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Jerzy Smardzewski[1], *Dariusz Wilk*[2], *Andrzej Piróg*[2]

Evaluation of Seat Comfort of Office Armchairs: an Impact of Articulated Seat Support and Gas Spring

Procjena udobnosti sjedala uredskih stolaca: utjecaj gibljivog postolja sjedala i zračne opruge

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ABSTRACT • *This paper describes the application of an alternative seating system. The aim of this alternative approach was to determine the comfort of office armchairs equipped with new construction solutions ensuring articulated support of the seat as well as articulated mounting of the gas spring. An office armchair with a different seat support and gas spring was selected. Operational loads were applied to the seat surface. The following parameters were measured and calculated in the course of the performed experiments: contact area, average contact pressure and coefficient of seat pressure distribution (SPD). A new discomfort coefficient D expressing seat quality was elaborated. Preliminary data suggests that the prototypes provided greater sitting comfort than did the conventional chair. It was demonstrated that the new construction solution of the gas spring support guaranteed the highest comfort of the use of the examined armchairs.*

Key words: *articulated support, discomfort coefficient, gas spring, office armchair, seat*

SAŽETAK • *U radu se opisuje primjena alternativnog sustava za sjedenje. Cilj provedenog ispitivanja bio je utvrditi udobnost uredskih stolaca opremljenih novim konstrukcijskim rješenjima koja osiguravaju gibljivost postolja sjedala i gibljivost zračne opruge. Izabran je uredski stolac s promijenjenim načinom potpore sjedala i zračne opruge. Površina sjedala izložena je uobičajenim opterećenjima. Tijekom provedbe eksperimenta mjereni su i izračunavani ovi parametri: kontaktno područje, prosječni kontaktni pritisak i koeficijent raspodjele tlaka na sjedalu (SPD). Uveden je novi koeficijent neudobnosti D kojim je izražena kvaliteta sjedala. Preliminarni podaci pokazuju da prototipovi sjedala osiguravaju veću udobnost sjedenja nego konvencionalni uredski stolac. Dokazano je da novo konstrukcijsko rješenje postolja zračne opruge jamči najviši komfor pri uporabi istraživanih stolaca.*

***Ključne riječi*:** *gibljivo postolje, koeficijent neudobnosti, zračna opruga, uredski stolac, sjedalo*

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1 INTRODUCTION
1. UVOD

Office armchairs, depending on the purpose of their utilization, can be used for several minutes or several hours. Despite advanced industrial developments, many workers are still required to adapt to the machines and thus accept less than ideal working conditions. Computer dominated jobs and industrial automation have created more sedentary tasks often characterized by constrained postures, high frequency (repetitive work), monotonous work requiring good eyesight, and precision work with repetitive movements in the arms, hands, and fingers. As a result of these limitations, a variety of musculoskeletal conditions, involving the entire upper limb, neck and back, have approached the forefront of work related disorders (Fernandez *et al*., 1999). The authors concluded that in light assembly and computer work tasks, an arm support system would be recommended to minimize the effort and RPE, and to maximize comfort. A study by Zhu and Shin (2012) has shown that forearm support can help computer users lessen physical stress in typing, but only when the supports are positioned at resting elbow height. Also, evaluation of a dynamic arm support for seated and standing tasks suggested that a dynamic forearm support may improve subjective comfort and reduce static muscle loads in the upper extremity for tasks that involve horizontal movement of the arms (Odell *et al*., 2007).

The research on sitting comfort demonstrates a particularly pronounced relationship between seat pressure and comfort. De Looze *et al*. (2003) concluded that the most consistent predictor of seat comfort was related to seat pressure distribution and that this relationship was considerably more straightforward than with the research that measures muscle activity or spinal profiles. Using a specially designed seat fixture, Goossens (1998) varied pressures and found a strong correlation between the amount of pressure applied to the buttocks and discomfort. The values of maximum contact pressure and the seat contact area are most commonly employed as measures of their utilization comfort (Adler, 2007; Ebe and Griffin, 2001; Milvojevich *et al*., 2000; Tewari and Prasad, 2000; Uenishi *et al*., 2000). According to Dhingra *et al*. (2003), the distribution of contact pressure is more uniform on a soft seat than on a hard one. Ebe and Griffin (2001) confirmed that the values of contact pressure under ischium bones can be applied as the principal criterion of foam hardness and seat comfort. There is, therefore, a close correlation between the contact area and the value of contact pressure. Reswick and Rogers (1976) described the relationship between contact pressure, time of their action and the degree of soft tissue damages. Kosiak (1961, 1959) reported that microscopic pathological changes of soft tissues appeared already after one hour of pressure action of values not exceeding 8 kPa. On the other hand, no such changes were observed when the applied pressure had the value of 4.7 kPa. According to Hostensa *et al*. (2001), Landis (1930), Takahashi *et al*. (2010) pressures ranging from 2.7 to 4 kPa can close capillary blood vessels and cause discomfort during sitting. That is why the contact pressure of 4-8 kPa was employed as a criterion of comfort in many investigations dealing with designing of various seats and beds (Butcher and Thompson, 2010, 2009; Hamanami *et al*., 2004; Seigler and Ahmadian, 2003; Smardzewski, 2009; Smardzewski *et al*., 2010a, 2010b; Tewari and Prasad, 2000; Wang and Lakes, 2004; Wang *et al*., 2004). Rasmussen and Zee (2009) made an attempt at a numerical parameter optimization of an airplane armchair. Their conclusion was that, although there were some general characteristics of seats, numerous additional factors had to be taken into consideration during the modelling process before experimental results could be used in practice. Paoliello *et al*. (2008) made an analysis of armchairs loading during their daily use. Vlaović *et al.* (2008) proposed a questionnaire method for assessing seat comfort of office armchairs. Nero *et al*. (2011) described the application of an alternative seating concept for surgeons that reflects the research of Zen sitting postures, which require Zazen meditators to maintain fixed postures for long durations. The aim of this alternative approach was to provide sitters with a seat pan with sacral support that provides a more even distribution of seat pressures, induces forward pelvic rotation and improves lumbar, buttock and thigh support. The authors concluded that the sacral support of the prototype chair prevents backward pelvic rotation. Preliminary data suggests that the prototype provided greater sitting comfort and support for constrained operating postures than did the conventional chair. These findings support the selective application of concave-shaped seat pans that conform to users' buttocks and reflect Zen sitting principles. However, this solution is characterized by rigid support of seats and columns. What is lacking, however, is a wider discussion concerning the effect of the new construction of seat support on the comfort of utilization of office armchairs as well as ways of assessment of this comfort.

The principal goal of the present investigations was to determine the comfort of office armchairs with novel design solutions ensuring articulated support of the seat as well as articulated mounting of the gas spring. Another objective was to select the most advantageous construction design that would exert the strongest influence on armchair comfort.

2 METHODS AND MATERIALS
2. METODE I MATERIJALI

The armchair selected for the investigations was an office armchair with the backrest manufactured from 34 mm thick Atria® foam and 7.85 kPa hardness (PN-EN ISO 2439), whereas the seat was made from 47 mm thick and 8.9 kPa stiffness Event® foam (Fig. 1). The column of the pneumatic spring was mounted in a five-arm base using three different methods. The first of them was a stiff linkage typical for majority of office armchair constructions (Fig. 1a, 2a,d – type S).

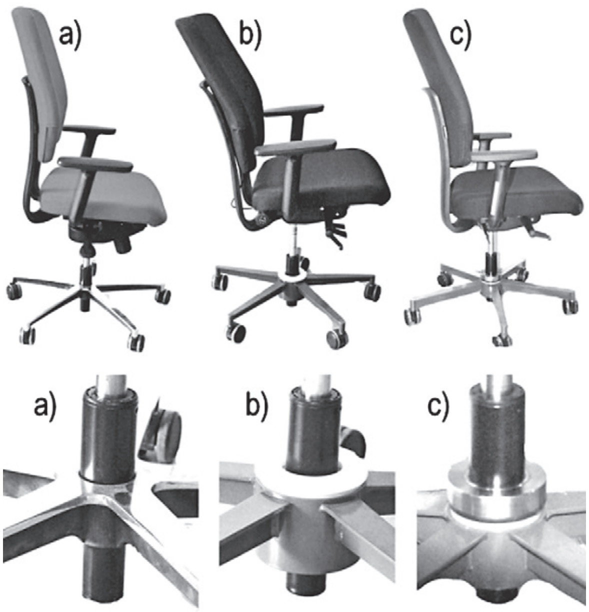

Figure 1 Examples of office armchairs: a) a seat with articulated support; gas spring with rigid support – type BS; b) a seat with rigid support, gas spring with articulated support and with possibility of regulation of the deflection angle – type AP; c) a seat with rigid support; gas spring with articulated support but without possibility of regulation of the deflection angle – type NP

Slika 1. Uzorci uredskih stolaca: a) sjedalo s gibljivim postoljem; zračna opruga s krutim postoljem – tip BS; b) sjedalo s krutim postoljem, zračna opruga s gibljivim postoljem i s mogućnošću regulacije nagibnog kuta– tip AP; c) sjedalo s krutim postoljem; zračna opruga s gibljivim postoljem, ali bez mogućnosti regulacije nagibnog kuta – tip NP

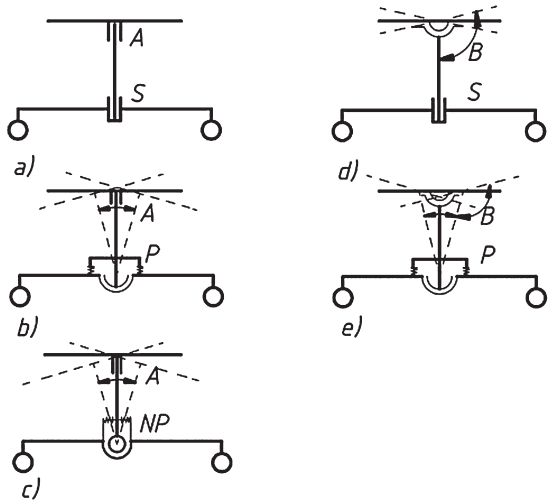

Figure 2 Methods of linkage of the seat and gas spring: a) AS – rigid support of the seat and gas spring; b) AP – rigid support of the seat and gas spring with articulated support and with possibility of regulation of the deflection angle; c) NP - rigid support of the seat and gas spring with articulated support but with no possibility of regulation of the deflection angle; d) BS – seat with articulated support and gas spring with rigid support; e) BP - seat with articulated support and gas spring with possibility of regulation of the deflection angle

Slika 2. Metode povezivanja sjedala i zračne opruge: a) AS – kruto postolje sjedala i zračne opruge; b) AP – kruto postolje sjedala i zračna opruga s gibljivim postoljem i mogućnošću regulacije nagibnog kuta; c) NP – kruto postolje sjedala i zračna opruga s gibljivim postoljem ali bez mogućnosti regulacije nagibnog kuta; d) BS – sjedalo s gibljivim postoljem i zračna opruga s krutim postoljem; e) BP – sjedalo s gibljivim postoljem i zračna opruga s mogućnošću regulacije nagibnog kuta

The second method ensured articulated support with a possibility of regulation of the deflection angle of the column from the perpendicular (Fig. 1b, 2b,e – type P), whereas the third one was also an articulated coupling but with no possibility of deflection regulation (Fig. 1c, 2c – type NP). The seat together with the backrest was fixed to the column of the pneumatic spring using two methods. The first method was a stiff connection with no possibility of seat deflection in the horizontal plane (Fig. 2, type A). The second solution consisted in the application of a VMS (Vertical Moving System) mechanism making it possible for the seat to be deflected in horizontal plane (Fig. 2, type B). In total, five different designs were investigated.

The examined armchairs were tested in accordance with the standard (PN-EN 1728:2012) (used only in relation to the load) (Fig. 3). An FSA Clinical, Vista Medical Ltd., sensor mat (sensing area 465 mm x 465 mm, poly thickness 2.5 mm, sensor size 11.1125 mm, sensor gap 3 mm, sensor arrangement 32 x 32, cover size 565 mm x 565 mm, number of sensors 1024, sensor surface 211 mm^2, standard calibration range 13.3 kPa) was placed on the seat surface. The mat was first calibrated and then connected to the computer (In-

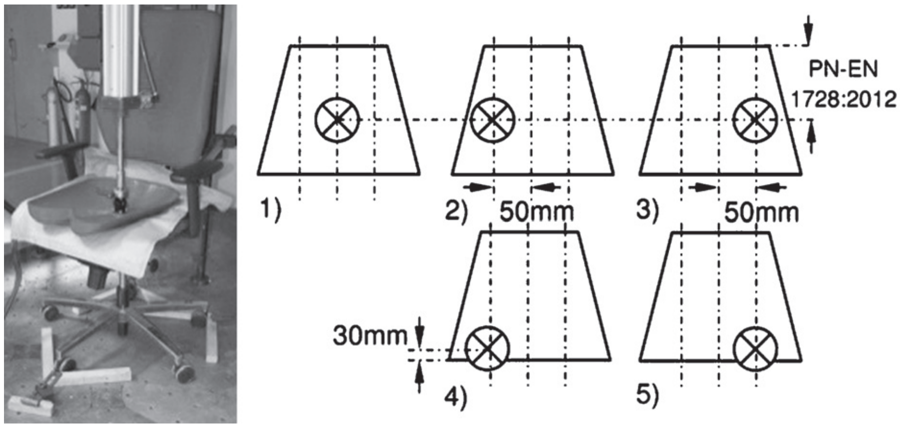

Figure 3 Method and place of loading of armchair seats. Loading types from 1 – 5

Slika 3. Način i mjesto opterećenja uredskog stolca; tipovi opterećenja 1 – 5 tel® Core™ i5 CPU, 2.53 GHz, RAM 4 GB, Windows 7®). Loads were applied only to the seat. The force of 300 N was imposed vertically downward in places indicated in Figure 3. Consecutive load schemes were designated from 1 to 5. Each loading lasted 60 seconds, during which values of the contact stresses between the indenter and the seat were measured with 10 Hz frequency and 0.01 kPa accuracy. Direct measurement results were recorded in a text file and presented graphically as distribution maps of contact pressure.

Indirect experimental results were collated in the form of diagrams comparing the following values: *A* (m^2) - contact area, p_m (kPa) - average contact pressure, *SPD* (%) **-** coefficient (Seat Pressure Distribution, Ahmadian *et al*., 2002).

$$SPD = \frac{\sum_{i=1}^{n} (p_i - p_m)^2}{4 \cdot n \cdot p_m^2} \cdot 100 \qquad (1)$$

where:

n – number of sensors in which contact pressure has non-zero values,

p_i – contact pressure in any mat sensor,

p_m – average contact pressure for n sensors.

Since the comfort of sitting depends directly on the contact area, values of contact pressure as well as on the above-mentioned *SPD* coefficient, a decision was also taken to define and calculate the value of the discomfort coefficient *D* (daN/m^4) determined on the basis of the following formula:

$$D = \frac{p_m}{SPD \cdot A} \qquad (2)$$

In the case of uniform distribution of contact pressure on the seat surface, the p_i pressure at any sensor should be equal to the average pressure p_m. In such case, the *SPD* coefficient should equal zero. Therefore, a seat characterized by low *SPD* values may indicate a more uniform support of the user's body in comparison with seats characterized by high *SPD* values. However, this does not rule out that the developing stresses will be too high for the sitting comfort. In the case of *D* coefficient, it should be expected that high discomfort of the user will be achieved at high p_m pressure as well as at low values of *A* and *SPD*. In such case, low values of the *D* coefficient will speak in favor of a high comfort of seat utilization.

3 RESULTS
3. REZULTATI

Figure 4 presents the distribution of seat contact pressure, when the seats are loaded in accordance with diagrams 1, 2 and 4. It is evident from this Figure that the smallest pressure occurred on seat surfaces of NP type design. At the same time, it should be observed that in the case of diagrams 2 and 4 causing deflection of the column and seat to the right, greater pressure developed on the left side of the seat. In addition, the pressure area exerted by the right thigh was larger than the area of pressure exerted by the left thigh.

Figure 5 presents differences between the contact area, *SPD* coefficient and average contact pressure of seats loaded with the force of 300 N in accordance with diagram 1 developed as a result of comparison of individual design solutions. It is evident that in the case of the NP construction, the contact area was the largest and amounted to 443 cm^2, whereas for BS and BP constructions, it was the smallest and amounted to 371 and 373 cm^2, respectively. In addition, average contact pressure on the NP seat reached the lowest value of

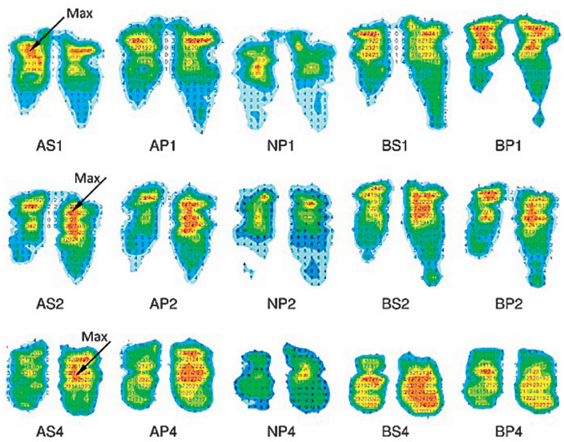

Figure 4 Distribution of contact pressure on the seat surface under loading of type 1, 2 and 4
Slika 4. Raspodjela kontaktnog pritiska na površini sjedala pod opterećenjem tipa 1, 2 i 4

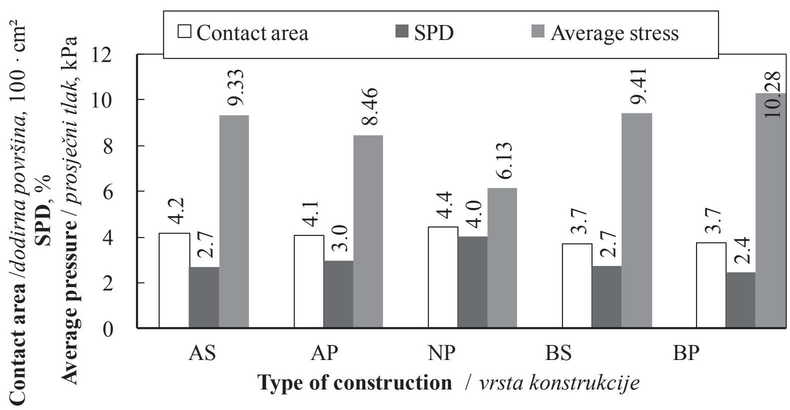

Figure 5 Characteristics of seat stiffness under type 1 loading
Slika 5. Obilježja krutosti sjedala pod opterećenjem tipa 1

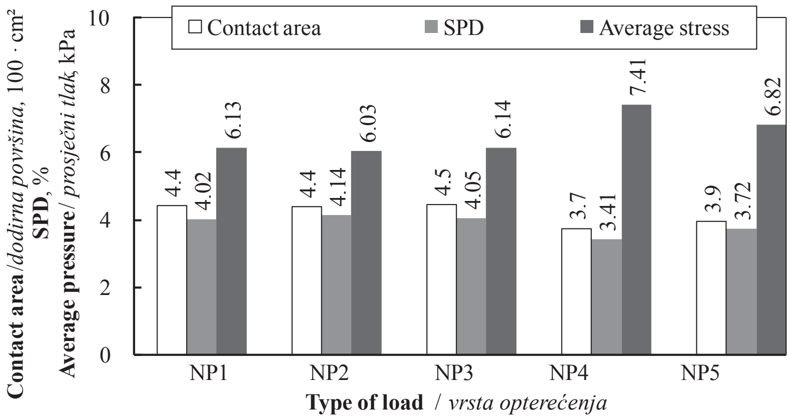

Figure 6 Stiffness characteristics of NP type seats under loads of type 1 – 5
Slika 6. Obilježja krutosti sjedala tipa NP pod opterećenjem tipa 1 – 5

6.13 kPa. These stresses for the BP type seat were the highest reaching 10.28 kPa, while for AS and BS constructions – 9.33 and 9.41 kPa. Despite favorable sizes of contact areas and average contact pressure for seats of NP design, in this case the *SPD* coefficient reached the highest value of 4.0 %, while its values for AP, AS, BS and BP constructions were determined at: 3.0, 2.7, 2.7 and 2.4 %, respectively. In this situation, this means that despite attractive values with respect to the contact area and contact pressure, the seat in the NP construction revealed the highest unevenness of pressure distribution. Therefore, Figure 6 illustrates the impact of load schemes on the quality of these seats. It is clear from Figure 6 that for load schemes 2 and 3 causing deflection of the gas spring column to the right or left, respectively, changes of the contact area, values of average contact pressure as well as of the *SPD* coefficient were small. On the other hand, for load schemes 4 and 5 causing deflection of the gas spring column forward, respectively, to the right or left, the contact area decreased, average value of contact pressure increased and the *SPD* coefficient decreased. In comparison with the load schemes 2 and 3, the value of the contact area, *SPD* coefficient and average contact pressure for the load schemes 4 and 5 changed by: -19 %, -21 %, +19 % as well as by -15 %, -9 % and +10 %.

This regularity appears to indicate that the NP construction favors comfortable sitting since it supports better the user's body during different positions adopted while working.

4 DISCUSSION
4. RASPRAVA

The above observations illustrate well the calculated values of the discomfort coefficient *D*. Figure 7 presents the influence of the seat type construction and load on the *D* coefficient values. It is quite apparent from this Figure that the NP construction ensured the lowest values of the *D* coefficient and, hence, the highest comfort for the user. For the type of load 1-3, the *D* coefficient attained values ranging from 33.1 to 34.4 daN/m^4, whereas for the type of load 4 and 5 – 58.1 and 46.4 daN/m^4, respectively. A typical, widely applied seat of AS construction is characterized by higher *D* coefficients; for example, for the type of load 1-3, the *D* coefficient reaches values from 78.6 to 83.6 daN/m^4, and for the type 4 and 5 - 150.4 and 118.3 daN/m^4, respectively. A change in the method of the gas spring column support from fixed to articulated (AP type) results in a discernible improvement of discomfort coefficient *D*. In such case, for type of load 1 and 3, the *D* coefficient reached the value of 69.3 daN/m^4, for the load type 2 *D*=88.1 daN/m^4 and for load type 4 and 5 - 162.9 and 110.5 daN/m^4, respectively. Moreover, it can also be noticed here that the articulated seat support, as in the case of BS and BP constructions, did not cause a significant comfort improvement. In the case of the BP construction for the load type 1 and 2, coefficient *D* reached the values 112.5 and 100.7 daN/m^4, for the load type 3 - *D*=95.6 daN/m^4, whereas for the type of load 4 and 5 - 178.7 and 147.5 daN/m^4, respectively.

In order to arrange the examined seats into groups characterized by similar properties, statistical analysis of clusters was performed and Figure 8 presents the results of this analysis. The analysis was performed with all types of construction, all loading types as well as four above-mentioned criteria of seat quality assessment. It is apparent from this Figure that two basic construction clusters were formed. The first cluster, characterized by large linkage distances, was formed by the following types: AS4, BP5, AP4, BP4, BS5 and BS4. Large link-

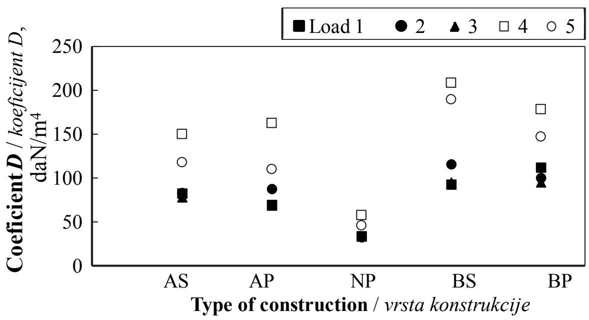

Figure 7 Changes of seating comfort under load type 1 – 5
Slika 7. Promjene udobnosti sjedala pod opterećenjem tipa 1 – 5

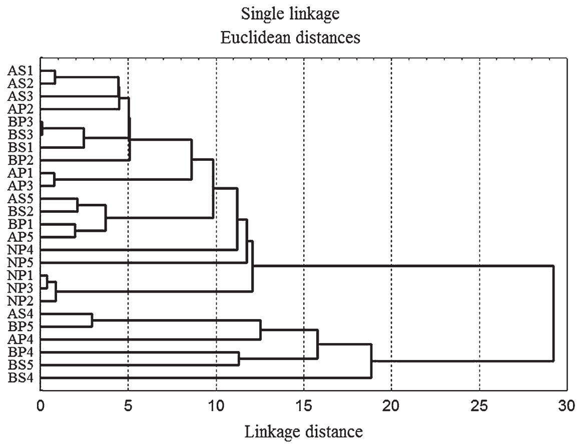

Figure 8 Collation of clusters of seats exposed to type of load 1 – 5
Slika 8. Usporedba klastera sjedala izloženih opterećenju tipa 1 – 5

age distances indicate greater differences between individual types in the cluster. The second cluster was formed by the remaining types. In this group, linkage distances were considerably smaller. On this basis, the second cluster analysis was conducted and four basic groups of similarity regarding comfort were distinguished (Fig. 9). It is evident from Figure 9 that the most important and decisive factor affecting the allocation into individual clusters was the discomfort coefficient *D*. The first cluster comprised the following construction types: AS1, AS2, AS3, BP3, AP1, AP2, AP3, BS1 and BS3; types NP1, NP2, NP3, NP4 and NP5 were allocated to cluster two; cluster three included the following types: AS5, BP1, BP2, AP5 and BS2 and the last, fourth cluster consisted of the following types AS4, BP4, BP5, AP4, BS4 and BS5. The first cluster is dominated by constructions with a fixed linkage of the seat and/or fixed linkage of the gas spring column. The second group is made exclusively of NP type construction characterized by a fixed support of the seat and articulated support of the gas spring. The third group is formed by miscellaneous types of construction but within the range of loads 1, 2 and 5. The last, fourth cluster is made of AS, BP, AP and BS with loads of type 4 and 5. On the basis of the present analysis of aggregations, it can be concluded that NP seats from the second cluster turned out to be the most uniform with respect to sitting comfort. This similarity refers to all load schemes.

