ic}-a/W relationships obtained from the SENB tests using Eqs. (1) and (2) and a comparison of these relationships with the results obtained by the DCB tests. A convex trend was identified in these relationships. This trend is different from that obtained by the SENB tests of western hemlock. That trend was almost constant in the a/W range of 0.1-0.7 and 0.1-0.9 when using Eqs. (1) and (2), respectively (Yoshihara, 2010a). The K_{Ic} value obtained from specimen A is larger than that from specimen B when comparing the same a/W value, except for a/W = 0.1, so the K_{Ic} values obtained from Eqs. (1) and (2) are regarded to be dependent on the specimen geometry. The point at the onset of nonlinearity, the load at which it was provisionally defined as the critical load for crack propagation P_c, could be found earlier in the *P-COD* relationship than in the P-δ relationship. Therefore, the K_{Ic} value obtained from the *P-COD* relationship is smaller than that obtained from the P-δ relationship.

Figure 3 suggests that the K_{Ic} values obtained using Eq. (1) and (2) are definitively smaller than that obtained by the DCB test because the development of a softened region ahead of the crack tip, such as fracture process zone (FPZ), is not taken into account in these equations. Due to the softened region, the cracked specimen often behaves as if the crack were longer than the actual length. Similar to the approach adopted in previous investigations (Yoshihara, 2010a, b; Yoshihara and Usuki, 2011), the relationship between K_{Ic} and a is modified by introducing an additional crack length Δ into Eqs. (1) and (2) as follows:

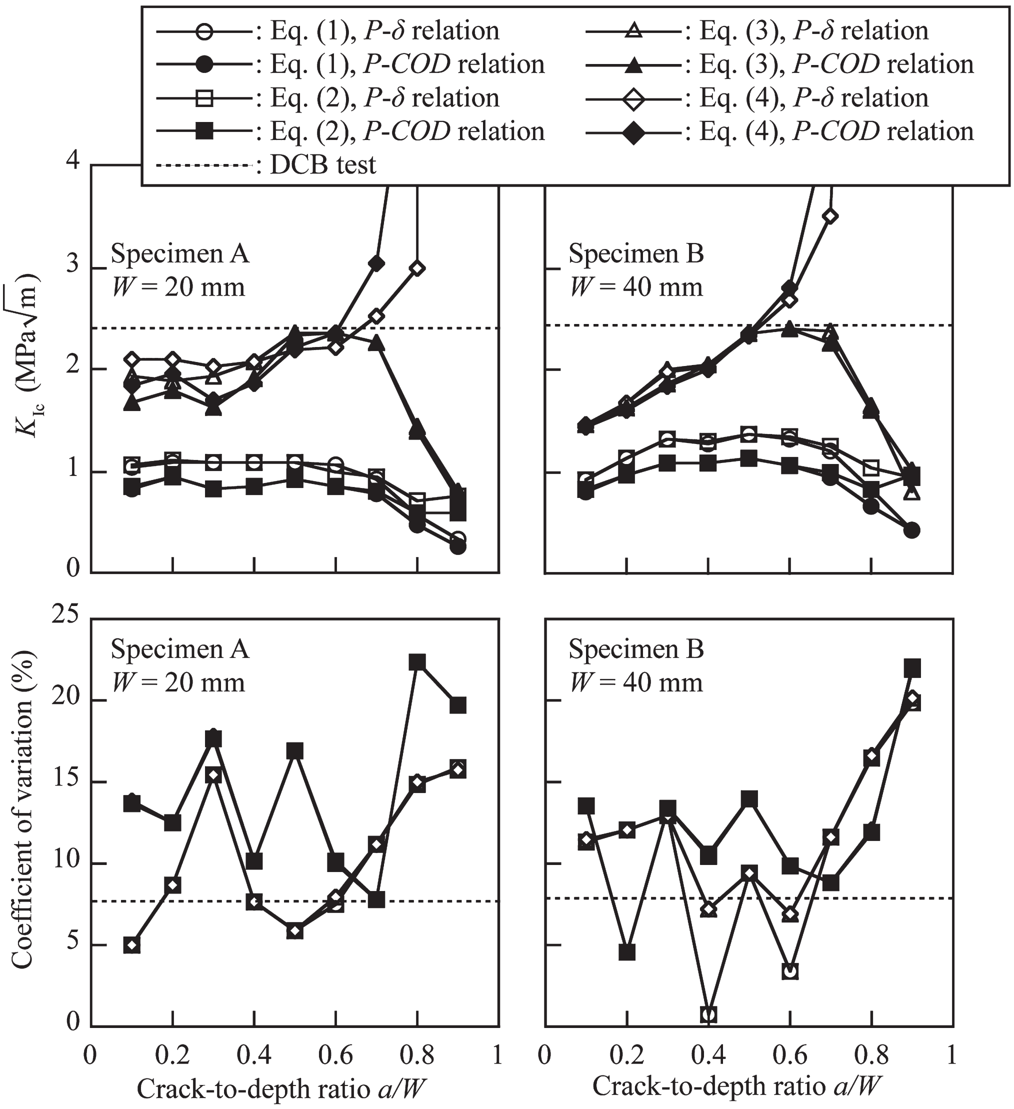

Figure 3 Comparison of the relationships between K_{Ic} and a/W obtained by SENB test and that obtained by DCB test
Slika 3. Usporedba odnosa između K_{Ic} i a/W dobivenoga SENB testom i DCB testom

$$K_{\mathrm{Ic}}=\frac{3\cdot P_{\mathrm{c}}\cdot L}{2\cdot B\cdot W^{2}}\cdot\sqrt{\pi\cdot(a+\Delta)}\cdot\left[1.09-1.735\cdot\left(\frac{a+\Delta}{W}\right)+8.20\cdot\left(\frac{a+\Delta}{W}\right)^{2}-14.18\cdot\left(\frac{a+\Delta}{W}\right)^{3}+14.57\cdot\left(\frac{a+\Delta}{W}\right)^{4}\right] \quad (3)$$

and

$$K_{\mathrm{Ic}}=\frac{3\cdot P_{\mathrm{c}}\cdot L}{2\cdot B\cdot W^{2}}\cdot\sqrt{\pi\cdot(a+\Delta)}\left[\frac{1.99-\left(\frac{a+\Delta}{W}\right)\cdot\left(1-\frac{a+\Delta}{W}\right)\cdot\left[2.15-3.93\cdot\left(\frac{a+\Delta}{W}\right)+2.7\cdot\left(\frac{a+\Delta}{W}\right)^{2}\right]}{\sqrt{\pi}\cdot\left[1+2\cdot\left(\frac{a+\Delta}{W}\right)\right]\cdot\left[1-\frac{a+\Delta}{W}\right]^{\frac{3}{2}}}\right] \quad (4)$$

The appropriate value of additional crack length Δ was determined from the following procedure, which was similar to those conducted in previous studies (Yoshihara, 2010a, b; Yoshihara and Usuki, 2011). By altering the value of Δ, the probability value (*p*-value) for the averages of *K*Ic obtained by the SENB test corresponding to each *a/W* and DCB test is calculated by Student's *t*-test. Then the *p*-values corresponding to each Δ are summed up. When the amount of the *p*-values is large, the average values of *K*Ic obtained by the SENB and DCB tests can be regarded as being close to each other. The Δ value was obtained by binary search algorithm as shown in Table 1. The Δ values listed in Table 1 are longer than those of western hemlock, which were 2 and 4 mm for specimen A and B, respectively (Yoshihara, 2010a).

Table 1 Additional crack length Δ derived by statistically comparing K_{Ic} values obtained from SENB and DCB tests (unit = mm)
Tablica 1. Dodatna duljina pukotine Δ dobivena statističkom usporedbom vrijednosti K_{Ic} ustanovljene SENB testom i DCB testom (jedinica mm)

W	**Equation** *Jednadžba*	**Relationship** / *Odnos*	
		P-δ	*P-COD*
20	(3)	4.1	4.8
20	(4)	4.2	5.7
40	(3)	6.1	7.9
40	(4)	5.9	7.6

The Δ value obtained from the *P-COD* relationship is larger than that obtained from the *P*-δ relationship. Figure 3 also shows the results calculated by Eqs. (3) and (4). The values of K_{Ic} obtained from Eq. (3) are close to those obtained by the DCB tests when *a/W* falls in the approximate range of 0.5 to 0.7. A statistical analysis of the difference between the K_{Ic} values obtained using the SENB and DCB tests shows that the difference is not significant in this *a/W* range, regardless of whether the P_{c} value is determined from the *P*-δ or *P-COD* relationship. This range coincides well with the range used to derive the appropriate K_{Ic} value in the SENT test (Yoshihara 2010b). When using Eq. (4), however, the applicable range of *a/W* is narrower than that obtained using Eq. (3). When the *a/W* value is smaller than 0.4, material nonlinearity precedes the crack propagation, so the load at the onset of nonlinearity in the *P*-δ and *P-COD* relationships P_{c} cannot be regarded as the critical load for crack propagation (Yoshihara 2010b). Therefore, the K_{Ic} values for *a/W* values smaller than 0.4 were measured to be smaller than those in the *a/W* range from 0.5 to 0.7. In contrast, the value of K_{Ic} calculated from Eq. (3) decreases in the *a/W* range larger than 0.8, whereas that calculated from Eq. (4) diverges when *a/W* exceeds 0.8 because the value of 1 - $(a+\Delta)/W$ contained in the equation is close to zero. Therefore, the K_{Ic}-*a/W* relationships obtained from Eqs. (3) and (4) are extremely different from each other when the value of *a/W* exceeds 0.8. Additionally, when the crack tip is close to the loading point, the compressive stresses due to the indentation of the loading nose hinder self-similar crack propagation (de Moura *et al*., 2010). From these reasons, the appropriate range for introducing the additional crack is restricted. From the results obtained here, the K_{Ic} value should be measured using Eq. (3) in the *a/W* range from 0.5 to 0.7.

In this research, the additional crack length Δ is determined by statistically comparing the K_{Ic} values obtained from the *P*-δ and *P-COD* relationships and that obtained by the DCB test. Therefore, the Δ value is dependent on the relationship used in the analysis, as shown in Table 1. Based on the concept of the FPZ, however, the value of Δ can be physically obtained (Vasic and Smith, 2002; Vasic *et al*., 2003; Morel *et al*., 2003; 2005; de Moura *et al*., 2008, 2010; Dourado *et al*., 2008, 2010). As shown in Figure 2, the K_{Ic} values obtained from both *P*-δ and *P-COD* relationships are similar to each other when correcting the crack length. Therefore, it is difficult to determine which relationship is more valid for determining the K_{Ic} value. Microscopic observation (Vasic and Smith, 2002; Vasic *et al*., 2003) and digital image correlation observation (Murata *et al*., 2011) around the crack tip during loading may be effective to reveal the validity of the relationships.

According to the research on the Mode II critical stress intensity factor K_{IIc} of wood and MDF as determined by an asymmetric four-point bending test, the K_{IIc} value can be obtained by introducing the additional crack length when *a/W* exceeds 0.8, when an appropriate equation is derived for the crack geometry factor (Yoshihara submitted). In the SENB tests of solid wood (Yoshihara, 2010a) and MDF, two previously proposed equations (Eqs. (1) and (2)) were used and modified by considering the additional crack length. Further research should be conducted to find a new equation that can derive the K_{Ic} value properly for the specimen with an *a/W* value larger than 0.8. In addition, the compressive stresses due to the indentation of the loading nose can be reduced when conducting the four-point SENB (4SENB) test in which the loading-line deviates from the crack pass, and the range of *a/W* can be extended. Therefore, further research should also be conducted on the 4SENB test of MDF and solid wood.

4 CONCLUSIONS
4. ZAKLJUČAK

A single-edge-notched bending (SENB) test of MDF was conducted to obtain the Mode I critical stress intensity factor K_{Ic}. The test results were compared with those of the double cantilever beam (DCB) tests, an approach that is thought to be valid because the K_{Ic} value can be determined based on energy considerations.

The above results are interpreted to indicate that the critical stress intensity factor K_{Ic} in Mode I can be obtained effectively by introducing the additional crack length Δ as in Eq. (3) under the range of the crack length/specimen depth ratio *a/W* from 0.5 to 0.7. This range coincided well with that obtained in the single-edge-notched tension (SENT) tests of MDF Yoshihara, 2010b). To determine the value of K_{Ic} under a wide range of *a/W*, further research should be undertaken on issues such as additional crack lengths, other equations for determining the K_{Ic} value, and other test methods including the four-point SENB (4SENB) test.

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Software "Image J" Application in Evaluating the Quality of Extracted Raw Wood Assortments

Primjena programa *Image J* za ocjenu kvalitete drvnih sortimenata

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ABSTRACT • *The goal of this paper was to investigate the possibility and verify the use of the software product "Image J" for the evaluation of the selected qualitative characters of wood as a renewable natural resource. For this purpose, the qualitative character "false heartwood" in beech wood was selected and evaluated in the sample of 63 logs. The aim was to compare the assessment of this qualitative character as it is performed today, namely by visual evaluation, against the use of the software product "Image J", which is considered to be more precise in assessing this qualitative character. The difference in quality grades of wood assortments between the two methods has also been quantified, as well as the potential economic benefits in the practical use of this software product. The possibilities of its use in the evaluation and measurement of other wood qualitative characters have been described, specifically those in which the quantification of the affected area is decisive. The results clearly demonstrate that the current visual evaluation of these qualitative characters is not adequately precise and that therefore, in some cases, it underestimates the quality of timber.*

Keywords: *raw wood assortments, quality of extracted wood, wood qualitative characters, automated quality assessment*

SAŽETAK • *Cilj ovog rada bio je istražiti mogućnosti i provjeriti primjenu programa ImageJ za vrednovanje odabranih kvalitativnih obilježja drva kao obnovljivoga prirodnog resursa. Za tu svrhu odabrano je kvalitativno obilježje trupaca bukve, tzv. lažna srž, i ocijenjeno na uzorku od 63 trupca. Cilj je bio usporediti procjenu toga kvalitativnog obilježja metodom koja se danas primjenjuje, tj. vizualnom metodom, s metodom u kojoj se primjenjuje softverski proizvod ImageJ, za koju se predviđa da je preciznija u procjeni toga kvalitativnog obilježja. Određena je razlika u kvaliteti razreda različitih drvnih sortimenata procijenjena tim dvjema metodama, te utvrđene potencijalne ekonomske koristi od praktične primjene toga softverskog proizvoda. Opisane su mogućnosti primjene softvera u ocjenjivanju i mjerenju drugih kvalitativnih obilježja drva, posebno onih u kojima je odlučujuća kvantifikacija površine. Rezultati jasno pokazuju da je sadašnja vizualna procjena kvalitativnih obilježja nedovoljno precizna te da je u nekim slučajevima kvaliteta drva podcjenjena.*

Ključne riječi: *drvni sortimenti, kvaliteta drva, kvalitativna obilježja drva, automatizirano ocjenjivanje kvalitete*

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1 INTRODUCTION
1. UVOD

Successful valorization and sale of timber grown and produced is not possible without the precise knowledge of its quantitative and qualitative characteristics (Demko *et al*., 1993). Problems of wood assortments are closely related to economic issues, as by assorting, decision is made about the valorization and capitalization of forest production capacity. Criteria for the evaluation of wood quality are presented by a system of qualitative characteristics. Raw wood still cannot be evaluated easily only according to positive quality features (e.g., only by species, color, etc.), and negative qualitative characteristics are also used. The evaluation is performed based on quantity and extent of characters (flaws), i.e. according to quantity and extent of normal characters, abnormalities, diseases and wood damage, which impair or in rare cases improve its utilization and valorization. The extent of these negative qualitative characteristics and quantitative dimensions of logs or raw wood are the basic criteria for the classification of wood into different grades and assortments according to industry standards.

Thorough knowledge of technical conditions of the production of wood assortments still does not guarantee the optimal capitalization of raw wood. It includes knowledge of the business environment, competitiveness (Jelačić *et al*., 2012) and long-term development on the market and price development of wood assortments. These pieces of information are the basis for an optimal evaluation and placement of wood and timber products on the market. Therefore, the optimal classification of wood assortments and a thorough knowledge of both the market and technology used in their production are critical in determining the final capitalization on the market, which is an essential and dominant source of income for the forestry industry in Slovakia.

This paper deals with the evaluation of the qualitative character ‚false heartwood', according to the current technical conditions and by the application of a modern software product. This software can be used in forestry to analyze the selected qualitative characteristics, particularly their areal extent. Both methods are compared and evaluated in assessing ‚false heartwood' character, including possible economic effects.

1.1 Legislative environment of SR
1.1. Pravni okvir u Republici Slovačkoj

For assessing wood quality and its classification into different grades, the system of technical specifications for raw wood assortments is used worldwide. European Union has been seeking to harmonize these technical norms for a long time and to this purpose European standards have been issued. Since EN classifies raw wood assortments not taking into consideration the intended use, they are practically unusable. Each EU country has its own technical specifications, which have a long tradition and these standards are being amended without regard of the common European standards.

The use of standards in SR is regulated by the Act 264/1999 about technical requirements for products and conformity assessment and by the Acts 436/2001 and 254/2003l, according to which standards are voluntary and only recommendatory. They become mandatory only in the following cases: 1. Technical legislation (law, decree, etc.) 2. Legislative act of Office of Standards, Metrology and Testing, 3. Treaty. Thus, standards become legally binding only when the purchasing contract is made between the supplier and customer, meaning that in SR wood can be traded by any technical standard which classifies the quality of wood (Suchomel *et al*., 2010). This is mostly used by different wood dealers but also by large processing entities.

The second reedition of the main standards for raw timber in 2004 does not make the situation any clearer. These facts affect the overall evaluation of wood in operational practice.

Currently, there are two groups of standards in Slovakia, which classify the quality of wood:
- Standards, which qualitatively classify raw-wood assortments, where the future use is known.
- Standards, which qualitatively classify raw-wood assortments, where the future use is unknown.

The first group includes the standards STN 48 0055, STN 48 0056, which qualitatively classify conifers.

1.2 Detection and evaluation of beech false heartwood
1.2. Otkrivanje i procjena "lažne srži" bukve

Beech false heartwood is defined as unhealthy red or brown colored false heartwood, sharply defined and ring, flame or starfish shaped, seen on beech logs (STN EN 844-10, 2000).

Evaluation of false heartwood (Klir, 1981)

Researches have shown that beech false heartwood has same mechanical properties as healthy wood. Wood of false heartwood is hard to impregnate. Marbled heartwood is the most difficult to impregnate. It reduces the yield of higher quality timber. It requires a different processing than in sawmills.

Classification of false heartwood

Classification of false heartwood, according to shape (Klir 1981):

a) round, mostly irregular oval;
   - simple, one-zone;
b) marble (mosaic), composed of numerous zones demarcated from each other;
c) double, the outer frost core zone, arising due to low temperatures;
d) radial, with sharp spurs and circumscribed with symptoms of rot beginning;
   - star, in the middle of log cut;
   - flue placed off-center;

Classification of false heartwood, according to health:
- Healthy false heartwood with unchanged mechanical properties from surrounding wood, with no signs of rot and without significant fungus discoloration.
- Partly healthy false heartwood with an initial stage of rot or with discoloration signs of fungus.
- False heartwood with advanced heart rot on most area of false heartwood.

- False heartwood with advanced stage of rot on the whole surface of the core with visible wood crushing.

Measuring false heartwood (STN EN 1310, 2000)

The diameter of the circle surrounding the contaminated area is measured. It is expressed as the percentage of thickness measured on the appropriate head (Fig. 1).

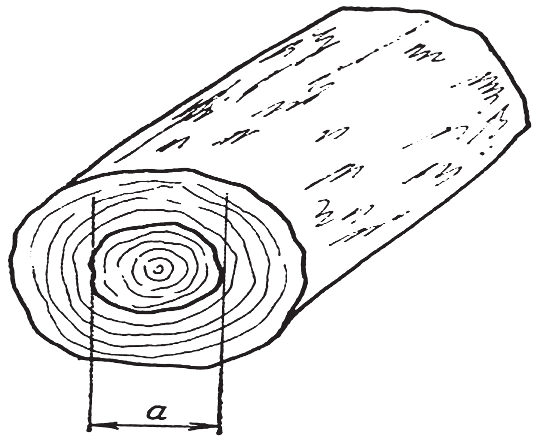

Figure 1 Measurement of false heartwood (STN EN 1310)
Slika1. Mjerenje "lažne srži" (STN EN 1310)

The impact of false heartwood on the quality of beech assortments

Table 1 describes the restriction of false heartwood in beech-specific ranges, according to various legislative regulations. The size of beech false heartwood is an important indicator for the classification to quality grade and proper assessment of its thickness share of the front side. Therefore, increased attention should be given to measuring its size. In addition with other quantitative and qualitative features, size of the false heartwood significantly influences the capitalization of raw wood assortments.

1.3 Application of mobile devices in forestry operations
1.3. Primjena mobilnih uređaja u šumarstvu

To a certain extent, forestry is a conservative sector. "Classic" areas of computer technology are in use (Tuček, 2011). Currently, the use of mobile devices in Slovak forestry is insufficient. Mobile devices, used in Slovakia, are mostly obsolete. The most used devices are made by Latschbacher (Slančik *et al*., 2007). Today, there is a variety of new advanced machines and equipment, which significantly facilitate and simplify the measurement and evaluation of qualitative characteristics, and which are connected to high-performance software tools.

Table 1 Assessment of the size of false heartwood of specific assortment quality, according to most commonly used technical standards in SR
Tablica 1. Procjena veličine "lažne srži" u razredima kvalitete konkretnih sortimenata prema najčešće primjenjivanim tehničkim standardima u SR

Quality grade *Razred kvalitete*	**I.**	**II.**	**III.A**	**III.B**	**III.C**	**III.D**	**IV. -V.**
STN 48 0056 (2007)	to 20 % of log butt end area *do 20 % površine na debljem kraju*	round and flame. to 1/3 of log butt end area *okrugla, do 1/3 površine na debljem kraju*	to 1/3 of log butt end area, flame red not allowed *do 1/3 površine na debljem kraju, jarko crvena nije dopuštena*	to 1/2 of log butt end area, flame red to 1/3 of log butt end area *do 1/2 površine na debljem kraju, jarko crvena do 1/3 površine na debljem kraju*	without limitation, flame red to 1/2 of log butt end area *bez ograničenja, jarko crvena do 1/2 površine na debljem kraju*	not classified *nije klasificirano*	allowed *dopušteno*
Conditions of Lesy SR, š.p. (2009)	to 20 % of log butt end area *do 20 % površine na debljem kraju*	to 1/3 of log butt end area *do 1/3 površine na debljem kraju*	to 1/3 of log butt end area, flame red not allowed *do 1/3 površine na debljem kraju, jarko crvena nije dopuštena*	to 1/2 of forhead area, flame red to 1/3 of log butt end area *do 1/2 površine na tanjem kraju, jarko crvena do 1/3 površine na debljem kraju*	without limitation, flame red to 2/3 of log butt end area *bez ograničenja, jarko crvena do 2/3 površine na debljem kraju*	not classified *nije klasificirano*	allowed *dopušteno*
Quality grade *Razred kvalitete*	**F-A**	**F-B**		**F-C**			**F-D**
STN EN 1316-1	≤ 20 % log butt end area, flame red not allowed *≤ 20 % površine na debljem kraju, jarko crvena nije dopuštena*	≤ 30 % log butt end area, flame red core in % thickness ≤ 10 % *≤ 30 % površine na debljem kraju, jarko crvena srž u postocima debljine ≤ 10 %*		is allowed, flame red false heartwood in % of log butt end area ≤ 40 % *dopušteno, jarko crvena lažna srž u postocima površine na debljem kraju ≤ 40 %*			is allowed *dopušteno*

Programs developed and used in mobile devices are primarily applied in processing and recording of timber. New types of mobile devices (e.g. the Trimble Nomad) make new software solutions possible because of their modern interface. In the future, it may be possible to consider software implementation of various technical specifications, possibly with photographic documentation of typical quality characters, or with the implementation of software applications that will allow evaluating and measuring qualitative characteristics based on a digital image. (e.g. ImageJ software product).

These possibilities would certainly increase the productivity of workers in handling the wood stock and expand their opportunities to make the right decisions for the best capitalization of wood in order to maximize the generated profit of sold assortments, including an efficient control system. The qualitative characteristics (of wood) must meet the requirements of customers in the context of comprehensive quality management, achievement of economic efficiency and therefore profitability. High quality of specific products can bring the company a significant competitive advantage (Koprolčec *et al*., 2012; Merkova *et al*., 2012).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Examined material
2.1. Istraživani materijal

For comparative analysis, beech false heartwood was selected as qualitative character, since it is a relatively frequent character with variable dimensions that may significantly affect the final quality of raw wood assortments.

Qualitative analysis was made of a total of 567 pieces of beech from the University forest company TU Zvolen, from district forest areas: Tŕnie, Mláčik, Ľubica, Sekier, Ostra Luka, Blážová, Čertove Kúty, Geberanica, Bukovina, Podzámčok, Hákovo, and Michalková. The character of false heartwood occurred in 340 (60 % occurrence) assortments with an average size of 15.9 cm circular area. Out of 340 units with the occurrence of beech false heartwood, 63 selections were chosen for the analysis by software ImageJ, and incidence of false heartwood on the log butt end was photographically recorded.

2.2 Evaluation of false heartwood according to STN EN 1310
2.2. Procjena "lažne srži" prema normi STN EN 1310

The size of false heartwood was determined on all 63 logs according to STN EN 1310, as described in section 1.2. Consequently, the measured values were expressed as percentages of false heartwood on the log. False heartwood was measured with the calibrated caliper and band.

2.3 Evaluation of false heartwood by use of software product ImageJ
2.3. Procjena "lažne srži" primjenom programa *ImageJ*

All 63 logs were assessed on the basis of the known log thickness in cm, which is called reference dimension and the program needs this parameter to calculate the area in cm^2.

Figure 2 Analysis of false heartwood by software product ImageJ
Slika 2. Analiza "lažne srži" programom *ImageJ*

In ImageJ, the scale for the calculation of the surface area of the log butt end, as well as the surface area of false heartwood, is determined with a real reference dimension – the log thickness in cm. The program calculates the surface area of the log butt end, as well as the surface area of false heartwood, after digital bordering. Log butt end area and false heartwood area are bordered by the mouse on a digital photography in program ImageJ (Fig. 2). After the calculation of the surface areas in cm^2, it is easy to express the percentage of false heartwood in the total surface area.

Qualitative evaluation took place in log conversion depot Lieskovec from June 15, 2012 to Aug. 31, 2012.

2.4 Determination of volume and price for raw wood assortments
2.4. Određivanje volumena i cijene drvnih sortimenata

The volume of assortments was determined individually by Smalian formula (1):

$$v = \frac{\pi}{4} \cdot \frac{d_0^{\,2} + d_n^{\,2}}{2} \cdot L \tag{1}$$

Where:
v - log volume in m^3
d_0 - log thickness (thicker end) in m
d_n - stud thickness (thinner end) in m
L - length of log in m

Each log was qualitatively classified according to the size of qualitative character in terms of STN 48 0056 of 2007. Classification was made with respect to the size of false heartwood detected, according to STN EN 1310 and according to the evaluation by software ImageJ.

For each log, the price was determined per 1 m^3 based on the volume and average price (second quarter of 2012) of beech wood in forest public entities with the dominant market share in Slovakia. The prices of assortments are without VAT (tax) at log conversion depot, and they were quoted from "Newsletters National Forest Centre" (Brezinova, 2012).

In cases where assessment of the size of false heartwood caused a different classification into qualitative grades, by either of the used methods, a price difference was calculated for the specific log.

Due to the limited scope of this paper, only the local market was considered. Therefore, long-term price development of wood assortments in the surrounding countries was not reflected in this paper. Only domestic prices of the second quarter of 2012 were used.

2.5 Used tools
2.5. Upotrijebljeni alati

For simple calculations and graphical evaluation, MS Excel 2010 was used. A steel meter (band) was used to measure the size of false heartwood, and a standardized caliper was used to measure the assortment thickness. Photographic documentation was made with the digital camera SONY DSC - P41 with effective pixel count of 4,065,000 and lens with a focal length $f = 5.0$ mm. Printed graphics and other evaluations were performed by software product ImageJ 1.37 v.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Analysis of false heartwood according to STN EN 1310
3.1. Analiza "lažne srži" prema STN EN 1310

The average size of false heartwood, measured by STN EN 1310, was 19.2 cm with an average log thickness of 42.4 cm. The average percentage area of false heartwood was therefore 44.5 %. According to STN EN 1310, the largest size of false heartwood was recorded in the analyzed log No. 26 (60 cm). The smallest false heartwoods were recorded on logs No. 6 and 49 (5 cm). The largest percentage area of false heartwood on the log was recorded in the analyzed log No. 26 (90.91 %), and the smallest on log No. 6 (9.49 %).

The disadvantage of the analysis according to STN EN 1310 is that it does not reflect the irregularity of false heartwood surface. It provides accurate results for regular (round) shape of false heartwood. The least accurate results are those for very irregular shapes of false heartwood. Under these conditions, this method systematically overestimates or underestimates the assessment, and thus creates incorrect determination of false heartwood proportion depending on log thickness. This may then result in a lower grade classification, which basically means worse capitalization of wood assortments and smaller profit from its sale. On the basis of objective assortment classification (better grades), better revenues would actually be achieved. The size of false heartwood in cm, measured in accordance with STN EN 1310, for all the analyzed assortments are shown in Fig. 3.

3.2 Analysis of false heartwood according to ImageJ
3.2. Analiza "lažne srži" primjenom programa *ImageJ*

On the basis of the reference dimension, thickness of log, the program calculated the surface area of log butt end and false heartwood surface in cm^2, and then expressed as percentage of false heartwood on the log butt end. The surfaces of false heartwood in cm^2 computed by ImageJ software are presented in Figure 4. The largest surface of false heartwood was recorded on log No. 26 and the smallest on log No. 6, which was confirmed by the analysis made in accordance with STN EN 1310. For qualitative classification, the percentual share in the log surface is important.

The largest percentage of false heartwood was recorded on log No. 26 (60.49 %), and the smallest percentage on log No. 6 (0.3 %). These results confirm that the analysis made by the software product and assessment according to STN EN 1310 are much more accurate, especially for very irregular false heartwood,

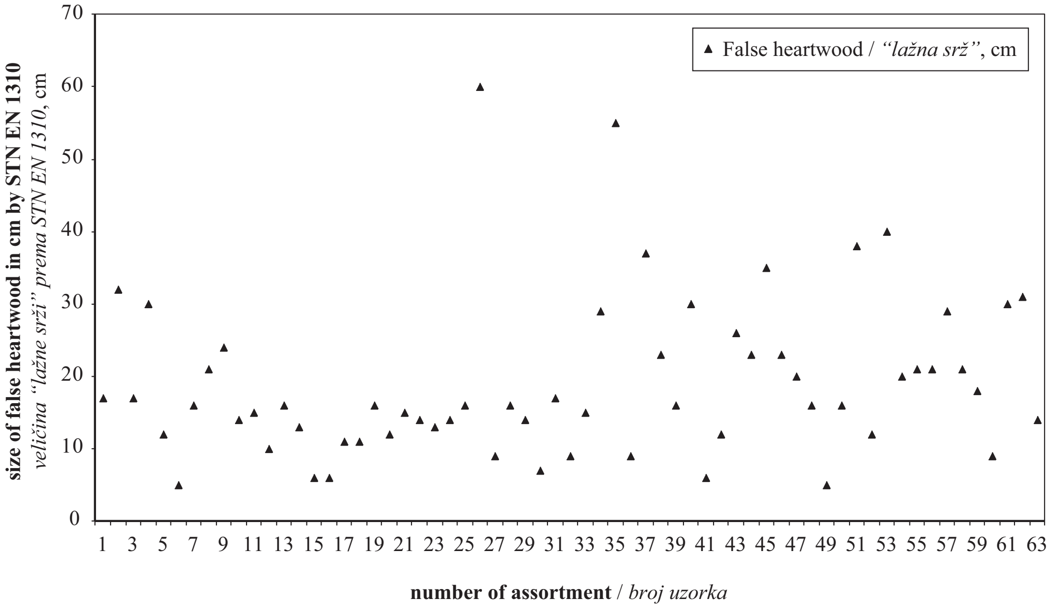

Figure 3 Size of false heartwood in cm according to STN EN 1310
Slika 3. Veličina "lažne srži" u centimetrima prema STN EN 1310

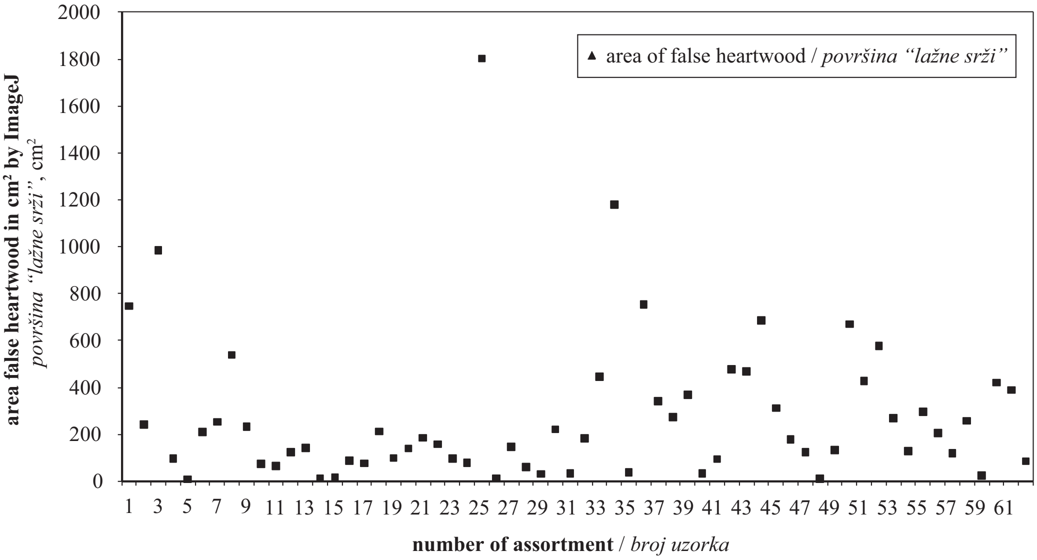

Figure 4 Areas of false–core in cm² by ImageJ
Slika 4. Površina "lažne srži" izražena u cm² dobivena primjenom programa *ImageJ*

where the area of damage is systematically overestimated

3.3 Comparative Analysis
3.3. Komparativna analiza

The results of comparative analysis show that the assessment of false heartwood according to STN EN 1310 systematically overestimates the area of irregular false heartwood, because it is considered as regular shape, which is almost never the case with false heartwood. The results of comparative analysis confirmed that taking into account 63 logs, the average difference of false heartwood area on the log of each assortment was 28.2 % (i.e. false heartwood evaluated by ImageJ was on average 28.2 % smaller than that assessed according to STN EN 1310). In some cases, this difference has significant influence on potential classification of assortments into quality grades. The average percentage size of false heartwood evaluated according to STN EN 1310 was 44.6 %. The average percentage of false heartwood, evaluated by software ImageJ, was 16.37 %. The average butt end area of the log, calculated by ImageJ, was 1605.700 cm² and the average area of false heartwood was 272.319 cm².

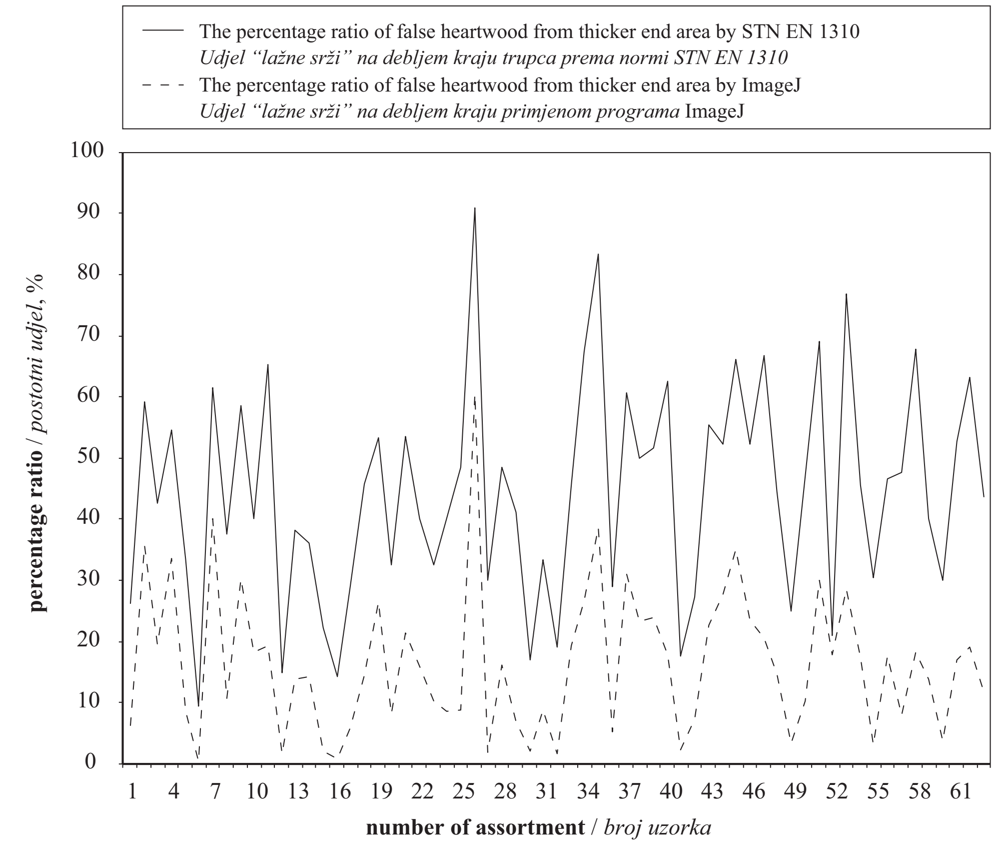

Figure 5 Percentages of false heartwood on total log area according to STN and program ImageJ
Slika 5. Postotak površine "lažne srži" na ukupnoj površini trupca prema normi STN dobiven primjenom programa *ImageJ*

Figure 6 Analyzed log No. 52
Slika 6. Analizirani trupac broj 52

Figure 7 Analyzed log No. 58
Slika 7. Analizirani trupac broj 58

Figure 5 graphically represents percentages of false heartwood according to both methods (STN and ImageJ). For better clarity and illustration of differences between these two methods, the results were connected into curves. The image clearly shows systematic overestimation of false heartwood share according to STN EN 1310. The smallest difference between these two methods was recorded with log No. 52 with log thickness of 57 cm (3.24 %), probably due to relatively regularly shaped false heartwood (Fig. 6). The analysis of other logs confirmed that differences between these two methods are smaller when false heartwood is smaller and more regular; this confirms the fact that the assessment according to STN EN 1310 achieves the desired accuracy only when false heartwood is small and regularly shaped. Conversely, the biggest difference between methods is recorded when false heartwood is at the larger butt end of the log and of very irregular shape, smaller in proportion to log butt end area (49.6 % difference with log No. 58 - Fig. 7).

The assessment of irregular false heartwood according to STN EN 1310, significantly overestimates its actual dimensions, which in practice results in the classification of logs to lower quality grades for most assortments with false heartwood. Based on the actual size of false heartwood, according to software ImageJ it is possible to classify some logs into better grades, and thus achieve better price for wood and higher level of capitalization of assortments in operational practice.

This software product could be used in feedback analysis and quality control of manufactured and shipped timber assortments i.e. in auctions and research, of course, provided that the photographic documentation is available.

3.4 Economic benefits of software deployment
3.4. Ekonomska korist od primjene programa

The total volume of analyzed assortments was 39.62 m^3 (Smalian calculation formula). All assortments were qualitatively classified according to STN 48 0056 of 2007 into appropriate quality grades. The assessment of the proportion of false heartwood in log butt end had significant impact on classification into different grades. Up to 22 units were classified in the same quality category by both types of analyzes. In other cases, the evaluation of false heartwood by ImageJ resulted in classification to better quality grades (sometimes two grades better). Percentages of assortments in specific quality grades for both assessment methods of false heartwood are shown in Figure 8.

On the basis of volume and price per 1 m^3 (last quarter 2012), the final price was calculated for each assortment. Overall evaluation of the sample determined with classical assessment of false heartwood according to STN EN 1310 was estimated at € 2,036.83. By assessing the false heartwood according to ImageJ, the overall assessment of the sample was € 2,436.37. Difference is € 399.54. On average, higher capitalization of about 10.1 €.m^{-3} could be achieved when assessing false heartwood according to software "Image J". Maximum 22 m^3 of assortments can be loaded on one truck. In this case, the economic benefit of one load can be quantified approximately to € 300.30. The prices of assortments used for the calculation were the following (Brezinova, M. 2012): Assortment II. grade 89.12 €·m^{-3}, assortment III.A grade 69.27 €·m^{-3}, assortment III.B grade 55.11 €·m^{-3}, assortment III.C grade 44.96 €·m^{-3}, assortment of fiber and other industrial wood 36.93 €·m^{-3}.

In practice, the costs of implementing this method only include the prices of mobile devices, which vary depending on the equipment, starting at € 1,300 per 1 piece. The costs of digital camera are relatively low. The software is free, and freely distributable, meaning that after purchasing a mobile device, the costs are rentabile after dispatching about 173 m^3. This conclusion would only apply if the entire amount was assessed by this one mobile device and the resulting assortment quality affected only the qualitative character 'false heartwood'. When several characters (their area) are assessed, the effectiveness of this method is multiplied.

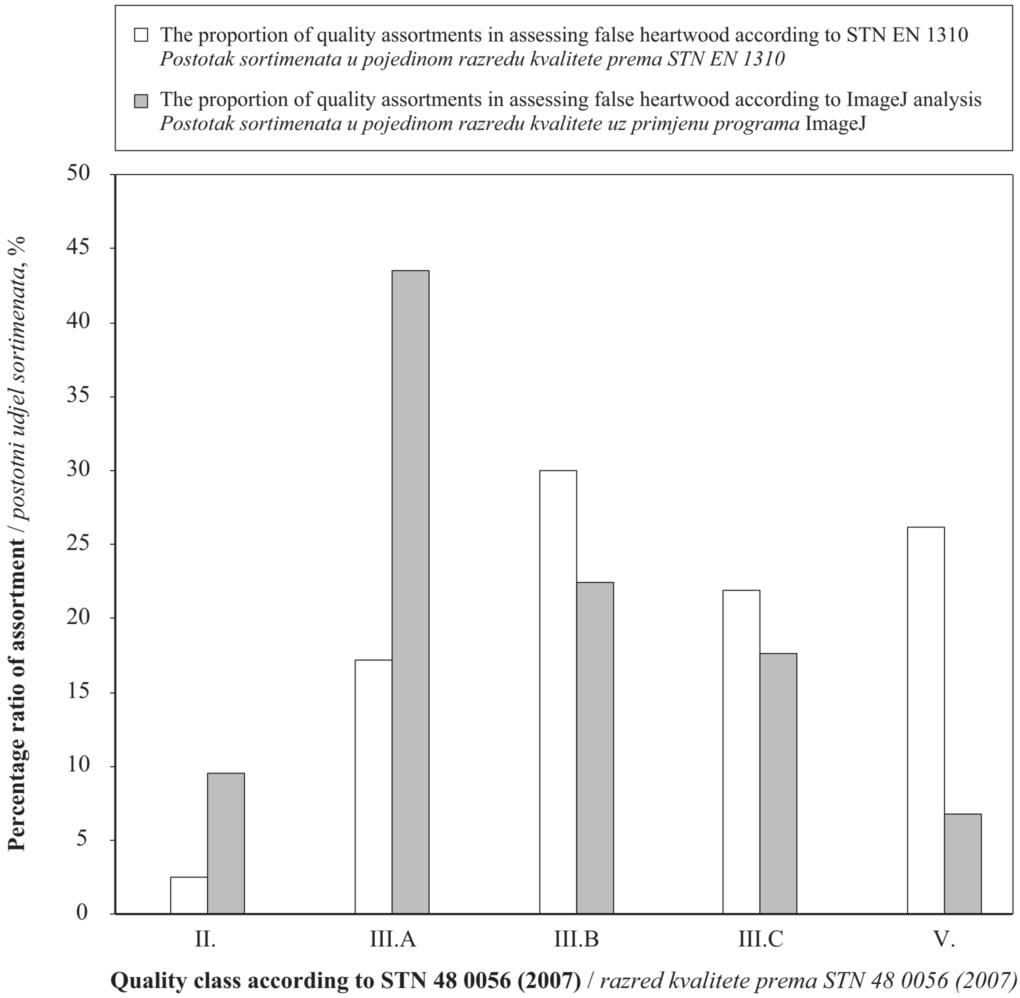

Figure 8 Percentages of assortments in quality grades by assessment of false heartwood according to STN EN 1310 and ImageJ
Slika 8. Postotak sortimenata u pojedinom razredu kvalitete procjenom "lažne srži" prema normi STN EN 1310 i uz primjenu programa *ImageJ*

4 CONCLUSION
4. ZAKLJUČAK

The results presented in this paper document the significant impact that the increased focus on accurate assessment of negative qualitive characters of wood will bring in near future, particularly in view of potential economic benefits. Some countries already have legislative regulations for electronic timber sorting and more accurate assessment of negative qualitative characteristics (e.g. Austria). The first CT scanners are already applied (e.g. company Microtec), providing perfect measurement and evaluation of all wood qualitive characters that are visible on log surface or hidden inside. It can be assumed that this trend will continue and timber traders, who want to sell wood profitably, will focus on opportunities to minimize the negative evaluation of timber regarding the characters and thus reach its higher value (Motik *et al*., 2008).

Although in Slovakia the use of advanced technologies in forestry sector is not at the required level, change can be expected in near future. Therefore, there is room for possible deployment of technologies, which would allow to forestry to get more revenue because the sale of wood assortments is the dominant source of its income. Such technologies include the tested software "ImageJ" along with mobile devices and other devices of modern technology.

In view of the income from timber sales, prices and market developments are also important. Recently, they have been affected by global economic crisis and, in Slovakia particularly, also by poor structure of processing industry. Forestry companies, if they want to get the most revenue, will have to make marketing analysis and research of long-term price trends. These activities are not implemented in our forestry companies. The interest in renewable energy resources and research of its energy characteristics will be constantly growing (Dzurenda *et al*., 2012). Continuous technological development and progress will bring new and effective wood processing options of raw wood material, enabling the reduction of the requirements on overall wood quality (Teischinger, 2010). Development in the last 300 years only confirms this finding (Teischinger, 2010).

Global climate and economic changes will bring in future further turbulences on the market of timber and renewable energy sources, and so the issue of its capitalization will increase in importance.

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Properties of Liquid and Polycondensed UF Resin Modified with pMDI

Svojstva tekuće i polikondenzirane UF smole modificirane s pMDI

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ABSTRACT • *The aim of this study was to determine the properties of liquid and cured UF (urea-formaldehyde) resin modified with pMDI (polymeric 4, 4'-methylenediphenyl isocyanate). Analyses showed that when introduced to liquid UF resin already at 10 %, its reactivity increases, which is reflected in a shortening of gel time and reduction of activation energy of the polycondensation process. In turn, analyses performed on polycondensed resin showed that, thanks to modification with pMDI, its hydrophobicity is considerably improved, as manifested in a reduction of absorbability and swelling in thickness of cured resin.*

Key words: *UF, pMDI, hybrid resin, FTIR, hydrophobicity*

SAŽETAK • *Cilj istraživanja bio je utvrditi svojstva tekuće i otvrdnute UF smole (urea-formaldehida) modificirane s pMDI-jem (polimernim 4, 4'-metilendifenil izocijanatom). Analiza je pokazala da dodavanjem pMDI-ja tekućoj UF smoli već u 10 %-tnoj količini rezultira povećanjem reaktivnosti, izraženoj skraćivanjem vremena želiranja i smanjenjem energije aktiviranja procesa polikondenzacije. Osim toga, analiza svojstava polikondenzirane smole pokazala je da je, zahvaljujući modifikaciji s pMDI-jem, znatno poboljšana hidrofobnost, što se očituje smanjenjem apsorpcije i bubrenja otvrdnute smole u debljinu.*

Ključne riječi: *UF, pMDI, hibridni smole, FTIR, hidrofobnost*

1 INTRODUCTION
1. UVOD

In order to improve water resistance of urea-formaldehyde resin (UF), an adhesive, commonly used in the manufacture of wood-based materials, is modified first with water resistant melamine-formaldehyde (MF) or phenol-formaldehyde (PF) adhesives. Despite their obvious advantages, a combined melamine-urea-phenol-formaldehyde (MUPF) resin does not completely exhibit the advantageous properties of its individual components, particularly in terms of resistance to the action of variable ambient conditions (Cremonini *et al*., 1996a; Kamoun and Pizzi, 1998; Prestifilippo and Pizzi, 1996; Prestifilippo *et al*., 1996; Tomita and Hse, 1992; Tomita *et al*., 1995; Weinstabl *et al*., 2001). As a result, wood based materials manufactured with its use have lower water resistance than when produced using pure PF resin. For this reason, MUPF resins are applied in the production of plywood and construction boards with enhanced resistance only to the action of variable weather conditions (Cremonini and Pizzi, 1999; Cremonini *et al*., 1996b,1996; Zhao and Pizzi, 2000).

Another direction leading to an enhancement of water resistance in amine resins is their modification with pMDI (polymeric 4, 4′-methylenediphenyl isocy-

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anate) (Pizzi *et al*., 1993; Osman *et al*., 2005; Mansouri *et al*., 2006; Lei *et al*., 2006). Analyses showed that a 40 % addition of isocyanates to UF resin makes it possible to manufacture plywood with an even better water resistance than that specified in the respective standard binding for MF resin (Pizzi *et al*., 1993). In turn, the use of UF/pMDI hybrid adhesive, thanks to a reduction of the pMDI share to 15 %, reduces the costs and improves its water resistance, but only to a limited extent. Plywood produced with this adhesive exhibited good water resistance only after 27 min of boiling instead of 2 h, as specified in the standard for melamine-based resin (Mansouri *et al*., 2006). In contrast, Lei *et al*. (2006) stated that an addition of pMDI to MUPF resin generally did not improve mechanical properties, but it considerably improved the board water resistance. These researchers showed that, when pMDI is added to MUPF resin at as little as 5 % tensile strength of particleboards, after 2 h boiling the water resistance increases from 0.09 to 0.21 N/mm^2. The presented modification method of amine resins, apart from an increase in water resistance, also contributes to a reduction of costs associated with pMDI use.

This study analyzed the basic properties of liquid and polycondensed UF resin modified with pMDI.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

Analyses were performed on UF resin and pMDI, commonly applied in the wood based material industry to manufacture materials used indoors and outdoors. The basic properties of resins used in the study are shown in Table 1.

Table 1 Properties of liquid pure resins used in the study
Tablica 1. Svojstva čiste tekuće smole upotrijebljene u istraživanju

Determined parameter *Svojstvo*	**pMDI**	**UF**
No. 4 Ford cup viscosity, s *viskoznost prema Fordu, s*	-	89
Viscosity at 25°C, mPa·s *viskoznost pri 25 °C, mPa·s*	215	-
Density at 20°C, g/cm^3 *gustoća pri 20 °C, g/cm^3*	-	1.282
Solids content, % *sadržaj suhe tvari, %*	100	65.0
pH	-	8.2
Hydrolytic chlorine, mg·kg^{-1} *hidrolitički klor, mg·kg^{-1}*	96	-
Gel time at 100°C, s *vrijeme želiranja pri 100°C, s*	-	75
Miscibility with water, cm^3/g *mješljivost s vodom, cm^3/g*	-	1.4
NCO content, % / *sadržaj NCO, %*	30.9	-

pMDI was used as a UF resin modifier, introduced at 10 % in relation to the urea resin solution weight. In the case of liquid hybrid resin (UF/pMDI), its viscosity was determined by measuring flow time with a Ford's cup and gel times within the temperature range of 80, 90, 100 and 110 ºC, based on which relative activation energy of the cross-linking process was calculated (Wang *et al*., 1995). It was assumed that the curve illustrating the curing process in time, at specific temperatures of 80, 90, 100 and 110 ºC, was a linear function till the curing point was reached. Since the reaction rate increases with the rise in temperature, and the curve illustrating the curing rate depending on the inverse of the absolute temperature shows a very good linear correlation, the activation energy (E_a) can be calculated based on the Arrhenius equation:

$$k = A \cdot e^{-Ea/R \cdot T}$$

where k means the curing reaction rate constant, A is the pre-exponential factor, R is the gas constant and T is the absolute temperature.

After transformation, the Arrhenius equation acquires the form:

$$\ln k = \ln A - (E_a/R) \cdot 1/T$$

The activation energy has been determined by graphical method. For this purpose, the course of dependence $R \times \ln k$ on $1/T$ has been analyzed. In accordance with this method, the activation energy E_a is equal to the coefficient of the slope of the line $R \times \ln k = f(1/T)$ and $1/T = 0$ is equal $\ln A$ (Proszyk *et al*., 1996).

Sample preparation methodology for these analyses was presented in a study by Dziurka and Łęcka (2004).

In contrast, the content of water-leached substances, absorbability and swelling in length were determined for the polycondensed pMDI-amine resin mixture. On the basis of these properties, inferences may be made on the course of polycondensation. Additionally, infrared spectroscopy was applied in order to clarify the effect of pMDI on the chemical structure of cured hybrid UF/pMDI resin. Since the IR spectrum is highly characteristic of these substances, it may be treated as an analytical tool for the identification of structural groups present in tested compounds, as well as for analyses of occurring chemical processes.

The samples for the analyses contained pMDI and 10 % (by weight) of UF resin were cured at 120 ºC for 24 h in a glass tube of 0.5 cm in diameter. Thus cured samples were next comminuted in an impact mill and sieved at mesh size of 0.25, 0.2 and 0.125 mm or cut into samples of 18 mm in length. Further analyses, in case of substances leachable with water, FTIR spectroscopy and formaldehyde content determinations were conducted on the fraction left on the sieve with mesh size of 0.2 mm.

The amount of substances leachable with water from polycondensed resin was determined based on the loss of weight in comminuted resin after 24 h soaking in water. The perforator method was used to measure formaldehyde content in accordance with the standard PN-EN 120. In order to facilitate the analyses of HCHO contents, due to the considerable surface area of the comminuted UF resin, it was necessary to modify the perforator method so that the analyses were performed on 5 g resin samples. The contents of HCHO

Table 2 Properties of UF/pMDI adhesive mixture
Tablica 2. Svojstva smjese ljepila UF/pMDI

Type of mixture *Vrsta smjese*	**Gel time at 100 °C** *Vrijeme geliranja pri 100 °C*	**No. 4 Ford Cup viscosity** *Viskoznost prema Fordu*	**Substances leached with water** *Tvari isprane vodom*	**Absorbability** *Sposobnost apsorpcije*	**Swelling** *Bubrenje*	**Activation energy** *Energija aktivacije*	**Content of HCHO** *Sadržaj HCHO*
	s		%			kJ/mol	mg/100 g d.r.s*
UF	75	89	2.91	15.38	4.18	78.36	88.5
UF +10% pMDI	63	107	2.32	12.62	3.56	65.75	71.65

* dry resin solids / *suhe tvari smole*

were determined in aqueous solutions by colorimetry with p-fuchsin.

Prior to FTIR analysis, all samples were vacuum dried in an exsiccator over P_2O_5. Samples were prepared by pelleting with KBr, which is one of the best and most commonly applied preparation methods used for solids. In order to obtain pellets, a mixture of the tested substance and anhydrous KBr was prepared at a 1:50 weight ratio. Infrared spectra were recorded using a Fourier transform spectrophotometer within the wavelength range of 4000 – 500 cm^{-1}.

Samples of polycondensed resin of 18 mm in length were prepared for determinations of absorbability and swelling in length. Calculations were made on the basis of measured increments in weight and length after 24 h soaking in water at 20 ± 1ºC.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of analyses concerning properties of liquid and polycondensed UF resin/pMDi mixture are presented in Table 2, while testing results for properties of particleboard manufactured with such modified urea resin were presented in a study by Dziurka and Mirski (2010).

Analyses conducted on properties of particleboards, presented in the cited study, showed that even boards manufactured at pressing time reduced to 16 s/mm board thickness exhibited better properties than the reference board manufactured under identical conditions and resinated with pure UF resin. The increase in bending strength, modulus of elasticity and internal bond recorded under these conditions amounted to 32, 14 and 23 %, respectively. It should be particularly stressed that water resistance of these boards, measured in the V100 test, practically met the limit specified in the standard for P3 boards (0.09 N/mm^2).

Such a considerable improvement in properties of manufactured boards is confirmed by testing results for properties of the UF resin/pMDi mixture. A mean decrease, amounting to 16 %, in absorbability and swelling in thickness observed for the polycondensed resin mixture may indicate the reaction of hydrophilic hydroxymethylene groups of UF resin with pMDI, thus reducing its susceptibility to hydrolysis. This is confirmed by a considerable improvement of water resistance in manufactured boards (Dziurka and Mirski, 2010). This course of polycondensation in UF resins modified with pMDI is also indicated by the results of analyses of their formaldehyde contents. It is a well-known fact that free formaldehyde is released as a result of hydrolysis of hydroxymethylene bonds in resin. Blockage of these groups, either through their reaction with NCO groups or by direct substitution to the aromatic ring, will result in its lower content in resin. In turn, as it results from data presented in Table 1, the content of HCHO as previously in UF resin with a 10 % addition of pMDI is lower by approx. 20 % in relation to free UF resin, which confirms the above mentioned line of reasoning.

While the increase in hydrophobicity of hybrid resins and the related reduction of formaldehyde emissions are evident, there is still no insight into the mechanism of the reaction occurring during the mixing of both types of resins (Pizzi and Walton, 1992; Pizzi *et al*., 1993; Simon *et al*., 2002a, 2002b; Despres *et al*., 2006; Wieland *et al*., 2006, 2007). Simon *et al*. (2002a, 2002b) proved that in the acid environment required for curing urea resin, methylene bridges are dominant structures, formed as a result of direct substitution of isocyanates of the methylol groups in UF resin to the benzene ring (Figure 1).

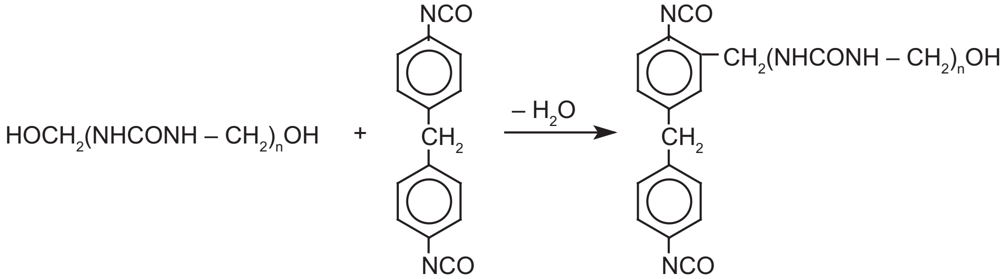

Figure 1 Reaction scheme of pMDI with methylol groups of UF resin
Slika 1. Shema reakcije pMDI-ja s metilol grupama UF smole

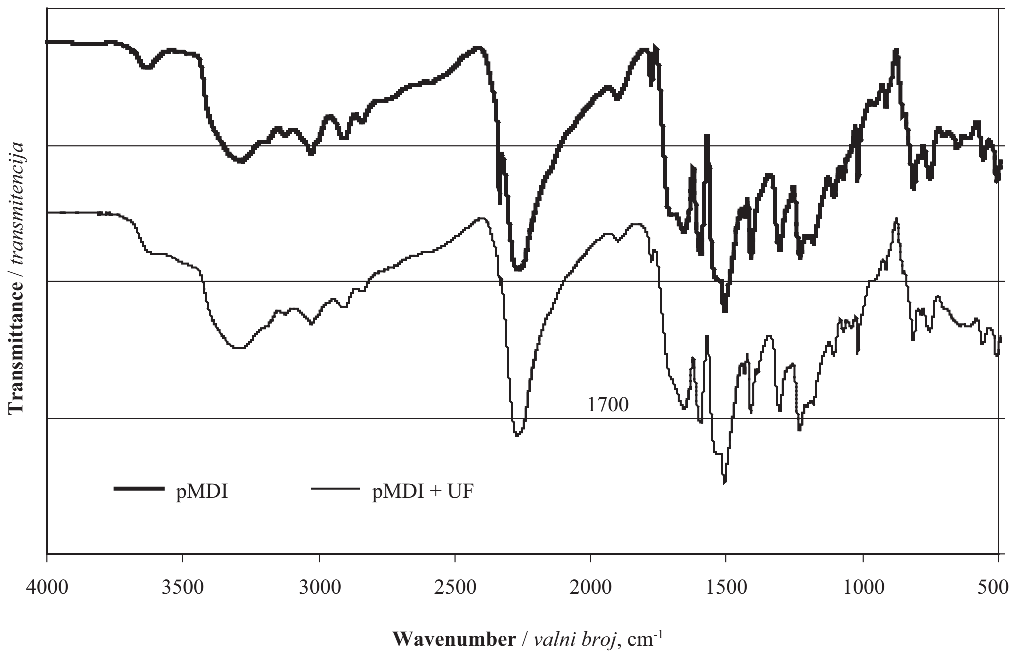

Figure 2 IR spectra of UF resin modified with pMDI
Slika 2. IR spektar UF smole modificirane pMDI-jem

In turn, urethane bridges, so characteristic of the alkaline PF resin cured in the presence of pMDI, are also formed, but in much lower amounts.

However, in view of the overlapping characteristic bands, the recorded spectrum (Figure 2) of the hybrid UF resin/pMDI does not show clearly which of the above mentioned structures predominates. One of the characteristic bands at a wavelength of 1700 cm^{-1} is ascribed to vibrations of the carbonyl group of C=O in the multisubstituted ureas. It may originate both from the cured UF resin [-CH_2-NH<u>C</u>ON(-CH_2-)$_2$] and polyureas formed as a result of reactions of MDI with -CH_2OH, -NH_2 or -NH- groups of UF resin, or even from the carbonyl group of urethane bridges as a result of reactions between –N=C=O and -CH_2OH groups.

Although the mechanism of the reaction between both types of resin is not clear enough, there is no doubt that the introduction of pMDI to liquid UF resin results in an increase in its reactivity, manifested in a shortening of gel time (Table 2) and a reduction of activation energy of the polycondensation process (Figure 3, Table 2).

4 CONCLUSION
4. ZAKLJUČAK

To sum up, the analyses performed on properties of amine resin modified with pMDI indicated that its introduction to liquid UF resin already at 10 % results in an increase in its reactivity, manifested in a shorten-

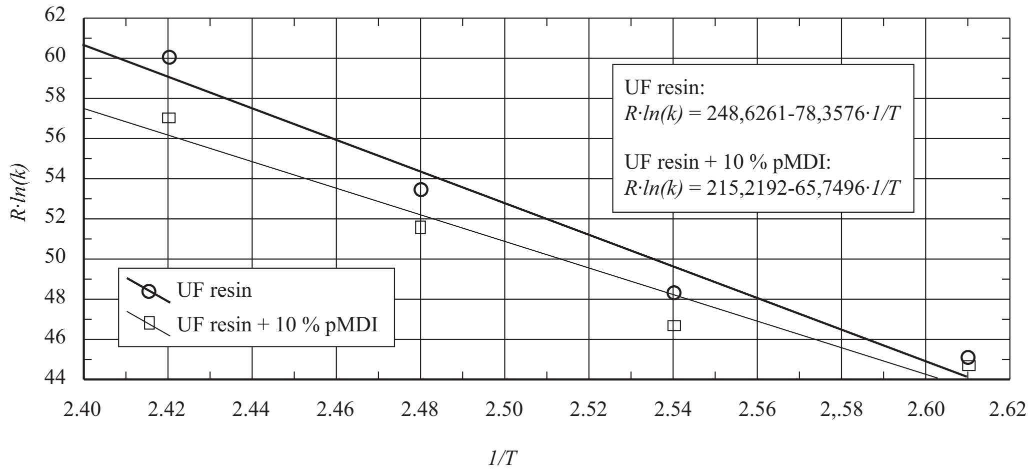

Figure 3 Reaction rate constant depending on temperature of pure UF resin and UF/pMDI glue mixture gel time
Slika 3. Ovisnost konstante brzine reakcije o temperaturi čiste UF smole i o vremenu želiranja smjese ljepila UF/pMDI

ing of gel time and a reduction of activation energy of the polycondensation process. Moreover, the analyses performed on properties of polycondensed resin showed that, thanks to the modification with pMDI, its hydrophobicity is improved considerably, as reflected in a reduction of absorbability and swelling in length of cured resin.

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Influence of Various Wood Species and Cross-Sections on Strength of a Dowel Welding Joint

Utjecaj vrste drva i presjeka na čvrstoću zavarenog moždanika

Original scientific paper • Izvorni znanstveni rad
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ABSTRACT • *Rotation welding is a new method used in wood welding. Heat that develops due to the friction on contact surfaces softens and melts the wood structure (melt is produced). When the friction stops, the melt cools down and solidifies forming a firm joint.*
This research is based on the examination of the influence of various wood species and cross-sections on the strength of joints produced by rotational welding. Using rotation frequency and shifts in the orientation of the horizontal axis, a beech dowel is welded to a base made of common beach (Fagus sylvatica L.), pedunculate oak (Quercus robur L.) and Norway spruce (Picea abies L.) (hereinafter only beech, oak and spruce). Welding direction is both parallel to the orientation of the base fibres (PP) and perpendicular to the orientation of the base fibres (R, RT, T).
Research results indicate that the dowel welded to the beech base retains the largest strength, whereas the dowel welded to the spruce base reveals the weakest results. Based on the research results, it can be concluded that beech dowels welded in the direction of beech and oak bases have the best strength of a joint. In spruce samples, reaction wood was used (compression wood in conifers) with somewhat different distribution of strength depending on the welding direction.

Key words: *welding of wood, dowel joints, withdrawal strength, embedded force, wood species, anatomical orientation*

SAŽETAK • *Rotacijsko zavarivanje novija je metoda spajanja drva. Zbog trenja na kontaktnim površinama pojavljuje se toplina koja omekša i rastali strukturu drva (nastaje talina) te se formira spoj. Prestankom trenja drvo se hladi i talina otvrdnjava te nastaje čvrsti spoj.*
Istraživanje se temelji na ispitivanju utjecaja vrste drva i presjeka na čvrstoću rotacijski zavarenog spoja. Bukov moždanik je uz pomoć frekvencije vrtnje i pomaka u smjeru uzdužne osi zavaren u podlogu izrađenu od drva obične bukve (Fagus sylvatica L.), hrasta lužnjaka (Quercus robur L.) i obične smreke (Picea abies L.) (u daljnem tekstu: bukovina, hrastovina i smrekovina). Zavarivanje se obavljalo u smjeru vlakanaca podloge (PP) i okomito na njihov smjer (R, RT, T).
Rezultati istraživanja pokazali su da moždanik zavaren u bukovu podlogu ima najveću čvrstoću, dok je najslabije rezultate pokazao moždanik zavaren u smrekovu podlogu. Iz rezultata istraživanja proizlazi kako bukov moždanik zavaren u smjeru vlakanaca bukove i hrastove podloge postiže najbolje rezultate glede čvrstoće spoja. Pri za-

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varivanju moždanika u smrekovinu rabljeno je i reakcijsko drvo (kompresijsko drvo četinjača) pa je raspored čvrstoće ovisno o smjeru zavarivanja bio nešto drugačiji.

Ključne riječi: *zavarivanje masivnoga drva, spoj s moždanikom, vlačna čvrstoća, izvlačna sila, vrsta drva, tip presjeka*

1 INTRODUCTION
1. UVOD

Suthoff and Kutzer (1997) have patented and demonstrated the rotational and vibration welding of wood. Since 2000 IBOIS (Swiss Federal Institute of Technology Lausanne) has been developing and researching the method of joining wood by friction welding without adding any adhesives (Gliniorz and Natterer, 2000; Gliniorz *et al*., 2001). This welding method is successfully used for joining two or more wood elements without adding glue or other adhesives. Friction wood welding is a process that causes chemical and physical reactions; the heat, which is a result of friction, melts and softens the wood structure. After cooling, the melt turns into a very hard compound. Chemical changes start with welding and continue after the process ends (while the melt solidifies). Wood structure cools down and becomes a hard compound. In this research the focus was not on the chemical changes occurring in the wood for which the authors used the knowledge from the literature at hand. The process of rotational welding produces gas emission and results in the decomposition of evaporable polymer components in the wood (Omrani *et al*., 2008). The analysis of evaporable compounds and gases emitted, such as smoke, which appears as a by-product during the rotational welding of the dowel to the beech and spruce base, revealed that the smoke consists of water vapour and CO_2. These two are obtained by the decomposition of the components from non-crystallized lignines and some evaporable terpenes (Norway spruce). When using a zig-zag pattern of rotationally welded dowels across the interface of a butt joint between two wood planks strong joints are obtained (Omrani *et al*., 2007). The average tensile strength of commercial beech wood with a zig-zag pattern of rotationally welded dowels 10 mm in diameter (rotational movement at 1600 min^{-1}) was 0.77 ± 0.07 MPa. The results obtained also indicate that further improvement and optimization of this process should consider a minimum compression level at the end of dowel rotation.

Pizzi *et al*. (2004) investigated welding of a 10 mm diameter beech dowel to a beech base. Welding penetration was 12 mm, rotation frequency 1200 min^{-1}, and tightness 2 mm. The maximum embedded force for these parameters was 1500 N, and the average embedded force 883 N. It was observed that welding in the tangent orientation showed the best results whereas the radial orientation had the lowest values. The average embedded force for dowels of 10 mm diameter inserted to 20 mm depth in single beech block (30 x 30 x30 mm) was 1979 ± 103 N (Pizzi *et al*., 2006). The geometry of the dowel joint allowed the joint to retain up to 88 % of its initial embedded force after 24 h immersion in cold water.

Dowel welding by high-speed rotation was used to join two wood blocks and strong joints were obtained (Bocquet *et al*., 2007). Dowel angle to the surface of the wood blocks to be joined had a marked influence on the mechanical performance of the joint. When the dowel was inserted at 90° to the substrate, the dowel was subjected to and resisted a shear force only. The results obtained show that welded-dowel structural joints can satisfy both the relevant standards and outperform the equivalent nailed joints and glued-dowel joints.

Leban *et al*. (2008) investigated the impact of rotation frequency on the strength of a beech dowel welded to the base made of Norway spruce. For this a 12 mm diameter dowel was used with the frequency of 1500 min^{-1}. The average embedded force was 2145 N, and welding time 4 s.

Leban *et al*. (2004) investigated the possibility of vibration welding of beech, oak and spruce wood with 150 x 20 x 30 mm samples, welding time of 3 s, pressure after welding 2 MPa during 5 s, and constant pressure of 1.3 MPa during the welding process. The samples were welded with the frequency of 100 Hz and vibration amplitudes of 3 mm. The strength of welded joints depended on the welding line thickness and balance. A thinner welding line has the ability to produce better strength compared to a thicker welding one. The average strength of a joint for breech reached 8.72 MPa, for oak 5.43 MPa and for spruce wood 4.2 MPa. Spruce wood showed poorer welding results due to its characteristic cell implosion and crumping. This unfavourable characteristic of spruce wood influences the strength of a joint if beech and spruce wood are welded. Implosion and crumping of cell walls increases the thickness of the welding line, especially for spruce wood. Beech wood falls under the category of harder wood species and its welding line can be easily noticed because it is dark and thin, which is an indicator of a decreased implosion of the cell wall and, also of better mechanical characteristics of the joint itself.

Kanazawa *et al*. (2005) explored the influence of welding penetration (for a beech dowel welded to a beech base) in radial and tangent orientation on embedded force. In all analysed welding penetrations (10, 20 and 30 mm), tangent orientation showed the best research results.

Ganne-Chedeville *et al*. 2005 researched welding of a hard wood dowel (beech) to a hard spruce wood base without drilling any holes. Research results indicate a significant dissipation of data and very intensive scuffing of the top of the dowel.

Župčić *et al*. (2009) investigated welding of a dowel to a base made of thermally treated and untreated hornbeam base. Thermal modification was carried out at 200 °C over 48 hours. Rotation frequency for a beech dowel was 1520 min^{-1}. The research showed that thermally unmodified dowels welded to a hornbeam base (perpendicular to the fibre orientation) indicated stronger embedded force (84 % on average, which is a statistically significant difference) than dowels welded to a thermally modified base. The average embedded force for dowels welded to an untreated base was 3754 N.