5 CONCLUSIONS
5. ZAKLJUČCI

On the basis of the analysis of the obtained research results, it can be concluded that office armchairs of NP type construction, consisting of fixed seat support and articulated gas spring column, were characterized by the highest utilization comfort. Armchairs with the articulated support of the seat and a fixed support of the gas spring column exhibited a distinctly lower utilization comfort. The remaining armchair designs examined in this study can be placed between the abovementioned two solutions and can be described as having intermediate utilization comfort. *D* discomfort coefficient can be treated as an objective criterion of comfort assessment of office armchair seats. Its low values indicate high seat quality. The performed cluster analysis made it possible to select a group of the most comfortable office armchairs and to propose coefficient *D* as a decisive factor affecting the quality of seats.

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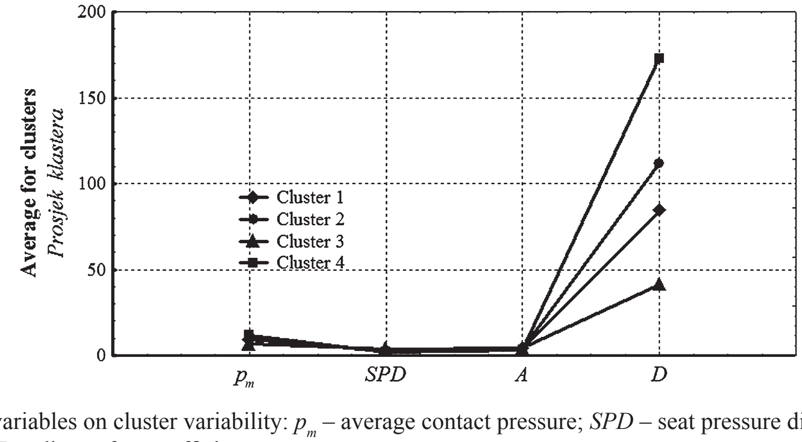

Figure 9 Impact of variables on cluster variability: p_m – average contact pressure; *SPD* – seat pressure distribution; *A* – contact surface; *D* – discomfort coefficient
Slika 9. Utjecaj varijabli na varijabilnost klastera: p_m – prosječni kontaktni pritisak; *SPD* – koeficijent raspodjele tlaka u sjedalu; *A* – kontaktna površina; *D* – koeficijent neudobnosti

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The Effect of Aging on Various Physical and Mechanical Properties of Scotch Pine Wood Used in Construction of Historical Safranbolu Houses

Utjecaj starenja na neka fizikalna i mehanička svojstva škotske borovine upotrebljavane za gradnju povijesnih kuća u Safranbolu

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ABSTRACT • *Wood has been a favourite construction material since the ancient times because of its natural beauty and excellent properties, such as high specific strength, heat insulation and ease of handling and processing. It was also used in Safranbolu, where Turkish Ottoman civil architectural samples have been carefully protected and preserved without losing their originality. It was inscribed to "The World Heritage List" by UNESCO in 1994. In this study, density, Brinell hardness and compression strength perpendicular to the grain of Scotch pine (Pinus Sylvestris Lipsky.) wood, from the floor joist of 10 different demolished historical Safranbolu houses for 10 different years, were determined and compared with those of wood from freshly cut trees. The highest decrease in compression strength perpendicular to the grain of salvaged Scotch pine wood used as floor joist for 210 years was nearly 27 percent lower than those of wood from freshly cut Scotch pine. The results indicate that the physical properties, Brinell hardness and compression strength perpendicular to the grain of the Scotch pine wood were significantly affected by the 210-year service life.*

Keywords**:** *historical Safranbolu houses, historical wood flooring, cultural heritage, density, Brinell hardness, compression strength perpendicular to the grain*

SAŽETAK • *Drvo je još od antičkih vremena zbog svoje prirodne ljepote i izvrsnih svojstava kao što su velika specifična čvrstoća, toplinska izolacija i jednostavnost rukovanja i obrade često upotrebljavano kao građevni materijal. Ono je za tu namjenu iskorištavano i u Safranbolu, gdje su tursko-osmanski civilni arhitektonski primjerci pažljivo zaštićeni i očuvani bez narušavanja njihova originalnog izgleda. Ta je kulturna baština 1994. godine upisana u Popis svjetske baštine UNESCO-a. U ovom su istraživanju prikazani rezultati mjerenja gustoće, tvrdoće*

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prema Brinellu i tlačne čvrstoće okomito na vlakanca na uzorcima drva škotskog bora (Pinus sylvestris Lipsky.) napravljenima od podnih greda iz deset različitih demoliranih povijesnih kuća iz Safranbola iz deset različitih godina. Te su vrijednosti uspoređene s vrijednostima izmjerenima na uzorcima od drva svježe srušenih stabala škotskog bora. Najveće smanjenje tlačne čvrstoće okomito na vlakanca izmjereno je na uzorcima od škotske borovine koja je 210 godina služila kao podna greda. Ta je tlačna čvrstoća bila gotovo 27 % manja od tlačne čvrstoće drva svježe srušenih stabala škotskoga bora. Rezultati pokazuju da je na fizikalna svojstva škotske borovine, tvrdoću prema Brinellu i čvrstoću okomito na vlakanca znatno utjecalo 210 uporabnih godina.

Ključne riječi: *povijesne kuće u Safranbolu, povijesni drveni pod, kulturna baština, gustoća, tvrdoća prema Brinellu, tlačna čvrstoća okomito na vlakanca*

1 INTRODUCTION
1. UVOD

Wood is a naturally durable material that has been recognized for centuries throughout the world for its versatile and attractive engineering and structural properties. However, like other biological materials, wood is susceptible to environmental degradation. When wood is exposed outdoor and above ground, a complex combination of chemical, mechanical and light energy factors contribute to what is described as weathering (Feist, 1982).

Safranbolu is a place where Turkish Ottoman civil architectural buildings have been carefully protected and preserved without losing their originality. It was inscribed to "The World Heritage List" by UNESCO in 1994 as one of the cities that has preserved and protected the characteristics of history to the present day. Hence, Safranbolu has become popular all over the world and the number of domestic and foreign tourists has gradually been increasing.

Safranbolu houses are very specific because they represent ancient urban life and architecture. Safranbolu houses are the structural cornerstones of Turkish urban culture, developed hundreds of years ago and still inhabited nowadays.

Wood is warm to touch and easy to process. Nonetheless, because of its biological nature, unprotected wood is susceptible to weathering, photooxidative degradation and acid precipitation. Although the weathering of woods depends on many environmental factors, such as solar radiation (ultraviolet, visible and infrared light), moisture (dew, rain, snow and humidity), temperature, oxygen and air pollutants, it is generally accepted that only a relatively narrow band of the electromagnetic spectrum of sunlight, i.e., ultraviolet light, is responsible for the primary photochemical process in the weathering or oxidative degradation of wood (Hon and Feist, 1980).

The interaction of photons with polymeric compounds distributed on the wood surface involves some exceedingly complex chemistry and physics. From a chemical point of view, it is not surprising that all chemical wood components - namely, cellulose, hemicelluloses, lignin, and extractive - are susceptible to degradation by sunlight or ultraviolet light. The consequence of this photoreaction normally leads to drastic changes in wood appearance, i.e., discoloration, loss of gloss and lightness, roughening and checking of surfaces and destruction of mechanical and physical properties (Hon, 1983; Turkulin and Sell, 1997).

It is well known that if wood is not exposed to inclement weather conditions, if it is not in contact with the ground and if used at relatively low moisture content in covered structures, it performs well without any treatment (Breyer, 1993).

Weathering of the wood surface due to the combined action of light and water causes surface darkening and leads to formation of macroscopic to microscopic intercellular and intracellular cracks or checks. Strength of cell wall bonds is lost near the wood surface (Feist and Hon, 1983).

In the future, a large amount of wood members from dismantled structures will be available for possible reuse. Wood members that have been protected throughout their life span will be more important than members that have not been protected (Chai *et al*., 2000; Falk *et al*., 1999). Therefore, the effects of service life and age on the mechanical properties of wood that is considered for reuse should be well understood. However, few studies have been conducted on this subject (Bektaş *et al*., 2003.; Fridley *et al*., 1996.; Green *et al*., 2001; Tutuş *et al*., 2004).

It should be appreciated that every application of wood in its natural or unprocessed state is potentially affected by the tendency to a relatively large cross-grain dimensional change, whenever significant moisture content changes in service are expected. For example, the performance of every structural wood connection, with the possible exception of a glued joint, can be affected by different dimensional changes in wood members (Bozkurt, 1986).

The aim of this study is to investigate the effect of 10 different years of service life on some physical and mechanical properties of Scotch pine wood used as floor joist in historical Safranbolu houses in order to determine changes related to services life.

2 MATERIAL AND METHOD
2. MATERIJAL I METODE

2.1 Material
2.1. Materijal

Scotch pine (*Pinus sylvestris* L.) log beams were taken from the floor joist of a demolished wood house in Safranbolu. The age of Scotch pine wood used in historical structures is given in Table 1. The joists had not been exposed to outdoor weathering.

The wood of freshly cut Scotch pine trees (70 years old) from a forest located in the region of Karabuk Turkey was used as a control specimen.

Table 1 Dendrochronology of the samples
Tablica 1. Dendrokronologija uzoraka

Sample No / *Oznaka uzorka*	**Date** / *Godine*
1	1800 - 1894
2	1805
3	1810 - 1891
4	1848 - 1893
5	1868 -1883
6	1822
7	1899 - 1953
8	1924 - 1961
9	1933
10	1929 - 2000

2.2 Determination of density
2.2. Određivanje gustoće

The dry densities of the wood materials used for the preparation of treatment samples were determined according to TS 2472. Accordingly, samples were dried in an oven up to 103 ± 2 °C until they reached constant weights. Then, the samples were cooled in a desiccator containing calcium chloride and weighed in an analytic balance with ± 0.01 g sensitivity. Afterwards, the dimensions of the wood materials were measured by a compass with ± 0.001 mm sensitivity and the volumes were determined by the stereometric method. The oven dry density δ_o (g/cm^3) was calculated with the following equation:

$$\delta_o = M_o / V_o \qquad (1)$$

Where M_o is the oven-dry weight (g) and V_o is the dry volume (cm^3) of wood.

2.3 Brinell hardness
2.3. Tvrdoća prema Brinellu

Both salvaged and freshly cut Scotch pine wood specimens, used to determine mechanical properties, were exposed to 20 °C ± 2 °C and 65 ±5 percent relative humidity (*RH*) until a moisture content (*MC*) of approximately 12 % before the specimens were tested. The following mechanical tests were then performed on a Hardness Tester FV-700 testing machine.

Brinell hardness specimens, 5 cm (longitudinal length), 5 cm (radial length), 5 cm (tangential length), were tested using a Hardness Tester FV-700 according to ASTM-D-4366. In this test, a hemispherical head with a 1 cm diameter was forced into the center of the specimens to a depth of 1 mm with the head speed of 15 min/mm. The load required was recorded in kgf and reported as Newton (N).

$$HB = \frac{2 \cdot F}{\pi \cdot D \cdot (D - \sqrt{D^2 - d^2})}, \text{ kg/mm}^2 \qquad (2)$$

2.4 Compression strength perpendicular to the grain
2.4. Tlačna čvrstoća okomito na vlakanca

The wood samples cut from sapwood were exposed for 3 months to 20 ± 2 °C and 65 ± 3 % relative humidity in a climatization room until they reached constant weight.

Compression strength perpendicular to the grain TS 2473 was determined on match basis. By using a universal test machine, 6 mm/min shear force was applied to the samples. The experiment results are measured, and the compression strength σ_b (N/mm^2) can be calculated from the equation (3).

$$\sigma_b = F_{max} / A \qquad (3)$$

Where:
F_{max} – maximum force at crush (N)
A – sample cross section area (mm^2)

2.5 Statistical analyses
2.5. Statistička analiza

For each physical property of the salvaged and freshly cut Scotch pine wood, averages of 30 measurements were considered. Data for each test were statistically analyzed by using SPSS program. The results were statistically evaluated using analysis of variance (ANOVA) and regression mean separation tests.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

According to Table 1, dendrochronological characteristics of 10 different historical Safranbolu houses were determined. The oldest historical structure sample was 210 years old. Among the specimens, the one that is nearest to today's houses is approximately 10-70 years old. The average densities are given in Table 2.

Table 2 A comparison of various physical properties of salvaged Scotch pine wood and freshly cut Scotch pine wood (g/cm^3)
Tablica 2. Usporedba različitih fizikalnih svojstava uzoraka od starog drva škotskog bora sa svojstvima uzoraka od svježe srušenih stabala

Sample No. *Oznaka uzorka*	**Air-dry density** *Gustoća prosušenog drva* g/cm^3	**Oven-dry density** *Gustoća standardno suhog drva* g/cm^3
1	0.399	0.350
2	0.394	0.348
3	0.404	0.357
4	0.406	0.358
5	0.435	0.382
6	0.437	0.383
7	0.439	0.388
8	0.442	0.389
9	0.451	0.398
10	0.459	0.404
Control (freshly cut wood) / *Kontrolni uzorak (svježe oboreno drvo)*	0.52	0.46

The highest density (0.520 g/cm^3) was obtained in freshly cut samples of Scotch Pine wood. The lowest density (0.394 g/cm^3) was obtained in salvaged Scotch pine wood used as floor joist for 210 years. The averages of Brinell hardness are given in Table 3.

The highest values of Brinell hardness (5.1 N/mm^2) was obtained in freshly cut samples of Scotch Pine wood. The lowest values of Brinell hardness (3.1

Table 3 Average values of Brinell hardness (N/mm²)
Tablica 3. Prosječne vrijednosti tvrdoće prema Brinellu

Sample No. *Oznaka uzorka*	**Sample number** *Broj uzoraka*	**Brinell hardness** *Tvrdoća prema Brinellu* N/mm²
1	30	3.1
2	30	3.1
3	30	3.3
4	30	3.5
5	30	3.8
6	30	3.8
7	30	4.1
8	30	4.5
9	30	4.6
10	30	5
Control (freshly cut wood) *Kontrolni uzorak (svježe oboreno drvo)*	30	5.1

N/mm²) was obtained in salvaged Scotch pine wood used as floor joist for 210 years. The results of multivariance analysis (Brinell hardness) are given in Table 4.

According to the variance analysis, the effects of the years, the effects of the density, and the effects of the years and density together are statistically significant. The results of regression analysis are given Table 5.

According to the regression analysis, in order to determine air dry density and Brinell hardness as well as the relationship between them, regression equations were studied, and it was determined that the best linear equation for all Brinell hardnesses and densities was $HB = a + b \cdot \delta_{12}$. The averages of compression strength perpendicular to the grain are given in Table 6.

The highest compression strength perpendicular to the grain (26.43 N/mm²) was obtained in specimens taken from freshly cut Scotch Pine. The lowest compression strength perpendicular to the grain (19.16 N/

Table 4 Results of multivariance analysis (Brinell hardness)
Tablica 4. Rezultati multivarijantne analize podataka o tvrdoći prema Brinellu

Source *Izvor*	**Type III Sum of Squares** *Tip III - zbroj kvadrata*	***Df***	**Mean Square** *Kvadrat srednje vrijednosti*	***F***	**Sig.**
Corrected Model	118.504	79	1.500	1198.303	0.00
Intercept	3735.359	1	3735.359	2983947.146	0.00
A	7.872	8	0.984	786.058	0.00
B	1.094	47	2.327E-02	18.591	0.00
A* B	0.412	23	1.790E-02	14.302	0.00

a R Squared = 0.998 Factor A - Years Factor B - Density

Table 5 Regression analysis (Brinell hardness and density)
Tablica 5. Regresijska analiza (tvrdoća prema Brinellu i gustoća)

		Unstandardized Coefficients *Nestandardizirani koeficijenti*		**Standardized Coefficients** *Standardizirani koeficijenti*	***t***	**Sig.** *Razina signif.*
Model		B	Std. Error	Beta		
1	(Constant) *konstanta*	-6.799	0.236		-28.749	0.000
	Density *gustoća*	25.136	0.556	0.934	45.220	0.000

a Dependent Variable: Brinell hardness / *zavisna varijabla: tvrdoća prema Brinellu*

Table 6 Average values of compression strength perpendicular to grain
Tablica 6. Prosječne vrijednosti tlačne čvrstoće okomito na vlakanca

Sample No. *Oznaka uzorka*	**Sample number** *Broj uzoraka*	**Compression strength perpendicular to grain** *Tlačna čvrstoća okomito na vlakanca* N/mm²
1	30	19.16
2	30	19.49
3	30	20.02
4	30	19.94
5	30	21.52
6	30	21.45
7	30	21.73
8	30	22.74
9	30	22.61
10	30	24.11
Control (freshly cut wood) *Kontrolni uzorak (svježe oboreno drvo)*	30	26.43

Table 7 Results of multivariance analysis (compression strength perpendicular to grain)
Tablica 7. Rezultati multivarijantne analize vrijednosti tlačne čvrstoće okomito na vlakanca

Source *Izvor*	**Type III Sum of Squares** *Tip III - zbroj kvadrata*	***Df***	**Mean Square** *Kvadrat srednje vrijednosti*	***F***	**Sig.**
Corrected Model	167.210	79	8.446	33.161	0.00
Intercept	9226.753	1	9226.753	1440650.031	0.00
A	10.302	8	5.038	219.781	0.00
B	2.925	47	3.223E-02	11.244	0.00
A* B	1.674	23	4.277E-02	8.286	0.00

a R Squared = 0,923   Factor A - Years   Factor B - Density

Table 8 Regression analysis (compression strength perpendicular to grain and density)
Tablica 8. Regresijska analiza (tlačna čvrstoća okomito na vlakanca i gustoća)

		Unstandardized Coefficients *Nestandardizirani koeficijenti*		**Standardized Coefficients** *Standardizirani koeficijenti*	***t***	**Sig.** *Razina signif.*
Model		B	Std. Error	Beta		
1	(Constant)	-4.096	1.763		-2.323	0.04
	Density	59.394	4.040	0.980	14.702	0.00

a Dependent Variable: Compression strength perpendicular to grain / *zavisna varijabla: tlačna čvrstoća okomito na vlakanca*

mm^2) was obtained in salvaged Scotch pine wood used as floor joist for 210 years. The results of multivariance analysis (compression strength perpendicular to the grain) are given in Table 7.

According to the variance analysis, the effects of the years, the effects of density, and the effects of aging and density together were statistically significant. The results of regression analysis are given in Table 8.

According to the regression analysis, in order to determine the relationship between air dry density and compression strength perpendicular to the grain, regression equations were studied, and it was determined that the best linear equation for all compression strengths perpendicular to the grain and densities was $HB = a + b \cdot \delta_{12}$.

4 CONCLUSION
4. ZAKLJUČAK

For Scotch pine wood used in Safranbolu houses, the decrease in air-dry and oven dry density was approximately 23 percent and 24 percent, respectively. According to Bektas *et al*. (2003), the decrease in air-dry and oven dry density of Scotch pine wood, used for 120 years as a roof beam in a residential house in the district selected in this study, was approximately 10 percent and 8 percent, respectively. It was also reported by Chai *et al*. (2000) that the decrease in air-dry density of about 5 percent was found when southern pine wood was used as floor joist in a warehouse for 90 years.

The highest decrease in Brinell hardness of salvaged Scotch pine wood, used as floor joist for 210 years, was nearly 39 percent lower than that of freshly cut Scotch pine wood. The lowest decrease in Brinell hardness of salvaged Scotch pine wood, used as floor joist for 10-70 years, was nearly 1.9 percent lower than that of freshly cut Scotch pine wood. It was reported by Bektas *et al*. (2003) that the shear strength and Janka hardness of salvaged Scots pine wood, used as roof beams for 120 years, were, respectively, nearly 45 and 11 percent lower than those of freshly cut Scotch pine wood. It may be presumed that given almost the same load and climate conditions, the differences in the decrease of mechanical properties between Crimean juniper used for 180 years and Scots pine used for 120 years may be due to the higher natural durability of juniper wood (Richardson, 1978).

Brinell hardness is affected by the density, humidity, anatomical structure and direction of the material. According to the regression analysis, this kind of relation has been observed between the density of wooden material used in historical structures and their Brinell hardness. Decrease has been observed in both density and Brinell hardness in historical structures, especially in wooden materials for outer surfaces. However, due to continuous adsorption and desorption occurring at the change of seasons, the repetition of this event in historical structures has diminished the hysteresis difference in wooden materials and EMC. This is the reason for the decrease in the evaluation values after 70 years.

The highest decrease in compression strength perpendicular to the grain of salvaged Scotch pine wood, used as floor joist for 210 years, was nearly 27 percent lower than that of freshly cut Scotch pine wood. The lowest decrease in compression strength perpendicular to the grain of salvaged Scotch pine wood, used as floor joist for 10-70 years, was nearly 9 percent lower than that of freshly cut Scotch pine wood. The chemical components responsible for the strength properties of wood can be theoretically viewed from three distinct levels: the macroscopic (cellular) level, the microscopic (cell wall) level, and the molecular (polymeric) level. At the molecular level, the relationship of strength and chemical composition deals with the individual polymeric components that make up the cell wall. The physical and chemical properties of cellulose, hemicelluloses, and lignin play a major role in the chemistry of strength (Winandy and Rowell, 1994).

When certain organisms come into contact with wood, several types of degradation occur. The mechanical damage caused by metabolic action can result in significant losses in strength. Microbial activity via enzymatic pathways induces wood fiber degradation by chemical reactions such as hydrolysis, dehydration and oxidation (Cowling, 1961).

When Scotch pine wood was used as floor joist (in the form of logs) in the houses for different years, its physical properties (including density, compression strength perpendicular to grain and Brinell hardness ratios) were considerably affected by service life.

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The Influence of Cyclic Loading on Ultimate Bending Strength of Beech Solid and Laminated Wood

Utjecaj cikličnog opterećenja na čvrstoću savijanja masivne i lamelirane bukovine

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ABSTRACT • *This work investigates the influence of cyclic loading of beech solid and laminated wood of various thicknesses on ultimate bending strength (ultimate flexural strength) σ_p during bending in radial direction. For identification of ultimate bending strength, the static bending test with three-point loading was used. The ultimate bending strength was detected on testing samples that were not cyclically loaded and the results were compared with other results obtained from samples that were cyclically loaded. The results of this work show that the influence of cyclic loading on values of ultimate bending strength for solid and laminated wood is not significant. Thickness influence is a significant factor for both tested materials. The results show that the increase of thickness causes the decrease of ultimate bending strength. In our opinion, the decrease of ultimate bending strength is not caused by the sample thickness but by different sample lengths. With the increase of the sample length, the influence of inhomogeneous wood properties also increases.*

Key words: *cyclic loading, laminated wood, solid wood, ultimate bending strength, beech wood, PVAC adhesive*

SAŽETAK • *U radu se opisuje istraživanje utjecaja cikličnog opterećenja masivne i laminirane bukovine različitih debljina na graničnu čvrstoću savijanja (maksimalnu čvrstoću izvijanja) σ_p tijekom savijanja u radijalnom smjeru. Za određivanje granične čvrstoće savijanja primijenjen je statički test savijanja s tri točke opterećenja. Granična čvrstoća savijanja određena je na uzorcima drva koji nisu bili ciklično opterećivani te je uspoređena s rezultatima dobivenima na uzorcima koji su bili ciklično opterećivani. Rezultati istraživanja pokazuju da utjecaj cikličnog opterećenja na vrijednosti granične čvrstoće savijanja za masivnu i lameliranu bukovinu nije statistički značajan. Debljina uzoraka imala je znatan utjecaj na graničnu čvrstoću savijanja u obje skupine uzoraka; rezultati pokazuju da se s povećanjem debljine smanjuje granična čvrstoća savijanja. Pretpostavlja se da smanjenje granične čvrstoće savijanja nije prouzročeno povećanjem debljine materijala već različitom duljinom uzoraka. S porastom duljine uzoraka povećava se i utjecaj nehomogenih svojstava drva.*

Ključne riječi: *ciklično opterećenje, lamelirano drvo, masivno drvo, granična čvrstoća savijanja, bukovina, PVAc ljepilo*

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1 INTRODUCTION
1. UVOD

Lamination is the technology for producing a wood composite material - lamella. This technology is known mainly in the U.S., Canada and Scandinavian countries, but it is usually used in construction (Razumov *et al*., 2013) and not in the furniture industry. In Slovakia, the lamellae are mainly used for the production of some parts of beds.

Laminated veneer lumber is produced by combining thin wood veneers. Veneers are usually 3 mm thick and made by slicing (Barcík *et al*., 2011; Glos *et al*., 2004; Frese and Blaß, 2006). Direction of veneer fibers of laminated veneer lumber is parallel to the length of the finished products. The resulting product is characterized by improved mechanical properties and good dimensional stability compared to solid wood, which is why it is increasingly applied for the production of finished products for various purposes. Both hard and soft woods can be used for the production of laminated wood, depending on the needs of the customer. It is also possible to combine different types of wood according to their strength - e.g. outer layers of lamellae composed of softwood for aesthetic appearance and inner layers made from hardwood to achieve higher strength (Gáborík *et al*., 2001).

The aim of this research was to determine the effect of cyclic loading on strength properties of beech solid and laminated wood. Durability (lifetime) of these products varies considerably, affecting the properties of the material itself. As a result of long term use, the characteristics of furniture components change and over time cease to perform the function for which they were intended (Brutovský, 2013; Gaff, 2003; Gáborík and Dudas, 2006, 2008).

Our goal is to expand the knowledge related to certain products, which should largely determine the influence of monitored factors on the related characteristics and thus help to produce quality furniture products.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

The aim of this experiment was to determine the influence of cyclic loading on the ultimate bending strength σ_p of beech wood (*Fagus sylvatica* L.) - solid and laminated wood, when bending in the radial direction. The experiment investigated the changes of monitored characteristics that occurred after 0, 1000, 2000, 3000 cycles. For the purpose of detecting the influence of material thickness, tests were performed on samples made of 2 mm thick veneer glued together. The exact categorization of test pieces, for individual sets, is shown in Figure 1. The final dimensions of the test samples (after laminating) were b = 40 mm (width), h = 4, 6, 10, 18 mm (thickness), l = (20·h) mm. The moisture content of test samples was 8 %. Laminated wood was glued by PVAC adhesive Duvilax D3 Rapid, with the following parameters:

- dry matter content: 49 %,
- viscosity: 4000 - 8000 m Pa·s,
- pH: 3-4,
- minimum film-forming temperature: 10 °C,
- working time: 10 minutes,
- working temperature: 15-100 °C,
- drying time at 20 °C: 10 - 30 minutes,
- wood moisture content: 8-12 %.

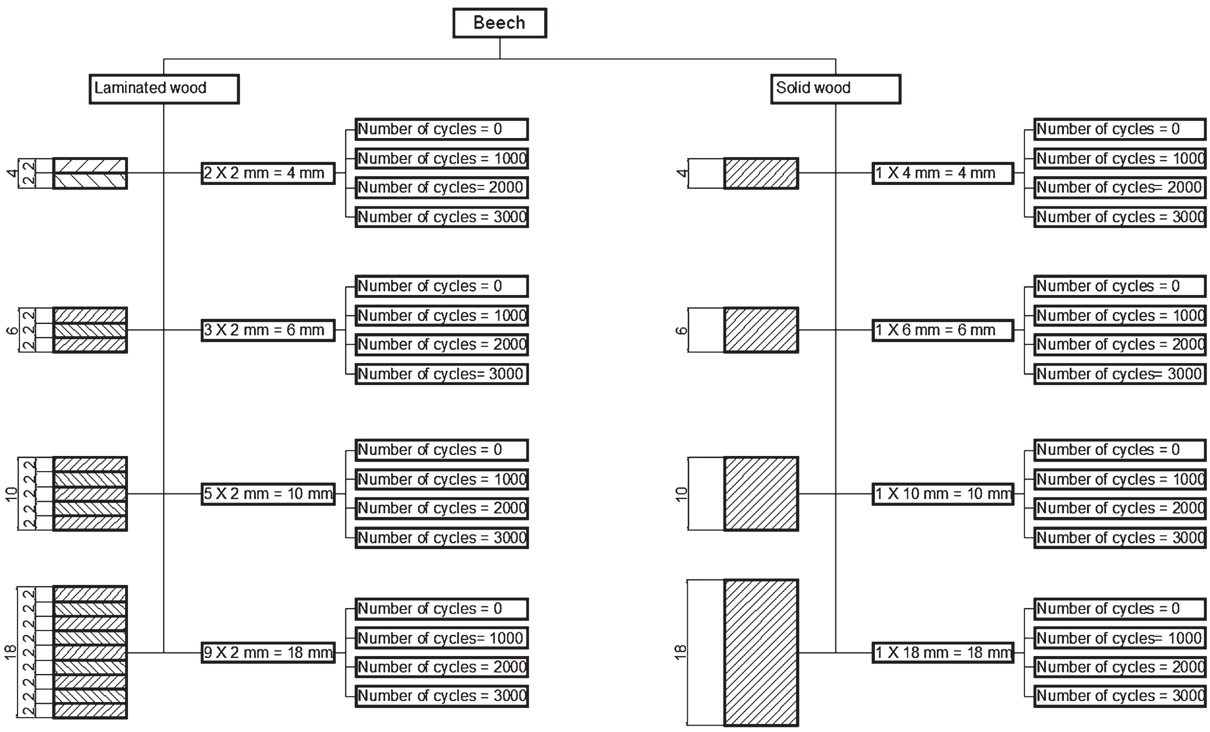

Figure 1 Categorization of testing sample sets
Slika 1. Kategorizacija uzoraka za provedbu istraživanja

2.1 Determination of ultimate bending strength
2.1. Određivanje granične čvrstoće savijanja

The varying thickness of test samples had to comply with the condition, which provides a span of 20·*h*. Loading rate was set so that the breaking of the test sample occurred during the 1.5 ± 0.5 min from the start of loading. Flexure was measured at the center of the test sample under bending pin to the accuracy of 0.1 mm, and the measured value was recorded together with the corresponding loading measured to the accuracy of 1 % of the measured values (Fig. 2). Loading break was recorded to the accuracy of 1 % of the measured value.

The ultimate bending strength, at three-point bending, was calculated according to Equation 1 from STN 490115 and Gáborík *et al*. (2011):

$$\sigma = E \cdot \varepsilon = \frac{3 \cdot F \cdot l_0}{2 \cdot b \cdot h} \quad (1)$$

Where:
σ – ultimate bending strength, MPa,
F – load (force) at fracture point, N,
l_0 – axial length of support span (l_0 = 20·h), mm,
b – test sample width, mm,
h – test sample thickness, mm,
E – modulus of elasticity (flexural modulus), MPa,
ε – relative strain (deformation).

Measured and calculated values are converted to ultimate bending strength at 12 % moisture content rounded to 1 MPa according to STN 490115 and Equation 2:

$$\sigma_{12} = \sigma_w \cdot [1 + \alpha \cdot (w - 12)] \quad (2)$$

Where:
σ_{12} – ultimate bending strength of wood at 12 % moisture content, MPa,
σ_w – ultimate bending strength of wood at a certain moisture content, MPa,
w – moisture content of the test sample during testing, %,
α – moisture correction factor, which is 0.04 for all wood species.

2.2 Cyclic loading by bending
2.2. Ciklično opterećenje na savijanje

Cyclic loading of samples was performed by a cycler machine (Fig. 3), which is based on the principle of cyclic bending of test samples by uniaxial (unilateral) loading. The number of cycles was 0, 1000, 2000 and 3000. In preliminary tests, test samples were loaded by static bending in order to detect ultimate strength and proportionality limit, because the test samples were to be loaded to 90 % of proportionality limit (Maro, 2012; Brutovský, 2013). 90 % proportionality limit was chosen so as not to exceed the value due to the diversity of material properties. This action will ensure that all test samples will be loaded so that the limit of elastic area is not exceeded.

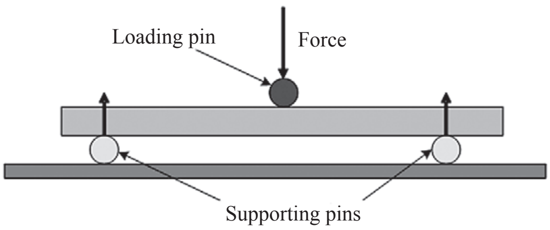

Figure 2 Basic principle of three point bending test
Slika 2. Osnovno načelo testa savijanja s tri točke

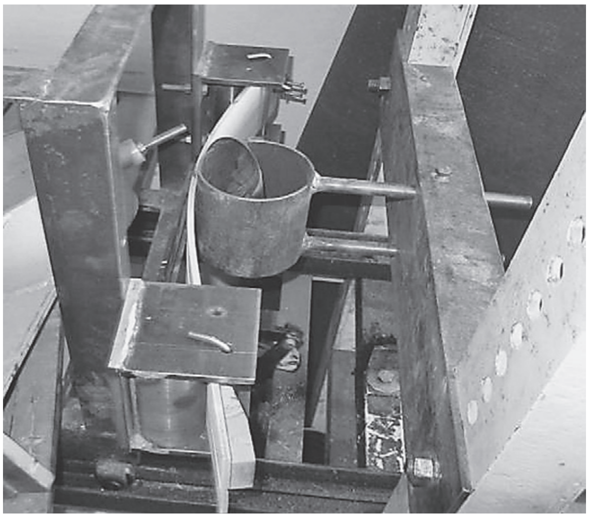

Figure 3 Cycler machine
Slika 3. Uređaj za ciklično opterećenje

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Laminated wood
3.1. Lamelirano drvo

Table 1 shows the results of variance analysis that evaluates the influence of the material thickness, number of cycles and their mutual interaction. According to these results, it can be concluded that the influence of cyclic loading has no significant effect on the values of ultimate bending strength for laminated beech wood (Fig. 4).

Table 1 also shows that the second test factor – material thickness, has a significant influence on the values of the tested characteristics. Mutual interaction, between the number of cycles and material thickness, also has a significant effect.

However, the influence of the test factor, number of loading cycles, on the values of ultimate bending strength can be considered as insignificant (Fig. 4).

If material thickness increases, then the values of ultimate bending strength go down (Fig. 5). Statistically the most significant difference occurs at material thicknesses of 6 mm, 10 mm and 18 mm.

Basically the variance analysis that evaluates the influence of interaction between the two factors – material thickness and number of cycles on ultimate bending strength (Tab. 1), shows that statistically the effect of this interaction of factors is moderately significant (Fig. 6).

Graphs of 95 % confidence intervals represent the influence of material thickness and number of cycles on ultimate bending strength during bending of laminated wood (Fig. 6) and show that the influence was proved because of expressive effect of various material thicknesses.

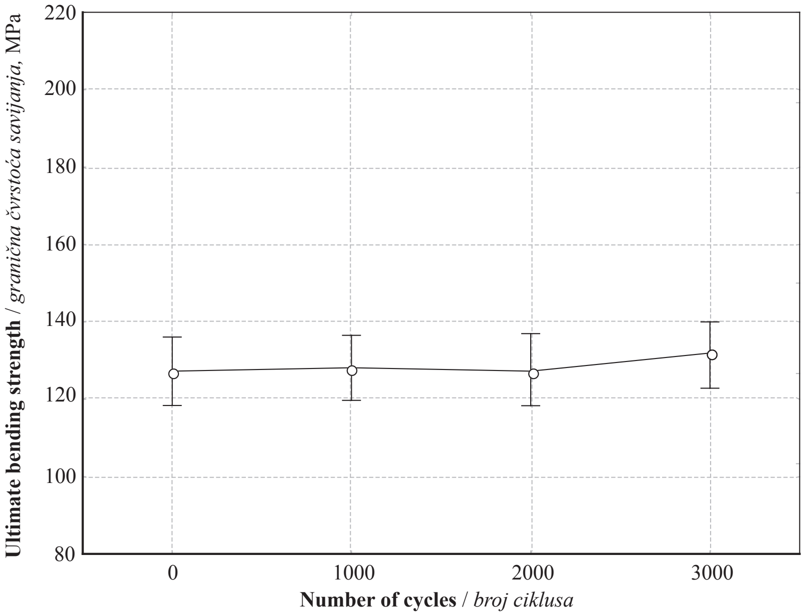

Figure 4 Influence of number of cycles on ultimate bending strength during bending of laminated wood
Slika 4. Utjecaj broja ciklusa opterećenja na graničnu čvrstoću savijanja uzoraka od lamelirane bukovine

Table 1 Basic table of two-factor analysis of variance that evaluates the influence of individual factors on the change of ultimate bending strength values of laminated wood
Tablica 1. Osnovna tablica analize varijance za ocjenu utjecaja pojedinačnih činitelja na graničnu čvrstoću savijanja lameliranog drva

Monitored factor *Promatrani činitelj*	**Sum of squares** *Zbroj kvadrata*	**Degrees of freedom** *Stupanj slobode*	**Variance** *Varijanca*	**Fisher's *F* – Test** *Fišerov F-test*	**Significance level *P*** *razina signifikantnosti P*
Absolute term / *apsolutni razmak*	2,647,947	1	2,647,947	17,583.79	0.000000
Number of cycles / *broj ciklusa*	594	3	198	1.31	0.271996
Material thickness *debljina materijala*	69,112	3	23,037	152.98	0.000000
Number of cycles * Material thickness / *broj ciklusa * debljina materijala*	4,424	9	492	3.26	0.001215
Error / *pogreška*	21,685	144	151		

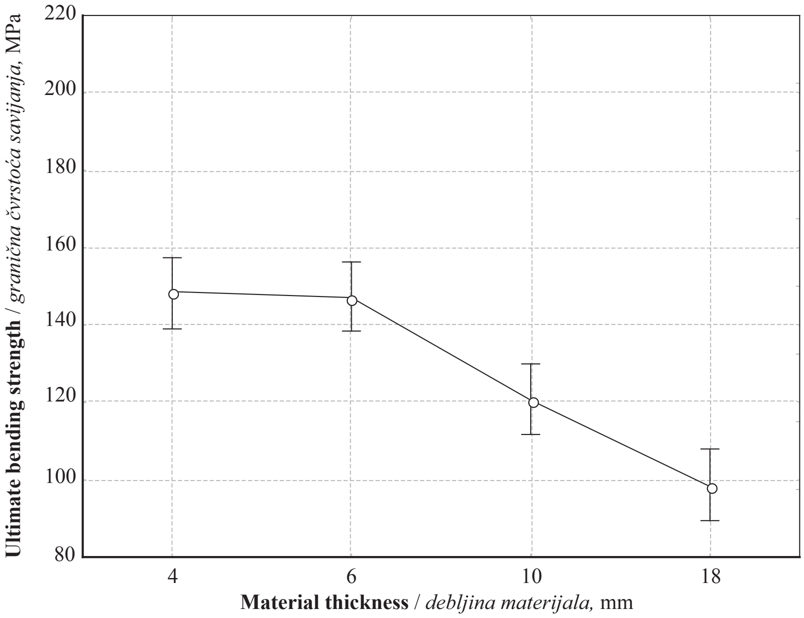

Figure 5 Influence of material thickness on ultimate bending strength during bending of laminated wood
Slika 5. Utjecaj debljine materijala na graničnu čvrstoću savijanja uzoraka od lamelirane bukovine

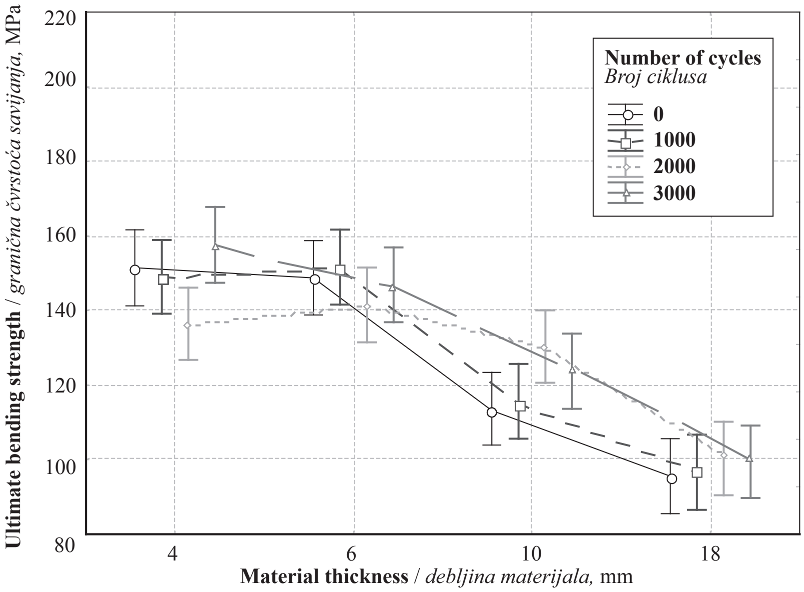

Figure 6 Influence of material thickness and number of cycles on ultimate bending strength during bending of laminated wood
Slika 6. Utjecaj debljine materijala i broja ciklusa opterećenja na graničnu čvrstoću savijanja uzoraka od lamelirane bukovine

3.2 Solid wood
3.2. Masivno drvo

When evaluating the influence of test factors on ultimate bending strength of solid wood (Tab. 2), the same results were obtained as for laminated wood (Tab.1). The influence of the number of cycles was statistically insignificant, while the influence of material thickness was statistically significant in affecting the values of ultimate bending strength of solid wood.

Statistically, the interaction between the test factors was moderately significant, similarly as with laminated wood. Statistically insignificant influence of the number of cycles on ultimate bending strength is also proved by the results shown in Figure 7.

The values of ultimate bending strength decrease with the increase of thickness of solid wood as shown in Figure 8. This figure also proves that the lowest values of ultimate bending strength were measured at 18 mm material thickness.

The graph of confidence intervals represents the influence of the number of cycles and material thickness on ultimate bending strength during bending of solid wood (Fig. 9). This graph shows that with the increase of material thickness, the values of ultimate bending strength go down. The number of cycles has no statistically significant effect on values of ultimate bending strength.

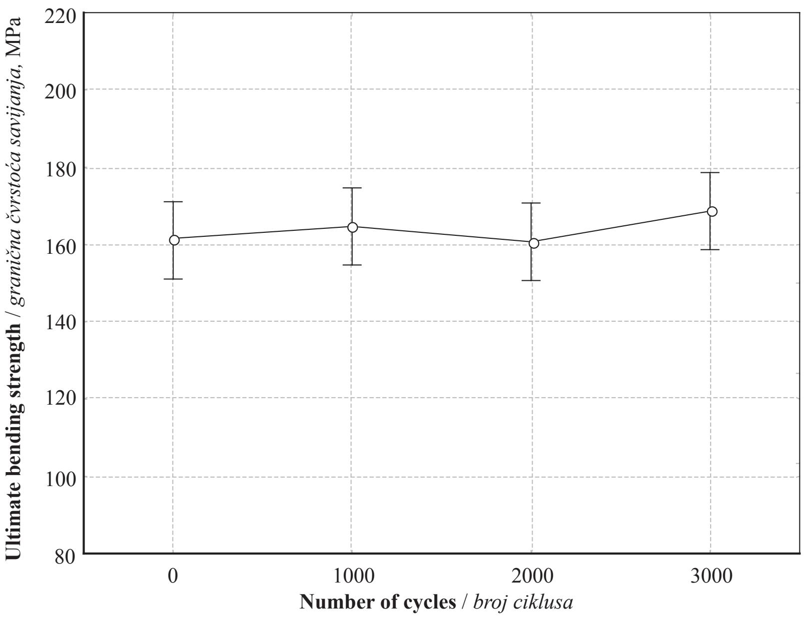

Figure 7 Influence of number of cycles on ultimate bending strength during bending of solid wood
Slika 7. Utjecaj broja ciklusa opterećenja na graničnu čvrstoću savijanja uzoraka od masivne bukovine

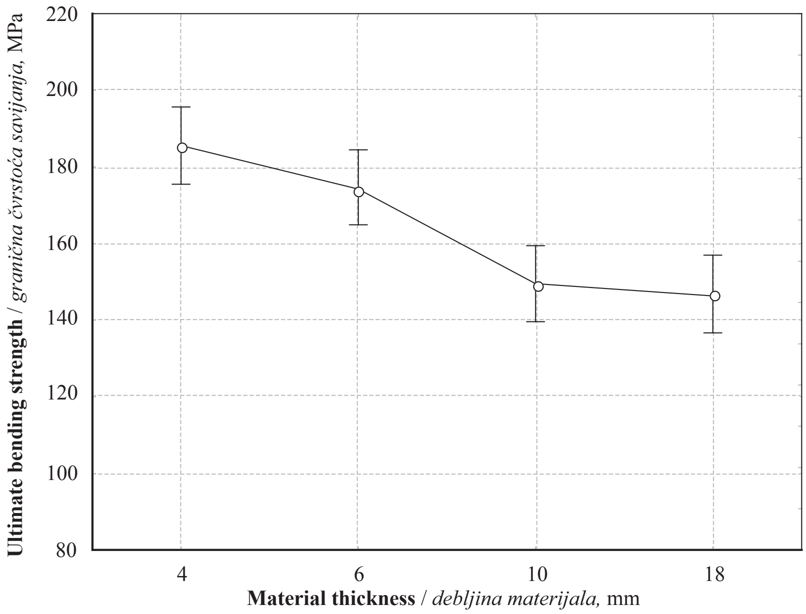

Figure 8 Influence of material thickness on ultimate bending strength during bending of solid wood
Slika 8. Utjecaj debljine materijala na graničnu čvrstoću savijanja uzoraka od masivne bukovine

Table 2 Basic table of two-factor analysis of variance that evaluates the influence of individual factors on change of ultimate bending strength of solid wood
Tablica 2. Osnovna tablica analize varijance za ocjenu utjecaja pojedinačnih činitelja na graničnu čvrstoću savijanja masivne bukovine

Monitored factor *Promatrani činitelj*	**Sum of squares** *Zbroj kvadrata*	**Degrees of freedom** *Stupanj slobode*	**Variance** *Varijanca*	**Fisher's *F* – Test** *Fišerov F-test*	**Significance level *P*** *razina signifikantnosti P*
Absolute term / *apsolutni razmak*	4,298,682	1	4,298,682	16,011.79	0.000000
Number of cycles / *broj ciklusa*	1,548	3	516	1.92	0.128635
Material thickness / *debljina materijala*	43,619	3	14,540	54.16	0.000000
Number of cycles * Material thickness *broj ciklusa * debljina materijala*	7,303	9	811	3.02	0.002456
Error / *pogreška*	38,660	144	268		

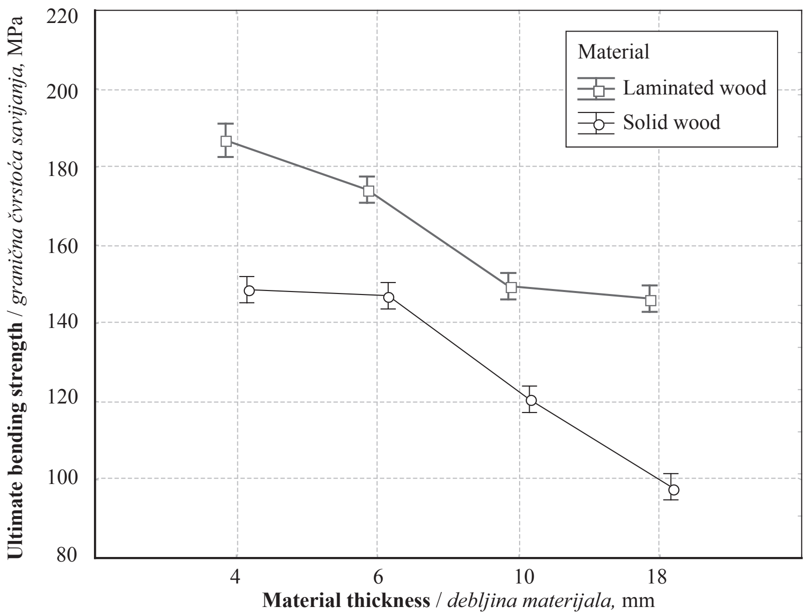

Figure 9 Influence of material thickness on ultimate bending strength during bending of laminated wood and solid wood
Slika 9. Utjecaj debljine materijala na graničnu čvrstoću savijanja uzoraka od lamelirane i masivne bukovine

Generally, laminated wood showed the lowest values of ultimate bending strength (Fig. 9).

Measurements prove that solid wood has about 30 MPa higher values of ultimate bending strength than laminated wood. These results (ultimate bending strength goes down with increasing material thickness) also correspond to the results of Stark (1997), who found out that if conditions of slenderness ratio (20 x material thickness) are kept at a level, the values of ultimate bending strength goes down because of increasing of material length. In fact, heterogeneous distribution of properties is higher with the increase of material length.

Other possibilities of modification of these materials should be sought aimed at improving the properties of furniture.

4 CONCLUSIONS
4. ZAKLJUČAK

Based on the results of this study, the following conclusions and recommendations can be made:

- number of loading cycles has no significant effect on values of ultimate bending strength with either test material (solid and laminated wood),
- material thickness has a strong influence. With the increase of material thickness, the values of ultimate bending strength of both types of material go down significantly,
- the interaction of material thickness and number of cycles affects the values of ultimate bending strength. However, Figure 5, 6, 9 and 10 show that this influence is caused by material thickness,
- generally, when comparing individual results, it can be stated that the values of ultimate bending strength of laminated wood are on average about 30 MPa lower.

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Data Filtration Methods of Electronic Measurement of Log Dimensions

Metode filtriranja podataka elektroničkog mjerenja dimenzija trupaca

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ABSTRACT • *The article deals with the processing of log dimension data collected by electronic measurement during reception at sawmills. The subject of the work concerns the filtration of data before their use for calculation. Filtration methods were designed based on simple mathematical and statistical methods, and compared and evaluated with the use of a designed comparative methodology. As a result, five filtration methods were selected that best suit the reception requirements. At the same time, the impact of filtration on the measurement results is evaluated in relation to the calculation method of wood volume. Furthermore, the calculation by sections is recommended, as it is less affected by filtration errors.*

Key words: *log yards, round wood, electronic reception, electronic measurement, data filtration*

SAŽETAK • *Članak se bavi obradom podataka dobivenih elektroničkim mjerenjem dimenzija trupaca pri ulasku u pilanu. Posebna se pozornost pridaje filtriranju podataka prije upotrebe za izračun. Metode filtriranja dizajnirane su na osnovi jednostavnih matematičkih i statističkih metoda te uspoređene i vrednovane primjenom dizajnirane komparativne metodologije. Rezultat rada je pet odabranih metoda filtriranja podataka koje najbolje odgovaraju zahtjevima preuzimanja trupaca. Također, procijenjen je utjecaj metode filtriranja podataka na metodu proračuna obujma trupaca. Osim toga, preporučena je metoda za izračun obujma trupaca na koju najmanje utječu pogreške pri filtriranju podataka.*

Ključne riječi: *stovarište trupaca, oblo drvo, elektronički prijem, elektroničko mjerenje, filtriranje podataka*

1 INTRODUCTION
1. UVOD

In 2009, electronic receptions of logs were performed in approx 45 plants in the Czech Republic (Solař and Janák 2011). Regarding the number of sawmills, the number of installed devices is relatively small. Despite this fact, 6.8 million m^3, i.e. 75 % of all sawlogs, passed through them. The majority (70 %) is measured by 3D devices, which scan the whole peripheral curves of sawlogs. These devices are usually installed at large plants whose output exceeds 100 000 m^3 of processed logs per year. 2D devices are typical for sawmills with the output of 30 000 m^3 to 100 000 m^3. Although these devices prevail in the Czech Republic (70 %), only 30 % of the volume of electronically received material passes through them. 1D scanning for the needs of the reception is rather rare (approx 1 % of electronically received material).