The species of wood to which a dowel is welded is a very important factor. Thus, the objective of this paper was to investigate the influence of a wood species (beech, oak and spruce) on the strength, or embedded force, of a welded joint when a dowel is welded (in the same orientation or perpendicular to the fibre orientation) to a base. Apart from some of the factors mentioned above, the authors also looked into the influence of the welding orientation (radial, tangent and radial and tangent) on the strength of a joint.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Shape and dimensions of the samples
2.1. Oblik i dimenzije uzoraka

Research in the influence of cross-sections and species of wood on the strength of a welded joint was conducted at the Faculty of Forestry of the University of Zagreb. For the purpose of this research, beech grove dowels were used and welded to beech oak and spruce bases without defect (except spruce reaction wood which was used for research). All samples were prepared by sawing, milling and shortening to the defined measure. These samples were then pierced with an 8 mm diameter spiral drill. Dimensions of the base to which a dowel was welded perpendicular to the fibre orientation were 200 x 30 x 30 (mm) with three pierces in the radial (R), tangent (T) and radial and tangent (RT) orientation depending on the factor under scrutiny (Figure 1). A 30 x 30 x 64 (mm) base with a pierce in line with the fibre orientation was used for welding a dowel in the fibre orientation. Once welded, the sample was sawn off in two identical 30 x 30 x 30 mm pieces (Figure 2). Due to elastic deformations of the wood, upon movement of the cutting edge the drill hole diameter was reduced by 0.05 mm on average. Dowels were grouped into 1000 mm sticks and had to be shortened to the correct measure. The average dowel diameter (cross-cut measures were taken on the top of the grove) was 10.04 mm. Wood material prepared in this manner (welding base and dowels) was conditioned in a laboratory (temperature 23 ± 2 °C, relative humidity 50 ± 5 %) over a six-month period. Water content was determined according to HRN ISO 3130:1999 (the Croatian standard for determining water content for testing physical and mechanical characteristics of wood). The average water content, measured after samples were dried (103 ± 2 °C), was 9.13 % for beech wood, 9.33 % for oak wood and 10.37 % for spruce wood.

After determining the water content in the wood, the same probes were used for determining wood density according to HRN ISO 3131:1999 (the Croatian standard for determining wood density for testing physical and mechanical characteristics of wood). The average density for beech wood was 0.68 g/cm³, 0.69 g/cm³ for oak wood and 0.45 g/cm³ for spruce wood.

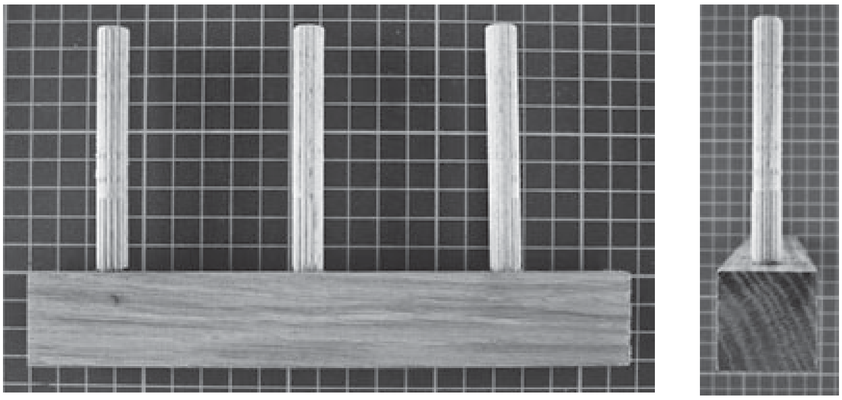

Figure 1 Test sample: Oak dowels welded perpendicular to the fibre orientation (RT)
Slika 1. Ispitni uzorak hrastovine, moždanici zavareni okomito na smjer vlakanaca (RT)

a) **b)** **c)**

Figure 2 Cross-section of the dowel welded parallel to the fibre orientation for: a) spruce; b) oak; c) beech
Slika 2. Presjek zavarenog moždanika u smjeru vlakanaca: a) u smrekovinu; b) u hrastovinu; c) u bukovinu

Table 1 Samples used in the research
Tablica 1. Uzorci rabljeni u istraživanju

Code *Oznaka*	**Description** / *Opis*
BPP	dowel welded to beech wood in the fibre orientation (transverse cross-section) *moždanik zavaren u bukovinu u smjeru vlakanaca (poprečni presjek)*
HPP	dowel welded to oak wood in the fibre orientation (transverse cross-section) moždanik zavaren u hrastovinu u smjeru vlakanaca (poprečni presjek)
SPP	dowel welded to spruce wood in the fibre orientation (transverse cross-section) *moždanik zavaren u smrekovinu u smjeru vlakanaca (poprečni presjek)*
BR	dowel welded to beech wood perpendicular to the fibre orientation (radial orientation) *moždanik zavaren u bukovinu okomito na vlakanca (radijalni smjer)*
HR	dowel welded to oak wood perpendicular to the fibre orientation (radial orientation) *moždanik zavaren u hrastovinu okomito na vlakanca (radijalni smjer)*
SR	dowel welded to spruce wood perpendicular to the fibre orientation (radial orientation) *moždanik zavaren u smrekovinu okomito na vlakanca (radijalni smjer)*
BRT	dowel welded to beech wood perpendicular to the fibre orientation (radial and tangent orientation) *moždanik zavaren u bukovinu okomito na vlakanca (radijalno-tangentni smjer)*
HRT	dowel welded to oak wood perpendicular to the fibre orientation (radial and tangent orientation) *moždanik zavaren u hrastovinu okomito na vlakanca (radijalno-tangentni smjer)*
SRT	dowel welded to spruce wood perpendicular to the fibre orientation (radial and tangent orientation) *moždanik zavaren u smrekovinu okomito na vlakanca (radijalno-tangentni smjer)*
BT	dowel welded to beech wood perpendicular to the fibre orientation (tangent orientation) *moždanik zavaren u bukovinu okomito na vlakanca (tangentni smjer)*
HT	dowel welded to oak wood perpendicular to the fibre orientation (tangent orientation) *moždanik zavaren u hrastovinu okomito na vlakanca (tangentni smjer)*
ST	dowel welded to spruce wood perpendicular to the fibre orientation (tangent orientation) *moždanik zavaren u smrekovinu okomito na vlakanca (tangentni smjer)*
PP	transversal cross-section / *poprečni presjek*
T	tangent cross-section / *tangentni presjek*
R	radial cross-section / *radijalni presjek*
RT	radial - tangent cross-section / *radijalno-tangentni presjek*

In total 365 samples were welded, and 359 samples were then used for further research. The code of samples used in the research is described in Table 1. Six samples started cracking during the welding process and were dismissed from further analysis. Welding penetration was 20 mm with constant rotation frequency of 1520 min^{-1}. The same pressure to the joint elements was kept after rotation for three seconds on average (min. two, max. four seconds). The average welding tightness was 2.09 mm.

2.2 Test of embedded force
2.2. Ispitivanje izvlačne sile

Tests on beech dowels rotationally welded to the base made of beech, oak and spruce wood were performed on the universal mechanical testing machine at the Faculty of Forestry of the University of Zagreb with testing time interval of 5 mm/min. A computer was used for measuring the force and displacement, and all values were accurately determined to the accuracy of 5 N. This research used 359 samples in total, which were welded precisely without any cracks caused by the welding process or any other errors.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The research results presented in Table 2 and Figure 3 indicate that the species of wood and orientation of dowel welding (parallel and vertical to the fibre orientation) have a considerable effect on embedded force, that is the strength of a joint (with identical welding parameters used for all samples and under assumption that the joint surface is also identical). The best results for the embedded force were found in beech samples with a dowel welded to transverse cross-section, or in the wood fibre orientation (5144.8 N on average), which was expected. There is a significant statistical difference (Table 3) between dowels welded parallel and perpendicular to the fibre orientation. In dowels welded perpendicular to the fibre orientation (R, T, RT), values for embedded force did not indicate any significant statistical difference (Table 3). Župčić (2010) conducted tests in order to investigate the influence of the welding orientation on dowels welded to a beech base and obtained very similar distribution of embedded force values. When welding grove dowels in the conditions described above, welded dowel surface is 560 mm^2, which is 16 % less compared to the surface before welding (Župčić, 2010). The average strength of welded joints in beech was 8.7 N/mm^2 and of glued joints 8.0 N/mm^2.

Distribution of embedded force values measured on oak and beech samples indicated very similar results; the only difference is that the values were lower with a significant statistical difference. The average embedded force value measured on dowels welded to the oak base parallel to the fibre orientation (PP) was

Table 2 Descriptive statistics for embedded force depending on wood species and cross-section
Tablica 2. Deskriptivna statistika izvlačne sile u ovisnosti o vrsti drva i presjeku

Code *Oznaka uzorka*	Number of samples *Broj uzoraka*	Embedded force						
		Means *Aritmetička sredina izvlačne sile* N	**Std. Dev.** *Standardna devijacija izvlačne sile* N	**Minimum** *Minim. izvlačna sila* N	**Maximum** *Maks. izvlačna sila* N	**Q25** *Izvlačna sila Q25* N	**Median** *Izvlačna sila medijan* N	**Q75** *Izvlačna sila Q75* N
BPP	31	5144.8	518.1	4190	6280	4660	5300	5420
HPP	30	4477.3	389.9	3560	5190	4240	4520	4750
SPP	32	1410.6	298.6	900	2220	1220	1355	1595
BR	30	4778.3	309.8	4300	5330	4520	4760	5050
HR	28	4166.8	370.6	3420	4850	3925	4180	4440
SR	28	2674.3	508.5	1900	3650	2250	2645	3105
BRT	30	4754.0	460.9	3150	5750	4610	4710	5040
HRT	30	3961.3	428.7	3020	4990	3660	3995	4190
SRT	30	1924.3	185.0	1540	2240	1780	1945	2040
BT	30	4846.7	338.4	4040	5540	4680	4810	5060
HT	30	4000.3	385.0	3280	4610	3640	4020	4220
ST	30	2688.3	824.1	1350	4200	2060	2370	3700
All groups *Sve grupe*	359	3730.1	1285.9	900	6280	2400	4130	4700

4477.3 N, or 13 % less than the values for beech samples. There is a significant statistical difference between dowels welded parallel and perpendicular to the fibre orientation. In dowels welded perpendicular to the fibre orientation (R, T, RT), embedded force values did not reveal any significant statistical difference.

Spruce samples indicated significantly different value distribution since reaction wood had been used for the preparation of samples. The largest average value of embedded force in ST and SR spruce samples was recorded in samples with reaction wood, and the smallest in SPP samples without reaction wood. It can be concluded that the reaction wood increases the embedded force of the above mentioned samples in comparison with SPP samples. It is a well-known fact that reaction spruce wood has much wider growth rings with a larger share of late wood resulting in higher density. Reaction spruce wood also has a larger portion of higher lignine content and lower cellulose content. The research results (Župčić, 2010) indicate that differences in density for the same wood species influence the strength of a welded joint where an increased density results in an increased strength of a welded joint. Chemical, physical and mechanical changes also influence the strength of a welded joint. However, this is not the focus of this research.

The average embedded force value for dowels welded to the spruce base parallel to the fibre orientation (PP) was 1410.6 N or 73 % less than the value for beech samples or 68 % less than the value for oak wood. Spruce wood indicated lower welding results due to its characteristic implosion and crumpling of cell walls (Lebanet *al*., 2004). During welding time a dowel volume decreased whereas the hole volume increased with two side-effects: cell walls implode, and interface surface density increases from its regular values which are up to 1.4 g/cm^3 (Pizzi *et al*., 2004). The other part of the volume vanishes due to frictional abrasion (of the dowel and side walls inside the hole) and draining of the melt from the interface zone. When the beech dowels was welded to the beech base parallel to the fibre orientation, the zone of implosion of cell walls exceeded 1.5 mm (Župčić, 2010).

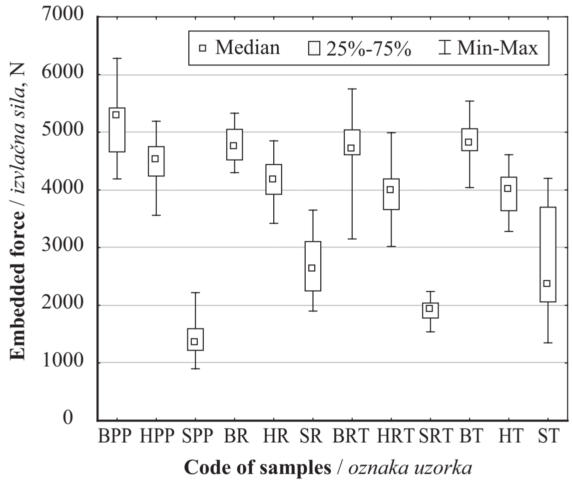

Figure 3 Influence of wood species and cross-section on embedded force
Slika 3. Utjecaj vrste i presjeka drva na izvlačnu silu

The research was also focused on the influence of ring thickness in SR and ST samples. The research results (Figure 4) indicate that the embedded force decreases with the increase of the number of growth rings, i.e. the decrease of growth ring width and share of late wood. It should be assumed that the width of growth rings in reaction spruce wood influences the strength of a welded joint. For the purpose of further researching this area, it is necessary to provide more samples and to research in detail the influence of reaction wood on the strength of joints. Dependency of embedded force and

Table 3 Multiple comparison rankings (Kruskal-Wallis test: $H(11, N = 359) = 297.9809$ $p = 0.000$)
Tablica 3. Višestruka usporedba rangova (Kruskal-Wallis test: $H(11, N = 359) = 297{,}9809$ $p = 0{,}000$)

Code *Oznaka uzorka*	BPP R:308.4	HPP R:233.7	SPP R:20.4	BR R:274.8	HR R:189.5	SR R:92.6	BRT R:271.7	HRT R:167.9	SRT R:50.9	BT R:285.3	HT R:171.1	ST R:94.4
BPP		0.3263	0.0000	1.0000	0.0007	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000
HPP	0.3263		0.0000	1.0000	1.0000	0.0000	1.0000	0.9330	0.0000	1.0000	1.0000	0.0000
SPP	0.0000	0.0000		0.0000	0.0000	0.4742	0.0000	0.0000	1.0000	0.0000	0.0000	0.3306
BR	1.0000	1.0000	0.0000		0.1161	0.0000	1.0000	0.0044	0.0000	1.0000	0.0072	0.0000
HR	0.0007	1.0000	0.0000	0.1161		0.0316	0.1686	1.0000	0.0000	0.0291	1.0000	0.0324
SR	0.0000	0.0000	0.4742	0.0000	0.0316		0.0000	0.3789	1.0000	0.0000	0.2638	1.0000
BRT	1.0000	1.0000	0.0000	1.0000	0.1686	0.0000		0.0070	0.0000	1.0000	0.0114	0.0000
HRT	0.0000	0.9330	0.0000	0.0044	1.0000	0.3789	0.0070		0.0008	0.0007	1.0000	0.4018
SRT	0.0000	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.0008		0.0000	0.0004	1.0000
BT	1.0000	1.0000	0.0000	1.0000	0.0291	0.0000	1.0000	0.0007	0.0000		0.0013	0.0000
HT	0.0000	1.0000	0.0000	0.0072	1.0000	0.2638	0.0114	1.0000	0.0004	0.0013		0.2785
ST	0.0000	0.0000	0.3306	0.0000	0.0324	1.0000	0.0000	0.4018	1.0000	0.0000	0.2785	

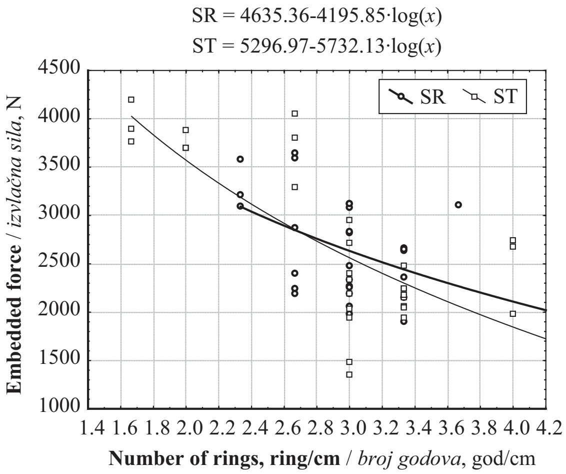

Figure 4 Influence of the number of growth rings (SR and ST) to embedded force
Slika 4. Utjecaj broja godova (SR i ST) na izvlačnu silu

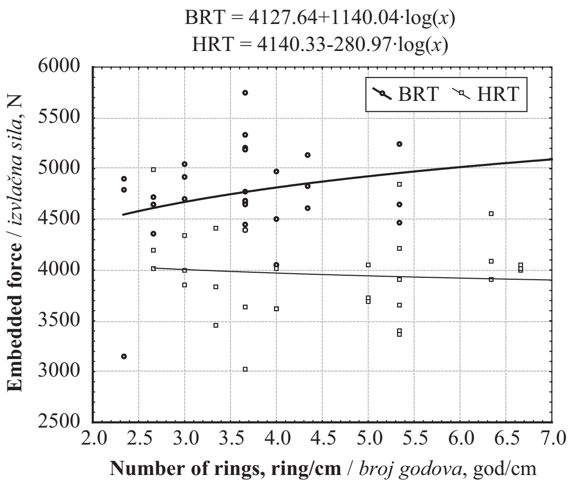

Figure 5 Influence of the number of growth rings (BRT and HRT) on embedded force
Slika 5. Utjecaj broja godova (BRT i HRT) na izvlačnu silu

number of growth rings of SR samples may be described by the following equation: $y = 4635.36 - 4195.84 \cdot \log x$, while ST samples may be described by the equation where $y = 5296.97 - 5732.13 \cdot \log x$.

Figure 5 indicates a slow growth for beech wood and a mild drop for oak wood in respect of embedded force with decreased width of growth rings (where the number of growth rings per centimetre increased). The influence of growth ring width has not been unequivocally determined, as indicated in the research papers (Župčić, 2010). Growth ring width has an effect on the strength of a joint but it is not statistically relevant. Beech and oak wood are species of wood with important differences in anatomic, physical, mechanical and chemical characteristics depending on the biotope, soil, altitude and position in the tree. These factors influenced the dissipation of data because the samples had been selected from the regular production of edge glued panels. Dependency of embedded force and number of growth rings for BRT samples may be described by the following equation: $y = 4127.64 + 1140.08 \cdot \log x$, while HRT samples may be described by the equation where $y = 4140.33 - 280.97 \cdot \log x$.

4 CONCLUSION
4. ZAKLJUČAK

Rotational welding can be successfully used for welding beech grove dowels to bases made of beech, oak and spruce wood parallel and perpendicular to the fibre orientation. The research results lead to the conclusion that the influence of wood species and welding orientation on the strength of a welded joint is statically relevant.

The research results reveal that beech wood is the best wood species for welding dowels, regardless of the fibre orientation - parallel or vertical. Statistically significant differences (Table 3) appear for all combinations except for oak wood welded to a transverse cross-section or perpendicular to the fibres in the radial orientation.

The average values for the embedded force measured in dowels welded to spruce wood are statistically significantly lower in relation to the average values for the embedded force measured in dowels welded to beech and oak wood. Such results were expected because of spruce wood structure, composition and other characteristics. Reaction wood also has a significant influence since it improves the strength of a welded joint.

Dowels welded parallel to the fibre orientation indicated higher values for the embedded force than dowels welded perpendicular to the fibre orientation (beech and oak wood test samples). Tests on spruce wood indicated that dowels welded perpendicular to the fibre orientation have stronger embedded force than dowels welded parallel to the fibre orientation due to the reaction wood which is known for its higher density and higher proportion of late wood.

Width of a growth ring does not have much statistical significance except for spruce wood (reaction wood) for which the embedded force grows with the increase of growth ring width.

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16. *** HRN ISO 3131:1999 (hrvatska norma za određivanje gustoće drva za ispitivanje fizikalnih i mehaničkih svojstava drva).

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Tree-Ring Chronology of Pedunculate Oak (*Quercus robur*) and its Potential for Development of Dendrochronological Research in Croatia

Kronologija godova hrasta lužnjaka (*Quercus robur*) i njezin potencijal za razvoj dendrokronoloških istraživanja u Hrvatskoj

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ABSTRACT • *We present the local tree-ring chronology of pedunculate oak (Qercus robur) from Kobiljak near Zagreb, Croatia (16º09' E, 45º49' N, 140 m a.s.l.). The chronology is based on 17 trees and is 127 years long and covers the period of 1883-2009. The well replicated part of the residual version of the ARSTAN chronology with SSS>0.80 (interval of 88 years, period 1922-2009) was used for dendroclimatological analysis, which showed that June precipitation has positive and temperature has negative effect on tree-ring variation. Comparison with 40 available oak chronologies from the surrounding countries confirmed its good teleconnection with 2 local oak chronologies from Austria, 2 from Hungary, and 3 from Slovenia. It also exhibits good heteroconnection, i.e. similarity with chronologies of beech (Fagus sylvatica), from various sites in Slovenia. The similarities can be ascribed to response to common climatic factors. The results indicate that the chronology could be a good reference point for constructing a longer regional chronology in Croatia and surrounding countries, which could be used for different purposes including dating of objects of cultural heritage.*

Keywords: *dendrochronology, pedunculate oak (Quercus robur), dendroclimatology, teleconnection, heteroconnection*

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SAŽETAK • *U radu je predstavljena lokalna kronologija godova hrasta lužnjaka (Qercus robur) iz Kobiljaka pokraj Zagreba, Hrvatska (16º09' E, 45º49' N, 140 m n.m.). Temelji se na 17 stabala i obuhvaća 127 godina, i to razdoblje od 1883. do 2009. Za dendroklimatološku analizu primijenjen je optimalan replicirani dio rezidualne inačice kronologije ARSTAN sa SSS>0,80 (dužina 88 godine, razdoblje 1922. – 2009.). Analiza je pokazala pozitivan učinak lipanjskih oborina na promjene širine godova, dok je učinak temperature u istome mjesecu negativan. Usporedba s 40 dostupnih hrastovih kronologija iz okolnih zemalja potvrdila je telekonekciju s dvije lokalne kronologije hrasta iz Austrije, dvije iz Mađarske i tri iz Slovenije. Ona također pokazuje dobru heterokonekciju, tj. sličnost s kronologijama bukve (Fagus sylvatica) s različitih staništa u Sloveniji. Sličnosti se mogu pripisati odgovoru na zajedničke klimatske čimbenike. Rezultati upućuju na zaključak da ta kronologija može biti dobro polazište za izradu dulje regionalne kronologije hrasta u Hrvatskoj i susjednim državama, koja bi onda mogla imati različite namjene, uključivši i datiranje objekata kulturne baštine.*

Ključne riječi: *dendrokronologija, hrast lužnjak (Quercus robur), dendroklimatologija, telekonekcija, heterokonekcija*

1 INTRODUCTION
1. UVOD

Numerous wood science laboratories in the world develop dendrochronology, which as a rule includes investigations of tree ring widths and wood structure. Oak (*Quercus* sp.) is considered the most important wood in European dendrochronology. It is mainly represented by the pedunculate oak (*Quercus robur* L.) and sessile oak (*Q. petraea* Liebl.), which cannot be differentiated by their wood anatomy. Despite different ecological requirements of the two species, their tree-ring patterns usually show good agreement. Therefore, they are often treated together as European oak or simply oak (*Quercus* sp.).

Since the 1990s, when the construction of the first multimillennial oak chronologies was completed (Baillie, 1995), oak dendrochronology has made considerable progress. The longest tree-ring chronology in the world is the oak chronology of the laboratory in Hohenheim reaching back to 8480 BC (Friedrich *et al*., 2004). There are several other millennial chronologies, which have been constructed all over the western and central Europe (e.g., for review see Haneca *et al*., 2009). Oak research has been at the same time extended also to areas, which were for a long time considered as less optimal for dendrochronology, like Flanders/Belgium (Haneca *et al*., 2006). It has also been extended to the areas east, and southeast of traditional oak research (e.g. Wimmer and Grabner, 1998; Gryaneus, 1996, 2003; Geihofer *et al.,* 2005; Morgos, 2005; Pukiene and Ožalas, 2007; Szántó *et al*., 2007; Čufar *et al.,* 2008a, 2010: Kern *et al*., 2009a, b; Grabner *et al*., 2011; Kolar *et al.,* 2012).

Long tree-ring chronologies have been used for investigating the past and for predicting future changes in the climate and environment (e.g. Friedrichs *et al.,* 2009a, b; Kern *et al.,* 2009; Haupt *et al.* 2011; Levanič *et al.,* 2011). In addition, they were used for dating of archaeological wood and artefacts from historic constructions and archaeological sites (e.g., for review see Čufar, 2007; Haneca *et al.,* 2009).

In Slovenia, a neighbouring country of Croatia, which has similar climate regimes to some extent (Alpine, Mediterranean and continental), the first local tree ring chronologies of oak were constructed in the 1990s (Čufar and Levanič, 1999), but their tree-ring patterns seemed to have no similarity with oak chronologies from other countries, such as those north of the Alps. Recently, a 548 years long regional oak chronology has been constructed in SE Slovenia, showing a good supra-regional signal reflected in the radius of ca. 500 km, which demonstrated to be climatic in its nature (Čufar *et al*., 2008a). It enabled reconstruction of climate for the span of the chronology, indicating that hot and dry June conditions limit the growth of oak in the area (Čufar *et al*., 2008b). Reconstructed years with extremely hot-dry and wet-cool conditions could be confirmed by the reports in archived documents. Interestingly, the extreme years did not agree with those reconstructed from oak tree-rings in Western Europe (Kelly *et al.,* 2002). The Slovenian oak chronology, which showed good teleconnection with the chronologies of the surrounding countries, has also been successfully used for dating the wood of the objects in Slovenia as well as the objects of the Croatian cultural heritage (Čufar and Šimek, 2008; Čufar *et al*., 2006, 2008c).

Since the tree-ring chronologies can be considered 'living organisms', it is necessary to work to improve and prolong the existing ones and to construct the new ones, especially in Croatia and neighboring countries where dendrochronological research still needs to be developed.

The objectives of this study are (1) to construct a local oak chronology for the site near Zagreb, Croatia, (2) to show how climatic factors influence tree-ring variation of oak in the sampling area, (3) to find out if there exists teleconnection of this chronology with oak chronologies in the surrounding countries (4) and if there exists heteroconnection of Croatian oak with other tree species. All of this would provide useful information to develop a strategy to improve dendrochronological research in Croatia.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Study Area and Wood for Tree-Ring Research
2.1. Područje i drvo obuhvaćeno istraživanjem

The sampling area Kobiljak (16º09' E, 45º49' N, 140 m a.s.l.) is located 20 km east of Zagreb. The sampling trees originated from the forest association *Genisto elatae-Quercetum roboris* Ht. 1938 composed of pedunculate oak (*Quercus robur* L.) mixed with big greenweed on the area where the level of ground water is high. The age of trees was estimated to 140-150 years.

2.2 Dendrochronological analysis
2.2. Dendrokronološka analiza

For dendrochronological investigations, disks from 17 felled *Quercus robur* trees (DBH 40 ± 5 cm) were taken at 4 m above ground. The wood was polished and tree-ring widths were measured along the mean diameter, i.e. two radii, to the nearest 0.01 mm using TSAP-Win program (Frank Rinn, Heidelberg, Germany). The tree-ring series were visually and statistically crossdated and compared with each other by calculating the *t*-values according to Baillie and Pilcher (1973) and coefficient of agreement (Gleichläufigkeit - Glk) (Eckstein and Bauch 1969) using TSAP-Win program. Tree-ring series, two per each tree, were crossdated, and series of 33 radii were found acceptable for further analyses.

Crossdated tree-ring series of individual trees were assembled into a chronology using the program ARSTAN (Holmes 1994). We calculated ARSTAN chronologies, a non-detrended - raw-data, and a detrended residual chronology.

2.3 Tree rings and climate
2.3. Godovi i klima

The climatic influence on tree growth was studied using the residual version of the ARSTAN chronology (expressed as tree-ring indexes vs. time), for which the original tree-ring width series were standardized in a two-step procedure. First, the long-term trend was removed by fitting a negative exponential function (regression line) to each tree-ring series. Second, a more flexible detrending was made by a cubic smoothing spline with a 50 % frequency response of 30 years to further reduce non-climatic variance. Subsequently, autoregressive modelling of the residuals and biweight robust estimation of the mean were applied (Cook and Peters, 1997).

The climatic data (average monthly temperatures and monthly sums of precipitation for the period 1922 to 2009) were obtained from the meteorological station Grič, Zagreb (Figure 1). The station is representative for the sampling area.

The climate/growth relationships were calculated using the program DendroClim2002 (Biondi and Waikul 2004), whereby the residual version of the tree-ring chronology was the dependent variable and the regressors were the monthly mean temperatures and monthly sums of precipitation for each biological year from the previous October to the current September over the time axis from 1922 to 2009. DendroClim2002 uses correlation functions and response functions, which are the most common statistical models used in dendrochronology. The term 'function' indicates a sequence of coefficients computed between the tree-ring chronology and monthly climatic variables, which are ordered in time from the previous-year growing season to the current one. In 'correlation' functions, the coefficients are univariate estimates of Pearson's product

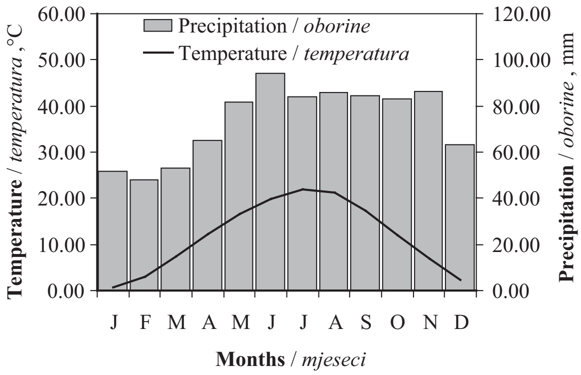

Figure 1 Bagnouls Gaussen Climatic Diagram, mean monthly average temperature (line) and mean monthly sum of precipitation (bars), of meteorological station Grič, Zagreb for the period 1922-2009; the mean annual precipitation is 879 mm and the mean annual temperature is 11.76 ºC
Slika 1. Dijagram klime, prosječne mjesečne temperature (linija) i prosječnog zbroja mjesečnih oborina (stupići) u meteorološkoj postaji Grič, Zagreb, za razdoblje 1922. – 2009.; prosjek godišnjih oborina iznosi 879 mm, a prosjek godišnje temperature 11,76 ºC

moment correlation, while in 'response' functions, the coefficients are multivariate estimates from a principal component regression model (Biondi and Waikul, 2004). The program applies a bootstrap process according to Guiot (1991) to assess the statistical significance of the correlation and response function.

The stability in time of the climate/growth relationships was checked by moving the correlation and response function, calculated for a 60-year time window, over the chronological life span from 1883 to 2009 (Biondi 1997).

2.4 Teleconnection and heteroconnection
2.4. Telekonekcija i heterokonekcija

The residual oak chronology of Kobiljak was tested for teleconnection. It was compared with oak chronologies from Austria, Hungary, Slovenia and Serbia (Čufar *et al*., 2014). For this purpose, we prepared residual chronologies of 40 sites (27 from Austria, 9 from Hungary, 3 from Slovenia and 1 from Serbia) according to the same procedure described above.

In addition, we also tested the residual oak chronology of Kobiljak with 15 available tree-ring chronologies of beech (*Fagus sylvatica* L.) (Čufar *et al.* 2008d) prepared according to the same procedure.

Comparison of the chronology of Kobiljak and others was made by calculating the *t*-values and coefficients of agreement (Gleichläufigkeit - Glk) using TSAP-Win.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Chronology
3.1. Kronologija

The obtained oak chronology of Kobiljak (abbreviation HR1) is based on tree-ring data from 17 trees (33 radii). It is 127 years long and covers the period 1883-2009 (Figure 2), however its optimally replicated

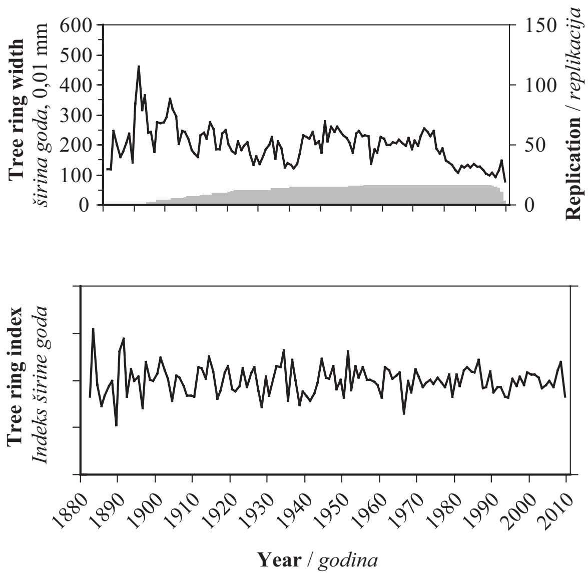

Figure 2 Oak tree-ring chronology of Kobiljak near Zagreb (HR1): raw-data chronology with replication (above) and detrended residual chronology (below); the optimally replicated part of the chronology extends from 1922 to 2008 and is 88 years long. It is based on 17 trees with subsample signal strength (SSS) >0.80
Slika 2. Kronologija godova hrasta iz Kobiljaka pokraj Zagreba (HR1): kronologija nestandardiziranih širina godova s replikacijom (iznad) i rezidualna kronologija (ispod); optimalno replicirani dio kronologije proteže se od 1922. do 2008. i dug je 88 godina, temelji se na 17 stabala sa signalom jakosti poduzorka (SSS)>0,80

Table 1 Descriptive statistics of Kobiljak near Zagreb (HR1) oak chronology, period 1922-2009, based on 17 trees
Tablica 1. Opisna statistika kronologije hrasta iz Kobiljaka pokraj Zagreba (HR1), razdoblje 1922. -2009., utemeljene na 17 stabala

Chronology type *Tip kronologije*	**Raw** *Neobrađeno*	**Residual** *Rezidual*
Mean, mm *Prosjek, mm*	2.0055	0.9975
Median, mm *Median, mm*	2.0270	1.0038
Mean sensitivity *Srednja osjetljivost*	0.1561	0.1655
Standard deviation, mm *Standardna devijacija, mm*	0.6070	0.1540
Autocorrelation order 1 *Autokorelacijski red 1*	0.6959	-0.0508
Autocorrelation order 2 *Autokorelacijski red 2*	0.1672	-0.0602
Autocorrelation order 3 *Autokorelacijski red 3*	0.0686	0.0079
Mean correlation between trees *Prosječna korelacija između stabala*	0.220	0.241
Signal-to-noise ratio *Omjer signal-šum*	3.360	4.118
Variance in first eigenvector, % *Varijanca prvog svojstvenog vektora, %*	32.92 %	30.44 %

part, based on 13 or more trees, extends from 1922 to 2009 and reaches the subsample signal strength (SSS) > 0.80. The statistics of the raw-data and residual chronologies HR1 is given in Table 1.

3.2 Climatic signal in chronology
3.2. Klimatski signal u kronologiji

Below-average temperature and above-average precipitation in June, i.e. a cool and moist June, are the most significant factors favoring oak growth on the site (Fig. 3). The correlation (r) between the residual tree-ring chronology and June precipitation is 0.333, while the correlation with June temperature series is -0.325.

In addition, both precipitation and especially temperature showed a consistent stability over a period of about 60 years (Fig. 4).