The experience of suppliers and entities processing and buying logs with the results of electronic reception are different. The suppliers are mostly complaining (not always) about the lower final material volume calculated by 3D measuring. In contrast, the

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entities processing and buying logs are satisfied with this situation. According to the experience of both sides, the reception results of 2D measurements are more or less satisfactory. The experience is always based on manual measurements of the material in the forest. The accuracy of measuring diameter and length of sawlogs by all checked devices is high and balanced. According to the results of measurements performed by an accredited calibration laboratory, the mean deviation of sawlog diameter measurements ranges around ± 2 mm.

On the basis of the conducted research at the Faculty of Forestry and Wood Technology, Mendel University in Brno (Janák *et al*., 2005), it is possible to divide the factors affecting the results of electronic reception into the following areas:

- wood properties (shape, defects, mechanical damage),
- method of dimension scanning (mainly 3D and 2D),
- data processing method (evaluation of dimensions and volume of sawlogs).

Foreign works mainly deal with the accuracy of the measuring device itself, simplification of calculation operations, etc. The work *Automated Detection of Surface Defects on Barked Hardwood Logs and Stems Using 3-D Laser Scanned Data* (Thomas, 2006) can be mentioned as an example. Similarly, possible methods of classifying logs for specific purposes on the basis of surface features, detectable with the use of 3D scanning, are dealt with by Jäppinen (2000) in his dissertation. Many works concern improved accuracy of harvester measuring devices and their calibration, respectively. The processes of log dimension and quality evaluation with different degree of automation is dealt with by e.g. Marshall (2005). Among others, he describes the factors affecting the measurement quality. He considers the type of measuring device, speed of dimension scanning, degree of automation, tree species, and the method of sawlog volume calculation as the significant factors.

The research, partly addressed by this study, is focused on processing the collected data.

The method to determine sawlog dimensions and volumes is specified in regulations and standards, according to which the electronic reception is performed. The regulation defines directions and intervals of sawlog diameter scanning, the method of data conversion from mm into cm, determination of diameter at the measurement place, bark measurement, sawlog mid diameter calculation, and the method of volume calculation. The mentioned steps can be performed by different methods, with different accuracy, and in different order. The specific regulation used for a given reception is always agreed on between the supplier of logs and customer.

The determination of volume from the measured data is performed by two methods: calculation based on mid diameter (so-called Huber method), or calculation by sections into which the sawlog is divided (e.g. of the length of 10 cm). Previous research makes it clear that the use of Huber method is subjected to measurement errors significantly more than the calculation by sections (Šmelko, 2003). This author claims that other errors occur due to the trunk shape and position of the sawlog in the stem. The volume determined by Huber method is lower for butt logs by approx 4 %, and by approx 5 % for top parts than the real volume. In the central part of sawlogs, the error does not exceed 1 %.

The experimental verification of the difference between the above mentioned methods of determining sawlog volume (Janák and Peter, 2004) confirmed that the total deviation of the method by sections from Huber method was 1.0 %, when calculated without rounding.

Measuring systems provide just a raw source signal with a number of errors occurring at the optical scanning of sawlog surface (shape anomalies of sawlogs, surface damage, torn grains, branch rests, bark, dirt, etc). Before using the collected data for the calculation specified in the regulations, it is necessary to eliminate the errors. This is the role of filtration, which then becomes a necessary step for the processing of the measured results. 2D scanning devices currently use the filtration based on simple methods, predominantly on moving average. Apart from the elimination of errors, the filtration may distort the data on shape and dimensions of the measured logs and thus affect the resultant volume. However, the filtration is not described in the regulations at all and neither is the method of its performance.

The aim of this study is to design different simple and complex filtration methods, evaluate their influence on the evaluated shape and volume of stem sawlogs, and recommend suitable filtration procedures for reception. A subsequent aim is to evaluate the effect of filtration methods on the evaluated volume of sawlogs.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

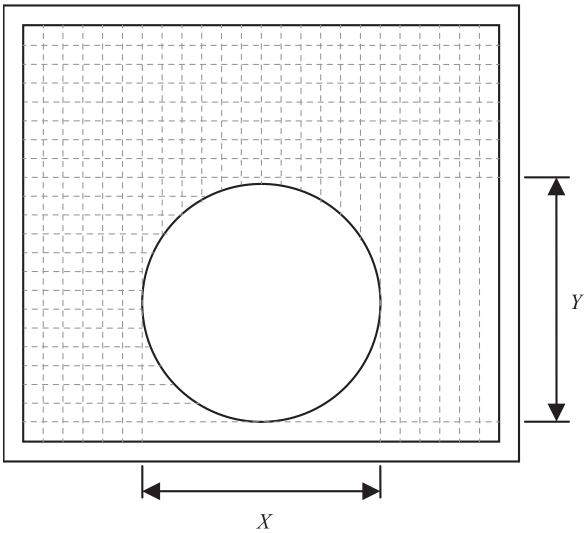
The designed filtration methods will be used for the correction of data collected within a common measurement for the needs of reception and processing of sawlogs. Therefore, they need to be based on the standard and currently used structure of scanned data.

Therefore, the data used for the research come from 2D measurement of sawlog diameter (Fig. 1). The measurements were performed vertically and horizontally. The values of pairs of mutually perpendicular sawlog diameter (hereinafter marked X and Y) are available in millimetres for every 10 cm of sawlog length.

The data were scanned by Inframat 760.2, made by Eltes Šumperk, and long-term stored on discs of computers in the plants of Pila Tetčice, a.s. and JILOS Horka, s.r.o. in 2008 and 2009. In total, data on 250 000 measured logs were stored.

For comparisons of simple filtration methods, data on 189 sawlogs were selected at random, and for comparisons of complex filtration methods, data on 901 sawlogs were selected.

In order to perform tests of filtration methods for end values, the pieces with defects close to the fronts



Length of the stem *duljina trupca*	Diameter *promjer*	
a cm	*X* mm	*Y* mm
0	354	348
10	336	357
20	345	351
30	369	357
40	354	351
50	336	351
60	336	351
70	339	357
80	345	360
90	345	375
…	…	…

Figure 1 2D measurement scheme and example of measured values
Slika 1. Shema 2D mjerenja i primjer izmjerenih vrijednosti

were selected. The selection was performed on the basis of a visual assessment of a graphic display of sawlog surface curve. The data set contained 27 sawlogs.

All filtration method tests were performed on sawlogs of 4 m length.

2.1 Used filtration methods
2.1. Primijenjene metode filtriranja

Filtration methods were designed in consecutive steps.

In the first phase, simple methods were designed. They were evaluated according to the effectiveness when removing values significantly differing from standard values. These methods were reliable regarding the sawlogs without shape anomalies. However, regarding more complicated shapes (buttresses, undercuts), they considerably distorted the total evaluated sawlog shape. Therefore, filtration methods focused only on these problematic sawlogs, and usually end parts of sawlogs were designed and evaluated. Based on the findings, more complex methods were designed that combine the advantages of individual simple methods and methods for end values. These methods were marked by letter *f* and a sequence number.

In total, 69 methods were designed for the filtration of measured data. They can be divided according to their purpose into:

- methods focused on filtration of values ± even course of sawlog shapes (mainly in the middle of the log),
- methods focused on identification and filtration of values of more complicated sawlog parts in terms of shape (mainly in their end parts),
- combined methods taking into account both types (both parts) of their courses.

Simple methods *(f1-f7)* use basic procedures for data processing and for the determination of general characteristics of individual files. They include moving averages and linear regressions. A method was derived for the filtration of data for electronic log reception. This method is based on the same principle as moving average, but it replaces the average with a median.

The moving average is calculated as an arithmetic average from a row of consecutive measurements and replaces its value with a value of this measurement which is in the middle of the row. When using the even number of values, it is necessary to further calculate the assigned value. Therefore, it is easier to use an odd number of values for the filtration purposes. The moving median works similarly, but assigns a median instead of arithmetic average. Thus, it is not affected by extreme values. The number of elements from which the moving average (median) is calculated is the smoothing width. Neither moving average nor median are able to calculate the values for data at the edges of data sets.

Simple filtration methods used in this study consist of moving average with the smoothing width of 3, 5 and 7 (*f1–f3)*, moving median with the smoothing width of 3, 5 and 7 (*f4–f6)* and linear regression (*f7*).

Filtration methods for end values (*f8–f17*) focus on areas near sawlog ends. There are often outstanding values caused by buttresses, undercuts, or oblique cuts. During a common filtration process, these values may influence the course of the whole evaluated sawlog shape. An undercut or an oblique cut are defects whose presence reduces the usable length of a sawlog. After its identification, it is necessary to reduce (filter) the sawlog length by the length of such defect. A buttress is a stem butt swelling, which, after detection, only needs to be smoothed by filtration, not removed. Each of the methods designed for the filtration of end values thus consists of a part for the identification of both defect types and subsequently for their filtration.

In order to detect an undercut or an oblique cut, the methods are based on the comparisons of sawlog diameter values measured in both mutually perpendicular directions. The difference between these values is compared with the selected limit value (methods *f8*, *f14* – value 150; *f9*, *f15* – value 100) or with one fifth (*f10*), or one quarter (*f11*) of the median, respectively, of nine values corresponding with the position measured 130 cm from the end of the sawlog. The last two methods compare the difference of a measured value on a given position and the median of all measured values in one direction with the value of 100 (*f16*) and one fifth of the median of all values (*f17*). In case the difference is greater than the compared value, the measured piece has most likely a large undercut or an oblique cut.

The second part of the methods for end values focuses on the detection of buttresses. In the Recommended Guidelines for measuring and classification of wood in the Czech Republic (composite authors 2007), an instruction is given to remove buttresses, so that their height over the round area does not exceed 3 cm. Based on this regulation, boundary values are determined as 73 (*f8*), 53 (*f9*), one sixth of the median at the position of 130 cm (*f10*, *f12*), one seventh of the same median (*f11*, *f13*), with which the difference between the measured value and the median on the position of 130 cm is compared.

Other methods determine the presence of the buttress with the use of a median from all values and the following values are considered the limit difference: 80 (*f14*), 60 (*f15*, *f16*) and one sixth of the median of all values (*f17*).

The above limit values (150, 100; 73, 80, 60) were derived from typical or permitted shape deviations of sawlogs and subsequently adjusted according to the filtration results.

Complex filtration methods (*f18 to f69*) consist of simple methods and end value methods for the evaluation of their advantages and drawbacks.

They can be divided into two groups. The first group includes the methods working on the principle of moving medians of different degrees of smoothing (3 to 7), which have the end values complemented with moved medians or with minimum values. The second group contains methods that compare the measured values with medians in order to detect the extreme. In case their difference or quotient exceeds the limit value (15, 20, 25 mm or 1.05 and 1.08), the initial measured value is replaced with a new one. In case it is not exceeded, the initial value is still valid. New values are based on the calculation of a median of a different degree of smoothing or on the detection of the minimum.

2.2 Evaluation of filtration methods
2.2. Evaluacija metoda filtriranja podataka

2.2.1 Visual evaluation of filtration methods for end values
2.2.1. Vizualna evaluacija metoda filtriranja za vrijednosti na kraju trupca

When testing the filtration methods for end values, the ability of the methods to identify individual defects is determined first (undercut or oblique cut, buttress). The values collected at the place of these defects are thus not replaced with new values, but only with numbers (*U* for undercuts, *B* for buttresses, *I* invalid value). Therefore, the values corresponding with the standard sawlog shape stay unmarked. That is the reason why the identification results are very comprehensible, but they can be evaluated only visually. In the next step, the unsatisfactory values behind the beginning of undercut are replaced with zero (as if the undercut would not continue), and the values at the areas of buttresses are replaced with the values calculated from the median. This completes the filtration.

The first evaluating criterion is the detection and replacement of buttresses, respectively. In Fig. 2, the scanned values corresponding with buttresses are marked with the area *B*, the values after the filtration are below them on the curve *F*.

The second criterion is an invalid insertion of a zero value in the place where an extreme value was measured. Fig. 2 shows a replacement of the upper extreme (*UE*) with zero value during the filtration (marked by number *0*). The method erroneously identifies an extreme as an undercut and filters it out.

The third criterion is the failure to identify an undercut or an oblique cut. The values identifying this defect are shown in Fig. 2 in the area *U*. The defect is evaluated and filtered out correctly there.

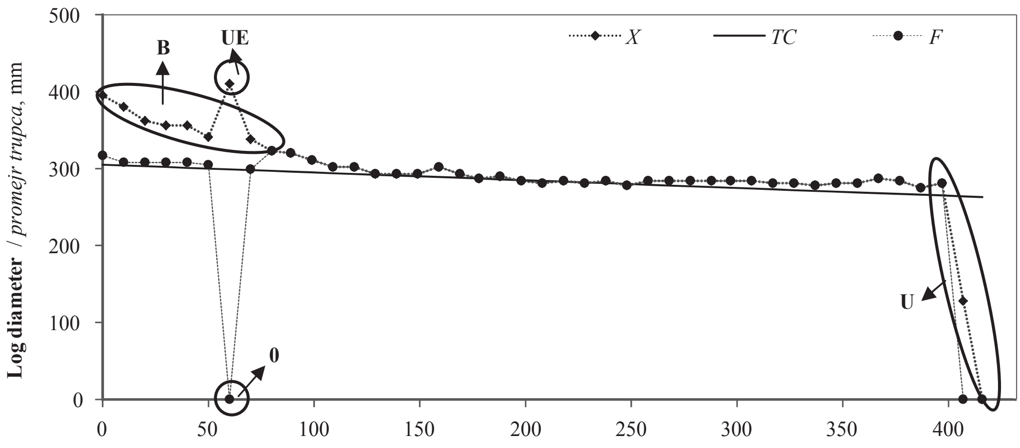


Figure 2 Graphic display of filtration methods for end values (*X* – measured values in direction *X*; *TC* – comparison curve; *F* – values determined by filtration; *B* – buttresses; 0 –invalid zero value; U – undercut or oblique cut; UE – upper extreme)
Slika 2. Grafički prikaz metoda filtriranja za vrijednosti na kraju trupca (*X* – izmjerena vrijednost u smjeru *X*; *TC* – krivulja za usporedbu; *F* – vrijednosti utvrđene filtriranjem; *B* – dno debla; 0 – pogrešna nula vrijednost; *U* – kosi rez; *UE* – gornji ekstrem)

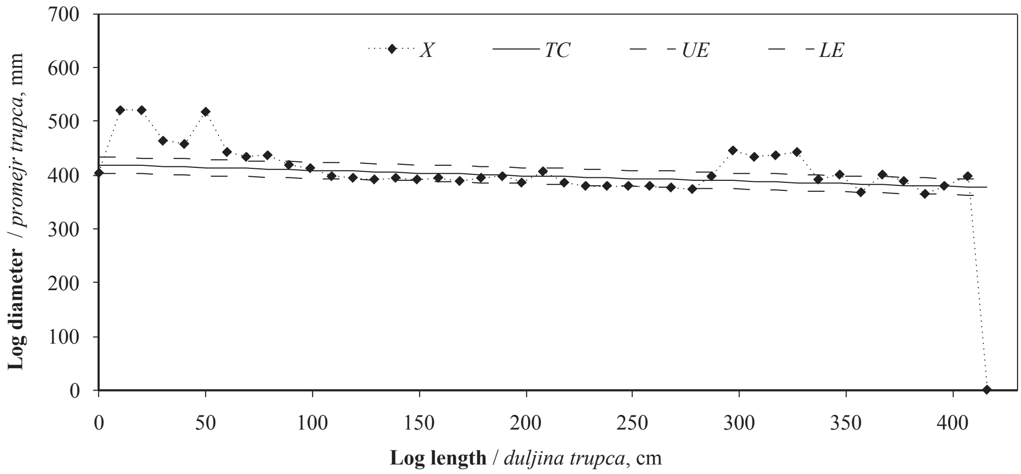


Figure 3 Graphic display of convergence line *TC* and limits for the upper (*UE*) and lower (*LE*) extremes. *X* curve represents the measured values in the horizontal direction
Slika 3. Grafički prikaz krivulje konvergencije *TC* i limita za gornje (*UE*) i donje ekstreme (*LE*); krivulja *X* predočuje vrijednosti izmjerene u horizontalnom smjeru

The errors are determined on the basis of a visual evaluation of curves and incorrectly identified values are summed.

2.2.2 Evaluation with the use of comparison curve
2.2.2. Procjena primjenom krivulje za usporedbu

In order to evaluate the filtration result without a visual check of every sawlog, a procedure is designed on the basis of a comparison of the measured values with the assumed values (a line corresponding with the normal rising gradient) and with the values calculated with the application of the filtration method.

The rising gradient line is calculated according to the rising gradient common for spruce in the Czech Republic, i.e. diameter increment of 1 cm per 1 cm of sawlog length. The line is interspersed with the median of all measured values in a given direction (*X* or *Y*). In the next step, a difference is calculated between the value determined by the given filtration method and the value according to the comparison line.

The values of the above mentioned differences of measured values, comparison values, and filtered values are compared, and it is evaluated whether:

- the value determined by filtration is identical to the measured value (not applicable to extreme values),
- the value determined by filtration stays in the field of extreme (measured value was marked as extreme),
- the measured extreme value above (below) the comparison line is replaced with a permissible value by the filtration,
- the measured value (despite not being extreme) is replaced with a new one – the value calculated by filtration,
- the calculated value, affected by an extreme, is at another position (an extreme is not removed by the filtration, it is just transferred).

With this method of evaluation of filtration procedures, the extreme values are those for which the filtration deviation of the calculated or initial value and comparison value is higher than 15 mm. An example of measured data in direction *X,* inserted comparison line *TC* and limits for marking values for the upper (*UE*) or lower extreme (*LE*) is shown in Fig. 3.

The classified values are summed in both the filtered data files and the initial measured data files. The difference is expressed in percentages. After the evaluation (in the next step), the numbers of extreme values are determined.

All criteria of effectiveness evaluation of filtration methods for individual sawlogs are gathered in data files that are statistically processed. The basic descriptive statistical indicators are calculated. The files do not have a normal classification, given by the method of effectiveness evaluation. The analysis of variance (ANOVA), which requires normality, cannot be used for the determination of the statistical significance of the difference between data files.

2.2.3 Evaluation of filtration selected methods by volume
2.2.3. Procjena odabranih metoda filtriranja primjenom obujma

Filtration methods are compared by their impact on the total sawlog volume. Two alternatives are selected for the calculation: from the sawlog mid diameter and by 10 cm long sections.

Diameter values (mid or of individual section) for the volume calculation are used in millimetres, without cm conversion, which excludes the impact of the conversion on the evaluation of filtration results.

2.2.4 Overall evaluation of filtration methods
2.2.4. Ukupna procjena metode filtriranja

Statistically processed evaluating criteria are ranked from the best to the worst regarding the required properties:

- upper extreme filtering rate (as many as possible should be filtered out),
- lower extreme filtering rate (as few as possible),
- rate of keeping initial values (as many as possible),
- rate of transfer of extremes (as few as possible),

- value of the sum of upper extremes (as low as possible),
- impact on the resultant sawlog volumes (as low as possible).

The methods are ranked with the use of robust characteristics of the descriptive statistics, i.e. median, modus, and the frequency of modus while taking into account outliers and extreme values.

According to the evaluated properties of the tested methods, methods for the use in practice are designed that best meet practical requirements under specific conditions. They are characterized by:

- prevalent dimensions or quality of measured logs,
- requirements for accuracy of the determination of individual log dimensions,
- speed of data processing on a given device,
- share of an operator in the course of reception,
- type of a scanning device and performance of the control system.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Simple filtration methods
3.1. Jednostavne metode filtriranja

Simple filtration methods were applied to values scanned from 189 sawlogs. The evaluation of their effectiveness was performed with the use of a comparison curve.

The results of comparisons of simple filtration methods are as follows:

- Regression analysis is unsuitable for data filtration, since it considerably simplifies the stem shape and is too affected by extreme values. The diversion of the regression line from the initial direction may cause a significant error in the estimate of end values, which are important for the classification of logs (an example shown in Fig. 4). The method can be used for finding the end values only if they are used for data which have already been smoothed by moving averages or medians, i.e. if extremes have been removed.
- Regarding moving averages, the wider the smoothing, the smoother the curve, but also the more distorted values by a single extreme value. An example of an affected result by a single extreme value is shown in Fig. 4. The transfer of an extreme to adjacent values is an important negative property of this method.
- The issue of end values also applies to median methods. It is necessary to complement them with another method (e.g. regression, use of minimum values or initial values, calculation of a median from another section). The advantage is that there is no impact on adjacent values by extremes (Fig. 4). Median methods reliably filter high solitary extremes, which may be represented by branch stubs and hanging bark. If more extreme values are present next to each other, which may be caused by e.g. larger tree burls, it is more probable that the information on such fault is not lost.

3.2 Filtration methods for end values
3.2. Metode filtriranja za vrijednosti na kraju trupca

Filtration methods for end values were tested on 27 samples, which had buttresses, undercuts, and oblique cuts. The evaluation is divided by evaluation criteria specified by the methodology.

3.2.1 Visual evaluation of filtration methods for end values
3.2.1. Vizualna procjena metoda filtriranja za vrijednosti na kraju trupca

a) Failure to detect buttresses

Regarding the filtering out of buttresses, the most effective seems to be the method *f11* (it compares the difference between sawlog diameter in both mutually perpendicular directions with one fourth of the median of nine values at the position of 130 cm) and *f13* (it compares the difference between the measured value and the median at the position of 130 cm with one seventh of the same median). When using these methods, the highest smoothing of the curve occurs in the area of buttresses with the lowest error rate (the failure to detect buttresses only occurred in six cases and it con-

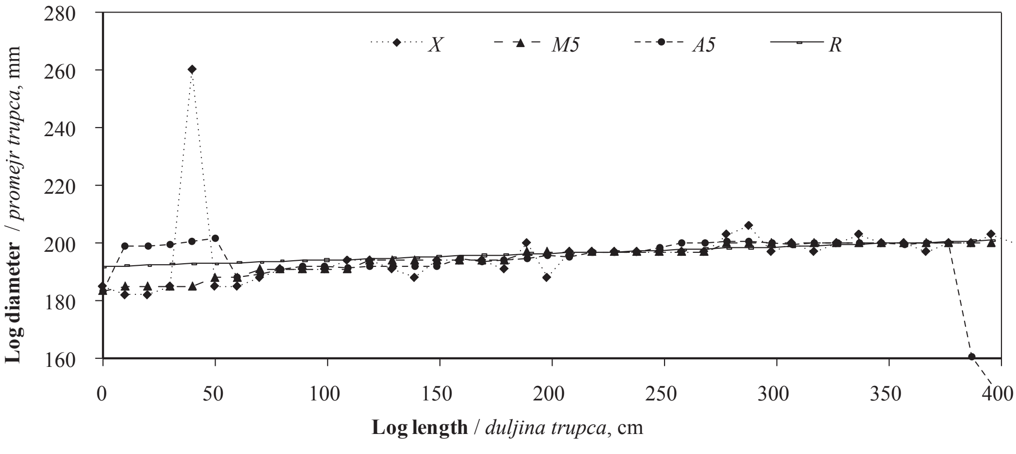


Figure 4 Impact on moving averages by a single extreme of sawlog No. 112 (*X* – measured values; *M5* – median out of five values; *A5* – moving average with the smoothing width 5; *R* – linear regression)
Slika 4. Utjecaj jednog ekstrema na trupcu broj 112 na pomične prosjeke (*X* – izmjerene vrijednosti; *M5* – medijan od ukupno pet vrijednosti, *A5* – pomični prosjek sa širinom poravnanja 5; *R* – linearna regresija)

cerned just one value, in one case two values). The methods *f8* and *f14* (they compare the difference of sawlog diameter in both mutually perpendicular directions with a fixed value) filter insufficiently, buttresses stayed undetected with 17 sawlogs. Most commonly, three values marked as buttresses stayed unfiltered, but in some cases there were five extremes.

The difference between the results of filtration of buttresses by individual methods is given by a determined comparison criterion. The methods *f8* and *f14* have the highest set fixed value for comparison. Another group consists of methods *f9*, *f15* and *f16*, where this value is lower. The third group consists of methods with a relative comparison criterion derived from the diameter of the measured sawlog (*f17*). Regarding sawlogs of smaller diameter, this approach reacts to small deviations. Regarding very thin pieces, high curve smoothing occurs. In contrast, even large deviations are tolerated in the cases of large sawlogs.

The search for extreme values with the help of a quotient of sawlog diameters brings a new calculation to the filtration process, which means higher demands on information technology and longer evaluation times.

b) Invalid insertion of zero value

Invalid insertion of zero value is the most important error in terms of the calculation of final sawlog volume. The visual checking makes it obvious that the error occurs due to an incorrect interpretation of a large difference between *X* and *Y* (sawlog diameter values scanned in both mutually perpendicular directions), such as an undercut or oblique cut. The lower the value with which the difference is compared, the more likely the difference between *X* and *Y* marked as an extreme.