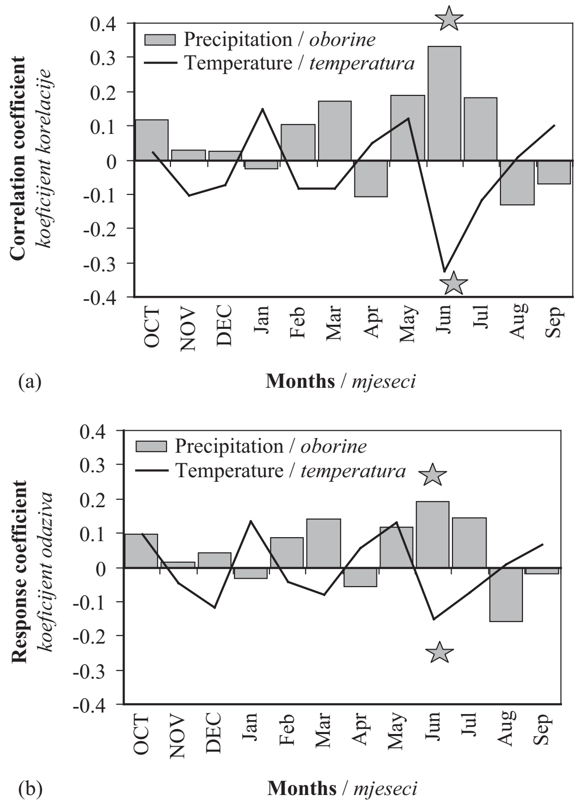

Figure 3 Correlation (a) and response coefficients (b) calculated between the residual version of oak chronology of Kobiljak near Zagreb (HR1) and monthly temperature (line) and precipitation (bars) from previous October to current September for the period 1922-2009; stars indicate significance at 95 % level
Slika 3. Koeficijenti korelacije (a) i odaziva (b) izračunani iz rezidualne kronologije hrasta iz Kobiljaka pokraj Zagreba (HR1) te mjesečnih temperatura (crta) i oborina (stupići) između prethodnog listopada i tekućeg rujna za razdoblje 1922. – 2009.; zvjezdice upućuju na značajnost pri razini vjerojatnosti od 95 %

3.3 Teleconnection
3.3. Telekonekcija

The results of teleconnection of the HR1 chronology with the chronologies from Austria, Hungary, Slovenia and Serbia is given in Table 2. Although the comparison of HR1 was made with 40 residual chronologies prepared according to the same standardiza-

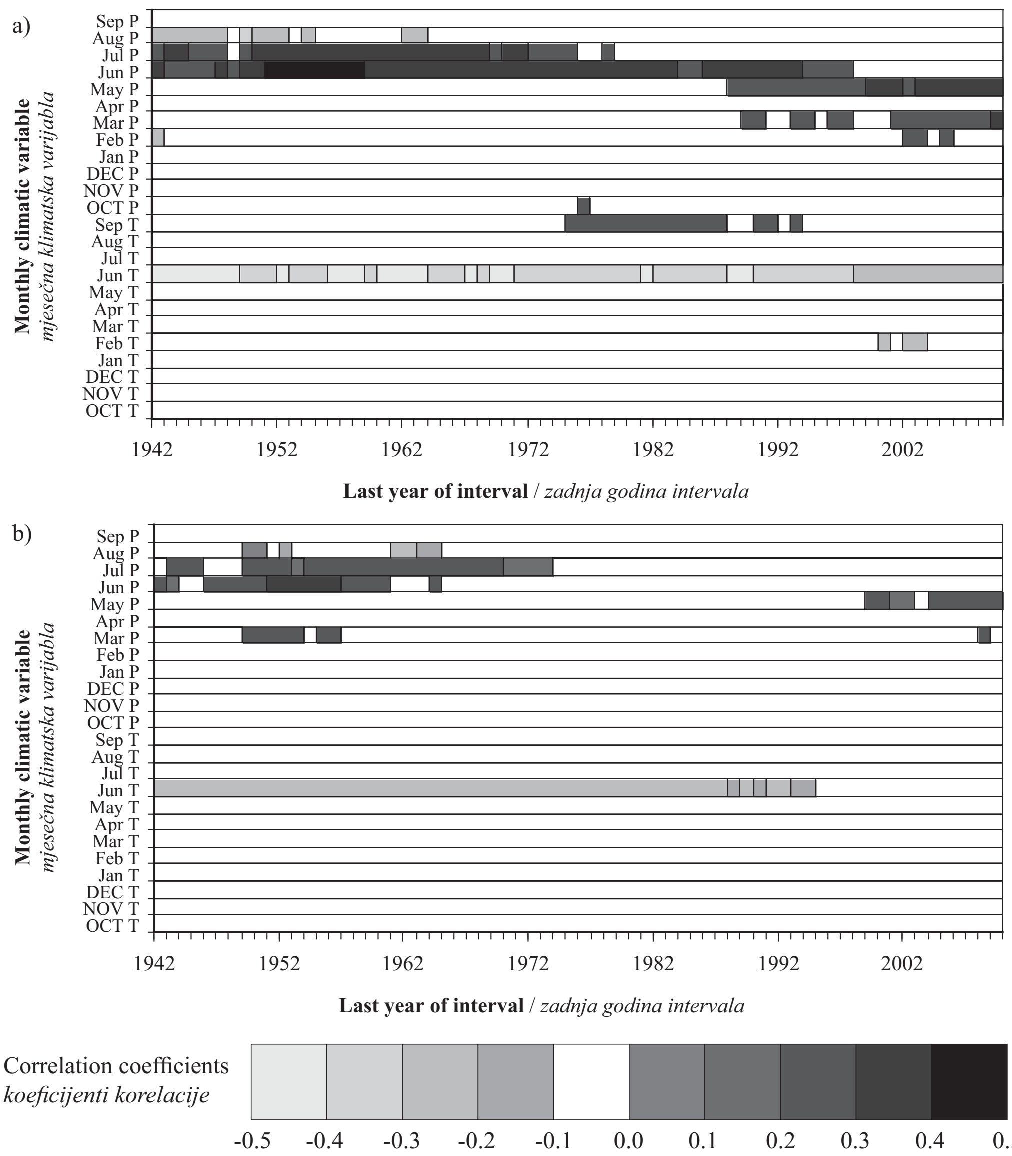

Figure 4 Moving correlation values (a) and response values (b), computed with DendroCLIM2002 (interval of 60 years); the first interval is from 1922 to 1981 and the last from 1950 to 2009; months written in capitals mean months of the previous year (*i.e.* DEC). Only significant values are shown.
Slika 4. Pomične korelacijske vrijednosti (a) i vrijednosti odaziva (b) (duljina intervala 60 godina); prvi se interval proteže od 1922. do 1981., a zadnji od 1950. do 2009.; mjeseci pisani velikim slovima znače mjesece prethodne godine (*npr.* DEC) . Prikazane su samo značajne vrijednosti.

Table 2 Crossdating parameters for comparison of the residual chronology of oak from Kobiljak near Zagreb, Croatia (HR1) with local residual oak chronologies from Austria (A*), Hungary (U*), Slovenia (SI*); for the locations, compare Fig. 5 (parameters: overlapping – Ovl, coefficient of agreement – Glk% and t-value – t_{BP})
Tablica 2. Parametri za usporedbu rezidualne kronologije hrasta iz Kobiljaka pokraj Zagreba, Hrvatska (HR1) s lokalnim rezidualnim kronologijama hrasta iz Austrije (A*), Mađarske (U*), Slovenije (SI*); lokacije usporediti sa slikom 5. (Ovl – preklapanje, Glk – koeficijent slaganja, t_{BP} – *t* vrijednost)

Comparison with oak chronology HR1, period 1922-2008, Longitude16º09' E, Latitude 45º49' N, Altitude 140 m a.s.l. *Usporedba sa kronologijom hrasta HR1, razdoblje 1922. - 2008., zemljopisna dužina 16º09 E, zemljopisna širina 45º49' N, visina 140 m n.m.*								
Code *Oznaka*	Ovl	t_{BP}	Glk (%)	Location *Mjesto*	Country *Zemlja*	Longitude *Dužina*	Latitude *Širina*	Altitude (m a.s.l.) *Visina (m n.m)*
U02	80	6.6	70.9	Zamárdi	Hungary	17.90°	46.83°	204
SI1	82	6.0	77.8	Novo mesto	Slovenia	15.18°	45.80°	220
SI2	82	5.1	75.9	Celje-Kozjansko	Slovenia	15.25°	46.25°	240
SI3	75	4.8	73.0	Ljubljana	Slovenia	14.48°	46.07°	299
U06	80	4.8	64.6	Bürüs	Hungary	17.77°	45.97°	120
A04	86	4.3	64.7	Fehring	Austria	16.02°	46.93°	270
A14	87	4.2	69.8	Baumgarten an der March	Austria	16.53°	48.31°	145

Figure 5 Teleconnection of Kobiljak near Zagreb oak chronology (HR1) with local oak chronologies from Austria, Hungary, Slovenia and Serbia; the chronologies showing $t_{BP} \geq 4$ are indicated with progressively large points and labels, small points without label represent chronologies with $t_{BP} < 4$; for details of teleconnection see Table 2
Slika 5. Telekonekcija kronologije hrasta iz Kobiljaka blizu Zagreba (HR1) s lokalnim kronologijama hrasta iz Austrije, Mađarske, Slovenije i Srbije. Kronologije koje pokazuju $t_{BP} \geq 4$ naznačene su oznakom i postupno većim točkama, a male točke bez oznake predočuju kronologije s $t_{BP} < 4$; statistički parametri telekonekcije navedeni su u tablici 2.

tion procedure, we list only the statistically significant agreements with $t_{BP} \geq 4$.

Out of 40 chronologies used for comparison, 7 showed significant similarity ($t_{BP} \geq 4$) with HR1 chronology in its well replicated part (1922-2009). The chronologies showing similarity are located NE, N and NW from Kobiljak. The most distant chronology A14 is from Baumgarten in Austria ca. 270 km away (as a crow flies), and the nearest one is SI1 from the area of Novo mesto in Slovenia ca. 60 km away. The highest agreement ($t_{BP} = 6.7$) was obtained with the U02 chronology of Zamárdi in Hungary, which is ca. 230 km away from Kobiljak. The values of coefficients of agreement were in all cases above 64 %. It should be noted that the chronology of the surroundings of Sremska Mitrovica, Serbia, had *t*-value 3.8 and Glk 69.1, which is just slightly below the significance value.

The similarities among the chronologies could be ascribed to a common positive response to climate, especially June temperatures (Čufar *et al.,* 2008, 2014). Besides the chronologies used in this study, great importance of June temperatures was also identified in Turkey oak (*Quercus cerris*) on sites in Central Italy (Corona *et al.,* 1995; Romagnoli and Codipietro, 1996) ca. 500 km away from Kobiljak, which could indicate that even teleconnection with Italian chronologies might be possible.

3.4 Heteroconnection
3.4. Heterokonekcija

The results of heteroconnection of the HR1 oak chronology with beech chronologies from 14 locations in Slovenia (Čufar *et al.* 2008d) showed agreement with 5 beech chronologies (Table 3, Figure 6). The locations of the chronologies are SE of Celje, near Novo

Table 3 Crossdating parameters for comparison of the residual chronology of oak from Kobiljak near Zagreb, Croatia (HR1) with local residual chronologies of beech (*Fagus sylvatica*) from various sites in Slovenia; for the location, compare Figure 6 (parameters: overlapping – Ovl, coefficient of agreement - Glk% and t-value – t_{BP})
Tablica 3. Parametri za usporedbu rezidualne kronologije hrasta iz Kobiljaka pokraj Zagreba, Hrvatska (HR1) s lokalnim rezidualnim kronologijama bukve (*Fagus sylvatica*) iz različitih staništa u Sloveniji; lokacije usporediti sa slikom 6. (Ovl – preklapanje, Glk – koeficijent slaganja, t_B – *t* vrijednost.

Comparison with oak chronology HR1, period 1922-2008, Longitude16º09' E, Latitude 45º49' N, Altitude 140 m a.s.l. *Usporedba sa kronologijom hrasta HR1, razdoblje 1922-2008, zemljopisna dužina 16º09' E, zemljopisna širina 45º49'N, visina 140 m n.m.*								
Code *Oznaka*	Ovl	t_{BP}	Glk (%)	Location *Mjesto*	Country *Zemlja*	Longitude *Dužina*	Latitude *Širina*	Altitude (m a.s.l.) *Visina (m n.m.)*
17	78	5.8	72.1	Mokronog	Slovenia	15.20º	45.91º	400
5	72	4.9	68.3	Celje A	Slovenia	15.54º	46.08º	300-600
6	72	4.6	67.6	Celje B	Slovenia	15.37º	46.11º	300-600
2	76	4.2	60.0	Gorjanci	Slovenia	15.29º	45.76º	300-600
16	78	4.0	71.4	Pivka	Slovenia	14.16º	45.80º	640

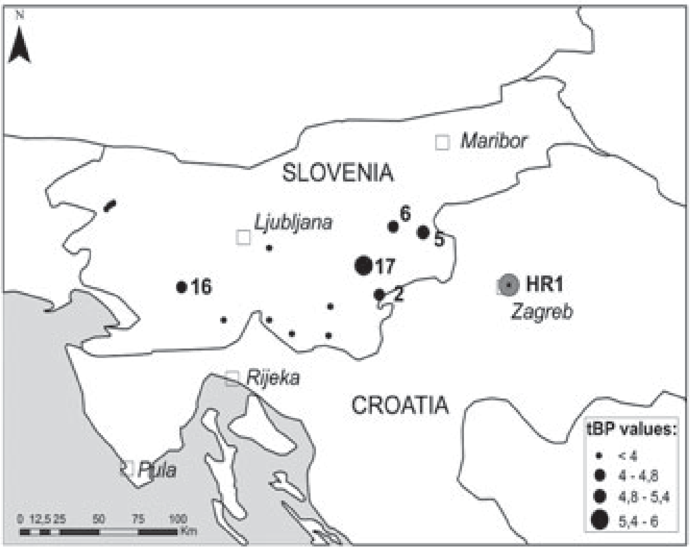

Figure 6 Heteroconnection of oak (*Quercus robur*) chronology of Kobiljak near Zagreb (HR1) with local beech (*Fagus sylvatica*) chronologies from Slovenia; the chronologies showing $t_{BP} \geq 4$ are labelled with numbers, small points without label represent chronologies with $t_{BP} < 4$; for details see Table 3
Slika 6. Heterokonekcija kronologije hrasta (*Quercus robur*) iz Kobiljaka pokraj Zagreba (HR1) s lokalnim kronologijama bukve (*Fagus sylvatica*) iz Slovenije; kronologije koje pokazuju $t_{BP} \geq 4$ naznačene su oznakom i postupno većim točkama, a male točke bez oznake predočuju kronologije s $t_{BP} < 4$; statistički su detalji navedeni u tablici 3.

mesto and near Postojna, at the distance of 60 – 150 km from Kobiljak.

3.5 Potential for improving chronology and different applications
3.5. Potencijal za usavršavanje kronologije i njezine različite primjene

Croatia has rich wooden cultural heritage, which also includes archaeological wood from the distant past. In the past two decades, the Croatian archaeologists contacted wood scientists from the University of Zagreb and Ljubljana to investigate archaeological wood from their excavations. They pointed out that dendrochronological dating of their artifacts was needed.

The archaeologists Tatjana Tkalčec and Tajana Sekelj Ivančan from the Institute of Archeology in Zagreb requested analyses and dating of wood from three different sites. The first investigations gave no encouraging results. Poor preservation of archaeological wood and low number of tree-rings were the main obstacles for dendrochronological dating (Čufar *et al.,* 2006). However, instructions of wood scientists as to how to properly collect and prepare the material soon led to first successfully dated timbers in the old town of Varaždin (Čufar and Šimek, 2008) and in Torčec gradić (Čufar *et al.,* 2008c). The timbers from Varaždin were dated to 1415 (*terminus post quem*) and those from Torčec gradić to 1263 (*terminus post quem*). In both cases, the Slovenian regional oak chronology was used as well as the over 800-year long regional oak chronology of the laboratory of the University of Natural Resources and Applied Life Sciences in Vienna (Wimmer and Grabner, 1998). Since the Austrian and Slovenian regional chronologies crossdate well ($t_{BP} = 9.7$) (Čufar *et al.,* 2008a), successful dating of archaeological wood showed that the chronologies from Austria and Slovenia could act as important reference points to develop dendrochronology in Croatia. Enhanced co-operation, also including other countries like Hungary, could help to develop a longer regional oak chronology in Croatia and to establish a chronology network in the area south and southeast of the Alps.

4 CONCLUSION
4. ZAKLJUČAK

The investigated wood from living trees of pedunculate oak in Kobiljak near Zagreb enabled us to build a 127 years long chronology spanning the period 1883-2009. The sufficiently replicated part is 88 years long and spans the period 1922-2009.

Dendroclimatological analysis showed positive effect of June precipitation and negative effect of June temperatures on tree-ring variation. Both signals are stable over time.

Although relatively short, the chronology exhibits good teleconnection, i.e. similarity with other oak chronologies of Austria, Hungary, and Slovenia. The parameters of agreement with the chronology of the surroundings of Sremska Mitrovica, Serbia were just slightly below the significance value.

Surprisingly, the oak chronology of Kobiljak also exhibits good agreement with some beech chronologies from Slovenia, which indicates that it has good potential for heteroconnection, i.e. similarity with chronologies of other species.

Good teleconnection and heteroconnection could be ascribed to a common factor - the climate.

The presented results indicate that the development of dendrochronology in Croatia would help to fill the spatial and chronological gaps to establish a better network of regional oak chronologies in the wider region.

The presented chronology could be improved and prolonged by including more trees and possibly additional sites and wood from the objects of cultural history. An improved chronology could be used for different purposes including dating objects of cultural heritage. Interest has arisen for this type of use.

Acknowledgements – Zahvale

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Effectiveness of Asymmetrical Veneering with Hardwood Species of Varying Shrinkage and Porosity

Učinkovitost asimetričnog furniranja furnirom tvrdih vrsta drva različitog utezanja i poroznosti

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ABSTRACT • *The aim of the study was to check deformations of asymmetrically veneered panels using glue with elastic bonding. In order to achieve the aim, a special stand was designed to analyse the geometry of furniture elements. It is known that boards became convex after veneering with rigid glue. However, the level of deformations for varying parameters of veneering was not equal. As the result of veneering with elastic glue, the boards preserved their primary shape. In any case, the level of deformation depended on wood veneer species. The deformation of the boards was not influenced by their shrinkage. It is supposed that the main influence is the difference in porosity.*

Keywords: *asymmetrical veneering, wood-based panels, deformations, shrinkage, porosity*

SAŽETAK • *Cilj istraživanja bio je provjeriti deformacije asimetrično furniranih panela primjenom elastičnog ljepila. Da bi se postigao cilj, dizajniran je poseban stalak za analizu geometrije dijelova namještaja. Poznato je da nakon furniranja primjenom krutog ljepila ploče postanu konveksne. Međutim, razina deformacija za različite parametre furniranja nije jednaka. Nakon furniranja primjenom elastičnog ljepila ploče su očuvale svoj primarni oblik. U svakom slučaju, razina deformacije ovisi o vrsti drva furnira. Na deformaciju ploče ne utječe utezanje ploče. Pretpostavlja se da najveći utjecaj na deformacije ploča ima poroznost drva.*

Ključne riječi: *asimetrično furniranje, ploče na bazi drva, deformacije, utezanje*

1 INTRODUCTION
1. UVOD

Veneering is one of the most important processes in today's furniture industry. The only fully recognised, tried and tested method is symmetrical veneering. In industry, the process of asymmetrical veneering was applied a long time ago (Hayward, 1949), but now is only used occasionally. On the one hand, it leads to cheaper products and production (Ostrowski and Roszkowski, 2009), but on the other hand, it causes warp of furniture elements. An analysis of deformation is espe-

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cially important when composite materials are taken into consideration (Negri *et al*., 2009). Asymmetrically veneered wood-based panels, used as furniture elements, are composites consisting of materials of different physical and chemical properties glued together. Therefore, the glue is the key to finding a solution to avoid deformations in the composites.

Industrial asymmetrical veneering is currently done intuitively. Obviously, it would be better if this method was supported with the results of studies. The purpose of the initial experiments was to find an adhesive that would bond veneer and board without causing significant geometric deformations in asymmetrical veneering. In order to achieve it, samples were veneered only on one side using 5 industrial and 1 experimental glue (Olenska *et al*., 2010; Olenska *et al*., 2011 a,b). The present research showed that samples, asymmetrically veneered using rigid glue bonds, had a general tendency to become deformed. However, the properties of the glue are the most important factor affecting the level of geometric deformations of the board. The main conclusion from the preliminary studies is that it is possible to avoid casting asymmetrically veneered panels by using an elastic bonding adhesive. Therefore, the following research was performed with this type of glue. Primary research showed the importance of shrinkage on asymmetrical veneering (Olenska *et al*., 2011c), and therefore extended research was continued.

The aim of our studies was to analyse the influence of species of different shrinkage on the geometric stability of furniture elements in asymmetrical veneering. Boards were veneered on both large sides or on only one large side using an elastic bonding adhesive.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

Measurements were done on a specially designed stand. The stand is composed of elements as shown in Figure 1.

The main idea of the stand is to define a reference virtual plane (1). This plane is created with four pegs. Three of them have a constant height of 30 mm (3, 4, 5). The fourth is adjustable (6) in order to avoid deflection of the sample, which is attached to the pegs. The force is axially positioned with pegs. During measurements, panels are always placed equally in position to each peg. The position of the panels is secured with three fixed blocks (7, 8, 9). The visible surface of the strip (10) forms the reference surface. The strip is placed with three blocks (8, 9, 11). The distance between the reference virtual plane and reference surface of the strip is constant. This is where the measured board is placed. The geometry is measured in five areas (2), five times in each area (3 mm gap) with a depth gauge. Its precision is 0.01 mm, and measurement error is 0.02 mm.

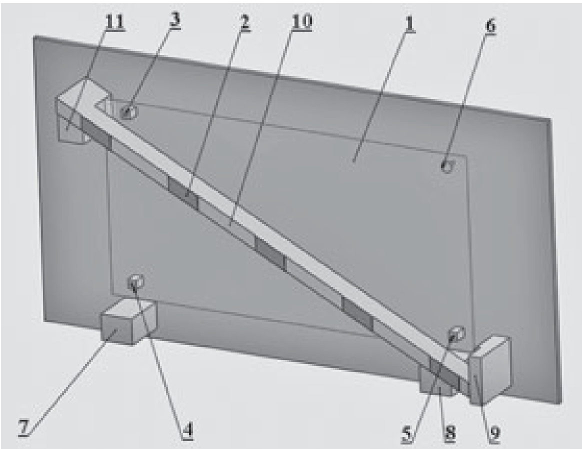

Figure 1 The scheme of the measurement station (explanation in the text)
Slika 1. Shema mjerenja (opis u tekstu)

Four samples of the dimensions of 900 x 450 mm and 18 mm thick were veneered in the same way. After veneering, boards were conditioned at 20 ±2 ºC and 65 ±5 % relative humidity for seven days. All the boards were measured in three states, as follows: unveneered board, unvarnished asymmetrically veneered board and varnished asymmetrically veneered board.

For choosing veneer pairs (each on one large side), a comparison was made of the linear shrinkage values of wood species. Contractions in volume for the used veneers are as follows: Beech (*Fagus sylvatica* L.) - 11.8%, African ebony (*Diospyros spp.* Hiern) - 12.8 %, Macassar ebony (*Diospyros celebica* Bakh.) - 5.1 % (EN 13556; Kokocinski, 2004). Porosity was defined basing on wood density according to standard equation (Kokocinski, 2004): porosity of African ebony – 20 %, porosity of beech – 55 % and porosity of Macassar ebony.

Studies were divided into three steps of different shrinkage value: 1 - small difference of shrinkage values: 11.8/12.8 %, 2 - significant difference of shrinkage values: 5.1/11.8 % and 3 - large difference of shrinkage values: 11.8/0 %.

All the boards were veneered using the same type of elastic bonding glue with the following characteristics: viscosity 2.5 Pa·s, density 0.80 g/cm^3, Young modoulus 2480 MPa (Papadopoulos *et al*., 2002; Konnerth and Gindl, 2006), Poisson's ratio 0.3 (Konnerth *et al*., 2007), contact angle 81° (Olenska *et al*., 2012) and spread 150 g/m^2. Linear shrinkage - 1.4 % and volume shrinkage - 4.2 % of glue were measured according to the method of Jakubiak and Linden (2001). Shore's hardness - 51 HD was measured according to PN- EN ISO 868: 2005P and ISO 7619-1. In addition, the following parameters of veneering were constant: pressure 1.5 MPa, temperature 22 °C, time 240 min.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figures 2 and 3 show as follows:

■ – difference between unveneered board and board veneered on both sides, unvarnished,

● – difference between unveneered board and board veneered on both sides, varnished.

Figures 2 and 3 show the results of the studies performed on board veneered on both sides. Beech ve-

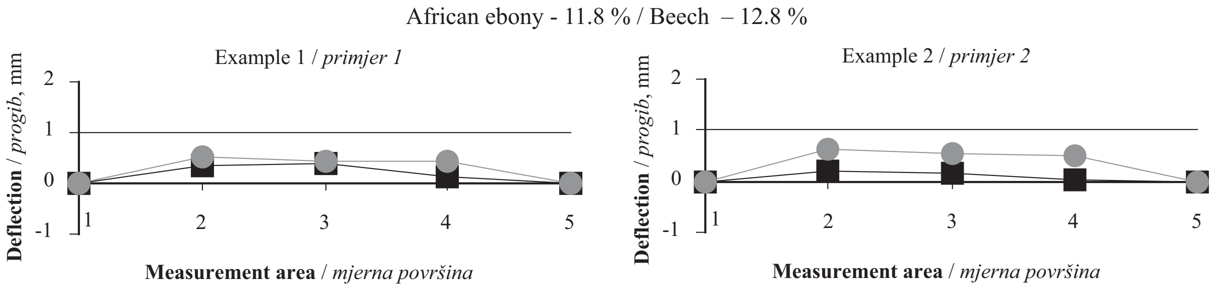

Figure 2 Deflection of the board asymmetrically veneered on both large sides - small difference of shrinkage values
Slika 2. Progib ploče koja je asimetrično furnirana s obje strane - mala razlika između vrijednosti utezanja

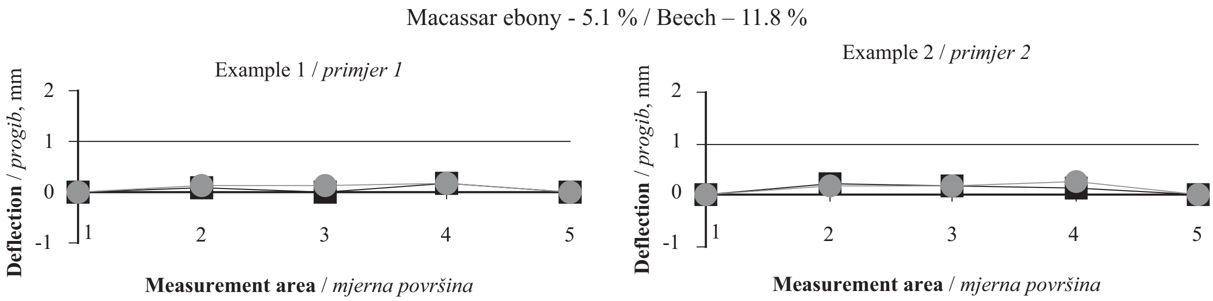

Figure 3 Deflection of the board asymmetrically veneered on both large sides - significant difference of shrinkage values
Slika 3. Progib ploče koja je asimetrično furnirana s obje strane - značajna razlika između vrijednosti utezanja

neer (*Fagus sylvatica* L.) is on one side. Figure 2 shows examples of the results obtained for the board veneered with African ebony (*Diospyros spp. Hiern*) on the other side - small difference of shrinkage values. Figure 3 shows examples of the results for the board veneered with Macassar ebony (*Diospyros celebica Bakh.*) on the other side - significant difference of shrinkage values.

The results of these studies show that the chosen glue provides shape stability after the process of both-side asymmetrical veneering, even if the shrinkage difference was high, and the values of deformations were low. At the critical point of deformation, boards 1 and 2 reached 0.51 mm and 0.61 mm, respectively.

Larger geometric deformations of boards 1 and 2, even for small difference of shrinkage values, can be explained by differences in the porosity of veneers. In boards 1 and 2, the porosity difference between African ebony and beech was 35 %. In boards 1 and 2, the porosity difference between Macassar ebony and beech was only 13 %. Thus, it seems that porosity, apart from shrinkage, is one of the main factors determining stability of asymmetrical veneered panels.

Figure 4 shows the results of the studies made on one-side veneered board using beech veneer - large difference of shrinkage values. The following variables were used:

■ – difference between unveneered board and one-side veneered board, unvarnished,
● – difference between unveneered board and one-side veneered board, varnished.

The results of these studies show that the examined adhesive provides stability of shape of the samples after veneering. Another advantage of the elastic glue bond line is small geometric deformation. At the critical point, deformation reached 0.37 mm.

4 CONCLUSION
4. ZAKLJUČAK

Samples veneered with elastic glue joint preserve their shape, or their deflection is small. Therefore, obviously the properties of glue joint contribute much to the level of geometric deformations of the board.

Studies show that shrinkage in hardwood species does not have an influence on deformations in the ve-

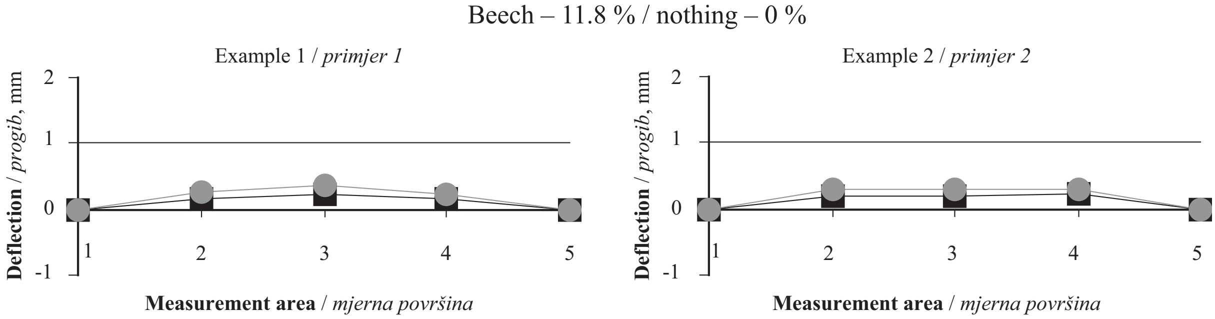

Figure 4 Deflection of boards asymmetrically veneered on one large side – large difference of shrinkage values
Slika 4. Progib ploča koje su asimetrično furnirane s obje strane - velika razlika između vrijednosti utezanja

neered board. The porosity of species used was the main factor affecting the deformations of asymmetrically veneered boards.

A high difference in porosity values causes higher geometric deformations of asymmetrically veneered boards. This can be solved by using optimised technology of gluing and varnishing.

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Biological Durability of Oil Heat Treated Alder Wood

Biološka otpornost johovine termički modificirane u ulju

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ABSTRACT • *The article presents preliminary results of the biological durability of oil heat treated (OHT) alder wood (Alnus glutinosa) against pure cultures of rot fungi (Postia placenta and Trametes versicolor) in lab conditions. The modification was performed by heating of specimens immersed in soya oil. There were four heating regimes of different duration (6 and 10 hours) at final temperature of 180 and 200 ºC. The increase in mass (MI) caused by modification and mass loss of wood caused by fungal decay (ML) were determined. In addition, the natural durability of alder wood was determined and compared to the natural durability of beech wood as the reference wood species.*
After modification of alder wood at 200 °C, MI was lower than after treatment at 180 °C. MI was also lower after 10 hours of treatment than after 6 hours of treatment. The results showed significantly increased biological durability of modified alder wood against both tested fungi. The effect of OHT on increasing the biological durability of alder wood was higher against the fungus P. placenta. It seems that the fungus T. versicolor favours the remained oil after modification causing higher mass loss. The results showed that alder wood, thermally modified in soya oil by testing regimens, is not suitable for applications in use classes 3-5.

Key words: *durability class, Postia placenta, soya oil, Trametes versicolor, use class*

SAŽETAK • *U radu su prezentirani preliminarni rezultati biološke otpornosti drva johe (Alnus glutinosa) termički modificiranoga u sojinu ulju protiv čistih kultura gljiva truležnica (Postia placenta i Trametes versicolor) u laboratorijskim uvjetima metodom mini blok prema CEN TS 15083-1. Modifikacija je izvedena zagrijavanjem uzoraka uronjenih u sojino ulje sobne temperature. Četiri načina termičke modifikacije razlikovala su se po trajanju držanja drva (6 i 10 sati) na konačnoj temperaturi (180 i 200 ºC). Usto je određena i prirodna otpornost johovine u usporedbi s prirodnom otpornosti bukovine kao referentne prirodno slabo otporne vrste drva. Mjereno je povećanje mase modifikacijom (DMM) i gubitak mase djelovanjem spomenutih gljiva (GMG). Nakon modifikacije pri višoj temperaturi DMM drva johe bio je manji nego nakon modifikacije pri nižoj temperaturi. Slično tome, dulji je tretman rezultirao nižim DMM-om nego kraći tretman. Rezultati su potvrdili povećanje biološke otpornosti modificirane johovine protiv obje testirane gljive truležnice. S povećanjem temperature modifikacije znatno se povećava biološka otpornost protiv obje gljive, dok produljenje vremena zagrijavanja ima blagi učinak povećanja biološke otpornosti. Utjecaj modifikacije na povećanje biološke otpornosti veći je protiv gljive smeđe truleži P. placenta. Utvrđeno je da je veći gubitkom mase modificiranih uzoraka djelovanjem gljive T. versicolor (u usporedbi s gubitak mase djelovanjem gljive P. placenta) najvjerojatnije nastao zbog razaranja preostalog ulja*

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u drvu nakon modifikacije. Dokaz tome je crvena boja mikroskopskih preparata modificiranih uzoraka (postojanje lignina) te lokalna plava obojenost u lumenima traheja (nedostatak lignina). U lumenima traheja ostalo je najviše ulja nakon modifikacije, pa se tu ujedno i najjače razvio micelij gljive bijele truleži T. versicolor, koji je, osim razgradnje ulja, djelomično uništio i lignin. Rezultati su pokazali da johovina termički modificirana u biljnom ulju, prema testiranim režimima, nije primjerena za upotrebu u razredima opasnosti 3 i višima.

Ključne riječi: *Postia placenta, razredi opasnosti, razred trajnosti, sojino ulje, Trametes versicolor*

1 INTRODUCTION
1. UVOD

Wood is a material that can be used for different purposes. However, it can be degraded by xylophagous microorganisms, xylophagous insects, UV rays, etc. (Hasan, 2010; Beyzar, 2012). It is flammable and hygroscopic, and its dimensions change depending on its moisture content. The above mentioned properties are undesirable and limit the application of wood in comparison to other new materials. There are many processes that can reduce/eliminate the undesired properties of wood. Hill (2006) mentioned some of the first scientists (Tiemann, 1915; Stamm and Hansen, 1937; Stamm *et al*., 1946; etc.) who have introduced various wood modification processes. The general goal of wood modification is to get wood with desirable properties during its service life, not toxic and not releasing any toxic substances (Hill, 2006). Among many modification processes, some chemical and thermal modifications have been the most investigated, but only some of them are commercialized.

Chemical modification implicates etherification or esterification between some chemical and OH groups of cellulose, hemicelluloses and lignin (Militz, 1993). The following parameters are important for successful chemical modification: temperature, type of chemical, processing time, type of catalyst and wood species (Hill, 2006; Hasan, 2010).

Thermal modification is a process where the wood cell wall polymers are destructed to the radicals that repolymerise with OH groups of wood cell wall compounds only by heating. Thermal modification is mostly conducted in operating cylinder at the temperature between 150 and 260 °C without the presence of oxygen (Leithoff and Peek, 1998; Rapp and Sailer, 2001a, 2001b; Rep and Pohleven, 2001; Yildiz *et al*., 2003; Hill, 2006; Beyzar, 2012). The type of heating medium, period of heating, final temperature and wood species are the most important parameters of thermal modification processes. By any such modification process, the dimensional stability and resistance of wood against rot-fungi are improved (eg. Rapp and Sailer, 2001a, 2001b; Hill, 2006 mentioned Tiemann, 1915, Stamm and Hansen, 1937 and Stamm *et al*., 1946; Hasan *et al*., 2008; Beyzar, 2012), but some mechanical properties are decreased (Bengtsson *et al*., 2002; Ladner and Halmschlager, 2002; Patzelt *et al*., 2002; Bak and Nemeth, 2012). Resistance against fungi increases at increasing the degree of modification as well as at increasing the oil uptake (Rapp and Sailer, 2001b; Sidorova, 2009; Bazyar, 2012). Wood thermally modified in vegetable oils has greater durability against rot fungi than when modified in air atmosphere (Rapp and Sailer, 2001a; Despot *et al*., 2008; Hasan *et al*., 2008; Hasan, 2010). Thermal modification of wood in air atmosphere at a final temperature ranging between 140 and 180 °C does not significantly increase biological durability compared to non-modified wood (Rapp and Sailer, 2001b; Hasan *et al*., 2006, 2007; Hasan, 2010; Despot *et al*., 2008). Feist and Sell (1987) reported that thermally modified wood was still sound without any sign of biodeterioration after 8 months of field testing. They explained that paucity of bluestain's and mould's mycelium on the surface of modified wood ensures reduced discoloration, and that durability against moulds and bluestain also increases with the increase of modification degree. They stated that the difference in discoloration becomes most significant between 8 and 14 months of field testing because the amount of simple carbohydrates decreases and chemical structure of parenchyma cells contents change during modification, so fungal enzymes become less effective (Feist and Sell, 1987).