The statistical evaluation of a visual check of the invalid insertion of zero value shows that the differences between the tested filtration methods are minimal. The occurrence of invalid values lies within the boundaries of statistical insignificance for all methods.

c) Undercut or oblique cut detection

The result of the evaluation of an undercut or oblique cut has only two alternatives: it was or it was not detected. The first four methods, *f8 – f11,* are very effective for the detection based on comparisons of the measured values in both directions (*X* and *Y*). The degree of effectiveness of other methods is about half of the above value. Despite this fact, the methods cannot be recommended due to their high error rate when inserting the zero value.

The mutual comparison of values *X* and *Y* can also be used for detecting an undercut or oblique cut and for the subsequent determination of sawlog length in compliance with Recommended Guidelines (composite authors, 2007). This operation can be performed only for end values as the first step before the filtration. When the difference between the end values *X* and *Y* is lower than a given criterion, the values can be considered as the new initial values, and with their use, it is possible to determine the sawlog length and the beginning of filtration.

3.2.2 Evaluation of filtration methods for end values according to a comparison line
3.2.2. Procjena metoda filtriranja za vrijednosti na kraju trupca primjenom usporedne krivulje

Similarly to the visual evaluation, when performing the evaluation according to a comparison line, it is impossible to claim with statistical significance that the methods differ from each other in a larger degree. However, it is obvious that some of them are stronger and some are weaker in terms of filtration.

The results of the evaluation of undetected buttresses are confirmed by the sum of the remaining upper extremes expressed as percentage. Regarding the filtration, buttresses are considered extreme values. Therefore, the sum of their deviations is relatively high. The statistical evaluation shows that filtration methods *f11* and *f13* are the strongest ones. Comparable results are reached by the method *f17*, which compares the difference of sawlog diameter values collected at a given place in both mutually perpendicular directions with one fifth of the median of all values. The highest sums of deviations were detected with methods *f8* and *f14*, comparing the same difference with a constant value of 150 (the highest use value).

When evaluating the sum of lower extremes, no difference was detected between the majority of methods, with the exception of methods *f8* and *f14,* which contained more errors. Nevertheless, the selected set of sawlogs contained very few extreme values under the comparison line (they occur exceptionally). Thus, the evaluation is based on a small number of observations.

A similar result can be seen when comparing the sums of deviations above and below the comparison line. The highest smoothing of the initial curve occurs with the use of filtration methods *f11* and *f13*, and the lowest with methods *f8* and *f14*.

Regarding the preservation of the initial values, which were not marked as extreme, it can be asserted that there is almost no difference between the filtration methods, and that the testing sawlogs mostly kept 78–79 % of the initial values. No transfer of extremes occurred in the used data file.

The evaluation of all criteria shows that the most acceptable method for the filtration of end values is the method *f13* and *f17,* respectively.

The method *f13* compares a measured value with the median of nine values at the position of 130 cm from the end of the sawlog. In case their difference is higher than a quarter of this median, the value is considered an undercut and replaced with zero. The calculation of an opposite difference with the aim to detect buttresses follows. The difference is compared with one seventh of the same median as in the previous step. In case the difference is higher, it is replaced with a value increased by 15 mm. The method is only applied to 10 end values.

The method *f17* works on a similar principle with the exception that a value of a median of all values in a given direction is used for the comparisons and calculations. The limit value for undercuts is one fifth of the median and one sixth for buttresses. A value marked as a buttress is, in this case, replaced with a median increased by 25 mm.

Both these methods are relatively strong at the filtration of buttresses and extreme values, and do not show errors of invalid zero insertion, which is an important factor in practice. In order to search for extreme values, both methods use criteria based on a quotient from sawlog diameter. Therefore, the degree of curve smoothing is dependent on diameter. This is not in contrast with the real variability of log surface, which is lower with thinner pieces. In contrast, higher unevenness, occurring with thicker pieces, is shown in the sawlog value even after the filtration.

3.3 Complex filtration methods
3.3. Složene metode filtriranja

The evaluation of individual criteria leads to the following conclusions:

Simpler complex methods are very effective in removing the upper extremes, but rank among the weakest in other criteria. Their only advantage is their simplicity and speed of data processing.

Contrasting results are shown by the methods where the difference between the original measured value and the median of three or six elements is compared with the limit value of 25 mm. They are less effective in removing the upper extremes, but keep the initial values and do not transfer extremes. Thus, the lowest differences occur between sawlog volumes, calculated from the measured and filtered values.

Regarding the number of positively evaluated properties, the previous methods are ranked before the method *f55*. It is a double-step method. In the first step, it filters end values by the above mentioned method *f13*. Afterwards, all the calculated values are compared with the median of three values. In case the difference is higher than 25 mm, the value is replaced with this median. However, it keeps fewer initial values.

In the majority of criteria, even the methods which replace the detected extremes by the minimum are considered favourable. However, they are weaker in removing extremes. They also show an increase in values below the comparison curve. In addition, *f49* shows weaker filtration of extremes, even though other characteristics rank among the better evaluated ones. This method compares the ratio of the initial value and the median of three elements with the value of 1.08 (i.e. 8% tolerance). It is influenced by the measured log thickness.

Double-step methods, which provide more intense (“stronger”) log curve smoothing, are more reliable for the filtration of the upper extremes. However, the consequence is a decrease in the resultant sawlog volumes. In addition, higher effectiveness methods lead to more complicated calculations.

3.4 Recommendations
3.4. Preporuke

Based on the analysis of properties, advantages and drawbacks of individual methods, the following methods are recommended for different conditions:

f21 – moving median of three values, for end values a median of the last two values is used

Advantages: simplicity, fast calculation, strong filtration of the upper extremes.

Drawbacks: removal of lower extremes, higher curve smoothing, lower percentage of preservation of initial values, transfer of extremes.

The method can be used for lower demands on accuracy, for measuring logs with bark (errors generated by the measurement with bark are usually higher than the errors caused by filtration). This corresponds with the practices of log conversion depots or small sawmills, where no high accuracy is required, as the classification is performed slowly and with cheaper machines, and an operator can significantly influence the process.

f32 – the measured value is compared with a moving median of three values; in case the difference is higher than 20 mm, the value is replaced with this median

Advantages: no complicated calculation algorithm, identical for all values, preservation of lower extremes, higher percentage of preservation of initial values.

Its drawback is a weaker filtration of the upper extremes.

This method is suitable for medium demands on speed, medium demands on accuracy, for logs of lower quality (keeping information on more complicated shapes of logs). This corresponds with the practices of small and meddle-size sawmills, where the classification is performed with cheaper machines, and where an operator can significantly influence the process.

f49 – quotient of the measured value and moving median of three values is compared with the value of 1.08; in case the quotient is higher, the value is replaced with this median

Advantages: the same (medium complex) calculation algorithm for all values, preservation of lower extremes, higher percentage of preserved initial values.

Drawbacks include a different degree of filtration for individual thickness classes, weaker filtration of the upper extremes.

The filtration method is suitable for medium demands on speed and accuracy, logs of lower quality (keeping information on more complicated shapes of logs), for logs with a wide range of thicknesses (more initial values are preserved with high thickness), for measurements with conveyors (effective filtration of extremes – driving dogs). This is suitable for small and middle-size operations, where medium accuracy is required, the classification is slower and performed with cheaper machines, and where an operator can significantly influence the process, logs of different thicknesses and quality are supplied, or a conveyor with driving dogs passes through a measurement frame.

f56 – the method works in two steps: coarse filtration is performed by the method *f13* (it compares the difference between the measured value and the median at the position of 130 cm with one seventh of the same median) and these values are subsequently filtered with the use of a moving median of three values. The other step is a comparison of the values from the first and the second filtration phase – the limit value for the difference is 20 mm; in case the value is exceeded, a value from the median from the second filtration phase is inserted.

Advantages: preservation of the lower extremes, higher percentage of preservation of initial values, stronger filtration of the upper extremes.

Drawbacks: more complicated calculation algorithm, different algorithms for end values, higher curve smoothing.

The method is suitable for higher demands on accuracy, for logs of higher quality (extremes are often caused by surrounding effects, their filtration does not lead to the loss of information on the curve shape), for logs with buttresses, oblique cuts and undercuts (the filtration includes algorithms only applicable to end values). This corresponds with middle-size sawmills, where higher speed and accuracy is required, and where higher performance control systems are available.

f59 (the method works in two steps: coarse filtration is performed by the method *f13* and these "filtered" values are subsequently filtered with the use of a median of five values; then follows a comparison of values from the first and the second filtration phases – the limit value for the difference is 20 mm; in case the value is exceeded, a value from the median from the second filtration phase is inserted)

Advantages: preservation of the lower extremes, higher percentage of preservation of initial values, stronger filtration of the upper extremes, low error rate.

Drawbacks: complicated calculation algorithm, different algorithms for end values, higher curve smoothing.

The method is suitable for high demands on accuracy, for logs of higher quality (extremes are more often caused by surrounding effects, their filtration does not lead to the loss of information on the curve shape), for logs with buttresses, oblique cuts and undercuts (the filtration includes algorithms only applicable to end values). This corresponds with middle-size and large sawmill operations with higher quality equipment, where an operator rarely influences the measurement.

3.5 Impact of data filtration on electronic reception of logs
3.5. Utjecaj filtriranja podataka na elektronički prijem trupaca u pilani

Wood volume is essential when selling and buying wood with the electronic reception of logs. Huber method is usually used to determine the volume. When using Huber method, the volume of the whole sawlog is dependent on the mid diameter. With the electronic reception of logs the diameter is determined by four measurements near the sawlog centre and their average value is calculated.

The filtration should remove shape anomalies and prevent a distortion of the sawlog volume calculated by an extreme value. However, the filtration of an extreme value collected near the measured area in the sawlog centre may cause the replacement of a correct value for an incorrect one (extreme transfer). The result of filtration may be contradictory to the initial intention.

Simple filtration methods do not allow determining the limit criterion for an extreme, which is to be filtered or which is not be filtered. Complex methods allow taking this limit into account.

In order to evaluate the properties of individual filtration methods, the differences in volumes determined from two values near the sawlog centre from the initial and the filtered vales were also calculated. Regarding simple methods, the difference of volume from the initial and filtered values can be both positive and negative. The difference is positive only with complex methods. Positive differences indicate lower volume after the filtration, i.e. the diameter was reduced by the filtration. Therefore, the positive extreme was filtered out. The filtration of negative extremes is undesirable.

Although the percentage deviations of extremes may reach the limit values of over 30 %, majority of extremes ranges in the area of 10 %. It is necessary to point out that the deviations in volumes only occurred at approx 10 % of all sawlogs. The total deviation, which may occur during the measurement, would then range in the area of around 1 %.

Negative deviations were also indicated with simple methods, i.e. after the filtration, the volume is higher than before the filtration. This phenomenon is caused by an impact on initially normal value by a potentially extreme adjacent value. Subsequently, the diameter increase occurs.

Therefore, it is more suitable to apply more complex methods.

In order to evaluate the effect of filtration methods on the resultant sawlog volume, it is more suitable to determine sawlog volume by sections, since it takes into account the filtration of the whole curve. The mentioned effect of filtration is expressed as the volume of a cylinder of the diameter that is equal to the log mid diameter (Huber method). When determining the sawlog volume by sections, the effect is much lower, since it only has an impact on the section affected by an error, not the whole sawlog. Therefore, it is more accurate to use the method by sections, in order to determine the effect of filtration methods on the calculated sawlog volumes.

This study determined the log mid diameter as an average value of four measurements near the sawlog centre. The same method is used for the determination of a section diameter, when determining the volume by sections. The compared sawlog volumes were determined from diameter values in mm, i.e. without conversion into cm. The difference of the volumes of sawlogs determined by the calculation from the mid diameter and by sections was only set in this work for illustrative purposes and substantially simplified. The finding that the sawlog volume determined by sections is on average by 1.0 % higher than the volume determined from the mid diameter is in line with the previous works (Janák and Peter, 2004).

4 CONCLUSION
4. ZAKLJUČAK

Data filtration is a necessary step for processing data collected by the electronic measurement of sawlog dimensions. It is also a factor affecting the evaluated shape and volume of sawlogs. Therefore, the filtration method has an impact on the results of the whole electronic reception and, up to a certain extent, on supplier-customer relations of wood trading.

69 methods were designed and evaluated for the analysis and recommendations of suitable data filtration methods. The methods were applied to sets of values collected from sawlogs in sawmills (not laboratories). The methods differ from each other in the calculation method (moving average, median, smoothing width) and in the type of application (simple or combined, different processing of individual sawlog parts). The impact of individual filtration methods on the resulting sawlog values was evaluated visually as well as by a comparison procedure based on the taper.

The evaluation shows that simple methods deform mainly the parts of sawlogs with buttresses and are unreliable concerning oblique cuts and bounced cuts at sawlog ends. The combined methods are more reliable but more demanding in the performance of the control system. Five filtration methods are recommended, which differ in their accuracy and calculation demands. Therefore, they are suitable for different areas of use (volume and predominant dimensions or measured log quality, requirements as to the accuracy of sawlog dimensions, degree of participation of an operator during electronic reception, type of scanning device and equipment).

The impact of filtration on the value of the calculated volume during electronic reception is mainly given by the method and effectiveness of filtration; the method of log volume calculation also plays an important role.

When calculating sawlog volume by Huber method (from the mid diameter, typical for Central Europe), the total volume of a given piece is given by four diameter values scanned near the sawlog centre. An initially correct value may be affected by an adjacent extreme value and changed when applying simple filtration methods based on moving the most common averages or medians. An error, which thus occurs, has a significant impact on the volume value of the whole piece. Therefore, it is recommended to apply more complex methods (searching for extreme values while using set criteria).

When calculating sawlog volume by sections, only one section is affected by a given error. Therefore, the calculation of sawlog volume by sections significantly reduces the impact of filtration and scanning errors, and is hence more suitable.

The research was performed in cooperation with the representatives of suppliers and customers of saw timber. Our aim was to satisfy all requirements that were identified during the research. The research results shall lead to complementing and improving the regulations for electronic log reception in the Czech Republic, and, as we believe, to improving the log reception itself.

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Variation in Mechanical Properties within Individual Annual Rings in the Resonance Spruce Wood [*Picea abies* (L.) Karst.]

Varijacije mehaničkih svojstava unutar pojedinih godova rezonantne smrekovine

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ABSTRACT • *This paper shows results of specific elastic modulus and specific tensile strength in the resonance spruce wood [Picea abies (L.) Karst.] in relation to its heterogeneity within individual annual rings. It also presents changes in the average values of microfibril angle in S2 layer measured in tangential walls of tracheids (MFA) within individual annual rings. On the grounds of the results, it can be concluded that specific modulus of elasticity and specific tensile strength of wood are strongly influenced by the position of the sample in annual rings. Generally, the values of these parameters increase along the width of annual rings. It is also noted that the specific modulus of elasticity and specific tensile strength depend on MFA. As MFA decreases, the values of these parameters increase.*

Key words: *resonance wood, spruce wood, specific modulus of elasticity, specific tensile strength, MFA*

SAŽETAK • *U radu se prikazuju rezultati istraživanja specifičnog modula elastičnosti i specifične vlačne čvrstoće rezonantnog drva smreke [Picea abies (L.) Karst.] s obzirom na njihovu heterogenost unutar pojedinih godova. Također su prikazane i promjene prosječnih vrijednosti kuta mikrofibrila u sloju S2 izmjerene u tangencijskim stijenkama traheida (MFA) unutar pojedinih godova. Na temelju dobivenih rezultata može se zaključiti da položaj uzorka u godovima ima velik utjecaj na specifični modul elastičnosti i na specifičnu vlačnu čvrstoću drva. Općenito, vrijednosti tih parametara povećavaju se uzduž širine godova. Također je zabilježeno da specifični modul elastičnosti i specifična vlačna čvrstoća ovise o MFA. Kako se MFA smanjuje, vrijednosti tih parametara se povećavaju.*

Ključne riječi: *rezonantno drvo, smrekovina, specifični modul elastičnosti, specifična vlačna čvrstoća, MFA*

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1 INTRODUCTION
1. UVOD

Wood quality is understood as a number of its attributes that are beneficial for its application. Therefore, the timber for different applications should be characterized by different specific properties. Resonance wood should meet specific demands for instruments production. High quality, defect-free spruce wood with thin growth rings (latewood should not exceed 30 %) is preferred to produce violin soundboards (Blossfeld *et al*., 1962). On the other hand, the definitions of the fundamental quantities characterizing the resonance properties of wood, such as sound velocity (*C*), acoustic impedance (*Z*), acoustic constant (*K*) and damping of sound radiation (*V*) that are shown below, imply that the high modulus of elasticity (*MOE*) at the lowest possible density (ρ) is the most important for instrument production (Wegst, 2006):

$$C = \sqrt{\frac{MOE}{\rho}}, \quad (1)$$

$$Z = \rho \cdot \sqrt{\frac{MOE}{\rho}}, \quad (2)$$

$$K = \sqrt{\frac{MOE}{\rho^3}}, \quad (3)$$

$$V = \frac{\sqrt{\frac{MOE}{\rho}}}{\rho}. \quad (4)$$

In other words, for this purpose wood should be characterized by a high ratio of *MOE* to density (*MOE*/ρ), known as the specific modulus of elasticity. This is why wood with poorly developed latewood (small contribution and low density of latewood) is the most suitable for the construction of musical instrument soundboards. According to Bucur (1995), a wide zone of latewood impedes the sound waves propagation. Some authors even believe that antique violins were made from trees grown during the Maunder Minimum (Topham and McCormick, 1998, 2000; Burckle and Grissino-Mayer, 2003). Moreover, good resonance wood should be characterized by small differences between early and latewood cells structure, which give low density gradient within individual annual rings (Buksnowitz, 2006; Spycher *et al*., 2008). Recently, a hypothesis has been put forward that the famous Stradivarius violins were made of the old and enzymatically degraded wood. This hypothesis seems to be confirmed by Schwarze *et al*. (2008), who studied the microstructure, density and *MOE* of partly enzymatically degraded wood of spruce and sycamore subjected to controlled enzymatic degradation. Consequently, wood density was reduced as a result of partial destruction of thick-walled anatomical elements. The resultant decrease in the modulus of elasticity (*MOE*) was small, which gave an increase in the *E*/ρ relative to that in the wood not subjected to degradation. Lower density and similar *MOE* give higher specific modulus of elasticity compared to non treated wood. It is generally believed that higher density gives higher *MOE* and vice versa, but *MOE* also depends on the microfibril angle in S2 layer (*MFA*). A good example illustrating the impact of cell wall ultrastructure on the *MOE* has been given by Easterling *et al*. (1982) regarding the balsa wood. Increased density of the wood from 78 to 218 kg/m^3 (2.8-fold) causes a 6.5-fold increase in *MOE* values. According to the authors, more than twice (2.3-fold) higher increase in *MOE* is attributed to changes in mechanical properties of cell walls. Cave (1968) and Cave and Walker (1994) have reported that the decrease in the average *MFA* value from 40 to 10° causes even a 5-fold increase in *MOE*. Many other authors (e.g. McMillin, 1973; Donaldson, 1992; Evans *et al*., 2000) have reported that *MFA* decreases with increasing height of the tree, increase in wood density and low rate of growth of trees. Therefore, in modeling the mechanical properties of wood, as well as its moisture deformation, not only the wood density and its microstructural parameters (shape and size of the cells) are taken into regard, but also the arrangement of microfibrils in the cell wall (Mark, 1967; Cowdrey and Preston, 1966; Cave, 1968, 1969; Astley *et al*., 1998; Xu and Liu, 2004; Mishnaevsky and Qing, 2008). All these factors are reflected in the acoustic properties of wood. They should be taken into account in the choice of wood for the production of musical instruments (Wegst, 2006), in using sound propagation speed to evaluate the wood quality (useful for construction) and for the production of pulp (Huang *et al*., 2003).

This paper presents results of a study on the resonance wood of spruce [*Picea abies* (L.) Karst.]. Of particular interest was the wood heterogeneity within individual annual rings manifested by differences in specific modulus of elasticity (*MOE*/ρ), essential for desirable acoustic properties of wood. In view of the fact that (*MOE*/ρ) depends not only on the density of wood, analysis of *MFA* was also made.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

The experimental material used in this study was a plank of spruce [*Picea abies* (L.) Karst.], previously classified as a resonant wood. The wood was obtained from the Chair of Wood Science at the University of Technology, Zvolen (Slovakia). The plank was 50 cm long, 95 mm wide along the radius and 35 mm thick in tangential direction. At the fronts of the board, a strip of about 5 mm in thickness was cut off. The front surface of the strip was sanded with fine sandpaper to visualize the annual rings. The width of individual annual rings and the width of the latewood zones were measured by a computer image analyzer. These measurements were made at wood moisture content of 7 %. The remaining part of the plank was adjusted to 9 mm thickness in the tangential direction using a planer. From this part of the plank, two adjacent wood samples were cut out from the region in which the borders of annual rings were straight lines parallel to the longer axis of the plank. Each sample was 80 mm in length. One of them was cut along the fibers into 3 pieces and each of them was placed in distilled water for two weeks.

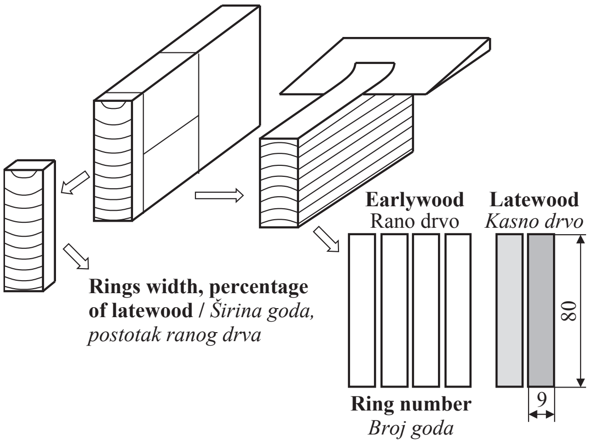

Figure 1 A scheme of sample preparation for determination of the density gradient, tensile strength along the grain and modulus of elasticity within individual annual rings
Slika 1. Shema pripreme uzoraka za određivanje gradijenta gustoće, vlačne čvrstoće uzduž vlakanaca i modula elastičnosti unutar pojedinih godova

As previously established, such a long wetting of wood allowed a correct slicing of wood samples without the need of pre-heating. Then, with the use of a microtome sledge, the tangentially oriented samples of about 200 μm in thickness were sliced. Each sample was marked to identify its position. A scheme of preparation of the microtome samples is shown in Figure 1.

The microtome samples were conditioned in laboratory to obtain equilibrium moisture content. Further measurements were made for the samples from 10 annual rings (No. 5, 10, 12, 17, 26, 30, 37, 54, 62 and 67 counted from the edge closest to the pith).

After stabilization of sample weight, the widths of the samples were measured in the middle of the length and at a distance of 2 cm from the centre, with a Brinell magnifying glass to the accuracy of 0.1 mm. At the same sites, the thickness of the sample was measured by a micrometer (with ratchet stop) screw gauge to the accuracy of 0.001 mm, and length – by a rule to the accuracy of 1 mm. Each sample was weighed on a laboratory balance to the accuracy of 0.0001 g, so as to be able to calculate the wood density.

After these measurements, the ends of samples were covered with hardboard of the size 20 x 20 mm and thickness of 3 mm with glue Pattex Compact. This procedure effectively protected the samples against damage in the jaws of the testing machine (Moliński and Krauss, 2008; Krauss, 2010; Krauss *et al*., 2011).

After laboratory conditioning that followed, the samples were subjected to tensile strength measurements on a testing machine ZWICK ZO50TH, equipped with an extensometer ZWICK 066550.02. The tensile test was applied at the rate of 0.6 mm/min, under the preliminary loading of 10 N and the extensometer base of 25 mm (Fig. 2).

The data were fed into a computer to calculate the mechanical strength and *MOE* along the grains. From each annual ring, the measurements were made for a few samples of earlywood and at least 1 sample of latewood. Only the results for the samples that broke up in the middle of the length were assumed reliable.

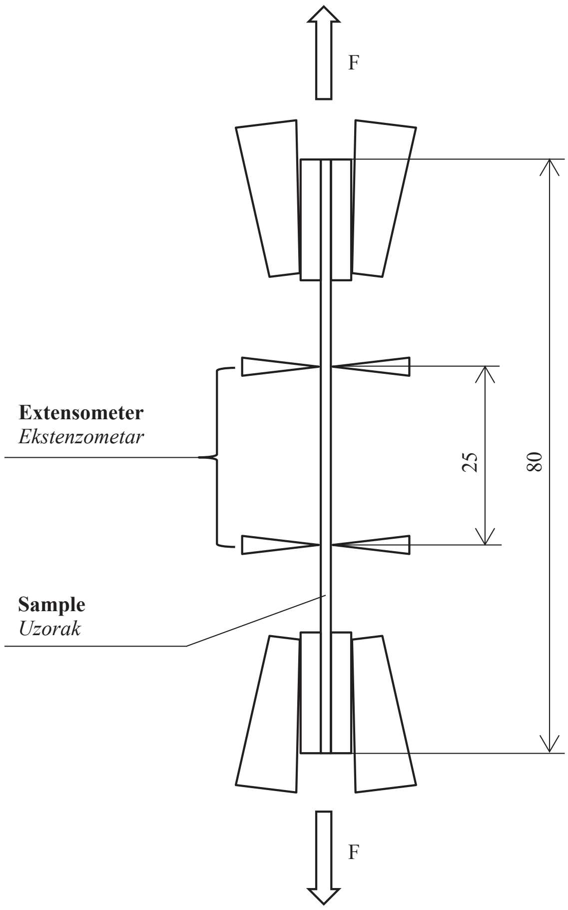

Figure 2 A scheme of sample mounting in the jaws of the testing machine and tensile strength measurement
Slika 2. Shema smještanja uzorka na uređaj za mjerenje vlačne čvrstoće

The next step was to determine the value of *MFA* in tangential tracheid walls. For this purpose, the samples in which macro-structural parameters were determined, were heated in a 20 % $Cu(NO_3)_2$ solution at 80 °C for 24 hours. After heating, samples were rinsed in distilled water. Then, the samples were boiled in distilled water at a temperature of 100 °C for 2 hours. This procedure allowed the visualization of *MFA* in the cell walls, also in other wood species (Wang *et al*., 2001; Fabisiak *et al*., 2006, 2009; Fabisiak and Moliński, 2007; Roszyk *et al*., 2010a, 2010b, 2012; Krauss *et al*. 2011). Then, tangential microscopic preparations, about 20 μm thick, were cut out of the front strip at the sites corresponding to the annual rings, from which the samples for tensile tests were taken. In those preparations, MFA was measured in tangential walls of tracheids by a computer image analyzer. From 10 to 15 angles were measured on each preparation. The results of these measurements allowed checking a correlation between the appropriate mechanical properties of wood and the average *MFA* for each timber sample.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Macrostructure of the tested wood is characterized by the data shown in Figure 3 and Table 1.

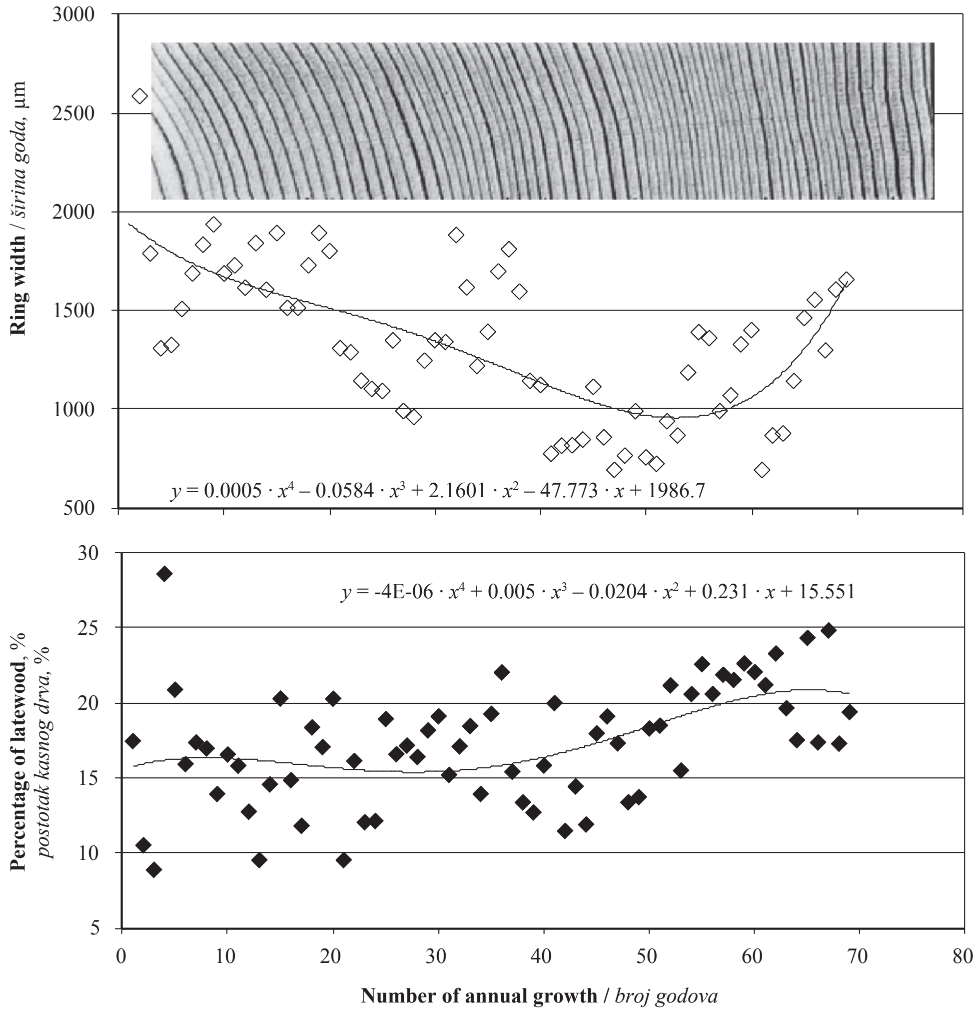

Figure 3 Changes in the width of annual rings and contribution of latewood in the rings (samples for measurements of wood density and mechanical parameters were sliced from the rings marked with points)
Slika 3. Promjene u širini godova i udio kasnog drva u godovima (uzorci za mjerenje gustoće drva i mehaničkih parametara izrađeni su od godova označenih točkama)

They show that the width of the annual rings (omitting the first ring and pith zone) ranged from 0.5 to 2 mm with average contribution of latewood of 17 %. In this respect, the wood meets the requirements of the industry standard (BN-85/9221-06). A certain disadvantage is the irregularity of the annual rings width; it undergoes a rapid decrease from ring 20 to 30 (counting from the edge of pith zone) relative to the width of preceding ones, and another decrease is noted for the rings 32 to 37, and a particularly pronounced decrease in width is observed for rings 40 to 52.

However, Spycher *et al*. (2008) claim that the quality of resonance spruce wood is more dependent on the latewood percentage contribution than on the ring width as in the narrow rings (less than 2.5 mm) no significant changes in the density of wood are noted. Nevertheless, these authors have observed a certain increase in the damping of sound propagation with increasing ring width. Analysis of the data in Figure 3 shows that the latewood percentage in rings from 20 to 30 is comparable to that in the preceding and subsequent rings. Taking into regard the claims of the above authors, it can be assumed that density of the wood with narrow and wide rings can be comparable as well. Nonetheless, the variation in macrostructural parameters of the wood studied is relatively high. Consequently, according to Spycher *et al*. (2008) and Buksnowitz (2006), this wood cannot be classified as a very good resonance material, even though it meets the requirements specified by standards.

Table 1 Macrostructural characteristics of the studied spruce wood
Tablica 1. Makrostrukturna obilježja istraživanog drva smrekovine

Examined property *Istraživano svojstvo*	**Basic statistical parameters** / *Osnovni statistički parametri*				
	min *min.*	average *sredina*	max *maks.*	Standard deviation *Standardna devijacija*	Coefficient of variation, % *Koeficijent varijacije, %*
Ring width, mm / *Širina goda, mm*	0.54	1.33	1.94	0.33	24.6
Percentage of latewood, % *Postotak kasnog drva*	8.9	17.3	27.8	3.9	22.5

Table 2 Density of earlywood and latewood of all examined rings
Tablica 2. Gustoća rana i kasnog drva istraživanih godova

Density, kg/m³ *Gustoća*, kg/m³	**Basic statistical parameters** / *Osnovni statistički parametri*		
	min – average – max *min. – srednje – maks.*	Standard deviation *Standardna devijacija*	Coefficient of variation, % *Koeficijent varijacije*, %
Earlywood / *Rano drvo*	175 - 240 - 342	46.9	19.5
Latewood / *Kasno drvo*	430 - 604 - 811	91.0	15.1

The macrostructural heterogeneity of the wood can be used only for initial qualification of its resonant properties. Definitely more important is the density of wood, which is a determinant of its elasticity. Thus, these two parameters are inextricably linked. Generally speaking, with the growth of wood density, its *MOE* increases as well (e.g. Kollmann and Côté, 1984; Gibson and Ashby, 1997). The wood density values obtained from measurements of 55 earlywood and 15 latewood samples, which were mostly broken in the middle of their length, are summarized in Table 2.

Border measurements of early and latewood are excluded. The table shows that the ratio of the average latewood density to average earlywood density is close to 2.5. The ratio of the maximum density of latewood to the minimum density of earlywood in the whole board exceeded 4.5 (811 kg/m³ : 175 kg/m³). Bearing in mind that wood density variation in resonance discs, even within a single annual growth, affects their vibration and determines the quality of the sound (Bucur, 1995; Yoshitaka *et al.*, 1997; Stoel and Borman, 2008; Spycher *et al.*, 2008; Schwarze *et al.*, 2008), the results confirm the above remark that the tested board cannot be classified as a suitable material for resonance purposes. It should be marked, however, that the masters of the violinmaking can reduce or even eliminate some faults in the material during the production process (Wegst, 2006). Buksnowitz *et al.* (2007) claim that luthiers can assess the resonance wood quality by its visible features, though such subjective prediction of acoustic quality is poor.

Density is not the only parameter that characterizes resonance wood quality. This parameter should be considered together with the modulus of elasticity (*MOE*/*ρ*). The higher the wood density is, the higher the *MOE* gets. However, as mentioned above, *MOE* is strongly related to the quality of the cell walls, so also to the arrangement of the formed microfibrils. The *MFA* variation within a single annual growth is relatively well known. *MFA* is claimed to be the largest in the elements produced in the early stages of tree growth (earlywood) and it decreases, sometimes quite significantly in the summer, when the latewood develops (Abe *et al*., 1992; Anagnost *et al*., 2002; Barnett and Bonham, 2004; Abe and Funada, 2005; Donaldson, 2008; Fabisiak *et al*., 2009). Their arrangement in the spruce wood (*Picea abies*) of Austrian origin differs from the general picture of the *MFA* variation in S2 layer of the cell wall. Reiterer *et al*. (1999) have shown that the *MFA* in the tangential walls of the early tracheids, between ring 17 and 37 (from the pith), is approximately 5 degrees, and in the walls of the late tracheids it is 20 degrees. In the rings up to 44, MFA were nearly the same in the early and latewood. Lichtenegger *et al*. (1999) presented similar research results. Analogous studies on the same species of wood, but of Swedish origin (Sahlberg *et al*., 1997), showed that the average *MFA* in the walls of the early and late tracheids is only about 1 degree higher. For comparable *MFA* in the tracheids from the walls of early and latewood, the specific modulus of elasticity (*MOE*/*ρ*), determined for samples cut from different places of annual growth, should be similar. From the perspective of homogeneity of wood tissue, such situation would be very beneficial. The changes in specific modulus of elasticity determined for annual rings across their width are illustrated in Figure 4.

This figure contains, for clarity, the data obtained from 8 rings only. The figures also show changes in the specific tensile strength along the grains. The data imply that both *MOE* and tensile strength along the grains are strongly influenced by the sample location in individual annual rings. In general, the parameters take the lowest values at the beginning of the earlywood zone. Then, they increase reaching a maximum in the latewood zone at a distance from the boundary with the next increment (ring 30, 37 and 62), or right at the boundary. The average values of these mechanical parameters, calculated separately for the early and latewood for all examined annual growth, are given in Table 3.

Table 3 Average values of specific tensile strength and specific modulus of elasticity along the grains in early and latewood
Tablica 3. Prosječne vrijednosti specifične vlačne čvrstoće i specifičnog modula elastičnosti uzduž vlakanaca ranoga i kasnog drva

Examined property *Istraživano svojstvo*	**Basic statistical parameters** / *Osnovni statistički parametri*		
	min – average – max *min. – srednje – maks.*	Standard deviation *Standardna devijacija*	Coefficient of variation, % *Koeficijent varijacije*, %
Specific tensile strength, kNm/kg *Specifična vlačna čvrstoća, kNm/kg*			
earlywood / *rano drvo*	41 - 150 - 285	52.8	35.2
latewood / *kasno drvo*	142 - 246 - 350	62.1	25.2
Specific modulus of elasticity, kNm/kg *Specifični modul elastičnosti, kNm/kg*			
earlywood / *rano drvo*	12 407 - 23 551 - 33 881	4 252	18.1
latewood / *kasno drvo*	18 547 - 32 516 - 42 947	5 898	18.1

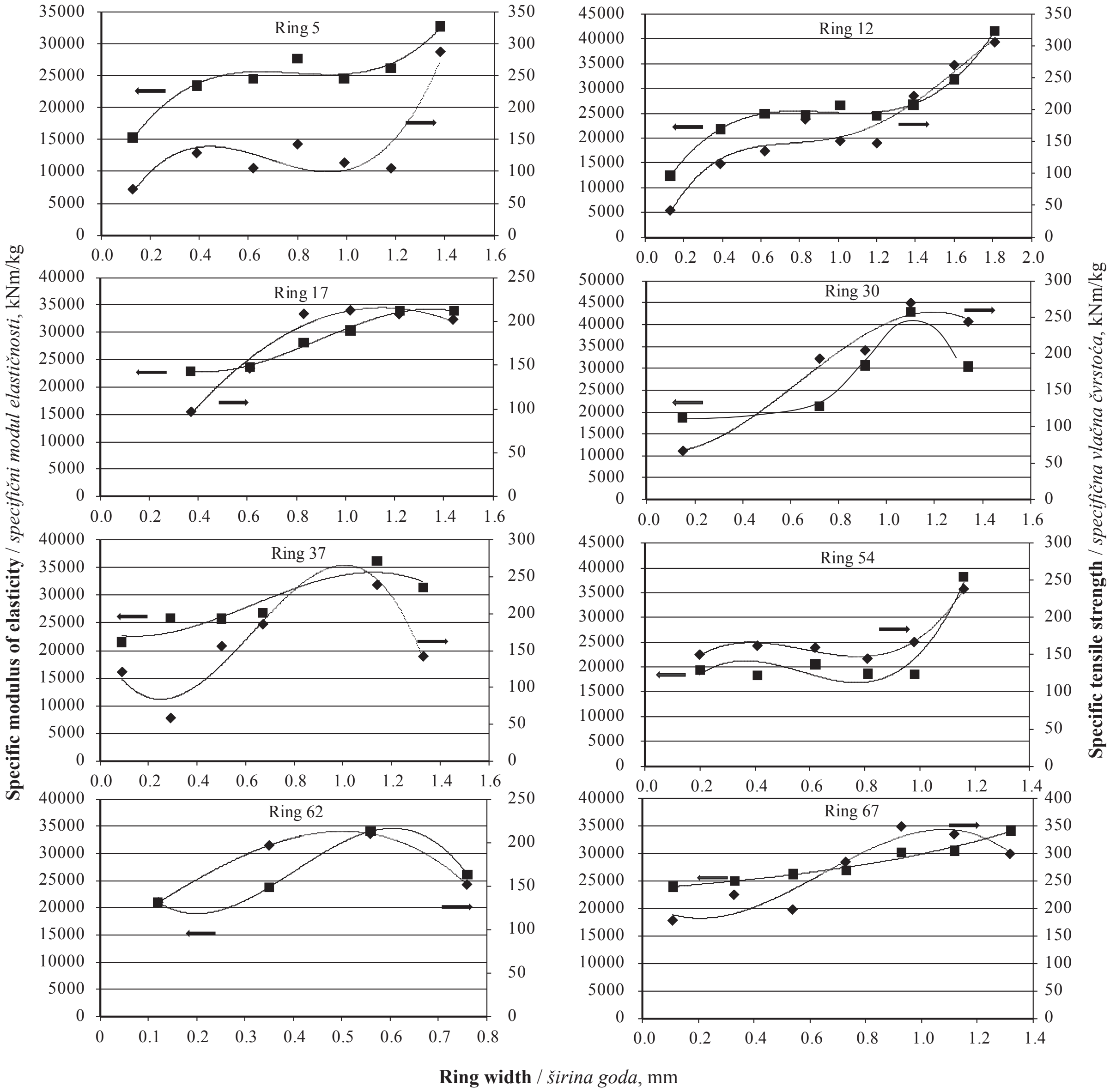

Figure 4 Specific modulus of elasticity and specific tensile strength along the grains in selected annual rings
Slika 4. Specifični modul elastičnosti i specifična vlačna čvrstoća uzduž vlakanaca u odabranim godovima

This table also gives the basic statistical parameters, similarly as that with the density of wood data. As fallows from the data, the average value of the relevant areas of modulus of elasticity for the earlywood zone (23-550 kNm/kg) is only 40 % lower than the corresponding figure for latewood (32-516 kNm/kg). This small variation is due to the fact that the earlywood zones included also the transition zone, as the classification of wood samples as early or latewood was made on the basis of their location in different rings and earlier measurements of the rings widths. Hence, such differences appear in the densities of these wood zones (Table 2). As to the specific tensile strength, the difference in its average values for early (150 kNm/kg) and latewood (246 kNm/kg) is much higher and exceeds 60 %. The difference in the parameters describing mechanical properties is related to the variation in *MFA* in the cell walls. Changes in the average *MFA* along the width of the selected annual rings are shown in Figure 5.

The average values of the *MFA* were very low (1.5 to 4.2°). However, the obtained *MFA* values correspond to the values reported by other authors (e.g. Lichtenegger *et al*., 1999; Gierlinger *et al*., 2010), who proved that the *MFA* in the spruce wood, especially in rings placed further from the pith, may be close to 0°. Bearing in mind that the correlations between *MFA* and modulus of elasticity and tensile strength are negative (Fig. 6), variations in these parameters within a single annual growth should be related to changes in *MFA* within the tracheids walls.

Based on the presented data, a relatively low coefficient of determination emerges probably due to the fact that the *MFA* measurements were made only in tangential cell walls. A similar conclusion was formulated by Roszyk *et al*. (2010a), who claimed that the trend in variation of the radial specific tensile strength and specific modulus of elasticity of a non-resonance spruce wood were a mirror image of the *MFA* changes in the coils walls of tracheids.

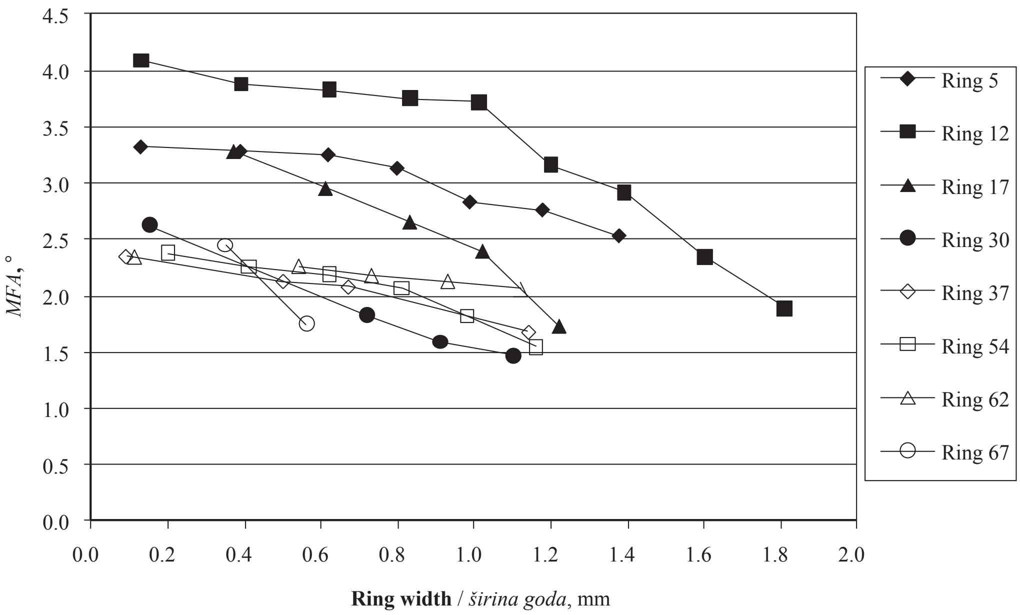

Figure 5 Changes in *MFA* values across the width of selected annual rings
Slika 5. Promjene vrijednosti *MFA* unutar širine goda u odabranim godovima

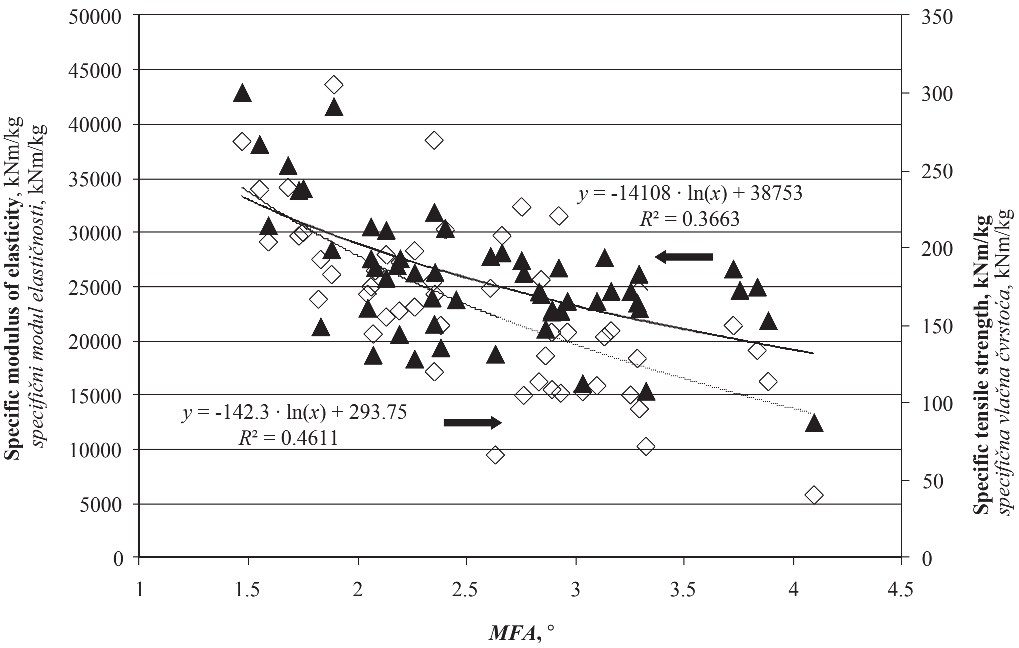

Figure 6 Correlation between *MFA* and specific modulus of elasticity and tensile strength along the grains
Slika 6. Korelacija između vrijednosti *MFA* i specifičnog modula elastičnosti te vrijednosti *MFA* i vlačne čvrstoće uzduž vlakanaca

4 CONCLUSIONS
4. ZAKLJUČCI

On the grounds of the variation in the specific modulus of elasticity and tensile strength in the resonance spruce wood [*Picea abies* (L.) Karst.] within a single annual growth, the following conclusions can be drawn.

Specific modulus of elasticity and specific tensile strength are strongly influenced by the sample position in the annual ring. Generally, the values of these parameters increase with the growth of annual rings.

The values of specific modulus of elasticity and specific tensile strength depend on the microfibril angle in S2 cell wall layer; these parameters increase with decreasing *MFA*.

Wood with similar characteristics as the plank tested cannot be classified as a high quality resonance wood because of its non-uniform character manifested as the variation in average *MFA* value of early and latewood.

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Changes Caused by Heat Treatment in Color and Dimensional Stability of Beech (*Fagus sylvatica* L.) Wood

Utjecaj toplinske obrade na promjenu boje i dimenzijsku stabilnost bukovine (*Fagus sylvatica* L.)

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ABSTRACT • *Thermal modification of wood permanently alters several of its chemical and physical properties. Beech wood is one of the most important hardwoods in Central and Eastern Europe and is extensively used in furniture production. In this study the effects of thermal modification of beech wood (Fagus sylvatica L.) on hygroscopic properties were examined and the color changes of the treated wood were determined. Beech wood has been subjected to a heat treatment at the temperature of 180 °C for five different durations ranging from 2 to 10 h. A more intense, gradual color change of the treated samples was observed after 4-h treatment, whereas in some other cases the recorded alterations were less intense. The most pronounced color differentiations compared to untreated samples occurred in 8-h and 10-h treatments. Dimensional stability and absorption were measured after 1-h, 3-h, 6-h, 1 day and 3 days immersion in water. The 8-h treatment duration exhibits the greatest reduction of swelling and absorption percentage.*

Key words: *beech wood (Fagus sylvatica L.), heat treatment, color change, hygroscopic properties*

SAŽETAK • *Toplinska modifikacija drva trajno mijenja neka njegova kemijska i fizikalna svojstva. Bukovina je jedna od najvažnijih vrsta tvrdog drva u srednjoj i istočnoj Europi, a uvelike se upotrebljava za proizvodnju namještaja. U ovoj su studiji predstavljeni rezultati istraživanja utjecaja toplinske modifikacije bukovine (Fagus sylvatica L.) na neka higroskopna svojstva i promjene boje toplinski obrađenog drva. Bukovina je podvrgnuta toplinskoj obradi pri temperaturi 180 °C i tijekom pet različitih trajanja procesa obrade, od dva do deset sati. Intenzivnije promjene boje toplini izlaganih uzoraka uočene su nakon četiri sata, dok su u drugim slučajevima zabilježene manje intenzivne promjene. Najintenzivnije razlike u boji u usporedbi s netretiranim uzorcima dogodile su se nakon osam i deset sati obrade. Dimenzijska stabilnost i apsorpcija mjerene su nakon jedan sat, tri sata, šest sati, jedan dan i tri dana potapanja uzoraka u vodi. Nakon potapanja uzoraka u vodi u trajanju od osam sati zabilježeno je najveće smanjenje bubrenja i postotka apsorpcije.*

Ključne riječi: *bukovina (Fagus sylvatica L.), toplinska obrada, promjena boje, higroskopna svojstva*

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1 INTRODUCTION
1. UVOD

Improvement of wood material properties and the increase of its lifespan have occupied scientists for numerous years as wood is an omnipresent and indispensable material for a very wide range of applications such as furniture production and building constructions. For this reason, ways to tackle its basic drawbacks such as dimensional stability, low resistance to microorganisms and volatility structure have been continuously elaborated. The most popular methods applied to improve timber are based on toxic substances and complicated recycling processes, and therefore many European countries have banned their use. Thermal modification of wood is a process that provides the improvement of some wood properties without imposing an extra burden on the environment, as preservatives apparently do. Specifically, thermal modification seems to enhance dimensional stability and biological durability of wood, although some mechanical properties appear to deteriorate. This change of properties is mainly induced by thermal degradation of hemicelluses and, generally, the changes continue as the temperature is increased. Due to moisture content decrease, swelling and shrinkage occur, color darkens, several extractives flow from the wood, ph decreases and thermal insulation properties are improved (Hill, 2006).