Latest research reports that thermally modified wood is not resistant against staining fungi, and in some cases it becomes even more susceptible to staining fungi.

Sidorova (2009) modified spruce, pine heartwood, pine sapwood and aspen in rapeseed oil at 180, 210 and 240 °C for 0.5, 1.0 and 1.5 hours. One set of specimens were taken away from the oil immediately after treatment and cooled in air atmosphere while the other set of specimens were cooled in the oil. Her results are similar to the results of Bazyar (2012). He also modified aspen wood in linseed oil at temperatures of 190, 205 and 220 °C for 4.5 and 6 hours. He reported that the WPG was about 83.9 to 86.2 %, and that the WPG was not significantly affected by time or temperature of modification. After the main heating stage, the oil was removed from the operating cylinder and specimens were vacuumed to remove surplus and remaining oil from the specimens. This is contrary to the results and procedure of Sidakova (2009).

Spear *et al*. (2006) reported the WPG of 89.9 and 87.4 % in Corsican pine wood and below 20 % in Norway spruce wood after oil heat treatment in linseed oil at 190 and 200 °C, respectively, at decreased pressure. Bazyar (2012) cited similar WPG data of Sailer and Rapp (2001). The increase of mass of wood after oil heat treatment was about 42 to 51 % for pine wood and 10 to 18 % for spruce wood, depending on the immersion time of wood in oil during the cooling phase.

Bazyar (2012) explained high values of WPG in his study as a result of the small size of specimens. He cited Jones *et al*. (2005), who reported that longer samples of sitka spruce have lower WPGs. Also, aspen is a hardwood with wide cells and it is permeable (Rowel 1984). He also explained that the high level of WPG could be related to anatomical changes of samples citing Hietala *et al*. (2002). Also Boonstra *et al*. (1998) reported that hardwood species such as beech and poplar are sensitive to the collapse of vessels and deformation of the libriform fibres near the vessels.

Oil heat treatment has been performed mainly on non-durable wood species such as spruce, fir and pine sapwood as well as on beech, alder and aspen (Bazyar, 2012; Sidorova, 2009; Hasan *et al*., 2008; Yildiz *et al.*, 2003; Bengtsson *et al.*, 2002; Patzelt *et al.*, 2002; Rapp and Sailer, 2001a, 2001b; Feist and Sell, 1987). Alder wood is a fast growing hardwood species and it covers a wide area of Europe (Kajba and Gračan, 2003; Prpić and Milković, 2005). Technical properties of alder wood are poor and it is a non-durable wood species. The idea of the authors is to try to increase some properties of alder wood through modification and to increase its commercial importance. The article presents preliminary results of the mass increase (MI) and improved biological durability (in lab conditions) of oil heat treated alder wood against rot-fungi.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Home-grown alder wood (*Alnus glutinosa*, L.) was used in the oil heat treatment and durability experiment. Beech wood (*Fagus sylvatica* L.) was used only untreated for comparison of the biological durability against the chosen test rot fungi, since it is reference species for natural durability rating due to its very low natural durability.

Lattices were sawn from the region close to the bark of an air-dried and afterwards kiln-dried (below 60 °C) plank for each wood species. Specimens were cut to dimensions 15×5×30 ± 0.2 mm (R×T×L). They were selected and marked successively according to CEN TS 15083-1 (2005) (Tab. 1).

Since Bak and Nemeth (2012) reported no significant influence of oil type on tested mechanical and physical properties, the cheapest oil on the market was used for this experiment. Soya oil was used as a heating medium, and the modification was performed in an open cylinder at ambient pressure.

2.1 Modification procedure
2.1. Postupak modifikacije

All specimens were oven dried at 103 ± 2 °C for 48 hours to constant mass, weighed (m_1), and then conditioned under the standard conditions (20 °C and 65 % relative air humidity) to constant mass. Each group of specimens modified at the same regime (48 specimens) was immersed into 1 l of fresh soya oil at room temperature. Then the oil was heated together with specimens. When the oil temperature of 180 and 200 °C, respectively, was reached, the groups of specimens were boiled for further 6 and 10 hours, respectively. Immediately after modification, specimens were removed from the oil and cooled in air atmosphere over the silica gel and weighed again (m_2).

2.2 Determination of mass increase and natural durability
2.2. Izračunavanje povećanja mase modifikacijom i određivanje biološke otpornosti

Increase of mass (MI) of modified specimens was calculated as a ratio of difference of oven-dried mass after modification (m_2) and oven-dried mass before modification (m_1) and m_1 (1).

$$MI = \frac{m_2 - m_1}{m_1} \cdot 100 \qquad (1)$$

Diological durability of oil heat treated alder wood was determined according to CEN TS 15083-1 (2005). White rot fungus *Trametes versicolor* (L.: Fr.) Pilat. and brown rot fungus *Postia placenta* (Fr.) M.J. Larsen & Lombard were chosen. “Potato dextrose agar (PDA)” by OXOID was used as a nutrient medium. Specimens were placed on the inert plastic network (1 mm thick) over the fungal mycelium in 90 mm Petri dishes and incubated for 9 weeks at 24 ± 1 °C and 70 ± 5 % relative humidity.

Mass loss of specimens caused by fungal decay (ML) was calculated by dividing the difference of oven-dried mass of specimens after fungal decay (m_3) and starting mass before decay (m_2) with starting mass before decay (m_2) (2).

Table 1 Distribution and number of specimens
Tablica 1. Raspored i broj uzoraka

Fungus species / *Vrsta gljive*	**Modification type** / *Postupak modifikacije*	**No. of specimens** / *Broj uzoraka*
Trametes versicolor (L.: Fr.) Pilat.	Oil heat treated alder wood at 180 °C, 6 h (OHT-18/6)	12
	Oil heat treated alder wood at 180 °C, 10 h (OHT-18/10)	12
	Oil heat treated alder wood at 200 °C, 6 h (OHT-20/6)	12
	Oil heat treated alder wood at 200 °C, 10 h (OHT-20/10)	12
	Alder wood control (AC)	24
	Beech wood control (BC)	24
Postia placenta (Fr.) M.J. Larsen & Lombard	Oil heat treated alder wood at 180 °C, 6 h (OHT-18/6)	12
	Oil heat treated alder wood at 180 °C, 10 h (OHT-18/10)	12
	Oil heat treated alder wood at 200 °C, 6 h (OHT-20/6)	12
	Oil heat treated alder wood at 200 °C, 10 h (OHT-20/10)	12
	Alder wood control (AC)	24
	Beech wood control (BC)	24

$$ML = \frac{m_2 - m_3}{m_2} \cdot 100 \qquad (2)$$

This mass loss percentage ML (%) is the unit that shows the durability of specimens. ML will be smaller when the wood is more durable, and vice versa. The durability was ranked as proposed in CEN TS 15083-1 (2005).

2.3 Examination of decay pattern using light microscopy
2.3. Istraživanje mehanizma biološke razgradnje uz pomoć svjetlosnog mikroskopa

About 20 μm thin sections were cut from alder wood specimens decayed by *T. versicolor* using Reichert-Shandon microtome. Sections were stained in safranin and astrablue solution. Cellulose in wood cell walls stained blue, while lignin stained red.

Stained slides were examined using Leitz Wetzlar light microscope, and photographs were taken at 100×, 280× and 400× magnification.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Mass increase (MI)
3.1. Povećanje mase modifikacijom

It is known that wood specimens lose their mass during thermal modification due to the evaporation of extractives and of volatile compounds formed during thermolysis mainly of hemicelluloses and partly of lignin (Hill, 2006 quoted Shafizadeh and Chin, 1977 and Sudo *et al*., 1985; Rapp and Sailer, 2001b quoted Sandermann and Augustin, 1963, Kollmann and Fengel, 1965, Topf, 1971 and Tjeerdsma *et al*. 1998; Sidorova, 2009). Although mass increase during OHT process is the actual result of mass loss of wood and oil uptake in wood, many authors reported this mass increase as WPG.

In this experiment, it was impossible to remove the remained oil from the specimens with the available equipment, so the mass loss of specimens could not be determined. The oil remained in the specimens, so they gained mass. The results of mass increase (MI) indicate that by increasing either modification temperature or modification duration, MI of specimens significantly decreases (Fig. 1).

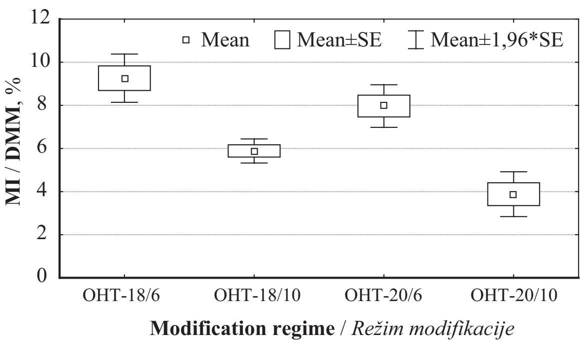

Figure 1 Mass increase of alder wood, MI after different modification regimes (OHT-18/6 = 180 °C, 6 h; OHT-18/10 = 180 °C, 10 h; OHT-20/6 = 200 °C, 6 h; OHT-20/10 = 200 °C, 10 h).
Slika 1. Povećanje mase uzoraka johovine (DMM) nakon različitih režima modifikacije

The obtained values of MI are similar to the results of Sidorova (2009). The only difference is that the mass increase of her specimens, which were cooled in the air, had the tendency to increase by increasing the time of modification at 180 °C, while at higher temperatures of modification, mass increase tends to decrease by increasing the modification duration.

3.2 Biological resistance against rot fungi
3.2. Biološka otpornost protiv gljiva truležnica

The results of this research confirmed significant increase of biological durability of modified alder wood compared to control specimens of both alder and beech wood. The biological durability of all modified alder wood specimens against both tested fungi was significantly higher than the controls. The effect of modification had greater impact on biological durability against *P. placenta* than against *T. versicolor*. By increasing the temperature, biological durability against both tested fungi increased. The only exception to this rule was found in ML caused by *T. versicolor* between OHT-18/10 and OHT-20/10 with no significant difference. Extended period of modification at both temperatures slightly affected, but not significantly, the increasing of biological durability (Fig 2 and 3). According to Rapp and Sailer (2001a, b), by increasing the mass loss of specimens during OHT, biological durability also increases.

Biological durability against both tested fungi of beech wood is slightly higher than that of alder wood. This can be explained by the difference in wood density between these two wood species (Fig 2 and 3).

Similar results of ML were obtained by Bayzar (2012) with aspen thermally modified in oil. Dirol and Guyonnet (1993) studied the effects of wood heat treatment at temperatures between 205 and 260 °C of three

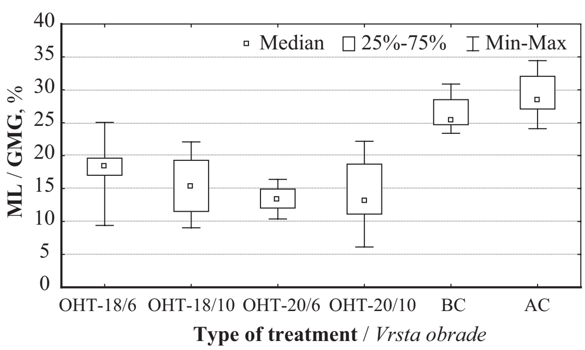

Figure 2 Mass loss of specimens caused by fungus *Trametes* versicolor (ML) of differently modified and non modified alder and beech wood (OHT-18/6 = 180 °C, 6 h; OHT-18/10 = 180 °C, 10 h; OHT-20/6 = 200 °C, 6 h; OHT-20/10 = 200 °C, 10 h, AC-alder wood controls, BC-beech wood controls; n = 24 control specimens, n = 12 for OHT specimens).
Slika 2. Gubitak mase uzoraka djelovanjem gljive *T. versicolor* (GMG) različito modificiranih uzoraka johovine i bukovine i nemodificiranih uzoraka

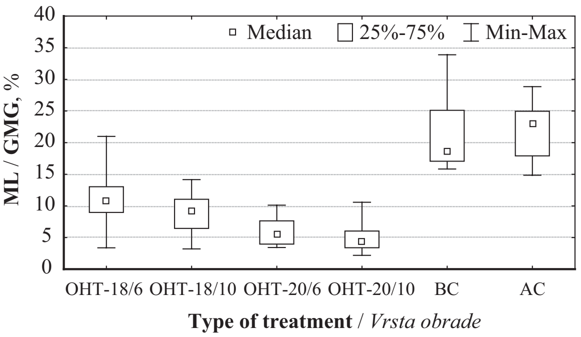

Figure 3 Mass loss of specimens caused by fungus *Postia placenta* (ML) of differently modified and non modified alder and beech wood (OHT-18/6 = 180 °C, 6 h; OHT-18/10 = 180 °C, 10 h; OHT-20/6 = 200 °C, 6 h; OHT-20/10 = 200 °C, 10 h, AC-alder wood controls, BC-beech wood controls; n = 24 for control specimens, n = 12 for OHT specimens).
Slika 3. Gubitak mase uzoraka djelovanjem gljive *P. placenta* (GMG) različito modificiranih uzoraka johovine i bukovine i nemodificiranih uzoraka

non-durable wood species including poplar wood on resistance to several rot fungi including *T. versicolor* and *Coniophora puteana*. They reported mass loss of less than 1 % for all modifications compared to mass loss of controls of 40 %. Rapp and Sailer (2001a, b) reported that spruce and pine sapwood oil heat treated at 190 to 220 °C have improved resistance to the fungus *C. puteana*. They reported the increase of mass loss from 48 and 40 % to about 11 and 5.5 % in pine sapwood and spruce, respectively. Welzbacher and Rapp (2002) showed that oil heat treatment of spruce and pine sapwood can improve durability against *T. versiclor* and *C. puteana*. Leithoff and Peek (2001) reported the temperatures above 170 °C to be effective for increasing biological resistance of two bamboo species.

The modification temperature of 180 °C, used in this research, does not significantly increase the durability class against white-rot fungus *T. versicolor*, while the modification at 200 °C increases the durability from class 4 to class 3. On the other hand, the temperature of 180 °C increases the durability against brown-rot fungus *P. placenta* from class 4 to durability class 2-3, while the modification temperature of 200 °C resulted in an increase of durability of OHT alder wood against brown-rot fungus *P. placenta* from class 4 do class 1-2.

Taking into account mass losses of both tested fungi, only the treatment at 200 °C can improve durability class of alder wood from class 4 to durability class 3 and hence broaden the application of alder wood.

3.3 Decay pattern
3.3. Mehanizam biološke razgradnje

Figure 4 shows the slides of non-decayed specimen that was oil heat treated at 200 °C for 10 hours. A lot of red colour and thickness of the wood cell double walls of the whole OHT slides prove completely non degraded wood (Fig. 4a and 4b).

Although OHT specimens of alder wood decayed by *T. versicolor* had greater ML compared to specimens decayed by *P. placenta*, the overall degree of wood degradation was very similar. Light microscopy examination shows that wood cell walls of OHT specimens decayed by *T. versicolor* were not as severely degraded as control specimens. The majority of blue colour of control slides proves the lack of lignin (great lignin degradation; Fig. 5a, 5b), while OHT slides are mainly red (proof of presence of lignin) with very local blue coloured regions (proof of lack of lignin; Fig. 5c, 5d). These very limited regions of blue colour are mainly in the vessels lumens. As the mycelium of the fungus *T. versicolor* was the most developed in the vessels lumens in OHT specimens, where the majority of oil remained (Olsson *et al*., 2001; Hill, 2006; Bazyar, 2012), it can be concluded that the fungus favours the presence of oil in wood (Fig. 5c, 5d, 6). This leads to the conclusion that the tested fungus *T. versicolor* mainly utilised the oil remained in vessels lumens causing grater ML, and also partially degraded lignin in the inner layer of the cell walls (blue colour; Fig. 5d). Another proof of poor and local lignin degradation in OHT specimens is the red colour of the whole OHT slides, which proves the presence of lignin, although *T.*

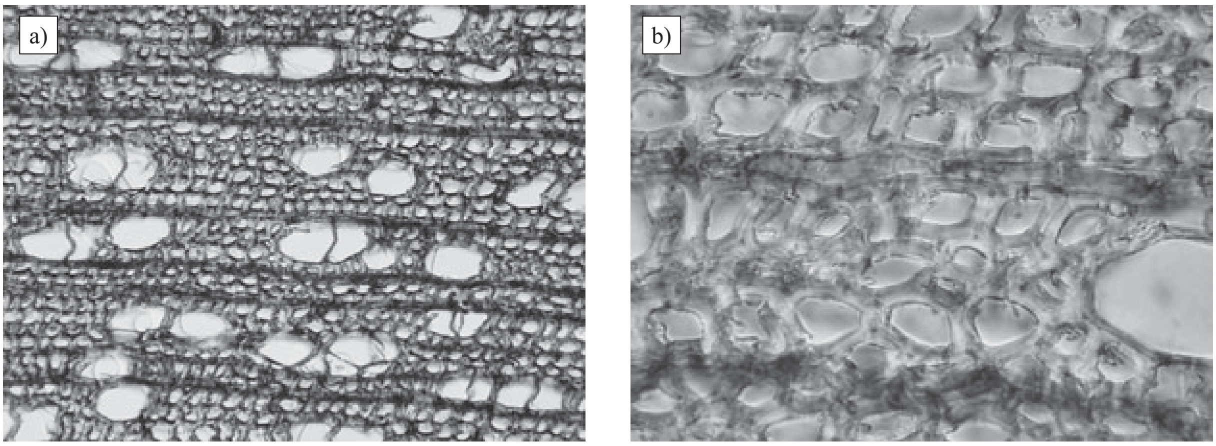

Figure 4 Cross section of non-decayed alder wood: a) OHT at 200°C for 10 h, 100×; b) OHT at 200°C for 10 h, 400×
Slika 4. Poprečni presjek nerazorenoga modificiranog uzorka johovine: a) OHT pri 200 °C za 10 h, povećanje 100 puta; b) OHT pri 200 °C za 10 h, povećanje 400 puta

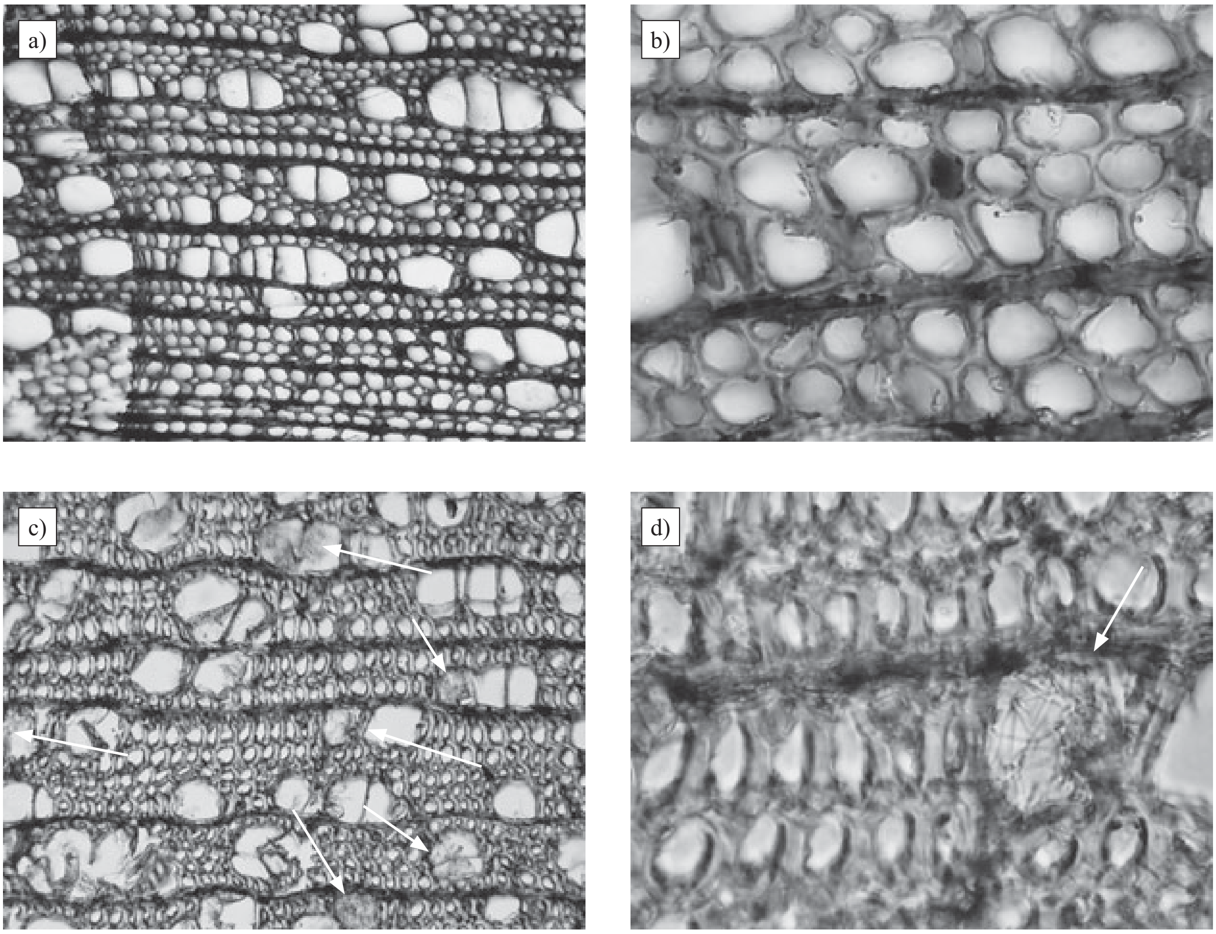

Figure 5 Cross section of alder wood decayed by white-rot fungus *Trametes versicolor*: a) control, 100×; b) control, 400×; c) OHT at 200°C for 10h, 100×; d) OHT at 200°C for 10h, 400×.
Slika 5. Poprečni presjek uzorka johovine razorenoga gljivom bijele truleži *T. versicolor:* a) kontrolni uzorak, povećanje 100 puta; b) kontrolni uzorak, povećanje 400 puta; c) OHT pri 200 °C za 10 h, povećanje 100 puta; d) OHT pri 200 °C za 10 h, povećanje 400 puta

versicolor is white-rot fungus and predominantly degrades lignin (Fig. 5c and 6a). Comparing the thickness of wood cell double-walls of modified non-decayed specimen (Fig. 4b), of control decayed specimen (Fig. 5b) and of modified decayed specimen (Fig. 5d), it is visible that the thickness of cell double-walls of modified non-decayed specimen and modified decayed specimen are very similar. At the same time, the thickness of cell double-walls of control decayed specimen is visibly thinner and lumens are larger.

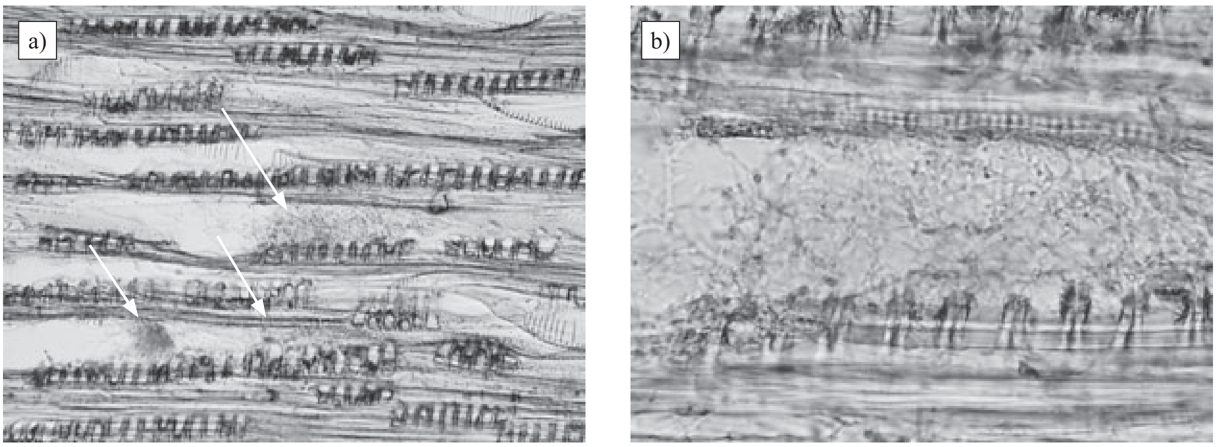

Figure 6 Tangential section of alder wood oil heat treated at 200 °C for 10 h decayed by white-rot fungus *Trametes versicolor*: a) magnification 100×; b) magnification 400×.
Slika 6. Tangentni presjek uzorka johovine modificiranog na 200 °C 10 sati i razorenoga gljivom bijele truleži *T. versicolor*: a) povećanje 100 puta; b) povećanje 400 puta

4 CONCLUSION
4. ZAKLJUČAK

The increase in mass of modified specimens decreased by increasing the duration of oil heat treatment modification at both tested temperatures. The results indicated that the increase of temperature as well as the increase of modification duration had a positive effect on biological durability of alder wood against tested fungi. The tested modification regimes were not adequate for the application of modified alder wood in use classes 3 to 5.

Light microscopy showed that the mycelium of the fungus *T. versicolor* was the most developed in the vessels lumens of modified specimens. Greater mass loss of modified alder wood, decayed by this fungus, can be explained by the fungal utilisation of the oil remained in vessels lumens.

Oil heat treatment is a simple and environmentally friendly method by which biological durability against wood rot fungi can be relatively easily improved. However, it is very important to put in mind that such modification can produce significant decrease in mechanical properties. Further research will show the actual effect of OHT on mechanical properties of alder wood.

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Specific Heat Capacity of Wood

Specifični toplinski kapacitet drva

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ABSTRACT • *Specific heat capacity is defined as the amount of heat that a kilogram of a given substance is required to absorb in order to increase its temperature by one degree. The temperature of a given substance can change either at constant pressure or at constant volume, so we differentiate between specific heat capacity at constant pressure (c_p) and specific heat capacity at constant volume (c_v). When doing research into the heat properties of wood, the quantity that most frequently remains constant is pressure, thus restricting our study on specific heat capacity to c_p. This paper provides an overview of the research that has so far been carried out into the specific heat capacity of wood depending on the temperature and moisture content. An analytical and graphical comparison has been performed of the results published in the Wood Industry Manual (1967) (DIP), Wood Handbook (1999) (WH) and work published by Deliiski (2012) (DEL).*

Key words: *specific heat capacity, wood, moisture content, temperature*

SAŽETAK • *Specifični toplinski kapacitet definiramo kao količinu topline koju kilogram neke tvari treba primiti da bi povećao svoju temperaturu za jedan stupanj. Temperatura neke tvari može se mijenjati uz konstantan tlak ili konstantan volumen, pa razlikujemo specifični toplinski kapacitet pri konstantnom tlaku (c_p) i specifični toplinski kapacitet pri konstantnom volumenu (c_v). Pri ispitivanju toplinskih svojstava drva najčešće je tlak veličina koja ostaje konstantna, zbog čega se naša razmatranja specifičnoga toplinskog kapaciteta ograničavaju na c_p. U radu su prikazani rezultati dosadašnjih istraživanja c_p drva u ovisnosti o temperaturi i sadržaju vode. Obavljena je analitička i grafička usporedba rezultata objavljenih u Drvnoindustrijskom priručniku (1967.) (DIP), Wood Handbooku (1999.) (WH) i radu Deliiskog (2012.) (DEL).*

Ključne riječi: *specifični toplinski kapacitet, drvo, sadržaj vode, temperatura*

1 INTRODUCTION
1. UVOD

The thermal properties of wood are essential physical properties, especially in the processes of drying, producing heat energy by combustion and other processes, which include the transfer of heat through wood. The thermal properties of wood are as follows: specific heat capacity (*c*), coefficient of thermal conductivity (*k*) and thermal diffusivity (α). These three properties of wood are interconnected by the expression:

$$\alpha = \frac{k}{c \cdot \rho} \tag{1}$$

where:
α - thermal diffusivity, $m^2 \cdot s^{-1}$,
k - coefficient of thermal conductivity, W/m·K,
c - specific heat capacity, J/kg·°C,
ρ – density, $kg \cdot m^{-3}$.

Wood, being a porous biomaterial, contains small holes that greatly influence the mechanism of heat transfer, and therefore also the specific heat capacity. Generally speaking, wood is a porous system composed of gas (air), liquid (water) and solid matter (wood). Water can be bound or free, and appears in a solid or liquid state (Chudinov, 1968; Twardowski *et al.*, 2006). The maximum amount of bound water in

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wood corresponds to its maximum hygroscopy, i.e. the moisture that the wood absorbs when the relative humidity of air equals 100 %. Maximum hygroscopy is called the fiber saturation point (u_{fsp}). The fiber saturation point depends on the type and density of wood.

In view of the structure of wood, it is considered that the specific heat capacity of wood (c_{pw}) is a sum of the specific heat capacity of a dry wood substance (c_{p0}), the specific heat capacity of free water (c_{pfw}) and the specific heat capacity of bound water (c_{pbw}) (Deliiski, 2012).

$$c_{pw} = c_{p0} + c_{pfw} + c_{pbw} \tag{2}$$

where:
c_{pw} - specific heat capacity of wood, J/kg·°C,
c_{p0} - specific heat capacity of wood of dry wood substance, J/kg·°C,
c_{pfw} - specific heat capacity of free water, J/kg·°C,
c_{pbw} - specific heat capacity of bound water, J/kg·°C.

If the volume of water is below the fiber saturation point, all of the water is bound, thus reducing the aforementioned expression to:

$$c_{pw} = c_{p0} + c_{pbw} \tag{3}$$

The specific heat capacity of free and bound water depends on the state of matter. Free and bound water change their state of matter at different temperatures. Free water in wood changes its state of matter in a temperature range of -2 °C to -0.1 °C, depending on the concentration of dissolved sugar in water (Kubler *et al.,* 1964; Chudinov, 1968), whereas bound water undergoes only a partial phase change in a wide temperature range at temperatures lower than -2 °C.

2 SPECIFIC HEAT CAPACITY OF DRY WOOD SUBSTANCE
2. SPECIFIČNI TOPLINSKI KAPACITET SUHE DRVNE TVARI

Over the course of the twentieth century, a lot of researchers dealt with the issue of the specific heat capacity of dry wood substance (c_{p0}). The main reference point in this area is Dunlop's paper from 1912. In this paper, the c_{p0} is determined by means of a modified Bunsen ice calorimeter. For the purposes of the experiment, the samples were cylindrical in shape, between 3 cm and 9 cm in length, 1.7 cm in base diameter. Out of a total of 110 samples, using 20 different wood species, varying from 0.23 and 1.10 in specific weight, Dunlop determined the specific heat capacity of dry wood substance in a temperature range of 0 °C to 112 °C. These results led to the conclusion that specific heat capacity does not depend on wood species or bulk density. The measurement results showed a linear dependence of specific heat capacity on the temperature ranging from 0 °C to 100 °C, as demonstrated by equation (4). On the basis of the data obtained by measurement, the value of constant *A* and *B* in equation (4) was determined. In the temperature range of 100 °C to 112 °C no connection between c_{p0} and temperature was established; on the basis of the data obtained by measurement, the average specific heat capacity for the given temperature interval was determined by means of equation (5) and it is 1.3688 kJ/kg·°C.

$$\{c_p\}_{J/kg\cdot°C} = A + B\cdot\{t\}_{°C} \tag{4}$$

where:
A - constant that represents specific heat capacity at 0 °C,
B - constant that represents the slope of a line,
t - temperature.

$$\overline{c}_p = \frac{\int_{t_0}^{t_1} c_p}{t_1 - t_0} \tag{5}$$

where: $\overline{c}_p$ - mean specific heat capacity, J/kg·°C,
c_p - specific heat capacity, J /kg·°C,
t_0 - initial temperature, °C,
t_1 - final temperature, °C.

Dunlop (1912), Volbehr (1896) and Koch (1969) measured the c_{p0} for several types of wood in a temperature range of 0 °C to 100 °C, while Kanter (1957) measured the specific heat capacity in a temperature range of -40 °C to 100 °C. The data obtained by the aforesaid authors showed a linear dependence of c_{p0} on temperature. On the basis of the data obtained by measurement, coefficients *A* and *B* (Table 1) in equation (4) were determined. Coefficient *A* represents c_{p0} at the temperature of 0 °C, and coefficient *B* determines the slope of the line. These results led to the conclusion that c_{p0} does not depend on the wood species, density or specific weight.

Table 1 clearly shows that the data published by certain researchers (Dunlop, 1912; Volbehr, 1896; Koch, 1969) are only slightly different, while the data of the research done by Kanter (1957) coincides closely with the other authors in constant *B*, whereas the specific heat capacity at 0 °C is significantly different from the values obtained by the other authors. However, apart from Kanter (1957), none of the other au-

Table 1 Comparison of constants *A* and *B* in equation (4), average specific heat capacity of dry wood substance $\overline{c}_{p_{01}}$ in a temperature range of 0 °C to 100 °C and average specific heat capacity of dry wood substance $\overline{c}_{p_{02}}$ in a temperature range of -40 °C to 100 °C according to the research by Dunlop (1912), Volbehr (1896), Koch (1969) and Kanter (1957)
Tablica 1. Usporedba konstanti *A* i *B* u jednadžbi (4), srednji specifični toplinski kapacitet suhe drvne tvari $\overline{c}_{p_{01}}$ u temperaturnom rasponu od 0 do 100 °C i srednji specifični toplinski kapacitet suhe drvne tvari $\overline{c}_{p_{02}}$ u temperaturnom rasponu od -40 do 100 °C prema istraživanjima Dunlopa (1912.), Volbehra (1896.), Kocha (1969.) i Kantera (1957.)

Author / *Autor*	*A*	*B*	$\overline{c}_{p_{01}}$(0 °C - 100 °C), kJ/kg·°C	$\overline{c}_{p_{02}}$(-40 °C - 100 °C), kJ/kg·°C
Dunlop	1.1136	0.004856	1.3564	1.2592
Volbehr	1.0841	0.005060	1.3371	1.2359
Koch	1.1097	0.004202	1.3198	1.2357
Kanter	1.5488	0.005023	1.7999	1.6994

thors provides such high values of the specific heat capacity at the temperature of 0 °C.

It should be noted that Wilkes and Wood (1949) determined the average specific heat capacity of 1.427 kJ/kg·°C of a fiberboard, the density of which was 0.232 g/cm³, in a temperature range of 27 °C to 100 °C.

For the same temperature interval, the result of 1.421 kJ/kg·°C is obtained by the Dunlop equation (1912), which differs slightly from Wilkes and Wood. Using the Kirsher method of measuring the specific heat capacity, Kühlman (1962) obtained values very similar to those obtained by Dunlop. Different sample preparations and use of different measuring devices provide an explanation for the subtle differences in the results.

Several authors (Brown *et al.*, 1952; Emchenko, 1958; Tiemann, 1951) misquote Dunlop by stating that constant *A* is 0.946 kJ/kg·°C (0.226 kcal/kg·°C) instead of 1.1134 kJ/kg·°C (0.266 kcal/kg·°C).

2.1 Specific heat capacity of wood
2.1. Specifični toplinski kapacitet drva

Volbehr (1896) determines the average specific heat capacity of wood fibers $\bar{c}_{pw}$ in a temperature range of 0 °C to 100 °C, with the wood moisture content (*u*) varying between 0 % and 30 %. In the said temperature range and moisture content, the $\bar{c}_{pw}$ was higher than the $\bar{c}_{p0}$ of dry wood substance in the same temperature range. On the basis of the data obtained by measurement, he draws the conclusion that $\bar{c}_{pw}$, apart from depending on a change in temperature, also depends on the volume of water. The mathematical dependence of $\bar{c}_{pw}$ on the temperature and volume of water is shown in expression (6).

$$\{\bar{c}_{pw}\}_{kJ/kg\cdot°C} = 1.08 + 4.08\cdot10^{-3}\cdot\{u\}_{\%} + 2.53\cdot10^{-3}\cdot\{t\}_{°C} + \\ + 6.28\cdot10^{-5}\cdot\{u\}_{\%}\cdot\{t\}_{°C} \quad (6)$$

where:
$\bar{c}_{pw}$ - mean specific heat capacity of wood fiber, kJ/kg·°C,
u - moisture content, %,
t - temperature, °C

Expression (6) served as a means to determine the $\bar{c}_{pw}$ with the wood moisture content between 0 % and 25 % in a temperature range of 0 °C to 100 °C. The obtained values can be seen in Figure (1).

Volbehr's research is tangible proof of the influence of the wood moisture content on the specific heat capacity of wood fibers.