Several studies involving thermally modified beech wood, as well as other hardwood species, have been conducted so far. Yildiz *et al.* (2002b) conducted research into the effects of heat treatment on mechanical and chemical behavior of *Fagus orientalis* at various temperatures (130 ºC, 150 ºC, 180 ºC, 200 ºC) and durations (2, 6 and 10h). Predictably, mechanical properties decreased when the treatment duration and temperature were increased, whilst, regarding chemical properties, it was observed that hemicelluloses was the wood-cell component mostly degraded by the heat treatment. Reppelin *et al*. (2005) evaluated the swelling of heat treated beech wood in relation to chemical composition, and Hakkou *et al.* (2006) studied the fungal durability of heat treated *Fagus sylvatica* in the temperature range of 200 to 280 ºC, and the results indicated a considerably good correlation between the process temperature and wood durability. Moreover, they demonstrated a sufficient correlation between decay resistant and mass loss measurements, which are directly correlated to hemicellulose degradation. Mohebby *et al*. (2005) studied the influence of thermal treatment on physical properties of beech wood at 160 ºC, 180 ºC and 200 ºC for 4, 5 and 6 hours. The highest absorption was determined in beech wood treated at 180 ºC for 4 and 6 hours, while the lowest moisture absorption was measured in the samples treated at 160 ºC for 4 h. Charani *et al.* (2007) studied the effects of thermal treatment on dimensional stability and water absorption of beech wood (*Fagus orientalis)* applied in three different temperatures (150 ºC, 160 ºC and 170 ºC) and four different durations (1 h, 3 h, 5 h and 7 h). The results indicated that the best anti-swelling efficiency value was achieved at higher temperature, whereas water absorption decreased in all heat modified samples. Arnold (2007) investigated the anisotropy, hardness, shear strength parallel to grain, swelling, tensile strength perpendicular to grain of thermally modified beech and spruce wood subjected to 180 ºC and 220 ºC. The results indicated that thermal modification has a negative impact on mechanical and physical properties, while swelling improved. Govorcin *et al*. (2009) studied certain physical properties of Ash (*Fraxinus excelsior* L.) after thermal treatment at 200 ºC. They ascertained that the mean value of density in absolutely dry conditions of recent ash was higher by 8.4 % than density of heat treated ash. In addition, shrinkage in radial and tangential direction and volume shrinkage of recent ash were higher than shrinkage in heat treated ash. Dimensional stability of ash under such procedure of heat treatment resulted in increased dimensional stability, and yet, the investigated mechanical properties were significantly lower. Arnold (2009) studied the effect of moisture on bending properties of thermally modified beech wood at 180 ºC, 220 ºC for 4 hours. Gonzalez-Pena and Hale (2009) conducted experiments on the effect of heat on the chemical composition and dimensional stability of beech wood at 190, 210, 230 and 245 for 30 min, 1, 4, 8 and 16 hours. They concluded that ΔE^* in thermally modified wood originates from chemical changes in the main wood polymers, more so in lignin than in polysaccharides, due to the darkening of the lignin itself. Sinković *et al*. (2011) studied particular physical properties of treated and untreated beech and hornbeam wood. They inferred that the average value of density in completely dry conditions of heat treated beech wood was smaller by 8.5 % than the untreated one, whereas, the reduction of average values of maximum shrinkage of heat treated beech wood was even bigger in relation to the untreated wood. Maximum radial shrinkage of heat treated beech wood was smaller by 7 %, maximum tangential shrinkage by 23.5 % and maximum volumetric shrinkage by 19.3 % compared to the same physical properties of untreated beech wood. Todorović *et al*. (2012) estimated the beech wood properties by color change at 170 ºC, 190 ºC and 210 ºC for four hours. This study demonstrated that higher temperatures led to a rise in mass loss and a decrease in mechanical properties, whereas the effect on modulus of elasticity (*MOE*) was negligible.

This study was conducted to assess the variation of dimensional stability (swelling, absorption) after immersion in water for 1 h, 3 h, 6 h, 24 h and 72 h, the weight loss caused by heat treatment, weight increase after 7, 14, 21 days and 5 months of air conditioning at 20 ± 3 °C and 60 ± 5 % relative humidity, and the color changes (ΔL, Δa, Δb, ΔE, ΔC) after heat treatment of beech (*Fagus sylvatica)* wood at 180 ºC for 2, 4, 6, 8 and 10 hours.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

Beech sawn timber used in this research was of Greek origin, obtained from the market. The timber was air dried for 1 year. Initially, lumber was cut in sawn samples of dimension 50 x 25 mm in cross section. The average density (oven dry weight/volume at 10.26 % moisture) of timber used was 0.68 g/cm^3 (Standard Deviation = 0.02), while the average moisture content was 10.26 % (Standard Deviation = 0.15) after conditioning at 20 ± 2 °C and 60 ± 5 % relative humidity. Thermal treatment of the specimen applications was carried out in a temperature-controlled, small, laboratory, heating unit (80 x 50 x 60 cm), where five different durations (2 h, 4 h, 6 h, 8 h and 10 h) were applied at 180 °C under atmospheric pressure in the presence of air. The specimens were placed in the unit after the desired temperature had been reached. Immediately after that, the weight loss of the specimens of each heat treatment was measured by weighing them and comparing their weight to the initial one. The measurements of weight increase were conducted after reconditioning of the heat treated specimens at 20 ± 2 °C and 60 ± 5 % relative humidity for 7, 14 and 21 days.

All specimens color measurements were recorded on the surface of wood specimens before and after heat treatments in radial, tangential and longitudinal directions with a colorimeter Minolta Croma-Meter CR-400. The color system CIE*Lab** was used for the measurements. L^* describes the lightness, a^* and b^* describe the chromatic coordinates on the green-red and blue yellow axis, respectively. From the $L^*a^*b^*$ values, the difference in the lightness (ΔL^*) and chroma coordinates (Δa^* and Δb^*), saturation (C^*) (ΔC^*) and total color differences (ΔE) were calculated using the following equations:

$$\Delta L^* = L^*_t - L^*_{ut} \quad (1)$$

$$\Delta a^* = a^*_t - a^*_{ut} \quad (2)$$

$$\Delta b^* = b^*_t - b^*_{ut} \quad (3)$$

$$C^* = (a^{*2} + b^{*2})^{½} \quad (4)$$

$$\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{½} \quad (5)$$

$$\Delta C^* = C^*_t - C_{ut} \quad (6)$$

Were L^*_t, a^*_t, b^*_t are L^*, a^* and b^* of the heated specimens and L^*_{ut}, a^*_{ut}, b^*_{ut} are L^*, a^* and b^* of the control specimens, respectively.

The color measurements were determined according to ISO 7724/3:1984 and the values reported are the average values with standard deviation.

The samples for hygroscopic properties were cut in final cross section dimensions (2 cm x 2 cm x 3 cm), according to the respective standard ISO 4859: 1982. For each experiment, 10 specimens were prepared. The swelling (in radial and tangential directions) and the absorption percentage were conducted after the immersion of samples in the water of 20 ± 3 °C for 1 h, 3 h, 6 h, 24 h and 72 h. Additionally, after conditioning at 20 ± 2 °C and 60 ± 5 % relative humidity, EMC (Equilibrium Moisture Content) and density of the specimens were estimated.

The swelling percentage was calculated with the use of the following equation:

Percentage swelling = ((*Swollen Dimension* - *Oven Dry Dimension*)/(*Oven Dry Dimension*))×100

Absorbed water percentage was calculated according to the following equation:

$$M\% = ((M_{wet} - M_{dry}) / M_{dry}) \times 100$$

Where M_{wet} the wetmass after immersion in water, M_{dry} the initial dry mass.

Twelve replicates for each variable (treatment) were performed to compute the color changes and hygroscopic properties.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

So as to estimate the color change of the specimens, the three color coordinates, L^*, a^*, and b^* were recorded before and after heat treatment. Figure 1 shows the changes in lightness of beech wood for tangential, radial and longitudinal direction with respect to

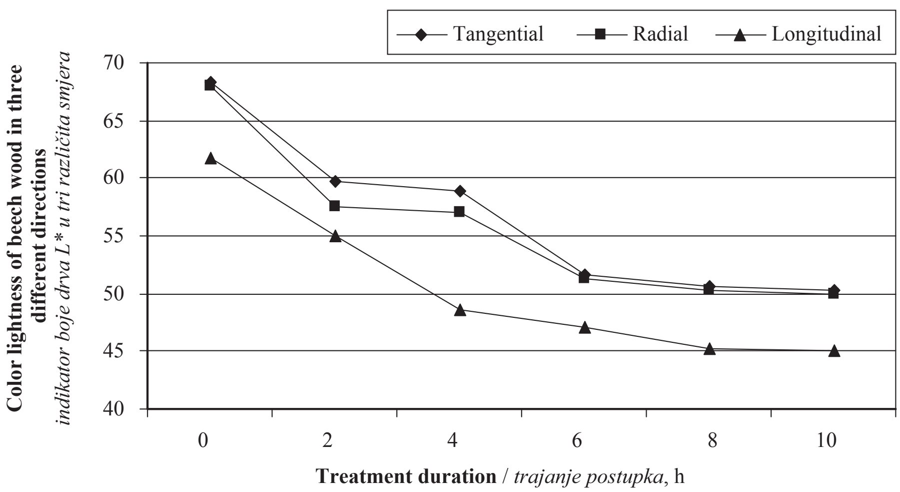

Figure 1 Effect of heat treatment duration in three different directions on L^*
Slika 1. Utjecaj trajanja toplinske obrade na indikator boje drva L^* u tri različita smjera

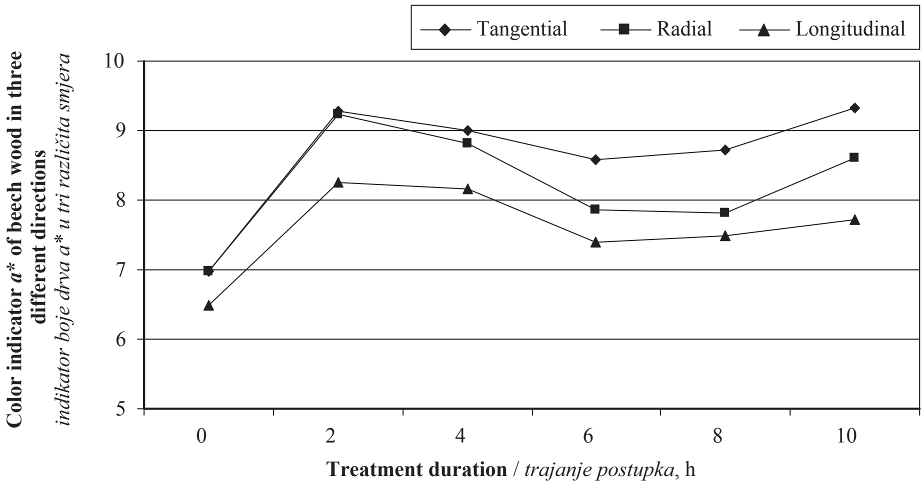

Figure 2 Effect of heat treatment duration in three different directions on *a**
Slika 2. Utjecaj trajanja toplinske obrade na indikator boje drva *a** u tri različita smjera

treatment duration. The resulting darkening was clearly observable and it intensified with treatment duration. Since *L*=0 is for black and *L*=100 is for white, it is evident that the lower *L* value, the darker color is observed. Heat treated beech wood exhibits a decrease of *L** indicator as the duration increases gradually. Additionally, tangential and radial directions show higher decrease compared to longitudinal direction. Concerning a* coordinate (Figure 2), which positions the color in a scale of green to red, it appears to be lower in untreated specimens, while it increases abruptly in specimens heat treated for 2 h and then it tends to decrease slowly with further increasing of treatment duration until 8-h treatment. Regarding coordinate *b** (Figure 3), which demonstrates the scale of yellow to blue, referring to longitudinal direction, it appears to increase till 4-h treatment unlike the radial and tangential direction.

The color coordinates, *L**, *a** and *b** were used in order to calculate the total color change (Δ*E*) and the color saturation (Δ*C**) (Table 1). A low value of ΔE corresponds to a low color change for the treated sample, compared to untreated specimens. According to the results, Δ*E* value of the specimens seems to increase, meaning that the color change of wood surface and the heat treatment intensity are proportional, while Δ*C** value seems to decrease, as the duration of the thermal treatment increases up to 6 h, where it appears to increase again until 10-h treatment, exceeding the values of 2-h treatment. The negative values of lightness (Δ*L**) indicated that the color became increasingly darker with the increase of treatment duration. The extent of thermal degradation is directly related to color darkening, therefore, the color can be used as an indicator of the process conditions (Guller, 2012).

Table 2 shows the average values of swelling of the treated and untreated specimens after immersion in water. Referring to swelling, all heat treatments in this study seem to enhance the hygroscopic behavior of beech wood. Swelling in tangential direction proved to be much higher than in radial direction. Nevertheless, thermal treatment proved to enhance tangential swelling more efficiently than radial swelling. As the duration of heat treatment is extended, tangential swelling tends to decrease and this tendency is similar to the case of swelling in radial direction, with the difference that when the treatment duration exceeded 8 h, the

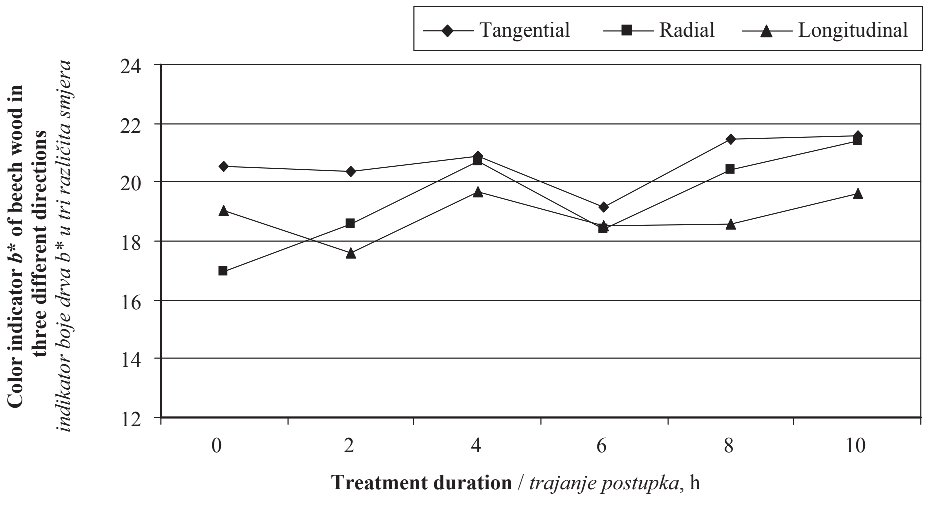

Figure 3 Effect of heat treatment duration in three different directions on *b**
Slika 3. Utjecaj trajanja toplinske obrade na indikator boje drva *b** u tri različita smjera

Table 1 Effect of heat treatment for three different durations on color changes of beech wood
Tablica 1. Utjecaj različitog trajanja toplinske obrade drva na promjene boje bukovine

Heat treatment time, h *Trajanje toplinske obrade, h*	**Direction** *Smjer*	**Unit**	**Color change values** /*Vrijednosti promjene boje*				
			ΔE	Δ*L*	Δ*a*	Δ*b*	Δ*C*
2 h	Tangential *tangencijalno*	Avg.	**9.09**	**-8.77**	**2.31**	**-0.3**	**0.70**
		±s	0.89	0.94	0.24	0.06	0.12
		s²	0.80	0.89	0.06	0.004	0.01
		CV	0.09	0.10	-0.10	-0.22	0.17
	Radial *radijalno*	Avg.	**11.27**	**-10.44**	**2.27**	**1.64**	**1.77**
		±s	0.99	0.84	0.37	0.21	0.23
		s²	0.99	0.72	0.14	0.04	0.05
		CV	0.08	-0.08	0.16	0.13	0.13
	Longitudinal *longitudinalno*	Avg.	**7.06**	**-6.74**	**1.78**	**-1.48**	**-0.59**
		±s	0.89	0.93	0.32	0.24	0.16
		s²	0.79	0.88	0.10	0.06	0.02
		CV	0.12	-0.13	0.18	-0.16	-0.27
4 h	Tangential *tangencijalno*	Avg.	**9.48**	**-9.42**	**2.02**	**0.34**	**1.07**
		±s	1.30	1.31	0.27	0.08	0.08
		s²	1.70	1.73	0.07	0.007	0.008
		CV	0.13	-0.13	0.13	0.25	0.08
	Radial *radijalno*	Avg.	**11.58**	**-10.92**	**1.85**	**3.76**	**3.70**
		±s	0.51	0.51	0.26	0.45	0.42
		s²	0.26	0.26	0.07	0.20	0.17
		CV	0.04	-0.04	0.14	0.12	0.11
	Longitudinal *longitudinalno*	Avg.	**13.37**	**-13.25**	**1.68**	**0.61**	**1.27**
		±s	0.62	0.61	0.19	0.18	0.15
		s²	0.38	0.37	0.03	0.03	0.02
		CV	0.04	-0.04	0.11	0.30	0.11
6 h	Tangential *tangencijalno*	Avg.	**16.84**	**-16.73**	**1.69**	**-1.29**	**-0.65**
		±s	0.90	0.87	0.46	0.15	0.11
		s²	0.82	0.76	0.21	0.02	0.01
		CV	0.05	-0.05	0.27	-0.11	-0.17
	Radial *radijalno*	Avg.	**16.84**	**-16.75**	**0.88**	**1.45**	**1.19**
		±s	0.87	0.87	0.16	0.19	0.11
		s²	0.76	0.76	0.02	0.03	0.01
		CV	0.05	-0.05	0.18	0.13	0.09
	Longitudinal *longitudinalno*	Avg.	**14.44**	**-14.40**	**0.91**	**-0.52**	**-0.17**
		±s	0.63	0.63	0.09	0.09	0.07
		s²	0.40	0.40	0.008	0.008	0.005
		CV	0.04	0.04	0.10	-0.17	-0.42
8 h	Tangential *tangencijalno*	Avg.	**17.68**	**-17.78**	**1.76**	**0.92**	**1.48**
		±s	0.83	0.89	0.18	0.11	0.15
		s²	0.69	0.80	0.03	0.01	0.02
		CV	0.04	-0.05	0.10	0.12	0.10
	Radial *radijalno*	Avg.	**18.14**	**-17.66**	**0.83**	**3.46**	**2.91**
		±s	0.78	0.94	0.09	0.25	0.258
		s²	0.61	0.89	0.009	0.06	0.06
		CV	0.04	-0.05	0.11	0.07	0.08
	Longitudinal *longitudinalno*	Avg.	**16.61**	**-16.58**	**0.99**	**-0.44**	**-1.10**
		±s	0.69	0.69	0.11	0.10	0.07
		s²	0.48	0.48	0.01	0.01	0.005
		CV	0.04	-0.04	0.11	-0.23	-0.69
10 h	Tangential *tangencijalno*	Avg.	**18.19**	**-18.01**	**2.35**	**1**	**1.73**
		±s	0.57	0.56	0.22	0.22	0.16
		s²	0.33	0.32	0.05	0.04	0.02
		CV	0.03	-0.03	0.09	0.22	0.09
	Radial *radijalno*	Avg.	**18.65**	**-18.04**	**1.63**	**4.44**	**4.13**
		±s	0.65	0.69	0.17	0.15	0.15
		s²	0.43	0.48	0.02	0.02	0.02
		CV	0.03	-0.03	0.10	0.03	0.03
	Longitudinal *longitudinalno*	Avg.	**16.80**	**-16.74**	**1.23**	**0.57**	**0.98**
		±s	0.57	0.58	0.14	0.09	0.10
		s²	0.32	0.33	0.01	0.009	0.01
		CV	0.03	-0.03	0.11	0.17	0.10

(Avg – Average / *srednja vrijednost*; ±s – Standard error / *standardna pogreška*, s² – Standard Deviation / *standardna devijacija*, CV – Coefficient of variation / *koeficijent varijacije*)

Table 2 Effect of heat treatment on dimensional stability (swelling) in tangential and radial direction of beech wood
Tablica 2. Utjecaj toplinske obrade na dimenzijsku stabilnost (bubrenje) bukovine u tangencionalnom i radijalnom smjeru

Treatment Duration *Trajanje obrade*	**Unit**	**Tangential swelling, %** *Tangencijalno bubrenje, %*					**Radial swelling, %** *Radijalno bubrenje, %*				
		Time of immersion in water / *Vrijeme potapanja u vodi*									
		1 h	3 h	6 h	24 h	72 h	1 h	3 h	6 h	24 h	72 h
0 h	Avg.	**1.10**	**2.06**	**2.91**	**6.40**	**8.04**	**1.12**	**1.54**	**2.04**	**3.52**	**3.99**
	±s	0.45	0.51	0.52	0.67	1.22	0.84	1	1.11	1.44	1.48
	s²	0.20	0.26	0.27	0.44	0.48	0.70	1	1.23	2.07	2.19
	CV	0.40	0.24	0.17	0.10	0.15	0.75	0.64	0.54	0.40	0.37
2 h	Avg.	**0.81**	**1.55**	**2.05**	**2.29**	**3.11**	**0.63**	**1.17**	**1.63**	**1.93**	**2.57**
	±s	0.36	0.44	0.50	0.58	0.72	0.20	0.28	0.39	0.58	0.63
	s²	0.13	0.19	0.25	0.34	0.51	0.04	0.07	0.15	0.34	0.40
	CV	0.44	0.28	0.24	0.25	0.23	0.32	0.47	0.24	0.30	0.24
4 h	Avg.	**0.87**	**1.39**	**1.93**	**2.30**	**3.17**	**0.76**	**1.13**	**1.54**	**1.85**	**2.73**
	±s	0.15	0.28	0.18	0.21	0.40	0.24	0.20	0.18	0.29	0.26
	s²	0.02	0.08	0.03	0.04	0.16	0.05	0.04	0.03	0.08	0.07
	CV	0.18	0.20	0.09	0.09	0.12	0.31	0.17	0.12	0.15	0.09
6 h	Avg.	**0.72**	**1.10**	**1.90**	**2.50**	**3.33**	**0.75**	**0.99**	**1.43**	**1.75**	**2.48**
	±s	0.16	0.11	0.21	0.19	0.28	0.13	0.14	0.28	0.33	0.30
	s²	0.02	0.01	0.04	0.03	0.08	0.02	0.02	0.08	0.11	0.09
	CV	0.22	0.10	0.11	0.07	0.08	0.14	0.14	0.19	0.18	0.12
8 h	Avg.	**0.67**	**1.01**	**1.49**	**1.98**	**2.58**	**0.73**	**0.98**	**1.33**	**1.71**	**2.51**
	±s	0.10	0.15	0.22	0.34	0.44	0.17	0.16	0.12	0.18	0.35
	s²	0.01	0.02	0.05	0.12	0.20	0.03	0.02	0.01	0.03	0.12
	CV	0.15	0.15	0.15	0.17	0.17	0.24	0.17	0.09	0.10	0.14
10 h	Avg.	**0.72**	**1.08**	**1.70**	**2**	**2.65**	**0.51**	**0.75**	**0.61**	**1.50**	**2.09**
	±s	0.26	0.33	0.45	0.51	0.58	0.14	0.18	1.31	0.58	0.57
	s²	0.06	0.11	0.20	0.26	0.33	0.02	0.03	1.72	0.34	0.33
	CV	0.36	0.30	0.26	0.25	0.21	0.28	0.25	2.12	0.38	0.27

(Avg – Average / *srednja vrijednost*; ±s – Standard error / *standardna pogreška*, s² – Standard Deviation / *standardna devijacija*, CV – Coefficient of variation / *koeficijent varijacije*)

swelling values slightly increased only in tangential direction, without reaching the swelling values of the untreated specimens.

The absorption of the treated specimens was affected positively compared to untreated specimens (Table 3). As the treatment duration increases, absorption decreases; however when exceeding 8 hours of treatment, absorption percentage values record a slight increase. This fact may be attributed to permanent changes typically occurring during heat treatments of long duration, namely in the chemical composition of wood and physical properties, such as mass loss, density loss, thermal degradation of polysaccharides and lignin, etc.