Kanter (1957) determines the specific heat capacity of pine, oak and birch in a temperature range of - 40 °C to 100 °C, with the moisture content varying between 0 % and 130 % (Figure 2). This data leads to the conclusion that the specific heat capacity of wood depends on the temperature and moisture content, while the variations between different wood species were very small.

The dependence of c_{pw} on temperature is linear in a range of moisture content from 5 % to 30 %, but for temperatures below 0 °C this dependence is broken into two lines with a different slope coefficient. This change in slope coefficients occurs at the temperature at which change in the phase of bound water ends.

For wood moisture content higher than 30 %, the dependence of c_{pw} on temperature is also linear with a sudden rise at a temperature slightly lower than 0 °C. This sudden rise is due to a change in the phase of free

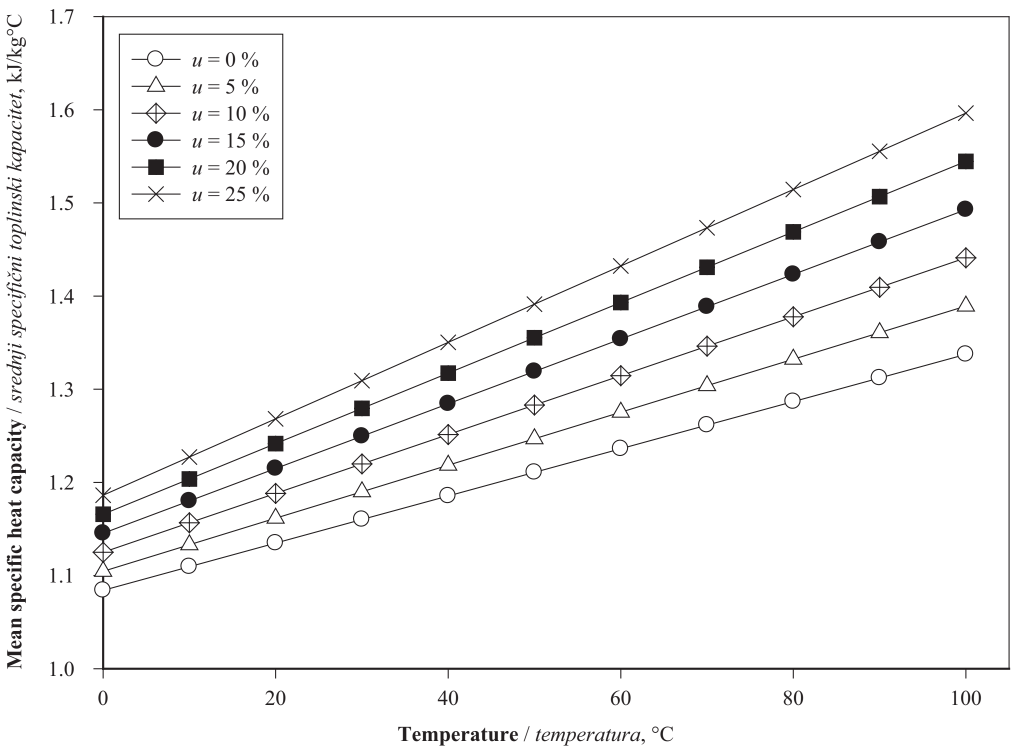

Figure 1 Dependence of specific heat capacity of wood fibers ($\bar{c}_{pw}$) on temperature with wood moisture content between 0 % and 25 %

Slika 1. Ovisnost specifičnoga toplinskog kapaciteta drvnih vlakanaca ($\bar{c}_{pw}$) o temperaturi za sadržaj vode od 0 do 25 %

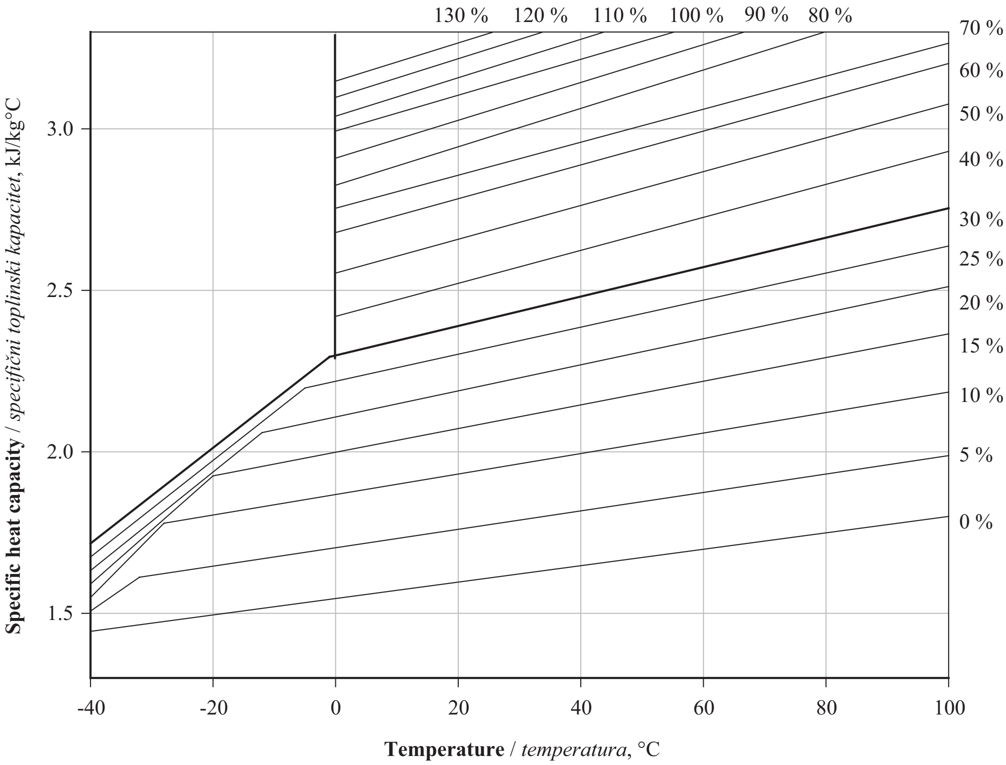

Figure 2 Dependence of specific heat capacity of wood on temperature (Kanter, 1957) and wood moisture content between 0 % and 130 %
Slika 2. Ovisnost specifičnoga toplinskog kapaciteta drva o temperaturi (Kanter, 1957.) za sadržaj vode od 0 do 130 %

water. At this point, there is also the change in the slope coefficient of the line.

Kuhlman (1962) determines the specific heat capacity of spruce, oak and beech wood in a temperature range of - 60 °C to 80 °C, with the moisture content below 30 %, by means of two different methods (the Esdorn – Kirsher method and the ice calorimeter method). Contrary to Kanter (1957), there were no significant changes in the specific heat capacity due to a change in the phase of bound water. The obtained values are considerably lower than those obtained by Kanter, but they coincide closely with the values obtained by the other authors at temperatures higher than 0 °C. Table 2 shows the average deviations of the available results of the other authors from Kanter's results.

Most of the authors arrive at the conclusion that the specific heat capacity of wood depends on the temperature and moisture content, while variations between wood species are very small. The available literature provides only two papers that mention greater variations between wood species. Narayanamurti *et al.* (1958) measured the specific heat capacity of nine Indian wood species (probably at room temperature), and the results cover the interval of (1.29 to 1.73) kJ/kg·°C. Koch (1969) published the results on the specific heat capacity

Table 2 The average deviations of the results of the other authors from Kanter's results for temperatures lower and higher than 0 °C and moisture content below and above 30 % (The USDA forest service general technical report FPL9, 1977)
Tablica 2. Srednja odstupanja rezultata ostalih autora od Kanterovih rezultata za temperature manje i veće od 0 °C te za sadržaj vode manji i veći od 30 % (USDA forest service general technical report FPL9, 1977.)

Author / *Autor*	**Mean deviation** / *Srednje odstupanje, %*			
	$t < 0$ °C		$t > 0$ °C	
	$u \le 30$ %	$u > 30$ %	$u \le 30$ %	$u > 30$ %
Chudinov (1968)	+ 6	+ 6	NA	NA
Chudinov, Stepanov (1971)	+ 14	+ 21	NA	NA
Dunlop (1912)	NA	NA	-19	NA
Emchenko (1958)	NA	NA	-15	NA
Hearmon, Burcham (1955)	NA	NA	-13	NA
Kanter (1957)	-	-	-	-
Koch (1969)	NA	NA	-18	NA
Komissarov (1969)	+ 1	+ 1	+ 1	+ 1
Kuhlmann (1962)	-20	NA	-17	NA
McMillin (1969)	NA	NA	-18	NA
Volbehr (1896)	NA	NA	-28	NA

of earlywood and latewood, as well as of hardwoods and softwoods. The results also suggest the possibility of variations between different types of wood.

Theoretical research into the specific heat capacity of wood was also directed at establishing a model of heat diffusion in the wood. A model that provides a satisfactory description of the change in the specific heat capacity with the change in the temperature and moisture content is obtained by solving the Fourier–Kirchhoff equation (Deliiski, 2012).

2 DISCUSSION
2. RASPRAVA

Due to the difference in results obtained by many authors, a comparison was drawn between the theoretical research conducted by Deliiski (2012) (DEL) and the research mentioned in the Wood Handbook (1999) (WH) and the Wood Technology Handbook (1967) (DIP). The temperature interval selected for the comparison was between 10 °C and 100 °C, and it results from a cross section of temperature intervals found in the literature. By means of equations from the studied literature, the specific heat capacity of wood was determined for a moisture content below the fiber saturation point (Figure 3) and for a moisture content above the fiber saturation point (Figure 4). It was assumed that the fiber saturation point corresponds to 25 % moisture content. Figures 3 and 4 clearly show that the research confirmed a linear dependence of the specific heat capacity of wood on temperature in the given temperature interval. The linearity is only disturbed in the Deliiski equation, but the term disturbing the linearity is very small; it equals $\frac{0{,}02}{\{u\}_{\%}+100}$, the order of magnitude of which is 10^{-4}. It should be noted that the results of the research mentioned in DIP cite the same equation of dependence of specific heat capacity on temperature, independent of the fiber saturation point. The equation of dependence of specific heat capacity on temperature in the research mentioned in the Wood Handbook is true in a temperature range of 7 °C to 147 °C, but the equation contains a linear dependence of c_{p0} on temperature, which, according to Dunlop's research, is linear in a temperature range of 0 °C to 100 °C.

By means of equation (5), the expression for the specific heat capacity was determined in a temperature range of 10 °C to 100 °C. The obtained average values are represented by equations (7), (8) and (9) for a moisture content below the fiber saturation point, and by equations (10), (11) and (12) for a moisture content above the fiber saturation point. Using the above equations, the average values of specific heat capacity were obtained for a moisture content between 0 % and 20 % (Figure 5) and for a moisture content between 80 % and 100 % (Figure 6). It is assumed that the fiber saturation point corresponds to 25 % wood moisture content.

$$\left\{\bar{c}_{\mathrm{pw(WH)}}\right\}_{\mathrm{kJ/kg\cdot °C}} = \frac{0.1031 + 0.0419\cdot\{u\}_{\%}}{1 + 0.01\cdot\{u\}_{\%}} + \frac{1.268}{1 + 0.01\cdot\{u\}_{\%}} - 6.191\cdot 10^{-2}\cdot\{u\}_{\%} - 1.33\cdot 10^{-4}\cdot\{u^2\}_{\%} + 0.0774\cdot\{u\}_{\%} \qquad (7)$$

$$\left\{\bar{c}_{\mathrm{pw(DEL)}}\right\}_{\mathrm{J/kg\cdot °C}} = \frac{2097\cdot\{u\}_{\%} + 82600}{\{u\}_{\%} + 100} + \frac{9.92\cdot\{u\}_{\%} + 255}{\{u\}_{\%} + 100}\cdot\frac{\{T_1\}_{\mathrm{K}} + \{T_0\}_{\mathrm{K}}}{2} + \frac{0.02}{\{u\}_{\%} + 100}\cdot\frac{\{T_1^3\}_{\mathrm{K}} - \{T_0^3\}_{\mathrm{K}}}{3} \qquad (8)$$

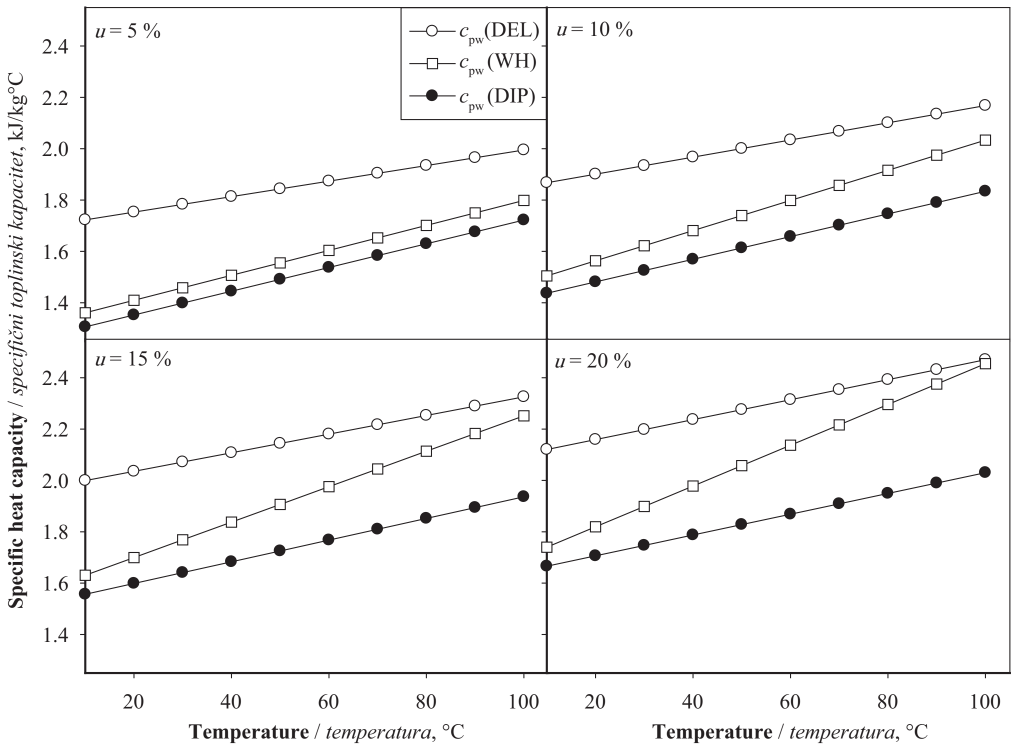

Figure 3 Dependence of specific heat capacity on temperature for a moisture content between 5 % and 20 %, according to DEL, WH and DIP
Slika 3. Ovisnost specifičnoga toplinskog kapaciteta o temperaturi prema DEL-u, WH-u i DIP-u za sadržaj vode od 5 do 20 %

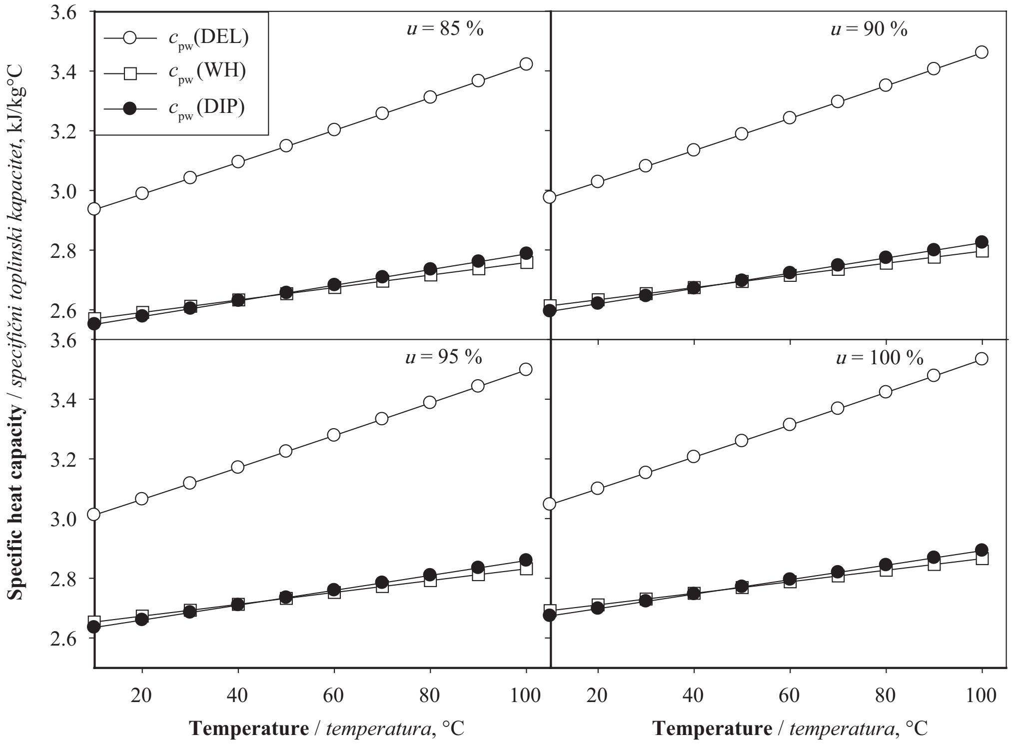

Figure 4 Dependence of specific heat capacity on temperature for a moisture content between 80 % and 100 %, according to DEL, WH and DIP
Slika 4. Ovisnost specifičnoga toplinskog kapaciteta o temperaturi prema DEL-u, WH-u i DIP-u za sadržaj vode od 80 do 100 %

$$\{\bar{c}_{pw(DIP)}\}_{kJ/kg\cdot°C} = \left(1 - \frac{100}{100 + \{u\}_{\%}} + \frac{26.6}{100 + \{u\}_{\%}} + \frac{0.116}{100 + \{u\}_{\%}} \cdot \frac{\{t_1\}_{°C} + \{t_0\}_{°C}}{2}\right) \cdot 4.186 \qquad (9)$$

$$\{\bar{c}_{pw(WH)}\}_{kJ/kg\cdot°C} = \frac{0.1031 + 0.0419 \cdot \{u\}_{\%}}{1 + 0.01 \cdot \{u\}_{\%}} + \frac{1.268}{1 + 0.01 \cdot \{u\}_{\%}} \qquad (10)$$

$$\{\bar{c}_{pw(DEL)}\}_{J/kg\cdot°C} = \frac{2862 \cdot \{u\}_{\%} + 55500}{\{u\}_{\%} + 100} + \frac{5.49 \cdot \{u\}_{\%} + 295}{\{u\}_{\%} + 100} \cdot \frac{\{T_1\}_K + \{T_0\}_K}{2} + \frac{0.36}{\{u\}_{\%} + 100} \cdot \frac{\{T_1^3\}_K - \{T_0^3\}_K}{3} \qquad (11)$$

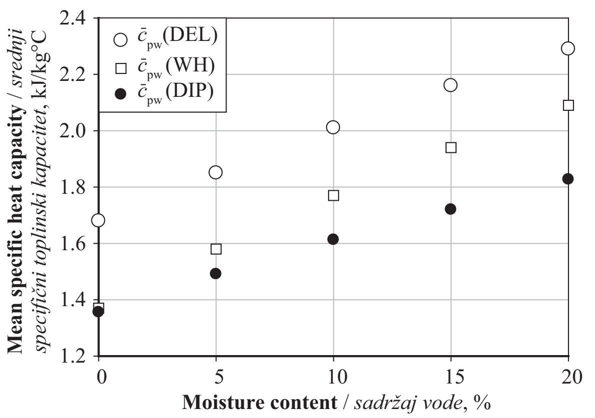

Figure 5 Dependence of the average specific heat capacity on moisture content for temperature ranging between 10 °C and 100 °C ($u < u_{fsp}$)
Slika 5. Ovisnost srednjeg specifičnoga toplinskog kapaciteta o sadržaju vlage za temperaturni interval od 10 do 100 °C; sadržaj vode je manji od točke zasićenja vlakanaca

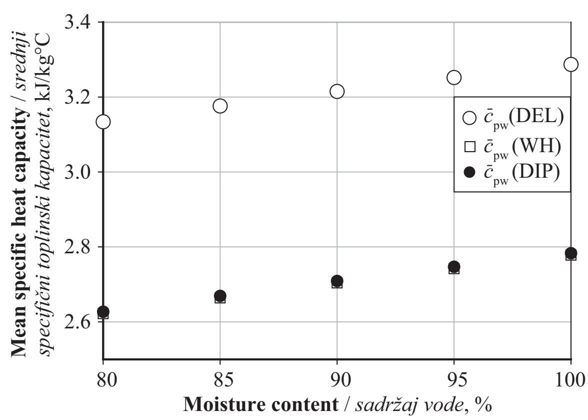

Figure 6 Dependence of the average specific heat capacity on wood moisture content for temperature ranging between 10 °C and 100 °C ($u > u_{fsp}$)
Slika 6. Ovisnost srednjega specifičnog toplinskog kapaciteta o sadržaju vode za temperaturni interval od 10 do 100 °C; sadržaj vode je veći od točke zasićenja vlakanaca

$$\left\{\overline{c}_{\mathrm{pw(DIP)}}\right\}_{\mathrm{kJ/kg\cdot °C}} = (1 - \frac{100}{100+\{u\}_{\%}} + \frac{26.6}{100+\{u\}_{\%}} + \frac{0.116}{100+\{u\}_{\%}} \cdot \frac{\{t_1\}_{°C} + \{t_0\}_{°C}}{2}) \cdot 4.186 \quad (12)$$

where:
$\overline{c}_{pw(WH)}$- mean specific heat capacity of wood (Wood Handbook),
$\overline{c}_{pw(DEL)}$ - mean specific heat capacity of wood (Deliiski),
$\overline{c}_{pw(DIP)}$ - mean specific heat capacity of wood (DIP),
u - moisture content,
T - temperature,
t - temperature.

3 CONCLUSION
3. ZAKLJUČAK

The present analysis leads to the conclusion that the differences in the results obtained by different authors are significant. Most of the authors conclude that specific heat capacity depends on the temperature and wood moisture content, while variations between different wood species are very small. Regarding the discrepancy in the results obtained from different sources, future research should determine the specific heat capacity of several different species of wood, in the same temperature range and the same range of moisture content. The measurements should be made by standardized methods for measuring specific heat capacity, in order to obtain reliable results with the lowest possible measurement uncertainty. Thus obtained data for specific heat capacity can be used for testing the validity of the models suggested so far, as well as their validity and efficiency for industrial purposes.

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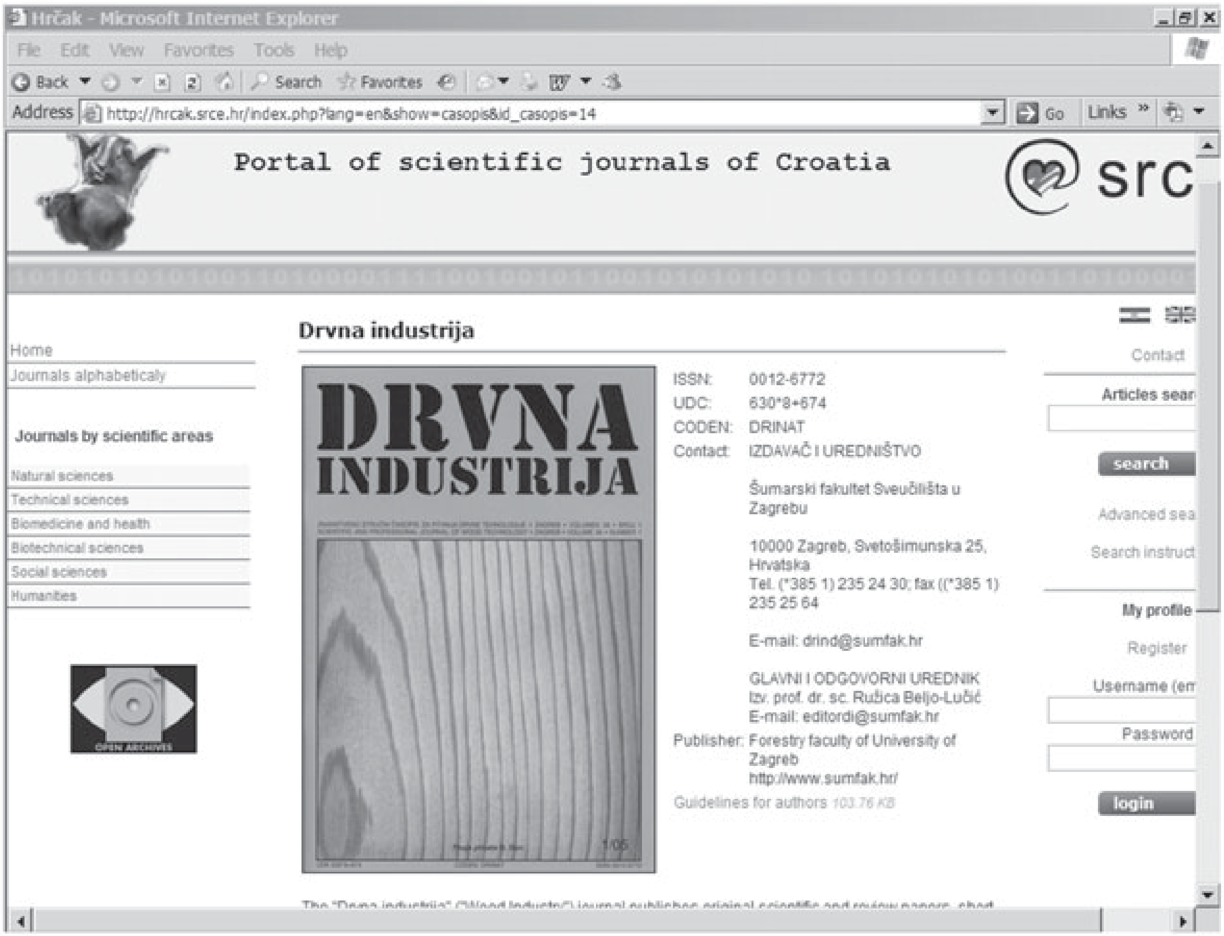

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Finite Element Analysis of Wood Materials

Analiza drvnog materijala metodom konačnih elemenata

Review paper • Pregledni rad
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ABSTRACT • *Continuous quality and reliability improvement of computers as well as their widespread application in design of furniture industry encourage the elaboration of optimization algorithms of furniture constructions, in which rigidity characteristics of the applied joints would be taken under consideration. In the last four decades, the finite element method, FEM, has become the dominant technique used for analyzing physical phenomena in the field of structural, solid and fluid mechanics as well as for the solution of field problems. This paper gives a bibliographical review of the FEM applied in the analysis of furniture products constructed with wood. The following topics are included: Wood as a furniture construction material and its mechanical properties. It is, therefore, reasonable to replace statistical methods of furniture optimization, which have been applied so far, by gradient methods which allow obtaining much more precise results.*

Key words: *wood, Finite Element Method, numerical analysis*

SAŽETAK • *Kontinuirano poboljšanje kvalitete i pouzdanosti računala, kao i njihova široka primjena u industrijskom dizajnu namještaja, potaknuli su razradu algoritama za optimizaciju konstrukcija namještaja, u kojima se posebno razmatra krutost primijenjenih spojeva. U posljednja četiri desetljeća metoda konačnih elemenata (FEM) postala je najčešća tehnika za analizu fizikalnih pojava na području strukturne mehanike, mehanike čvrstih tvari i fluida, kao i za rješavanje problema na tim područjima. U tekstu se daje bibliografski pregled primjene metode konačnih elemenata u analizi namještaja proizvedenoga od drva. Pritom je obuhvaćena tema drva kao konstruktivnog materijala za namještaj i njegovih mehaničkih svojstava. Dokazano je kako je razumno umjesto dosad primjenjivanih statističkih metoda optimizacije namještaja primijeniti gradijent-metode koje omogućuju dobivanje mnogo preciznijih rezultata.*

Ključne riječi: *drvo, metoda konačnih elemenata, numeričke analize*

1 INTRODUCTION
1. UVOD

The finite element method (FEM) is the dominant discretization technique in structural mechanics. The basic concept in the physical interpretation of the FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called "finite elements" or elements for short. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions, at a set of nodal points. The response of the mathematical model is then considered to be approximated by that of the discrete model obtained by connecting or assembling the collection of all elements. The disconnection-

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assembly concept occurs naturally when examining many artificial and natural systems. For example, it is easy to visualize an engine, bridge, building, airplane, or skeleton as fabricated from simpler components. Furthermore, FEM has become a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building, and bridge structures to field analysis of heat flux, fluid flow, magnetic flux, seepage, and other flow problems.

The main postulate of FEA is that complex domains can be discretized and represented by an assembly of simpler finite sized elements. This enables description of the global problem via a system of differential equations that account for inter element compatibility and boundary conditions requirements. The concepts, fundamentals and application of FEA are described in detail in many texts (Tanvir and Utku, 1987; Bathe, 1996; Cook, 1981; Zienkiewicz and Taylor, 1988; Zienkiewicz and Taylor, 1989). The tedium of handling the data and the possibility of errors creeping in as the number of elements increase are discouraging factors for the finite element analyst (Chandrupatla and Belegundu, 1991).

The aim of the bibliographic review is to research with FE method applied to the analyses of wood, and the following topics are included:

– wood as a construction material (material and mechanical properties, wood joining and fastening, fracture mechanics problems, drying process, thermal properties);
– wood products and structures (lumber, panels, chairs, skeleton furniture, stair stringers, lattice structure, bamboo scaffoldings, carcass furniture and case furniture).

2 NUMERICAL METHODS
2. NUMERIČKE METODE

There are many practical engineering problems for which exact solutions cannot be obtained. This inability to obtain an exact solution may be attributed to either the complex nature of governing differential equations or the difficulties that arise from dealing with the boundary and initial conditions. To deal with such problems, we resort to numerical approximations. In contrast to analytical solutions, which show the exact behavior of a system at any point within the system, numerical solutions approximate exact solutions only at discrete points, called *nodes*. There are two common classes of numerical methods: (1) finite difference methods and (2) finite element methods. With finite difference methods, the differential equation is written for each node, and the derivatives are replaced by difference equations. This approach results in a set of simultaneous linear equations. Although finite difference methods are easy to understand and apply to simple problems, they become difficult to apply to problems with complex geometries or complex boundary conditions. This situation is also true for problems with non-isotropic material properties. In contrast, the finite element method uses integral formulations rather than difference equations to create a system of algebraic equations. Moreover, a continuous function is assumed to represent the approximate solution for each element. The complete solution is then generated by connecting or assembling the individual solutions, allowing for continuity at the inter-elemental boundaries.

3 THE FINITE ELEMENT METHOD
3. METODA KONAČNIH ELEMENATA

The basic concept in the physical FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called *finite elements* or *elements* for short. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions, at a set of nodal points. The response of the mathematical model is then considered to be approximated by that of the discrete model obtained by connecting or assembling the collection of all elements. The disconnection-assembly concept occurs naturally when examining many artificial and natural systems. For example, it is easy to visualize an engine, bridge, building, airplane, or skeleton as fabricated from simpler components.

3.1 A brief history of the finite element method
3.1. Kratka povijest metode konačnih elemenata

The origin of the modern FEM may be traced back to the early 1900s when some investigators approximated and modeled elastic continua using discrete equivalent elastic bars. In 1941, Hrenikoff presented a solution of elasticity problems using the "frame work method". However, Courant (1943) has been credited with being the first person to develop the FEM. Courant used piecewise polynomial interpolation over triangular subregions to investigate torsion problems. The next significant step in the utilization of FEM was taken by Boeing in the 1950s when Boeing, followed by others, used triangular stress elements to model airplane wings. A book by Argyris in 1955 on energy theorems and matrix methods laid a foundation for further development in finite element studies. Turner *et al.* (1956) derived stiffness matrices for truss, beam, and other elements and presented their finding in 1956. The term *finite element* was first coined and used by Clough in 1960. Clough made the term finite element popular. During the 1960s, investigators began to apply the finite element method to other areas of engineering, such as heat transfer and seepage flow problems. In the late 1960s and early 1970s, FEM was applied to nonlinear problems and large deformations. Zienkiewicz and Cheung wrote the first book entirely devoted to the FEM in 1967. Mathematical foundations were laid in the 1970s. New element development, convergence studies, and other related areas fall in this category. In 1971, ANSYS™ was released for the first time. Then, Oden's book on linear continua appeared in 1972.

Bleich (1952), Goodier (1942), Vlasov (1961) and Timoshenko and Gere (1961) are among the researchers in the study of buckling of one-dimensional members. The methods of column deflection curves (Ellis *et al.*, 1964), finite difference (Vinnakota and Aoshima, 1974) and finite integral (Brown and Trahair, 1968) were employed for solving the differential equilibrium equation for columns and beams. The Rayleigh–Ritz (Roberts, 1981) method is based on a correctly assumed deflected shape and therefore it is again limited to simple problems, where the deflected shape can be defined accurately. Based on the energy method, a discretization concept and the invention of powerful computers, the finite element received more attention in the past few decades as a more general and powerful tool for obtaining the equilibrium condition at both the linear and non-linear ranges. The excellent book by Chen and Atsuta (1977) covers various aspects of numerical methods and analysis and design of beam-columns under different loading and boundary conditions. Recently, Lindner (2000) presented a summary of the recent work on member design used mainly in German standard and Euro-code.

ANSYS™ is an engineering simulation software provider founded by software engineer John Swanson. It develops general-purpose finite element analysis and computational fluid dynamics software. While **ANSYS™** has developed a range of computer-aided engineering (CAE) products, it is perhaps best known for its ANSYS™ Mechanical and ANSYS™ Multiphysics products.

ANSYS™ finite element analysis enables engineers to:

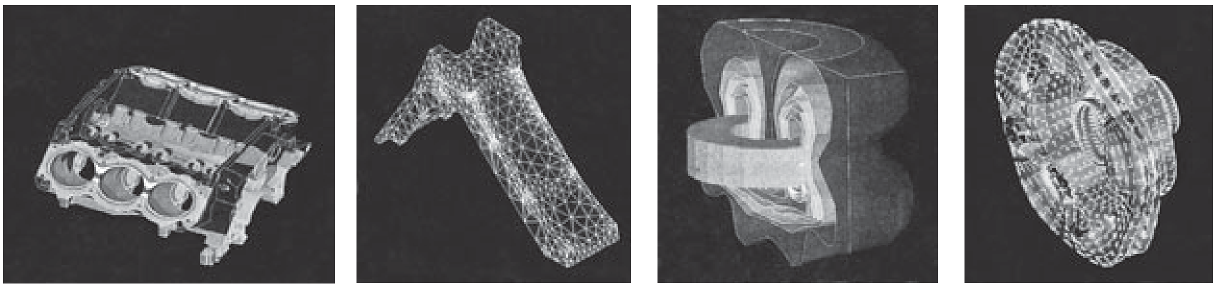
– build computer models or transfer CAD models of structures, products, components, or systems;
– apply operating loads or other design performance conditions;
– study physical responses, such as stress levels, temperature distributions, or the impact of electromagnetic fields;
– optimize a design early in the development process to reduce production costs;
– do prototype testing in environments where it otherwise would be undesirable or impossible (for example, biomedical applications) (Rutgers, 2009).

The software implements equations that govern the behavior of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to be analyzed by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations (Theja and Krishna, 2013).

ANSYS is a comprehensive general-purpose finite element computer program that contains over 100,000 lines of code. ANSYS is capable of performing static, dynamic, heat transfer, fluid flow, and electromagnetism analyses. ANSYS has been a leading FEA program for well over 20 years. The current version of ANSYS has a completely new look, with multiple windows incorporating Graphical User Interface (GUI), pull down menus, dialog boxes, and a tool bar. Today, you will find ANSYS in use in many engineering fields, including aerospace, automotive, electronics, and nuclear. In order to use ANSYS or any other "canned" FEA computer program intelligently, it is imperative that one first fully understands the underlying basic concepts and limitations of the finite element methods (Moaveni, 2003).

ANSYS™ Mechanical and ANSYS™ Multiphysics software are non-exportable analysis tools incorporating pre-processing (geometry creation, meshing), solver and post-processing modules in a graphical user interface. These are general-purpose finite element modeling packages for numerically solving mechanical problems, including static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems.

ANSYS™ Mechanical technology incorporates both structural and material non-linearities. ANSYS™ Multiphysics software includes solvers for thermal, structural, CFD, electromagnetics, and acoustics and can sometimes couple these separate physics together in order to address multidisciplinary applications. ANSYS™ software can also be used in civil engineering, electrical engineering, physics and chemistry. Some examples of the capabilities of ANSYS™ are shown in Fig. 1.



A v6 engine used in front-wheel-drive automobiles
Motor v6 za automobile s prednjim pogonom

Large deflection capabilities of ANSYS™
Mogućnosti velikog otklona programa ANSYS™

Electromagnetics capabilities of ANSYS™
Elektromagnetne mogućnosti programa ANSYS™

Structural Analysis Engineering Corporation
Strukturna analiza

Figure 1 Examples of ANSYS™ capabilities (Moaveni, 2003)
Slika1. Primjeri mogućnosti programa ANSYS™ (Moaveni, 2003)

In the last four decades, the FEM has become the prevalent technique used for analyzing physical phenomena in the field of structural, solid and fluid mechanics as well as for the solution of field problems.

3.2 Basic theory
3.2. Osnovna teorija

FE analysis obtains the temperatures, stresses, flows, and other desired unknown parameters in the FE model by minimizing energy functional. Energy functional consists of all the energies associated with the particular finite element model. Based on the law of conservation of energy, the FE energy functional must equal zero.

The FEM obtains the correct solution for any FE model by minimizing the energy functional. The minimum of the functional is found by setting the derivative of the functional with respect to the unknown grid point potential for zero. Thus, the basic equation for FE analysis is:

$$\frac{\partial F}{\partial p} = 0$$

where F is the energy functional and p is the unknown grid point potential (in mechanics, the potential is displacement.) to be calculated. This is based on the principle of virtual work, which states that if a particle is under equilibrium, under a set of a system of forces, then for any displacement, the virtual work is zero. Each FE will have its own unique energy functional.

As shown in Table 1, in the FE displacement method, the displacement is assumed to have unknown values only at the nodal points, so that the variation within the element is described in terms of the nodal values by means of interpolation functions. Thus, within any one element, $d = N{\cdot}u$, where N is the matrix of interpolation functions termed shape functions and u is the vector of unknown nodal displacements. The strains within the element can be expressed in terms of the element nodal displacements as $e = B{\cdot}u$, where B is the strain displacement matrix. Finally, the stresses may be related to the strains by use of an elasticity matrix (e.g., Young's modulus) as $s = E{\cdot}e$.

3.3 Basic steps in the finite element method
3.3. Osnovni koraci metode konačnih elemenata

The basic steps involved in any finite element analysis consist of the following:

Preprocessing Phase

1. Create and discretize the solution domain into finite elements; that is, subdivide the problem.
2. Assume a shape function to represent the physical behavior of an element; that is, a continuous function is assumed to represent the approximate solution of an element.
3. Develop equations for an element.
4. Assemble the elements to present the entire problem. Construct the global stiffness matrix.
5. Apply boundary conditions, initial conditions, loading and material information.

Solution Phase

6. Solve a set of linear or nonlinear algebraic equations simultaneously to obtain nodal results, such as displacement values at different nodes; other derived quantities, such as gradients and stresses, may be evaluated at this phase.

Post processing Phase

7. Obtain other important information. Present the results, the post processing stage deals with the presentation of results. Typically, the deformed configuration, mode shapes, temperature, and stress distribution are computed and displayed at this stage.

The role of FEM in numerical simulation is schematized in Fig. 2. Although this diagram oversimplifies the way FEM is actually used, it serves to illustrate terminology. The three key simulation steps shown are: *idealization*, *discretization* and *solution*. Each step is a source of errors. For example, the discretization error is the discrepancy that appears when the discrete solution is substituted in the mathematical model (FEM Modelling: Introduction, 2009).

Idealization:

Idealization passes from the physical system to a mathematical model. This is the most important step in engineering practice, because it cannot be "canned." It must be done by a human.

Discretization:

Mathematical modeling is a simplifying step. However models of physical systems are not necessarily simple to solve. They often involve coupled partial differential equations in space and time subject to boundary and/or interface conditions. Such models have an *infinite* number of degrees of freedom. This process divides the medium of interest into a number of small subregions and nodes.

Table 1 Physical significance of vectors *u* and *f* variations according to model application
Tablica 1. Fizikalno značenje promjena vektora *u* i *f* s obzirom na model primjene

Application problem *Problem*	**State (DOF) vector *u* represents** *Veličine koje predočuje vektor u*	**Forcing vector *f* represent** *Veličine koje predočuje vektor f*
Structures and solid mechanics / *strukturna mehanika i mehanika čvrstih tvari*	Displacement/ *pomak*	Mechanical force / *mehanička sila*
Heat conduction / *vodljivost topline*	Temperature/ *temperatura*	Heat flux / *tok topline*
Acoustic fluid / *akustika fluida*	Displacement potential / *potencijal pomaka*	Particle velocity / *brzina čestica*
Potential flows / *potencijalni tokovi*	Pressure / *tlak*	Particle velocity / *brzina čestica*
General flows / *opći tokovi*	Velocity / *brzina*	Fluxes / *protoci*
Electrostatics / *elektrostatika*	Electric potential / *električni potencijal*	Charge density / *gustoća punjenja*
Magnetostatics / *magnetostatika*	Magnetic potential *magnetni potencijal*	Magnetic intensity *magnetni intenzitet*

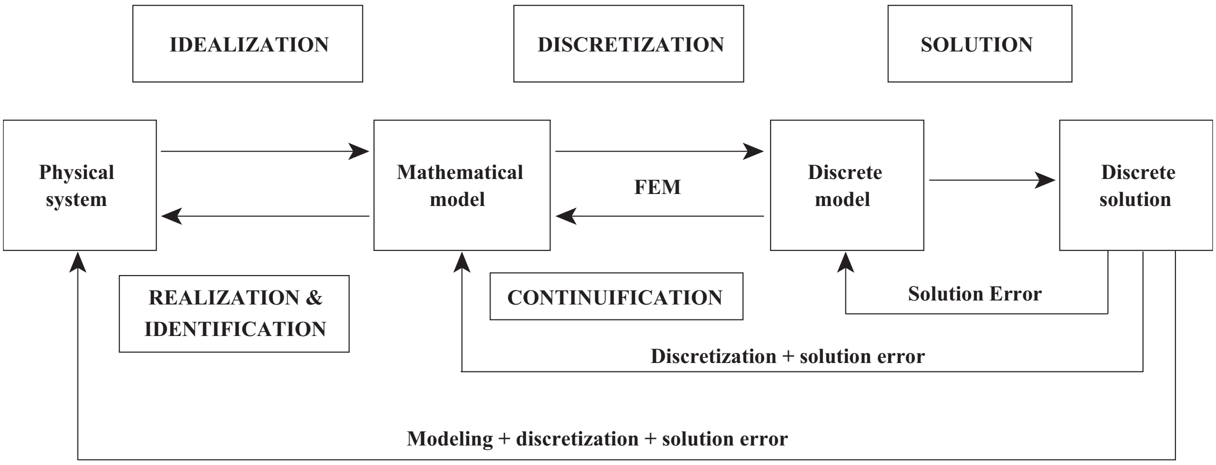


Figure 2 A simplified view of the physical simulation process, primarily useful to illustrate modeling terminology
Slika 2. Pojednostavnjeni prikaz simulacije procesa, osobito primjenjiv za ilustraciju terminologije modeliranja

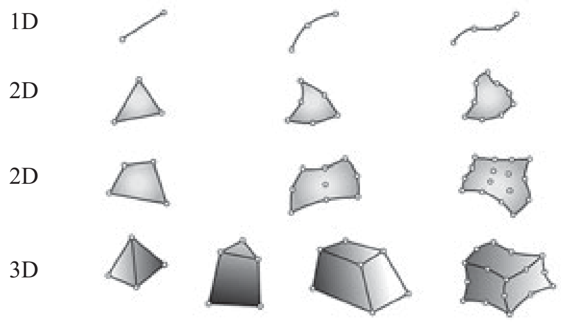


Figure 3 Higher order element *nodes*
Slika 3. Elementarni čvorovi višeg reda

Solution:

Solve the system of equations involving unknown quantities at the nodes (e.q. displacements).

A typical FEA on a software system requires the following information:

1. Nodal point spatial locations (geometry)
2. Elements connecting the nodal points
3. Mass properties
4. Boundary conditions or restraints
5. Loading or forcing function details
6. Analysis options

The geometry of the element is defined by the placement of the geometric nodal points. Most elements used in practice have fairly simple geometries. In one-dimension, elements are usually straight lines or curved segments. In two dimensions, they are of triangular or quadrilateral shape. In three dimensions, the most common shapes are tetrahedra, pentahedra (also called wedges or prisms), and hexahedra (also called cuboids or "bricks"). Fig. 3 *Nodes* are usually located at the corners or end points of elements, as illustrated in Fig. 2. In the so-called refined or higher-order elements, nodes are also placed on sides or faces, as well as possibly the interior of the element.

3.4 The use of FEA in furniture design
3.4. Primjena metode konačnih elemenata u dizajnu namještaja

A natural objective of the designer is to minimize manufacturing costs of given articles which, in turn, are connected with minimization of material consumption. This stresses the need to elaborate computer programs capable of applying numerical optimization of furniture constructions. In the case of carcass furniture, significant savings can be achieved by minimizing dimensions of the cross section of wood elements. Typical computer applications analyzing force distribution and internal stresses in construction members allow to verify the strength of a system, which was designed and dimensioned earlier or to compare several variants of the same design. Therefore, their application, in the case when a simultaneous decision concerning several dimensions of the same construction must be taken, may be difficult or even impossible. The selection of the best construction parameters can be achieved by applying numerical optimization algorithms working on mathematical models of the projected system (Dietrich, 1986).

Both scientific experience and engineering practice indicate that decision making processes in the course of solving complex designing problems require an analysis of a great number of different construction variants. These types of decision-making processes take much time and do not always result in the selection of an optimal solution. That is why deterministic or numerical optimization methods are applied in a wide range of technical areas, which assist in the selection of the best solution. One of the basic difficulties encountered during the optimization process of furniture constructions, which, in their majority, constitute statically indeterminable systems, is a variation in the distribution of internal forces affected by changes in cross-sectional dimensions of component elements. This indicates a need to develop optimization algorithms in which values of internal forces will be calculated after each change of geometrical conditions (Smardzewski and Gawroński, 2001).

Furniture design is almost always based on experience from traditions in handicraft manufacturing. No carpentry use static analyses for finding the internal forces inside the wooden members of e.g. a chair. However, some academic research groups have shown interest in this topic and the first to mention must be the work of Eckelman (1967).

In the paper he showed that a chair could be analyzed as a structure for taking up loads. By use of strain gauges he also presented some values for the maximum moments at different parts of the chair. He stated that the rigidity-strength procedure of furniture design comprises the determination of values of outside loads affecting the construction, the establishment of the distribution of inner forces and then the calculation of dimensions of elements and constructional joints (Eckelman, 1967; Eckelman and Suddarth, 1969).

The exact analysis of furniture frames has been a computationally complex process. At present, engineering design of furniture can be accomplished by utilizing solid modeling and structural analysis software. From a practicing furniture engineer's point of view, FEM provides the most convenient tool for analyzing furniture systems. All members of the product can be modeled parametrically and required changes can readily be optimized via advantages that are provided by the solid modeling. Likewise, strength calculations of the designed product could be made by means of the computer aided structural analysis software (Kasal, 2004).

In Poland, the research seems to have been concentrated around the Poznan University. Several papers have been published and some of them dealt with FEM, and various kinds of furniture chairs. Investigations in the field of furniture were undertaken by Smardzewski, who presented algorithms and results of optimization of a chair side frame using the method of 'systematic search and random walk'. The objective of those calculations was to determine cross-sectional dimensions of scantling elements and connection dimensions, while maintaining appropriate strength parameters and minimal volume of the applied material. In the above-mentioned study, values of internal forces, calculated by means of a separate FEM processor, were used as input data for the application, which realized the optimization process (Smardzewski, 1992). Then, Smardzewski and Dzięgielewski (1997), performed construction optimization of cabinet furniture employing the method of random walk. Olsson *et al.* (2004) examined the furniture design and the dialogue between designers and engineers specialized in using FE tools. Researchers examined the influence of the stiffness corner joints, particularly, on case furniture deflection, and proposed a new method for linear structural analysis of the case furniture using FEA (Cai and Wang, 1993).

They asserted that the corner joints were semi-rigid and could be modeled by introducing a small area adjacent to the joints, where the same type of element could be used as that used for modeling the joints itself, but with a reduced modulus of elasticity (E^*). If the same elastic properties were assumed for the elements within this area as for the whole joints, then the joint would be considered rigid. Although this model provides consistent results in terms of resultant deflections, the stress concentrations, which appear in the vicinity of the fixing components are not developed in the model in the same way as they are developed in the physical joints.

The overall structure is preferably analyzed by use of so called 'beam elements', while details such as joints can be studied more in detail by plain 'stress elements'. The joint is in the second case divided into small, but finite, rectangular parts while the rest of the structure is divided in larger pieces (Gustafsson, 1995).

Kasal and Puella (1995) have examined analytical and experimental results for chairs, sofas and book shelves. Further, they have studied the joints between different chair members in detail. A number of other researchers have also dealt with different types of furniture, e.g. cabinets, and two of them are Adanowicz, Dziegielewski (1976); Wang and Juang (1994).

Erdil (1995) included in the study the design and analysis of wood school chairs and desks based on conventional structural design methods, evaluation of the furniture by performance test equipment and procedures selected specifically for that purpose, and finally a comparison to the results obtained by performance testing and those predicted by conventional design procedures. Prototypes were tested utilizing low-cost performance testing equipment and the "cyclic stepped increasing load method". The prototype frames were structurally analyzed by means of FEM. The results showed that performance testing equipment, which was low-cost, simple, and easy to use and maintain, could be used for testing school chairs and desks, and 3-D structural analyses by means of FEM gave reasonable estimates of the overall strength of the furniture constructions. Ekström (1997); Aronsson and Lindgren (2000) studied the design of chairs with the help of FE.

Efe *et al.* (2003) constructed two school chairs with cylindrical mortise and tenon joints, and these were tested utilizing the "cyclic stepped increasing load method", and the specimens were structurally analyzed by means of FEM software. As a result, they determined that three dimensional structural analyses by means of FEM provided reasonable estimates of the overall strength of the frame furniture.

Smardzewski and Gawroński (2001) succeeded in integrating numerical methods of static optimization in FEM environment and developed an optimization algorithm of skeleton furniture, in which values of internal forces were determined after each step of optimization. This allowed taking into consideration the phenomenon of the alteration in the distribution of values of internal forces in a construction statically indeterminable in the result of the change of the cross section of component elements. Furthermore, the authors also reduced joints to rigid constructional nodes assuming that the rigidity of joints corresponded to the rigidity of the adjacent material.

Hrčka (1991) carried out an analysis of strength and rigidity of a wood construction connected by means of *Unimot joints* and employed two different approaches to the theoretical analysis of joint rigidity. The first approach assumed the introduction, into the static scheme, of semi-rigid bar elements to replace semi-rigid joints, while the second approach consisted in assigning constructional nodes appropriate reaction coefficients, which expressed the relationship between the deformation angle and bending moment operating in the node.

Cai *et al.* (1995) analyzed the strength and stiffness of the moltinject corner joints of cabinet furniture by comparison with the strength of two pin dowels corner joints. Furthermore, the deflection of cabinet furniture, whose corners were joined by the method of moltinject, was predicted reasonably in this study using FEM calculations.

Dzięgielewski and Smardzewski (1996) carried out laboratory experiments on wall angle joints in skeleton furniture and, for each type of the examined joints, determined equivalent modulus of joint elasticity. The obtained results provided, on the one hand, estimation of their rigidity and, on the other, served as data for numerical calculations of rigidity of furniture bodies. Elements with equivalent moduli of elasticity were then introduced into the static scheme of the analyzed construction to substitute real joints.

These problems were further investigated in studies, which discussed in detail principles for the calculation of connection dimensions in dowel and tenon joints on the basis of a recognized distribution of internal forces. Smardzewski (1998) carried out a research project for developing a computer program designed for rigidity/strength analysis of furniture side frames. Afterwards, he analyzed a side frame of a chair, and demonstrated that the computer program developed allows accurate, rapid, and multiple rigidity strength analysis of furniture side frames constructed of wood.

In another study, Smardzewski (2002) developed a mathematical model describing phenomena occurring in bent mortise joints prevalent in constructions of skeleton furniture, and also tried to determine factors influencing the strength of glued mortise and tenon joints. Analyses were treated with a computer assisted program prepared and developed at the Ponzan Agricultural University. According to the results obtained; shear strength of the glue utilized and compression strength of wood, of which the joints were constructed, affected the bending strength of glued mortise and tenon joints. Furthermore, it was mentioned that when members of the mortise and tenon joint were well fitted, compressing one another, stresses in the glue bond reduce and increase its strength.

Many later studies commonly employed FEM, which is based on the concept of 'rigidity matrix'. This method was also used by Gustafsson (1995) in the optimization process of the height position of a chair-connecting member. The author compared successive variants of the optimized construction assuming the maximum bending moment affecting the frame as the optimization criterion.

The elaborated model was verified qualitatively in the next study in which the problem of buckling of the compressed constructional elements was analyzed in detail. In a similar study, he prepared a simple birch chair and tested its strength under various loads, to which the chair could be exposed to during service. Furthermore, he determined stresses at various nodes with the FEM by modeling the chair. He has pointed out that the test results and data analyses were reasonably coherent with Gustafsson (1996a). Moreover, Gustafsson (1996b) compared the results of numerical calculations with the results of laboratory measurements of the deformed piece of furniture whose model was prepared on the basis of results of optimization calculations and arrived at the conclusion that, in many cases, the solution obtained with the aid of the applied computer program portrayed the true state of deformations and stresses. The observed numerical discrepancies were attributed to inexactitudes of laboratory tests resulting from technical problems, on the one hand, and, on the other, to differences in wood strength features during compression and tension, which were not taken into consideration in a typical FEM algorithm.

Nicholls and Crisan (2002) analyzed the stress and strain states in doweled and minifix type corner joints of the case furniture by using the FEM. As a result, they stated that the stress concentration areas in the models are developed as in the physical joints, and the stress-strain state in the corner joints can be accurately predicted. All the models were designed using ANSYS™ Parametric Design Language (APDL), which allows FEMs to be constructed in terms of parameters. In this way design changes can be made easily to achieve an optimum design.

The products can be designed using solid models in computer aided design (CAD) programs. These models can also be used for further studies with FE calculations. Stairs, flooring, wood products and furniture are examples of products that can have a complex three-dimensional geometry, which makes it preferable to use three-dimensional models (Pousette, 2007).

Salokangas (2003) used a 3-D CAD model of a complex, irregular lattice structure for a wood tower in Helsinki Zoo. The complex geometry data were imported into a FE model for structural analysis using three-dimensional linear beam elements to check the ultimate and serviceability limit states for applied loads.

One of the references is a study of the structural performance of wood-based stair stringers with full-scale tests by Lam *et. al* (2004). They tested stair systems and also used a commercial FE package to model a stair system for further insight into its structural response. They concluded that the FE program can be used to model stair systems with configurations and material properties other than the tested ones. Comparison of results of FE analysis of an entire wood spiral staircase to full-scale laboratory tests showed that a three dimensional solid model of the stair as a complete part was stiffer than the actual stair (Pousette, 2003).

The deformation behavior of wood around moment-resisting joints was analyzed using digital image correlation method (DIC) and FEM. The joints consisted of four drift-pins. The distribution of the strain perpendicular to grain and the shear strain parallel to the grain were examined around each drift-pin to evaluate the large deformed area and the location of initial failure. Areas of large compression strain perpendicular to the grain and large shear strain were observed in the predicted loading area of each drift-pin. Large tensile strain perpendicular to the grain was observed at the area close to the loading (contacting) area of the drift-pins, and the tension area was partly overlapped with the area of large shear strain. The overlapped area coincided with the location of initial cracks propagated parallel to the grain. The numerical results by FE analysis were compared with the experimental results obtained with DIC and they showed good agreement with each other (Seiichiro and Minoru, 2002).

A modified structural design for wooden school desks and chairs was proposed, in order to improve their performance in terms of functionality, convenience and safety. The modification was proposed based on a structural static analysis of the furniture. Analytical models of a desk and chair in a two-dimensional system of the FEM were first drawn up to simulate their mechanical behaviors, under the loading conditions specified by the Japanese Industrial Standard, JIS S1021. In this FEM simulation, wood is treated as an orthotropic material. Since the Hoffman Failure Criterion could be essentially modified to allow unequal maximum allowable stresses in tension and compression, such as in timber, it was used to examine the safety of the newly designed wooden desk and chair. Analysis of the distribution of Hoffman Failure Criterion indices in the models of a desk and chair revealed the stress concentration sections and the corresponding allowable stress levels. The structural performance of the modified desk and chair designs were analyzed repeatedly until their load bearing capacity fell within the acceptable limits. Improvement in the existing designs of wooden desks and chairs will make it possible to convert low grade logs, such as thinning materials, into environmentally and ecologically friendly school facilities (Yang *et al.* 2002).

The method of finite elements was applied by Smardzewski (1990) in his computer application of Panda-1 utilized to analyze the construction of carcass furniture with symmetrical side frames.

Blanchet *et al.* (2006) demonstrated the suitability of the FEM in the design process of new engineered flooring and stated that their work confirmed the potential of the FE method for product design of such products.

The aim of another study was to use FEM as a tool to analyze microwave scattering in wood and to verify the model by measurements with a microwave scanner. A medical computed tomography scanner was used to measure distribution of density and moisture content in a piece of Scots pine (*Pinus sylvestris* L.). Dielectric properties were calculated from measured values for cross sections from the piece and used in the model. Images describing the distribution of the electric field and phase shift were obtained from the FEM simulation. The model was verified by measurements with a scanner based on a microwave sensor. The results show that simulated values correspond well to measured values. Furthermore, discontinuities in the material caused scattering in both the measured and simulated values. The greater the discontinuity in the material, the greater was the need for computational power in the simulation (Lars *et al*., 2006).

The equations of two-dimension heat transfer processes in wood were deduced by using Galerkin's Method of Weighted Residual Method of FEM in Cai and Chang's paper (1995). The heat transfer processes were calculated by using computer program according to the heating case.

3.5 Examples of FEM models used in wood products
3.5. Primjeri primjene FEM modela za drvne proizvode

FE calculations were made with 3D solid models in IDEAS Anonymous (1998). The element type was 8-node brick elements (linear hexahedral elements). In the models, the treads and the spacers of the center pole were connected with contact elements (Fig. 4). Linear elastic calculations were made, and the contact elements were linear (Pousette, 2007).

In another study, the material is represented as an array of nodes connected by a network of discrete beam or spring elements. Fig. 5 shows a possible dis-

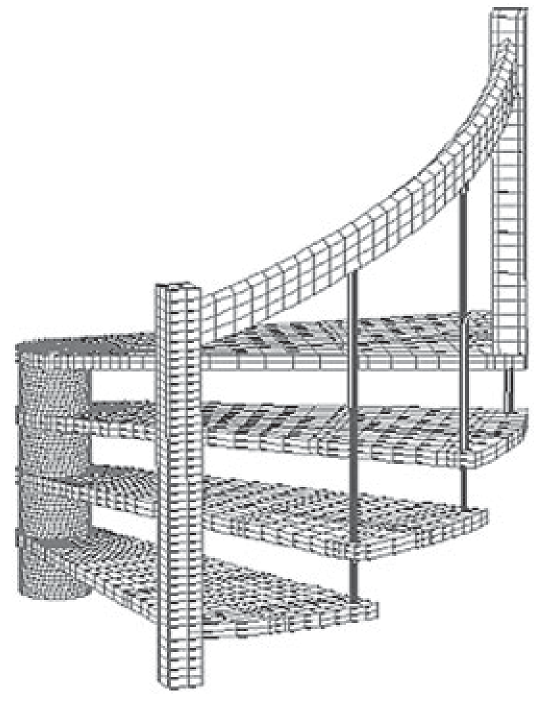


Figure 4 Contact elements with linear elastic calculations
Slika 4. Kontaktni elementi s linearnim elastičnim izračunima

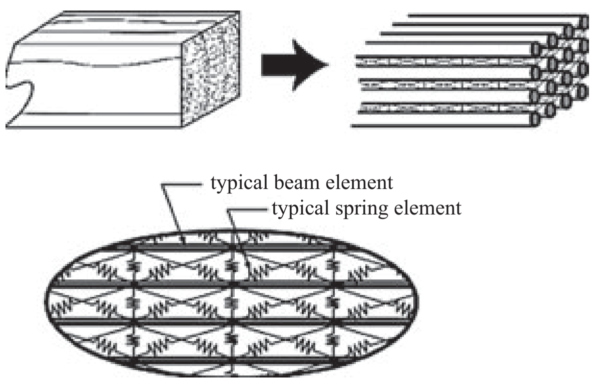


Figure 5 Discrete beam and spring elements
Slika 5. Zasebni elementi grede i opruge

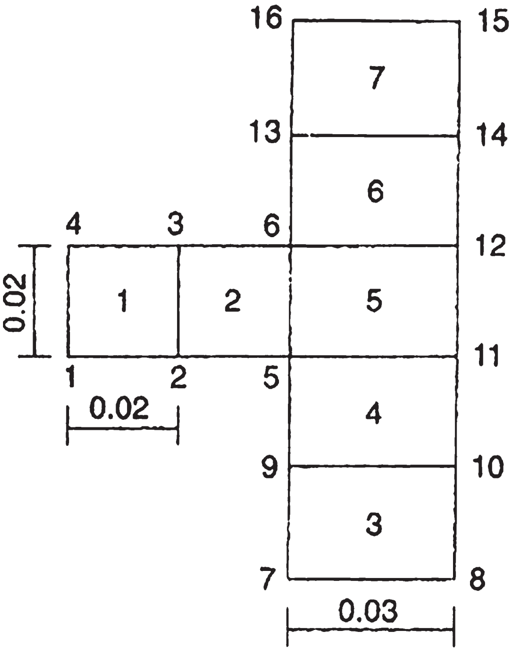


Figure 6 Part of finite element mesh for the seat and back rail joint
Slika 6. Dio mreže konačnih elemenata za spoj sjedala i naslona

cretization appropriate for wood. The longitudinal wood cells are represented by beam elements (large horizontal elements in the figure) while a network of diagonal spring elements simulates their connectivity. The chosen size of a lattice cell in the specific example corresponds to a bundle of cells so that the modeling is at the scale of wood growth rings. In order to account for pre-existing heterogeneities, disorder of wood ultra structure is introduced via statistical variation of element stiffness and strength characteristics. Stiffness and strength characteristics can be assumed to fit a Gaussian distribution with specified mean and standard deviation (Vasic *et al.,* 2005).

A theoretical study using advanced FE analysis of one element per member was reported by Chan to assess the load carrying capacities of bamboo scaffoldings (Chan *et al.,* 1998).

In his study, Gustafsson (1997) showed how to analyze and design a chair with FEM, and gave stress diagrams and test results of the real size ash wood chair**.** The connection between the seat and back rails have also been studied by use of FEM method, the one with plain stress elements. The structure was then divided into thirteen elements with 26 nodes, each located in the corners of the elements; Fig. 6 shows a part of the structure. The result of the FEM analysis showed that the maximum compression stress in the horizontal direction, i.e. -38.0 MPa, occurred just above node 2. Maximum tension with almost the same absolute value was found just under node 3 and around node 6. Fig. 7 shows that A equals -30.0, B equals -20.0 and G +30.0 MPa, respectively.

Semi-rigid joints used in the tests were modeled using ANSYS™. The stiffness obtained for the 100 mm wide corner joint, with one fixing element was used to determine the torsional stiffness in all models. A good correlation was obtained between experimental deflections and analytical results. Fig. 8 shows the distribution of Von Mises stresses for the two-dowel corner joint of 100 mm width and 18 mm thick, which was clamped at one end and subjected to an external load (F) of 40 N at the free end. The torsional stiffness used for the fixing components was k_9 = 301,051 N mm/rad (Nıcholls and Crisan, 2002).

In principle, this is an element that has two coincident nodes (i.e. they have the same location in space), however, each of them is connected separately to the links of the joint. These two nodes are connected to each other by an imaginary pin.

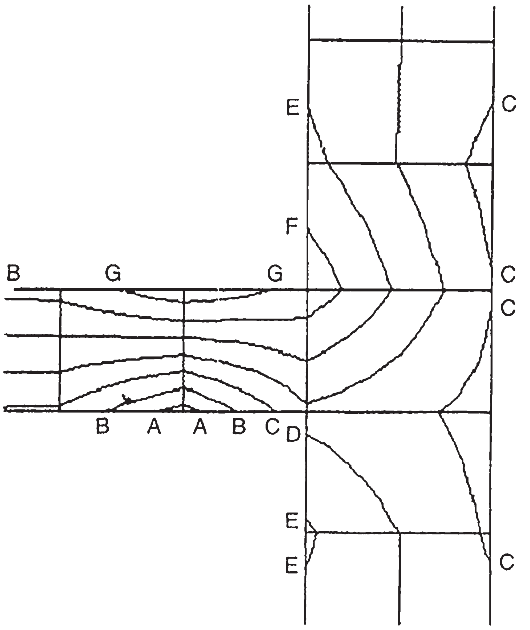


Figure 7 Stress in horizontal direction according to FEM calculations
Slika 7. Naprezanje u vodoravnom smjeru prema izračunima FE metodom

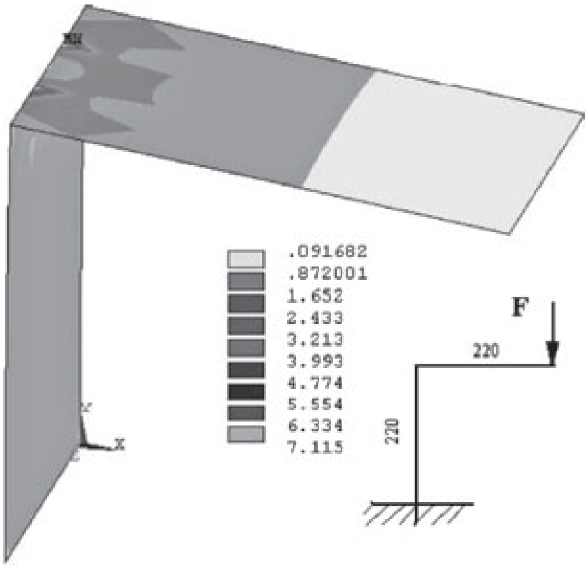


Figure 8 Distribution of Von Mises stress
Slika 8. Raspodjela Von Misesovih naprezanja

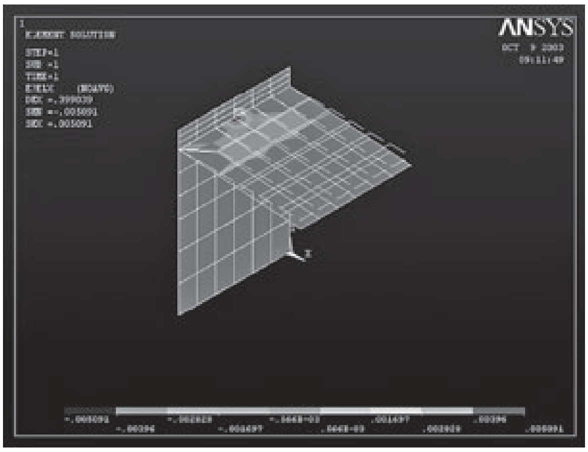


Figure 9 Loading simulation
Slika 9. Simulacija opterećenja

In other studies, brief information is given about the method and doweled furniture corner joints are modeled using FEM method. The models were analyzed using ANSYS™ commercial software (Güntekin, 2002). Loading simulation is shown in Fig. 9.

Efforts were made to develop a numerical evaluation method of the strength and durability of furniture using a chair for the purpose of quality control, a new product design. The objective of this research is to assess strength of laminated bamboo chair under static and dynamic loading and perform drop test analysis. The simulations are set up using nonlinear dynamic FE software, which is equipped with both implicit and explicit solvers. This virtual testing result focused on the improved design and development of laminated bamboo chair through virtual testing (Laemlaksakul, 2008). The static loading simulation is conducted using the implicit solver. The model setup for static loading simulation is illustrated in Figures 10, 11 and 12.

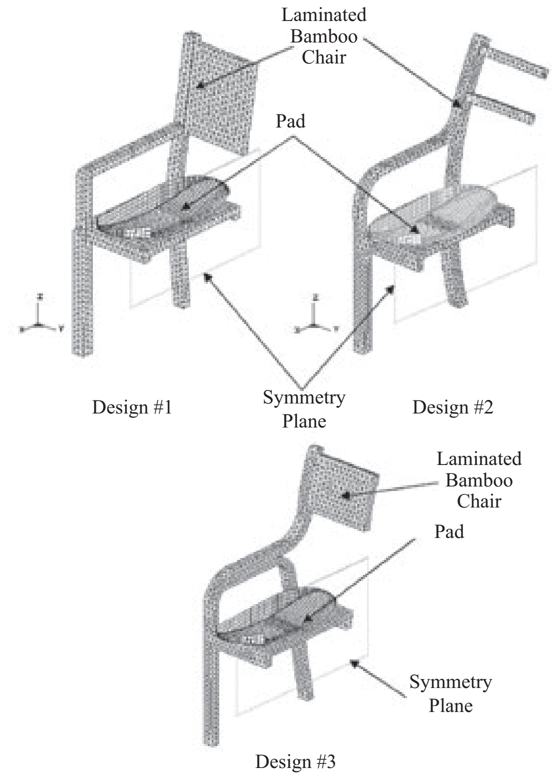


Figure 10 Isometric view of FEA models in static analysis
Slika 10. Izometrijski pogled na FEA modele pri statičkoj analizi

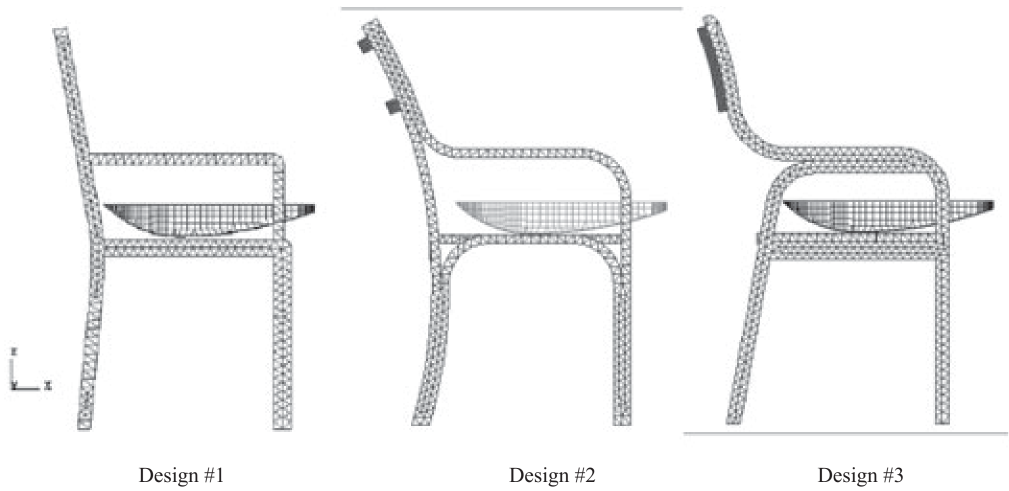


Figure 11 Side view of FEA models in static analysis
Slika 11. Bočni pogled na FEA modele pri statičkoj analizi

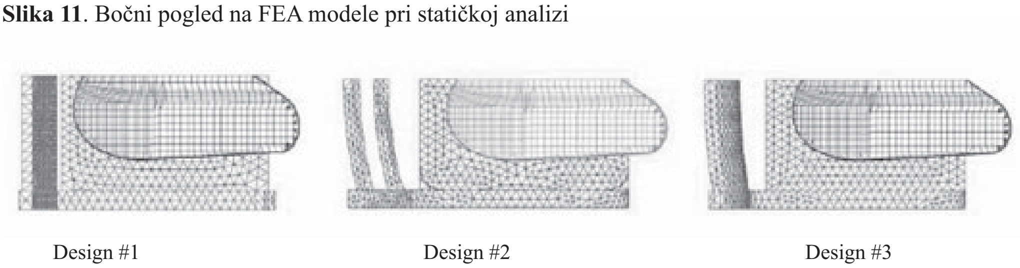


Figure 12 Top view of FEA models in static analysis
Slika 12. Pogled odozgo na FEA modele pri statičkoj analizi

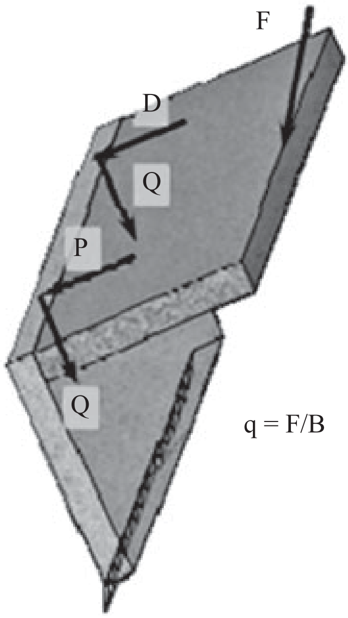


Figure 13 Dimensions of samples and direction of load (grid and boundary *L*= 200 mm, *A*= 125 mm (joint spacing), conditions) of a half of corner connection sample B= 200 mm, g=18 mm
Slika 13. Dimenzije uzoraka i smjer opterećenja (mreža i rubni uvjeti: *L*= 200 mm, *A*= 125 mm) polovice kutnog spoja *B*= 200 mm, *g*=18 mm

Another study presents strength problems of corner connections for *MDF boards*, resulting from loads causing the closure of the connection. The effect of excess load is the destruction of the connection as a result of edge delamination. The objects of experimental studies were models of wall corner connections of MDF boards with two invis joints (Fig. 13). Samples were subjected to a complex state of load of a quasi–static nature (traverse movement velocity of 2 mm/min). Solid linear brick and solid linear wedge elements were used for the purpose of digitization (Fig. 14). Stress patterns were obtained for the analyzed cases. The results show that very small loads (29 N) may cause local board delamination (Mostowski and Sydor, 2006).

4 RESULTS
4. REZULTATI

The basic premise of modern engineering is that models can be used to extrapolate beyond the range of test data. Therefore, if complex physical processes and phenomena related to fracture in wood are understood for representative situations, numerical models can be built to represent those processes beyond the range of those representative situations. FEA and other numerical analysis techniques can, therefore, never be a total replacement for experimental observations. They are a powerful adjunct that has to be allied with experimental observation and material characterization.

It is commonly accepted that the structural design of most furniture, the box-type furniture in particular, is usually based on experience or tradition in handicraft manufacturing. Development of new products in the joinery industry is usually based on traditional craftsmanship and testing of prototypes. FE modeling can be a valuable support in the process of product development.

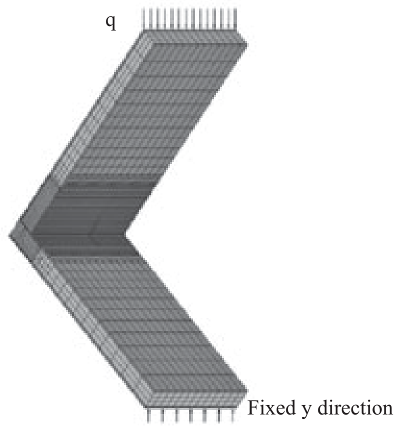


Figure 14 FEM model
Slika 14. FEM model

5 CONCLUSION
5. ZAKLJUČAK

Computer software, which has already taken roots in machine and construction industries, still finds a limited application in furniture industry. A majority of manufactured furniture continues to be designed exclusively on the basis of craftsmanship and engineering practice. However, pressures resulting from quality and reliability requirements of final products make it more and more necessary to pay increasingly more attention to rigidity-strength optimization of dimensioning of furniture elements and constructional joints.

This paper focused on strength analysis of wood products, specifically furniture structures by FEA methods. FE simulations can enable faster, less costly, and more optimized product development, as well as examinations of product performance that would not be possible even using very detailed prototypes. In the wood industry, these tools have not been much used, but in other industries such as the aerospace and automobile industry, they have been much used for many years. Wood is a more complicated material to model than steel, and studies of wood product design with FE models have been published in the academic world.

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In memoriam – Josip Jozo Tomašević

Dana 24. ožujka 2014. godine oprostili smo se od dragog kolege, suradnika i prijatelja Josipa Tomaševića, dipl. ing. šumarstva drvnotehnološkog smjera, tehnologa za drvo u zgradarstvu. Rođen je 23. srpnja 1927. g. u Koški, Našice, a umro je 15. ožujka 2014. u Senju.

Josip, Hrvat, rimokatolik, osnovnu je školu završio u Koški, šest razreda klasične gimnazije u Širokom Brijegu, maturirao je u realnoj gimnaziji u Osijeku, a diplomirao je 1955. na Poljoprivredno-šumarskom fakultetu u Zagrebu, Drvnoindustrijski smjer.

Nakon završenog fakulteta radio je kratko u DI Vrbovsko (do 1956.) zatim je 1961. započeo osnivanje i uhodavanje pripreme rada DIP-a Karlovac. Prvi u bivšoj Jugoslaviji uvodi oplemenjivanje drva tvrdih listača za tkalačke čunjeve. Dvije je godine radio u Zagrebačkoj tvornici pokućstva.

Nakon toga tijekom 25 godina, sve do umirovljenja 1988., radi u Institutu za drvo, na poslovima tehnoloških projekata za tvornice namještaja i građevne stolarije. Razvio je i organizirao rad Instituta unutar dva odjela – Odjela za finalnu obradu drva, Odjela za drvo u građevinarstvu, te uveo Službu kontrole kvalitete drvnih proizvoda u ispitnim laboratorijima, kao i izdavanje potvrda o kvaliteti za područje SFRJ. Primjenjivao je stručne norme europskih zemalja kao sukladne s budućim HRN normama.

Laboratorijska ispitivanja kvalitete bila su povezana sa službama permanentnih kontrola proizvodnje u inozemstvu i u našim proizvodnim pogonima, te u objektima u izgradnji.

Tijekom rada u Institutu sudjelovao je u organiziranju stručnih seminara o projektiranju drvnih građevinskih proizvoda s obzirom na složene klimatske uvjete, tj. o izdržljivosti i trajnosti vrata i prozora te podnih i zidnih obloga. Objavio je državni standard za ugradnju tih proizvoda suhim postupcima.

Provedene stručno-znanstvene pokusne radove i rezultate ispitivanja objavio je u knjigama, seminarskim radovima i časopisima.

Podsjetimo na najvažnije:

– Dugoročni razvoj šumsko drvnog kompleksa Južni bazen Hrvatske, 1972.
– Razvoj i mogućnosti drvne industrije Hrvatske za razdoblje 1970. – 1985., 1972.
– Organizacija i financiranje standarda za građevnu stolariju, 1973.
– Studija o proizvodnji gotovih parketnih platnica, 1977.
– Opravdanost proizvodnje gotovih podnih konstrukcija, 1981.
– Tehnološki aspekti razvoja drvne industrije Hrvatske, 1983.
– Drvo u podnim konstrukcijama, 1997.
– Primarni zahtjevi upotrebne vrijednosti prozora (Bilten ZIDI-ja)
– Potreba izučavanja suhe ugradnje građevne stolarije – uvjeti i perspektive tog postupka (Šumarski bilten).

Odradio je brojne vještačke ekspertize za ugrađene drvne proizvode prema pravilima struke i Hrvatskim normama.

Rezultate cjelokupnog djelovanja na unapređenju drvnotehnološke struke, kojemu je bio prethodnik u Institutu za drvo u Zagrebu, stavio je na raspolaganje i za izobrazbu svojim suradnicima te za praktičnu primjenu u neposrednoj proizvodnji diljem naše zemlje. Posebno treba naglasiti njegove zasluge za znanstveno i stručno unapređenje Drvnotehnološkog odjela Šumarskog fakulteta te za preseljenje laboratorijske opreme za ispitivanje kvalitete i dijela stručnog osoblja.

Josip je u teškim vremenima za Hrvatsku s kolegama krenuo kao dobrovoljac u Domovinski rat. Ujedno je bio i član HDS-a, Hrvatskih ratnih veterana i tajnik za međunarodne odnose Republike Hrvatske.

Nakon umirovljenja i prestanka rada u Institutu nastavio je aktivno pisati i poticati mlade kolege na unapređenje drvne industrije finalnih, izvoznih proizvoda te razvoj laboratorija za ispitivanje kvalitete. Predlagao je nove, suvremene tehnologije i organizaciju rada te zagovarao ekonomsko i marketinško povezivanje isplativih projekata u cjelovite investicijske programe.

Dragi naš Tomaš, kako smo te nazivali od milja, tvoji najbliži suradnici Stanislav, Božo, Hrvoje, Radek, Zoran, Tomica, Boris i Štef na današnjemu tužnom rastanku sa zahvalnošću ti odajemo počast za sve dobrobiti koje si nam darovao za cjelokupna unapređenja naše drvnotehnološke struke. Tvoje stručne spoznaje prenesene su praksom diljem naše Hrvatske, a posebno putem Drvnotehnološkog odsjeka Šumarskog fakulteta u Zagrebu.

Dragi naš Tomaš, sretan ti put u vječnost, uz našu molitvu. Počivao u miru Gospodnjemu!

prof. dr. sc. Stjepan Tkalec

Josip Miklečić obranio doktorski rad

Josip Miklečić, dipl. ing., obranio je 9. prosinca 2013. na Šumarskom fakultetu Sveučilišta u Zagrebu disertaciju *Postojanost poliakrilatnih nanopremaza na toplinski modificiranom drvu* pred povjerenstvom u sastavu: dr. sc. Hrvoje Turkulin, redoviti profesor (Šumarski fakultet), dr. sc. Boris Ljuljka, *professor emeritus* (Šumarski fakultet) i dr. sc. Marko Petrič, redoviti profesor (Biotehniška fakulteta u Ljubljani) i time stekao akademski stupanj doktora znanosti s područja biotehničkih znanosti, znanstveno polje drvne tehnologije. Mentorice rada bile su prof. dr. sc. Vlatka Jirouš-Rajković (Šumarski fakultet) i prof. dr. sc. Sanja Lučić Blagojević (Fakultet kemijskog inženjerstva i tehnologije).

PODACI IZ ŽIVOTOPISA

Josip Miklečić rođen je 5. siječnja 1983. godine u Koprivnici. Osnovnu školu pohađao je u Sv. Petru Orehovcu, a srednju Opću gimnaziju u Križevcima. Godine 2001. upisao je studij na Drvnotehnološkom odsjeku Šumarskog fakulteta Sveučilišta u Zagrebu, koji je završio u svibnju 2006. diplomskim radom *Utjecaj izlaganja drva vremenskim uvjetima na kvašenje i adheziju* iz predmeta Površinska obrada drva na Zavodu za namještaj i drvne proizvode pod mentorstvom prof. dr. sc. Vlatke Jirouš-Rajković.

Od 1. siječnja 2008. radi na Šumarskom fakultetu Sveučilišta u Zagrebu, u Zavodu za namještaj i drvne proizvode. Zaposlen je kao znanstveni novak u suradničkom zvanju asistenta na znanstvenom projektu MZOŠ-a 068-0682109-2096 *Oplemenjivanje i modifikacija površine drva*. Iste je godine upisao poslijediplomski znanstveni doktorski studij Drvna tehnologija.

Nastavni rad započeo je na predmetu Površinska obrada drva, a promjenom nastavnog programa osim na tom predmetu, radi u nastavi iz predmeta Tehnološki procesi površinske obrade drva i Površinska obrada proizvoda od drva. Sudjelovao je i sudjeluje u izradi više diplomskih radova s područja površinske obrade drva. Također radi u Laboratoriju za ispitivanje namještaja i dijelova za namještaj kao ispitivač.

Pohađao je seminar *Ustrojstvo laboratorija prema HRN EN ISO/IEC 17025* (2009.), u sklopu programa *Erasmus* bio je na studijskom boravku na Oddelku za lesarstvo u Ljubljani (2012.), odslušao je i položio kolegij Fizikalna kemija polimera na Fakultetu kemijskog inženjerstva i tehnologije Sveučilišta u Zagrebu (2009.).

Član je COST akcije FP1006 *Bringing new functions to wood through surface modification* i Tehničkog odbora TO571 *Sport, igrališta i ostali rekreacijski sadržaji i oprema*.

Aktivno sudjeluje na stranim i domaćim međunarodnim znanstvenim i stručnim skupovima. Kao autor ili suautor objavio je 12 znanstvenih radova i jedan stručni rad s područja površinske obrade drva, modifikacije drva te otpornosti drva i premaza na okolišne utjecaje.

PRIKAZ DISERTACIJE

Disertacija Josipa Miklečića, dipl. ing., s naslovom *Postojanost poliakrilatnih nano premaza na toplinski modificiranom drvu* sastoji se od 185 + XV stranica teksta u koji su uključene 83 slike, 27 tablica i 168 navoda citirane literature. Disertacija je podijeljena na sedam dijelova:

1. *Uvod,* 3 stranice,
2. *Dosadašnja istraživanja,* 14 stranica,
3. *Obrazloženje teme,* 2 stranice,
4. *Materijali i metode rada,* 36 stranica,
5. *Rezultati i diskusija,* 109 stranica,
6. *Zaključci,* 15 stranica,
7. *Literatura,* 13 stranica.

Pokusi, koji su osnova rada, izvođeni su na Šumarskom fakultetu Sveučilišta u Zagrebu, a mjerenja su obavljena na Šumarskom fakultetu, Fakultetu kemijskog inženjerstva i tehnologije, na Farmacijsko-biokemijskom fakultetu Sveučilišta u Zagrebu, na Oddelku za lesarstvo Biotehniške fakultete u Ljubljani i u laboratoriju tvrtke *Helios d.d.* u Sloveniji.

1. Uvod

U *Uvodu* su predstavljeni osnovni pojmovi vezani za poliakrilatne nanopremaze, toplinski modificirano drvo, utjecaj vanjskih čimbenika okoliša na drvo i premaz te utjecaj ekstraktiva na promjenu boje drva. Navedene su metode ispitivanja primijenjene u disertaciji, te predstavljen cilj rada i dijagram tijeka istraživanja.

2. Dosadašnja istraživanja

Poglavlje o dosadašnjim istraživanjima drugo je poglavlje disertacije u kojemu je u pet potpoglavlja obuhvaćeno toplinski modificirano drvo, premazi na osnovi poliakrilata, utjecaj vanjskih okolišnih uvjeta na drvo i premaz, zaštita drva i premaza od štetnog utjecaja Sunčeva zračenja te UV apsorberi u nanoveličinama.

3. Obrazloženje teme

U tom su poglavlju navedeni razlozi odabira teme i glavni ciljevi istraživanja. Postavljena je hipoteza istraživanja, koja glasi da se dodatkom nanočestica titanijeva dioksida (TiO_2) i cinkova oksida (ZnO) prozirnome poliakrilatnom premazu povećava postojanost toplinski modificirane bukovine. Uz glavnu hipotezu postavljena je i dodatna hipoteza prema kojoj toplinska modifikacija uzrokuje promjenu svojstava podloge, što može utjecati na svojstva sustava drvo – premaz i njegove promjene tijekom izlaganja vanjskim okolišnim uvjetima.

4. Materijali i metode rada

U poglavlju *Materijali i metode rada*, koje je podijeljeno na jedanaest dijelova, obrazložen je izbor toplinski modificiranog drva, poliakrilatnoga vodenog premaza, nanočestica titanijeva dioksida (TiO_2) i cinkova oksida (ZnO), te crvenoga i žutog pigmenta željeza. Opisan je način pripreme premaza (sedam sustava premaza), uzoraka toplinski modificiranog drva i slobodnih filmova premaza. Definirane su metode kojima je provedena karakterizacija uzoraka drva, uzoraka premaza i sustava drvo – premaz. Prikazani su uvjeti prirodnoga i ubrzanog izlaganja uzoraka vanjskim uvjetima okoliša te način praćenja promjena na uzorcima tijekom izlaganja. Autor se u svom radu služio različitim standardnim i nestandardnim metodama istraživanja koje je na dobar način prilagodio svojim potrebama. Upotrijebljene metode dobro su odabrane i primjerene su ispitivanju željenih svojstava. Metode koje nisu standardizirane (primjerice, ekstrakcija uzoraka drva potapanjem u vodi i smjesi etanol-benzena) kandidat je dobro opisao i postupci su ponovljivi.

5. Rezultati i diskusija

U petom je poglavlju autor sustavno prikazao rezultate i analizirao ih unutar zaokruženih logički obrađenih cjelina. To je važno poglavlje podijeljeno na pet dijelova koji sustavno prate slijed pokusa istraživanja u kojima je autor svaku temu prikazao relevantnim rezultatima. Rezultate utjecaja vanjskih okolišnih uvjeta na sustav drvo – premaz autor je statistički povezao klasterskom analizom. Nakon pojedinih rezultata istraživanja slijedila je rasprava o mogućim uzrocima dobivenih rezultata. Osnovna hipoteza da će dodatak nanočestica titanijeva dioksida (TiO_2) ili cinkova oksida (ZnO) prozirnom poliakrilatnom premazu povećati njegovu postojanost na toplinski modificiranom drvu nije dokazana iako se pokazalo da se dodatkom nanočestica u poliakrilatni premaz postiže veća stabilnost boje toplinski modificiranog drva tijekom njegova ubrzanog izlaganja. Predobrada toplinski modificiranoga drva otopinom HALS nije se pokazala učinkovitom u zaštiti toplinski modificiranog drva od promjene boje. Najbolju postojanost na modificiranom drvu pri izlaganju vanjskim uvjetima okoliša pokazali su poliakrilatni premazi koji su, osim anorganskih čestica, u nanoveličinama sadržavali i pigmente. Taj će rezultat biti osobito zanimljiv proizvođačima premaza za toplinski modificirano drvo.

6. Zaključak

Zaključak je dan u šestom, posljednjem poglavlju. U njemu se navode osnovna dostignuća rada izvedena iz rezultata istraživanja i rasprave o njihovu značenju. Zaključci nedvojbeno ističu novostečena znanja i njihovu vrijednost za povećanje postojanosti toplinski modificiranog drva izloženoga vanjskim uvjetima okoliša. Osnovni su zaključci disertacije sljedeći.

- Toplinska modifikacija bukovine smanjila je gustoću, povećala kiselost, izrazito smanjila polarnu komponentu slobodne površinske energije, povećala udio lignina te vodenoga i otapalnog ekstrakta.
- Dodatak nanočestica ZnO imao je veći utjecaj na svojstva tekućega poliakrilatnog vodenog premaza nego TiO_2 nanočestice.
- Nanočestice TiO_2 i ZnO povećale su čvrstoću, modul elastičnosti i staklište, a smanjile istezanje poliakrilatnoga vodenog premaza.
- Dodatkom nanočestica TiO_2 i ZnO poliakrilatnome vodenom premazu smanjila se promjena boje sustava toplinski modificirano drvo – premaz tijekom prirodnoga i ubrzanog izlaganja, ali je i dalje bila vrlo izražena i jasno vidljiva ljudskom oku.
- Bolji učinak stabilizacije promjene boje postignut je nanočesticama TiO_2 i povećanjem koncentracije nanočestica.
- Predobrada toplinski modificiranog drva otopinom HALS spojeva nije bila učinkovita u zaštiti od promjene boje tijekom prirodnoga i ubrzanog izlaganja.
- Dodatak pigmenata premazima s nanočesticama TiO_2 i ZnO najviše je stabilizirao promjenu boje toplinski modificiranog drva tijekom njegova ubrzanog izlaganja, a tijekom prirodnog izlaganja pigmenti su povećali stabilnost boje uzoraka drva obrađenih premazima s nanočesticama ZnO.
- Dodatkom nanočestica TiO_2 i ZnO poliakrilatnome vodenom premazu nisu se smanjile kemijske promjene sustava toplinski modificirano drvo – premaz tijekom prirodnoga i ubrzanog izlaganja, dok su se kemijske promjene smanjile kombinacijom pigmenata i nanočestica TiO_2 i ZnO.
- Ekstraktivne tvari pridonijele su većoj promjeni boje toplinski modificiranog drva pri višoj temperaturi (212 °C) tijekom ubrzanog izlaganja, što je vidljivo i na promjeni vrpce na 1595 cm^{-1}.

OCJENA DISERTACIJE

Doktorska disertacija Josipa Miklečića, dipl. ing., izvorno je znanstveno djelo, kako sadržajno, tako i formalno. Autor je stvorio objedinjenu i zaokruženu cjelinu novih spoznaja o svojstvima drvnog materijala, o svojstvima modificiranoga supstrata, o interakcijama nanopremaza i supstrata te o funkcijskim svojstvima, postojanosti i estetskoj vrijednosti proizvoda koji su bili predmet istraživanja. U nekim dijelovima disertacije obrađuju se teme koje su, doduše, u literaturi već objavljene, ali kandidatove spoznaje bacaju dodatno i originalno svjetlo na međusobnu povezanost znanstvenih pitanja: značajan je primjer utjecaj površine modificiranog drva na svojstva sustava drvo – premaz, pri čemu je potrebno uzeti u obzir da je kandidat izabrao specifične premazne sustave s dodacima nanodispergiranih apsorbera svjetlosti i pigmenata.

Dodatno treba naglasiti da se vrijedan doseg kandidatove disertacije zasniva na negativnim rezultatima (nanododaci u premazima nisu bitno pridonijeli otpornosti proučavanih sustava tijekom prirodnog starenja drva). U znanstvenoj smo literaturi najčešće upućeni na pozitivne rezultate, pa je disertacija još prihvatljivija u svim aspektima – znanstveno utemeljenome novom znanju koje proizlazi iz pozitivnih (očekivanih), ali i iz negativnih rezultata. Potonji su također izvorni doprinos razvoju znanosti.

Izvorni je doprinos ostvaren prikazom novih spoznaja u poznavanju svojstava pregrijanoga drva, postupaka površinske obrade drva uz poboljšanja prevlake dodacima nanodispergiranih apsorbera svjetlosti te postojanosti takvih površinskih sustava. Sa stajališta izvornosti posebno se ističu ishodi ispitivanja interakcija premaza s nanodispergiranim apsorberima svjetlosti i modificiranog drva, predobrade HALS stabilizatorima boje i utjecaja ekstraktivnih tvari. Rezultati su u disertaciji jasno i nedvosmisleno poduprti vrijednim prikazima statističkih korelacija među pojedinim varijablama, zaključno s klasterskom statističkom analizom značaja utjecaja pojedinih ispitnih varijabli. Time je doktorat opsegom iscrpio većinu gradiva koje je predviđeno prijedlogom i obrazloženjem teme. Prvo, pokazao je da premaz i površina pregrijanoga drva pokazuju interakcije koje su bitno različite od pojava na površini prirodnoga drva. Drugo, dobivena su nova znanja o promjenama svojstava pokrivnih filmova s različitim nanodispergiranim dodacima za zaštitu drva od svjetlosti i starenja. Naposljetku, iskazani su novi, iako katkad tehnički razočaravajući, aspekti poboljšanja životnoga vijeka površine pregrijanoga drva izložene vanjskim utjecajima. Rad je dodatno rezultirao i zaključcima o mogućim budućim razvojnim tehnikama za poboljšanje životnog vijeka površine pregrijanoga drva izložene vanjskim utjecajima.

prof. dr. sc. Vlatka Jirouš-Rajković

Dan kvalitete Šumarskog fakulteta Sveučilišta u Zagrebu

The Quality Day of Faculty of Forestry University of Zagreb

Dana 24. ožujka 2014. godine obilježen je Dan kvalitete Šumarskog fakulteta. Bio je to spomen na 24. ožujka 2011. godine, kada je Fakultetsko vijeće prihvatilo inicijativu za uvođenje sustava upravljanja kvalitetom (SUK). Svečani događaj obilježen je pod motom „Osiguravanje kvalitete Sveučilišta u Zagrebu Šumarskog fakulteta u europskom prostoru znanosti i visokog obrazovanja". Svečani skup svojom je nazočnošću uveličala prof. dr. sc. Mirjana Hruškar, predsjednica Odbora za upravljanje kvalitetom Sveučilišta u Zagrebu. Velik doprinos skupu dali su nezaobilazni vanjski sudionici sustava kvalitete Šumarskog fakulteta, dr. sc. Aida Kopljar iz Ministarstva poljoprivrede, članica Povjerenstva za upravljanje kvalitetom Šumarskog fakulteta, te dr. sc. Željko Tomašić iz Hrvatskih šuma d.o.o., član Povjerenstva za unutarnju neovisnu prosudbu sustava kvalitete Šumarskog fakulteta. Prisutnost brojnih zaposlenika Šumarskog fakulteta potvrda je razvoja svijesti o važnosti kvalitete i razvoju kulture kvalitete.

Slika 1. Predavanje dekana Šumarskog fakulteta prof. dr. sc. Milana Oršanića

Program Dana kvalitete sastojao se od tri predavanja.

Dekan Šumarskog fakulteta prof. dr. sc. Milan Oršanić otvorio je manifestaciju pozdravnim govorom. Potom je održao vrlo konstruktivno uvodno predavanje u kojemu je sa šireg stajališta prikazao svojstva i značaj europskog prostora znanosti i visokog obrazovanja, s naglaskom na postignućima Šumarskog fakulteta u uspostavi i razvoju sustava kvalitete. U sklopu predavanja dekan Šumarskog fakulteta govorio je o primjeni Standarda i smjernica za osiguravanje kvalitete u Europskom prostoru visokog obrazovanja (Standards and Guidelines for Quality Assurance in the European Higher Education Area), o Zakonu o osiguravanju kvalitete u znanosti i visokom obrazovanju (NN 45/09) te o Pravilniku o sustavu osiguravanja kvalitete na Sveučilištu u Zagrebu, čija je zajednička primjena u sustavu kvalitete dovela Šumarski fakultet na visoko mjesto unutar sastavnica Sveučilišta. Također je naveo kako je u idućem razdoblju osnovni zadaća Fakulteta očuvati postignutu razinu kvalitete i raditi na stalnom unapređenju jer prostora za napredak još uvijek ima.

Nakon dekana Šumarskog fakulteta skupu se obratila predsjednica Odbora za upravljanje kvalitetom Sveučilišta u Zagrebu prof. dr. sc. Mirjana Hruškar, koja se u svom govoru vrlo pohvalno izrazila o postignutoj razini sustava kvalitete te istaknula kako je Šu-

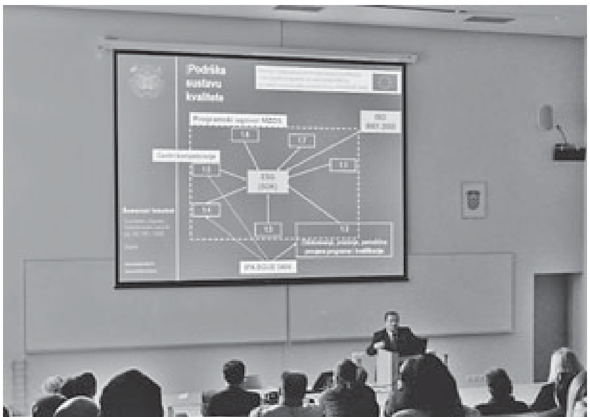
Slika 2. Obraćanje skupu prof. dr. sc. Mirjane Hruškar, predsjednice Odbora za upravljanje kvalitetom Sveučilišta u Zagrebu

Slika 4. Predavanje Kristine Klarić, mag. ing. techn. lign., zamjenice voditelja sustava ISO 9001:2008

marski fakultet prema ocjeni postignutoj u postupku reakreditacije u samom vrhu na Sveučilištu.

Sljedeće predavanje s temom *Razvoj sustava kvalitete znanosti i visokog obrazovanja Šumarskog fakulteta* održao je voditelj sustava upravljanja kvalitetom Šumarskog fakulteta prof. dr. sc. Vladimir Jambreković. U svom je izlaganju dao pregled razvoja sustava kvalitete u visokom obrazovanju te aktivnosti Šumarskog fakulteta u razvoju sustava kvalitete i donošenju ključnih dokumenata sustava upravljanja kvalitetom. U nastavku je izložio aktivnosti izgradnje sustava kvalitete, provedene vanjske i unutarnje evaluacije sustava. Prof. dr. sc. Vladimir Jambreković u izlaganju se osvrnuo na vanjsku neovisnu prosudbu Sveučilišta u kojoj je Šumarski fakultet prema kvalitativnome modelu izabran kao jedan od četiri fakulteta što ih je posjetilo Povjerenstvo za prosudbu, koje je u svom izvještaju istaknulo dva vrlo bitna zapažanja: „Šumarski fakultet prepoznao je SOK kao mehanizam praćenja kvalitete i uspješnosti na *bolonjski*m studijima“, te: „Na Šumarskom fakultetu uspješno se kombinira sustav upravljanja (ISO) za administraciju te osiguravanje kvalitete temeljeno na ESG-u za ostale aktivnosti“.

Također je iznio i komentirao vrlo visoke, ali i obvezujuće ocjene iz završnog izvještaja Povjerenstva za reakreditaciju, odobrena namjenska sredstva iz Pro-



Slika 3. Predavanje prof. dr. sc. Vladimira Jambrekovića, voditelja sustava upravljanja kvalitetom Šumarskog fakulteta

Slika 5. Uspomena na Dan kvalitete Šumarskog fakulteta

gramskih ugovora s Ministarstvom znanosti, obrazovanja i sporta te aktivnosti i sredstva projekta IPA BGUE 0406, kao potpore razvoju sustava kvalitete. Na kraju predavanja prof. Jambreković naveo je koji su nužni zahvati u sustavu kvalitete te prikazao novi pristup u razvoju sustava kvalitete koji osigurava visoku razinu kvalitete te mjesto među vodećima na Sveučilištu i u regionalnom okruženju.

Posljednje predavanje u prigodi obilježavanja Dana kvalitete Šumarskog fakulteta održala je Kristina Klarić, mag. ing. techn. lign., zamjenica predstavnika Uprave za sustav ISO 9001:2008 Šumarskog fakulteta. U svom je izlaganju predstavila Sustav kvalitete ISO 9001:2008 Šumarskog fakulteta. U sklopu predavanja Kristine Klarić provedena je edukacija o ISO 9001: 2008 Sustav upravljanja kvalitetom – Zahtjevi prema PL ŠF 09 01 Plan edukacije Šumarskog fakulteta.

Nakon predavanja otvoreni su novouređeni prostori Laboratorija za drvne ploče (LAP), kojima se osiguravaju visoki standardi u održavanju praktične nastave te u realizaciji znanstvenoistraživačkog rada. Druženje, razmjena iskustava i dogovori o razvoju suradnje nastavljeni su svečanim domjenkom u ugodnom ambijentu multimedijske dvorane objekta fakultetske pilane.

Kristina Klarić, mag. ing. techn. lign.

BUBINGA

UDK: 674.031.738

NAZIVI I NALAZIŠTE

Drvo vrste *Guibourtia tessmannii* J. Léonard iz botaničke porodice *Leguminosae/Caesalpinioidae* potječe iz zapadne Afrike: Nigerije, Kameruna i Gabona. Široko je raspostranjeno u tropskim kišnim šumama.

Trgovački i lokalni nazivi su mu bubinga (Njemačka, Velika Britanija, Kamerun, Kongo); bubingo, bevazingo, bvang (Gabon); essingang, nomélé, okweni, owogn, simingan (Kamerun); waka (Kongo); akume (SAD).

STABLO

Drvo vrste *Guibourtia tessmannii* J. Léonard listača je srednje visine, između 20 i 45 m (do 50 m). Promjer debla kreće se između 90 i 160 cm. Debla su cilindrična, obično čista od grana, vrlo visoka, što omogućuje dobivanje trupaca velike tehničke dužine.

Visina do prve grane iznosi do 20 m. Kora drveta je raspucana, a sa starenjem se ljušti. Debljina kore kreće se do 1,0 cm.

DRVO

Makroskopska obilježja

Srž i bjeljika jasno se razlikuju bojom. Bjeljika je široka od 2 do 8 cm, bijelosivkasta, crvenkastozelena do blijedožuta. Sirova srž je crvena, ljubičastocrvena, tamnosmeđa, s tamnijim prugama.

Drvo je fine do srednje grube teksture. Žica drva je ravna, katkada i uskukana. Granica goda je uočljiva. Pore i drvni traci povećalom su jasno (dobro) vidljivi.

Mikroskopska obilježja

Drvo je rastresito porozno. Pore su malobrojne, pretežito pojedinačne i u paru. Promjer pora iznosi od 65...130...170 mikrometara. Gustoća im je od 1 do 3 do 5 pora po milimetru četvornome poprečnog presjeka. Volumni udjel pora je oko 8 %. Pore mogu biti ispunjene svijetlim i crvenkastosmeđim sadržajem. Aksijalni je parenhim drva apotrahealno graničan, paratrahealno aliforman do konfluentan.

Udio aksijalnog parenhima iznosi oko 10 %. Staničje drvnih trakova je homogeno. Drvni su traci difuzno raspoređeni. Visoki su 165...330...550 mikrometara (od 10 do 30 stanica), a široki su 15...35...45 mikrometara (od 2- 3 do 4 stanice). Gustoća trakova je od 4 do 7 ili 8 po mm poprečnog presjeka. Udio drvnih trakova iznosi oko 16 %. Vlakanca su libriformska, vlaknastih traheida.

Debljina stijenki vlakanaca kreće se od 2,0...3,0 do...4,5 mikrometra, a promjer lumena od 5,0...11,0...18,0 mikrometara. Dužina vlakanaca iznosi 1630...1780...1860 mikrometara. Volumni udjel vlakanaca kreće se oko 66 %. U stanicama trakova i aksijalnog parenhima nalaze se kristali prizmatičnog oblika. U ponekoj se stanici može nalaziti kristal. Stanice s kristalima normalne su veličine. U stanicama drvnih trakova nema silicija.

Fizikalna svojstva

Gustoća standardno suhog drva, ρ_0	oko 750 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	800...950 kg/m^3
Gustoća sirovog drva, ρ_s	950...1200 kg/m^3
Poroznost	oko 51 %
Totalno radijalno utezanje	5,0...7,5 %
Totalno tangentno utezanje	6,0...9,5 %
Totalno volumno utezanje	11,0...14,4 %

Mehanička svojstva

Čvrstoća na tlak	65,0...74,5 MPa
Čvrstoća na savijanje	125,0... 160 MPa
Čvrstoća na vlak okomito na vlakanca	3,6...4,8 MPa
Modul elastičnosti	oko 13,0 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Usprkos velikoj gustoći, drvo se relativno lako obrađuje ručnim i strojnim alatima, no ako je drvo nepravilne žice, valja ga pažljivo obrađivati. Obradom alatima postiže se glatka i blago sjajna površina. Ako je pravilno pareno, drvo se dobro reže.

Također, dobro drži vijke i čavle, no potrebno ga je prethodno izbušiti. Dobro se brusi, ljušti i lijepi. Treba napomenuti da bruševina u čovjeka može prouzročiti dermatitis. Poliesterske i uljne premaze treba izbjegavati zbog sporog sušenja filma. Kad se upotrebljava na otvorenome, drvo je dovoljno samo površinski premazati.

Sušenje

Prije sušenja u sušionici preporučuje se prirodno prosušivanje drva. Drvo valja polako sušiti kako bi se izbjegle pukotine i iskrivljenost. Trupce za sušenje treba pažljivo složiti i omogućiti dobru cirkulaciju zraka između njih.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva otporna je na gljive truležnice (razred otpornosti 2) i termite (razred otpornosti D). Otpornost srži na tercijarne kukce klasificirana je kao trajna (razred otpornosti 2). Srž nije permeabilna (razred 4).

U skladu s normama, može se koristiti u razredu opasnosti 4 (u dodiru sa zemljom ili vodom).

Uporaba

Drvo se rabi za uređenje eksterijera i interijera, posebno za izradu dekorativnih furnira, parketa, namještaja visoke kvalitete, glazbenih instrumenata, željezničkih pragova i rudničkog drva, za izradu drvenih čamaca za spašavanje i kanua, drvene galanterije (drvenih kutija, škrinja i gajbi, drški noževa, drvenog nakita, instrument-ploča luksuznih vozila) i skulptura od drva

Sirovina

Drvo na tržište dolazi u obliku trupaca i piljene građe. Trupci su obično većih dimenzija.

Napomena

Drvu vrste *Guibourtia tessmannii* J. Léonard za sada ne prijeti nestanak (ne nalazi se na popisu CITES – Convention on International Trade in Endangered Species, niti na popisu IUCN – Red list of Threatened Species).

Drvo sličnih svojstava imaju ove vrste: *Guibourtia arnoldiana* J. Léonard, *G. coleosperma* J. Léonard, *G. demeusei* J. Léonard, *G. pellegriniana* J. Léonard, *Guibourtia. spp.*, *Dalbergia variabilis* Vog., *Dalbergia spp., Pterocarpus spp.*

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

Upute autorima

Opće odredbe

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

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

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

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

drind@sumfak.hr ili techdi@sumfak.hr

Upute

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

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

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

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

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

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

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

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

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

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

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

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

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Primjer

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

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Primjeri

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

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

Ostale publikacije (brošure, studije itd.)

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

Web stranice

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

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Examples:
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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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