The dominant effect of heat treatment is the decrease in equilibrium moisture content. This, along with the oven dry density of all heat-treated samples, decreased in relation to the untreated wood except for density specimens treated for 2 h, whose values slightly increased, which is compatible with previous studies. Yildiz (2002b) reported a minor density increase of beech wood (2.25 %) after 2-h treatment at 130 ºC, but mentioned that for more intense treatments the density decreased by 10 %. Regarding equilibrium moisture content, the 10-h treatment was the most effective, decreasing the equilibrium moisture by 47.12 %. This EMC reduction suggests that thermal treatment affects the dimensional stability

Table 3 Absorption percentage of thermally treated and untreated beech wood
Tablica 3. Postotak apsorpcije toplinski obrađenoga i neobrađenog drva

Treatment duration *Trajanje obrade*	**Time of immersion in water** *Vrijeme potapanja u vodi*				
	1 h	3 h	6 h	24 h	72 h
0 h	9.78 (1.40)	14.05 (1.80)	18.18 (1.74)	30.06 (1.88)	48.79 (1.73)
2 h	6.53 (1.23)	12.45 (1.58)	16.20 (1.61)	27.63 (1.28)	49.29 (1.35)
4 h	6.13 (0.70)	10.34 (0.94)	14.99 (1.09)	25.34 (1.59)	47.15 (1.39)
6 h	6.11 (0.28)	10.12 (0.56)	13.73 (1.02)	24.04 (1.19)	43.70 (1.09)
8 h	5.46 (0.47)	8.33 (0.81)	12.56 (1.42)	22.65 (1.24)	42.80 (1.200
10 h	5.82 (0.78)	8.62 (1.14)	12.84 (0.71)	22.71 (0.95)	42.72 (1.04)

*Standard Deviation is quoted in parenthesis. / *Standardna devijacija navedena je u zagradi.*

Table 4 Equilibrium moisture content obtained after heat treatment and conditioning at 20 ºC and 65 % relative humidity
Tablica 4. Ravnotežni sadržaj vode postignut nakon toplinske obrade i kondicioniranja bukovine pri 20 ºC i relativnoj vlažnosti zraka 65 %

Treatment duration *Trajanje obrade*	**EMC** %	**Percentage of decrease, %** *Postotak smanjenja, %*	**Density, g/cm³** Gustoća, g/cm³	**Percentage of decrease, %** *Postotak smanjenja, %*
Untreated	10.26	-	0.68	-
2 h	6.53	36.32	0.71	-5.81
4 h	6.40	37.53	0.64	4.89
6 h	6.11	40.42	0.62	7.93
8 h	5.60	45.37	0.62	7.80
10 h	5.42	47.12	0.61	10.15

*EMC – Equilibrium moisture content / *ravnotežni sadržaj vode*

Table 5 Mean values of weight loss and weight increase of heat treated beech wood
Tablica 5. Srednje vrijednosti gubitka mase i povećanja mase toplinski obrađene bukovine

Treatment duration at 180 °C *Trajanje obrade pri 180 °C*	**Mean weight loss directly after heat treatment** *Srednja vrijednost gubitka mase odmah nakon toplinske obrade* %	**Mean weight increase after 7 days** *Prosječni porast mase nakon 7 dana* %	**Mean weight increase after 14 days** *Prosječni porast mase nakon 14 dana* %	**Mean weight increase after 21 days** *Prosječni porast mase nakon 21 dan* %
2 h	11.25	4.92	1.05	0.19
4 h	11.68	4.45	0.97	0.13
6 h	12.09	4.50	0.87	0.13
8 h	13.41	3.93	0.85	0.12
10 h	13.34	4.21	0.78	0.10

and water adsorbing capacity of wood to a great extent (Table 4). Esteves *et al*. (2009) concluded that the water adsorption of beech wood decreased at treatment temperatures higher than 100 ºC, decreasing with the increase in treatment time. The reason of the decrease in the equilibrium moisture content is that less water was absorbed by the cell walls after the heat treatment as a result of chemical change (Jamsa and Viitaniemi, 2001). Additionally, the polycondensation reactions in lignin result in further cross-linking that might also contribute to the reduction of equilibrium moisture content (Tjeerdsma, 2005).

The weight loss of the heat treated specimens, measured directly after each treatment, (Table 5) are an indicator of treated wood quality (Esteves *et al*., 2009). The higher the treatment duration, the more weight loss is recorded. This can be attributed not only to moisture content loss but also to evaporation of volatile extractives and other chemical constituents such as hemicelluloses. In this research, the specimens that were conditioned at 20 ± 2 ºC and 60 ± 5 % relative humidity, for three different periods, present an increase of their weight due to regaining moisture as shown in Table 4. The specimens treated at mild treatments exhibited higher weight increase compared to the specimens exposed to more intense treatment. Furthermore, as the conditioning period was extended, the weight increase was reduced.

4 CONCLUSIONS
4. ZAKLJUČAK

Assessment of color changes and hygroscopic properties leads to the following conclusions.

The color coordinates L^*, a^* and b^* of the heat treated specimens changed, meaning that the color of the wood surface was modified. The color difference (ΔE) appears to increase depending on treatment intensity unlike color saturation (ΔC), which decreases proportionally to treatment severity. The most intense color differences occurred in 8-h and 10-h treatments, the difference between them not being significant.

The EMC and density decrease abruptly in the initial treatments, whereas as the duration increases, this decrease tends to be slower and more gradual. Among different treatment durations, the 8-h at 180 ºC combination provided the most effective results with the largest EMC percentage decrease. Swelling and absorption percentage were positively affected by heat treatment. The swelling values increased only in tangential direction after 8-h treatment and generally the tangential direction proved to be better than the radial one.

It can be concluded heat treatment modification enhances some of the most significant wood features such as hygroscopic properties and color change. According to the dimensions of the treated specimens and conditions used in this investigation, it can be stated that 8 h was the best treatment duration, as it showed the largest decrease in the hygroscopic properties with an attractive dark color approaching tropical species, providing an optimization of beech wood in a wide range of applications.

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Razlike u vrijednostima volumena neokrajčenih piljenica kao posljedica različitih načina mjerenja njihove širine

Differences in Values of Volume of Unedged Sawn Boards as a Result of Different Width Measurement Methods

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SAŽETAK • *U radu su razmatrani različiti načini mjerenja širine neokrajčenih piljenica nominalnih debljina 50, 60 i 80 mm te značenje tih načina mjerenja na proračun njihova volumena. Polazište pri određivanju načina mjerenja širine bili su propisi hrvatskih i europskih normi te uobičajeni načini mjerenja u hrvatskim pilanama. Eksperimentalno je mjerenje izvedeno u jednoj pilani u Hrvatskoj. Na temelju dobivenih rezultata istraživanja zaključeno je da postoje razlike u izračunanim volumenima neokrajčanih piljenica koje su posljedica različitih načina mjerenja njihovih širina. Za piljenice debljine 50 mm najveće su vrijednosti izračunanoga volumena dobivene metodom koja se često primjenjuje u hrvatskoj pilanarskoj praksi, a označili smo je sa P2, a zatim slijede načini mjerenja prema HRN2, EN, te još jednoj metodi koja se rabi u hrvatskoj pilanarskoj praksi, a koju smo označili sa P1, kao i prema HRN1, no te razlike nisu statistički značajne. Način mjerenja širine za piljenice debljine 60 i 80 mm prema EN daje najveće vrijednosti volumena, zatim slijede HRN2, u pilanama označenima sa P2, P1 i HRN1, no te su razlike statistički značajne samo za debljinu od 80 mm. Načini mjerenja širine prema EN, HRN2 i pilani označenoj sa P2 za sve istraživane debljine rezultiraju manjim međusobnim odstupanjima. S povećanjem debljine vidljiv je i porast razlike volumena piljenica, no on je statistički značajan tek za debljine piljenica od 80 mm.*

Ključne riječi: *mjerenje piljenica, neokrajčene piljenice, širina piljenica, volumen piljenica*

ABSTRACT • *The paper discusses various methods of measuring the width of unedged sawn boards with nominal thickness of 50, 60 and 80 mm, as well as the importance of measuring methods for the calculation of their volume. The starting point in determining the method of measuring the width of the boards were Croatian and European regulations as well as common methods of measuring used in Croatian sawmills. Experimental measurements were performed in a sawmill in Croatia. Based on the research results, it was concluded that there is a difference in the calculation of the volume of the unedged sawn boards as a result of the different methods used to calculate*

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their width. For 50 mm thick sawn boards, the highest values of the measured volume were obtained by applying a measurement method common in Croatian sawmills, labelled as P2. This was followed by measurement methods according to HRN2, EN, and another method used in Croatian sawmills, labelled as P1, and finally by the HRN1 method; however differences in this case were not statistically significant. The EN method of measuring the width of sawn boards of 60 and 80 mm thickness resulted in the highest value of volume, followed by the HRN2 method, and finally methods used in the sawmills labelled as P2, P1 and HRN1; however differences were statistically significant only with 80 mm sawn boards. For all the observed widths, measurement methods according to EN, HRN2 and the sawmill method, labelled as P2, resulted in smaller mutual deviations. With an increase of thickness, an apparent increase in volume was observed; however it was statistically significant only for the planks with a thickness of 80 mm.

Keywords: *unedged sawn boards, measuring of boards, board width, volume of sawn boards*

1. UVOD
1 INTRODUCTION

Neokrajčene se piljenice (sl. 1.) prema obliku mogu definirati kao vrsta pilanskog proizvoda koji je s dvije plošne strane obrađen pilama, a na dvije uzdužne rubne strane ima ostatak zaobljenja trupca (Brežnjak, 1997.). S obzirom na kvalitetu, mogu biti izuzetno kvalitetne, ali i osrednje ili niske kvalitete. Nekada su se, a ponegdje je tako i danas, od najkvalitetnijih trupaca različitih vrsta drva izrađivale kladarke ili bul kao najvredniji primarni pilanski proizvodi takvoga oblika. Danas su takav proizvod samice, odnosno visokokvalitetne neokrajčene piljenice (Ištvanić i sur., 2003.). Samice se izrađuje na više načina, ali najčešće primarnim raspiljivanjem tehnikom piljenja ucijelo. Jedan od načina dobivanja samica jest onaj pri piljenju trupaca u kladarke, kada se piljenice koje kvalitetom ne zadovoljavaju svrstavanje u kladarke svrstavaju u samice. Samice se izrađuju i neposredno piljenjem trupaca koji kvalitetom ne bi dali kladarke. Pritom u kategoriju samica mogu biti uvrštene sve one neokrajčene piljenice koje se izrađuju od središnje i bočne zone trupca ako odgovaraju kvalitetom i ako nisu uže i kraće od normom propisane širine i duljine samica. Samice se izrađuju i od duljih neokrajčenih piljenica koje kvalitativno ne zadovoljavaju uvjete, ali se dodatnim poprečnim krojenjem (prikraćivanjem) dio tih piljenica može svrstati u samice (Prka, 1988.).

Slika 1. Kladarke i neokrajčene piljenice (samice)
Figure 1 Bouls and unedged sawn boards

U hrvatskim pilanama uobičajeno je da se izmjera piljenica provodi ručno, različitim vrstama krutih i sklopivih drvenih ili plastičnih mjernih alata odnosno čeličnim ili plastičnim mjernim vrpcama (sl. 2.). Mjerenje se najčešće obavlja nakon što se piljena građa ispili i otpremi u sortirnicu pilane ili na skladište piljenica. Pri ručnom mjerenju piljenog drva često nastaju greške koje kasnije utječu na volumen, pa i na krajnju cijenu piljenice. Uzroci pogrešaka najčešće su:

- nedovoljan broj mjernih mjesta
- neispravna uporaba mjernih uređaja
- neispravnost mjernih uređaja
- sustavna greška mjerila
- pogrešno očitanje mjeritelja.

Ručno se mjerenje obavlja metodama koje su propisane normama ili pak prema dogovorima i ugovorima. No izmjera se može provoditi i strojno, uz pomoć elektroničkih naprava. Tim se načinom mjerenja duljina i debljina mogu određivati za bilo koji oblik piljene građe, dok se širina određuje uglavnom samo u okrajčenih piljenica. Moguća su taktilna mjerenja kao što su ručno mjerenje ili upotreba dvostrane mehaničke ruke, ali umjesto toga, kao alternativa, moguće je upotrijebiti ultrazvučne, mikrovalne i optičke senzore (Vuorilehto, 2001.).

Prka i sur. (2001.) te Ištvanić i sur. (2003.) u svojim su istraživanjima razmatrali problematiku razvrstavanja neokrajčenih i poluokrajčenih hrastovih i bukovih piljenica prema normama i uobičajenim kriterijima u hrvatskim pilanama. Utvrdili su da postoje određene razlike u razvrstavanju prema kvaliteti, što je bio i prioritetni cilj istraživanja. No usput su uočili da postoje i određene razlike u pristupu načinu mjerenja širine piljenica. S obzirom na to da nisu pronađeni odgovori na pitanja koliko je to u konačnici važno pri preuzimanju i obračunu volumena piljenica, poduzeto je novo istraživanje te problematike.

U pilanskoj obradi drva u Republici Hrvatskoj nedostatni su podaci o utjecaju načina mjerenja širine neokrajčenih piljenica na njihov volumen. Budući da se u praksi propisuju i primjenjuju različiti načini mjerenja širine prema normama odnosno na praktičan način, cilj istraživanja bio je utvrditi značenje načina mjerenja širine na volumen neokrajčenih piljenica različitih nominalnih debljina.

Slika 2. Ručno mjerenje neokrajčenih piljenica
Figure 2 Manuel measuring of unedged sawn boards

2. MATERIJALI I METODE
2 MATERIALS AND METHODS

Preuzimanje i mjerenje piljenica provedeno je u jednoj hrvatskoj pilani specijaliziranoj za obradu tvrdih listača (sl. 3.). Kao pilanska sirovina za izradu piljenica korišteni su furnirski trupci F i L klase te pilanski trupci I., II. i III. klase kvalitete prema HRN normama. Neokrajčene piljenice (samice) gotov su pilanski proizvod koji se u toj pilani izrađuje tehnikom piljenja trupca ucijelo na tračnoj pili trupčari. Piljenice su prethodno prirodno prosušene, a nominalne su im debljine bile 50, 60 i 80 mm. Mjerenje je provedeno sukladno propisima *HRN D. B0. 022. - Razvrstavanje i mjerenje neobrađenog i obrađenog drva*, *EN 1309 – 1 Oblo i piljeno drvo, Metoda mjerenja dimenzija – I. dio: Piljeno drvo* i *EN 1312 – Oblo i piljeno drvo, Određivanje volumena složaja piljenog drva* te prema dvama praktičnim postupcima mjerenja u hrvatskim pilanama označenima sa P1 i P2. Pri tome se nije posebno pazilo na vrstu drva od koje su piljenice bile izrađene, ali svaki je izmjereni statistički uzorak od 30 komada piljenica bio od istovrsne vrste drva.

2.1. Načini mjerenja neokrajčenih piljenica
2.1 Measuring of unedged boards

2.1.1. Mjerenje prema normi HRN D. B0. 022.
2.1.1 Measurement according to Croatian standard – HRN D. B0. 022

Mjerenje debljine obavlja se na bilo kojemu mjestu piljenice. Duljina piljene građe mjeri se metrom na bilo kojemu mjestu od jednoga do drugog čela piljenice ako je ona pravokutno prepiljena. Ako čelne stranice nisu pravokutno prepiljene, duljina se mjeri na najkraćemu mjestu između obaju čela. Duljina se izražava metrima, s jednim decimalnim mjestom zaokruženo naniže. Širina piljene građe samica i polusamica mjeri se metrom i izražava centimetrima. U piljenica debljine do 47 mm širina se mjeri na užoj strani, na polovici duljine piljenice (sl. 4.a). Širina piljenica debljine 48 mm i više mjeri se na užoj i široj strani te se izračuna aritmetička sredina iznosa obiju širina (sl. 4.b). Tom normom izmjerena širina izražava se cijelim centimetrima zaokruženima na nižu vrijednost. No s obzirom na to da se u hrvatskim normama vezanima za neokrajčene piljenice pojedinih vrsta drva navodi da se izmjerena širina izražava cijelim centimetrima, pri čemu se širina piljenice do 5 mm zaokružuje naniže, a one od 6 do 9 mm naviše, pri proračunu je primijenjen taj propis zaokruživanja vrijednosti.

Slika 3. Preuzimanje i mjerenje neokrajčenih piljenica (samica)
Figure 3 Handling and measuring of unedged sawn boards

2.1.2. Mjerenje prema normi EN 1309 i EN 1312
2.1.2 Measurement according to European Standards – EN 1309 and EN 1312

Debljina se mjeri na oba čela neokrajčane piljenice. Mjesto mjerenja mora biti čisto i bez grešaka drva. Širina neokrajčenih piljenica mjeri se na polovici duljine piljenica, i to od polovice zaobljenosti s jedne strane do polovice zaobljenosti (ostatka plašta trupca) na drugoj strani. Ako se na tome mjestu nalazi neka greška drva koja značajno utječe na rezultat mjerenja, izvode se dva mjerenja na udaljenosti simetričnoj od polovice duljine piljenice. Piljenice koje se mjere moraju biti svježe ispiljene. Za dobivanje širine uzima se piljenica bez kore i mjeri njezina širina. S obzirom na vrlo nejasno objašnjenje načina izražavanja i zaokruživanja u mjernim jedinicama, prilagodili smo ga drugim istraživanjima mjerenja tako da smo širinu izrazili cijelim centimetrima, pri čemu smo širina piljenice do 5 mm zaokruživali naniže, a one od 6 do 9 mm naviše (sl. 4.c). Duljinu smo mjerili na najkraćemu mjestu između obaju čela piljenica i izražavali metrima s dva decimalna mjesta zaokruženo naniže.

2.1.3. Mjerenje prema postupku u pilani 1 (P1)
2.1.3 Measurement according to the method of Sawmill 1

Mjerenje debljine nije točno propisano. Širina piljene građe iskazuje se centimetrima. Širina neokrajčenih piljenica debelih do, uključivo, 38 mm mjeri se na užoj strani, na polovici duljine piljenice, od kore do kore. Širina neokrajčanih piljenica debljine 50 mm i više mjeri se na užoj strani piljenice, i to na polovici duljine, tako da se za širinu uzima dimenzija od početka zaobljenosti na užoj strani do polovice zaobljenja zaostaloga od trupca na široj strani piljenice (sl. 4.d). U oba primjera izmjerene se veličine zaokružuju na cijeli centimetar naniže. Duljina se mjeri na najkraćemu mjestu između obaju čela piljenica i izražava se metrima s jednim decimalnim mjestom zaokruženo naniže.

2.1.4. Mjerenje prema postupku na pilani 2 (P2)
2.1.4 Measurement according to the method of Sawmill 2

Mjerenje debljine ni u toj pilani nije strogo određeno. Širine piljenica svih debljina mjere se centimetrima i zaokružuju na puni centimetar naniže. Širina piljenica debelih do, uključivo, 38 mm mjeri se na užoj strani, na polovici duljine, tako da se za širinu uzima dimenzija od početka zaobljenja na jednoj strani do početka zaobljenosti na drugoj strani. Širina piljenice debljine 50 i više milimetara mjeri se na užoj strani piljenice, i to na polovici duljine, tako da se za širinu uzima dimenzija od početka zaobljenosti na užoj strani do samog kraja zaobljenosti šire strane piljenice na drugoj strani (sl. 4.e). U oba primjera izmjerene se veličine zaokružuju na cijeli centimetar naniže. Duljina se mjeri na najkraćemu mjestu između obaju čela piljenice i izražava se metrima s jednim decimalnim mjestom zaokruženo naniže.

2.2. Obrada podataka
2.2 Data processing

Proračun volumena izračunan je množenjem izmjerenih dimenzija temeljenom na nominalnoj debljini, širini i duljini piljenica prema izrazu 1:

$$V = d \cdot b \cdot l \quad (1)$$

V - volumen piljenice / *volume of sawn boards,* m^3
d - debljina piljenice / *thickness of sawn boards*, m
b - širina piljenice / *width of sawn boards*, m
l - duljina piljenice / *length of sawn boards*, m.

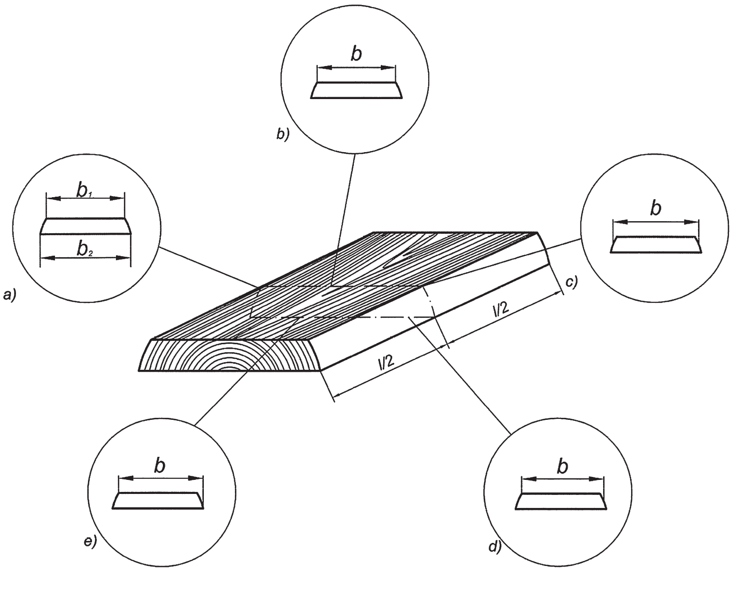
Za sve analizirane varijable provedena je opisna statistika (veličina uzorka, aritmetička sredina, standardna devijacija, minimum, medijan, maksimum te 95- postotni interval pouzdanosti procjene volumena neokrajčenih piljenica). Grafički prikazi kumulativnih vrijednosti volumena izračunanih na pet različitih načina (HRN2, HRN1, EN, P1, P2) izrađeni su u računalnom programu *Microsoft Excel*. Usporedba prosječnih vrijednosti volumena neokrajčenih piljenica unutar istraživanih debljina provedena je analizom varijance (*ANOVA*) uz pomoć računalnog programa *Statistica 7.1,.* u kojemu su izrađeni i grafički prikazi provedenih analiza.

3. REZULTATI
3 RESULTS

Uvjet homogenosti varijance zadovoljen je pri svim usporedbama unutar različitih nominalnih debljina neokrajčenih piljenica (tabl. 1.), te je za usporedbu prosječnih vrijednosti volumena neokrajčenih piljenica

Tablica 1. Usporedba varijanci volumena neokrajčenih piljenica
Table 1 Comparison of volume variances of unedged boards

Nominalne debljine neokrajčanih piljenica, mm *Nominal thickness of unedged boards, mm*	**Leveneov test homogenosti varijance** *Levene's test of homogeneity of variance*	
	F	*P*
50	0,28905	0,88471
60	0,20043	0,93777
80	0,07039	0,99087



Slika 4. Prikaz načina mjerenja širine neokrajčenih piljenica: a) prema HRN2 (piljenice debljine 48 mm i više), b) prema HRN1 te kao u pilani P1 i P2 (piljenice debljine do 47 mm), c) prema EN, d) prema pilani P1 (piljenice debljine 48 mm i više), e) prema pilani P2 (piljenice debljine 48 mm i više)
Figure 4 Methods of measuring the width of unedged sawn boards: a) HRN2 (from sawn boards with a thickness of 48 mm and more), b) HRN1 and sawmill P1 and P2 (from sawn boards with a thickness of up to 47 mm, c) EN, d) sawmill P1 (from sawn boards with a thickness of 48 mm and more), e) sawmill P2 (from sawn boards with a thickness of 48 mm and more)

Tablica 2. Deskriptivna statistička obrada izmjerenih dimenzija neokrajčenih piljenica nominalne debljine 50 mm
Table 2 Descriptive statistics of measured dimensions for 50 mm thick unedged boards

Način mjerenja *Method of measurement*	**Dimenzija** *Dimension*	**Veličina uzorka** N	**Minimum** *Minimum*	**Medijan** *Median*	**Maksimum** *Maximum*	**Aritmetička sredina** *Average*	**Standardna devijacija** *Stand. dev.*
HRN 2 *Croatian Standard 2*	*b*, cm	30	20	35	59	35	8
	V, m³	30	0,025	0,064	0,094	0,059	0,019
HRN 1 *Croatian Standard 1*	*b*, cm	30	20	33	55	32	7
	V, m³	30	0,023	0,056	0,090	0,055	0,017
EN *European Standard*	*b*, cm	30	21	35	55	35	8
	V, m³	30	0,025	0,065	0,096	0,059	0,020
Pilana 1 *Sawmill 1*	*b*, cm	30	20	35	59	34	8
	V, m³	30	0,025	0,058	0,092	0,057	0,018
Pilana 2 *Sawmill 2*	*b*, cm	30	20	36	59	36	8
	V, m³	30	0,027	0,065	0,092	0,060	0,018

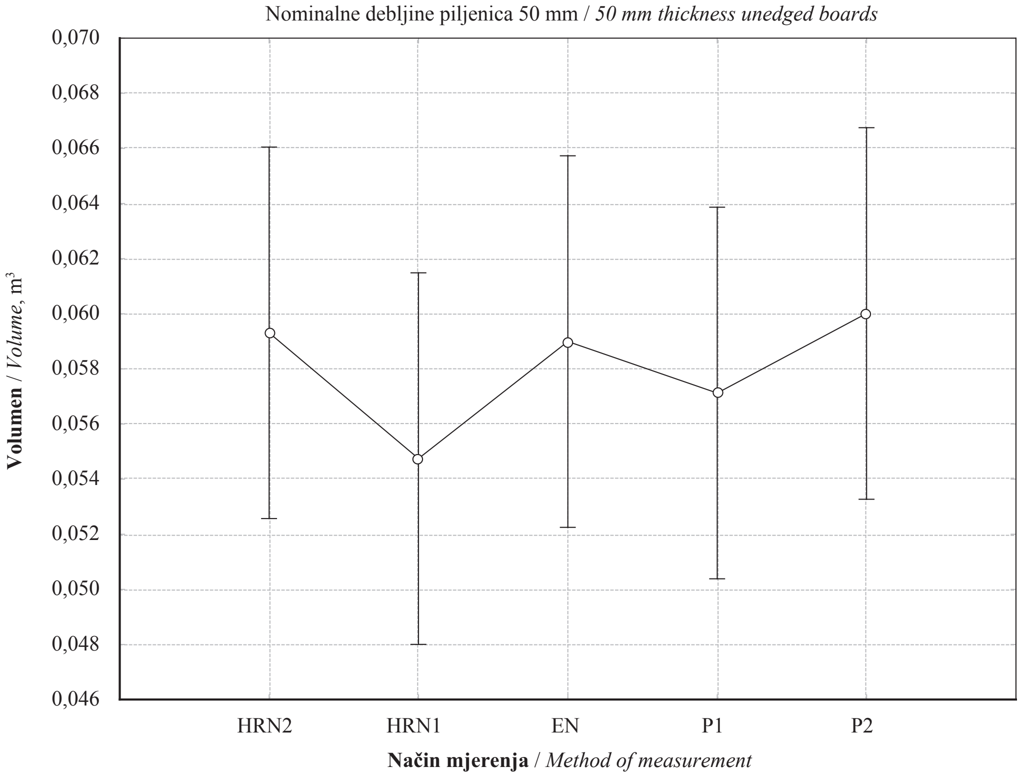
Tablica 3. Rezultati testiranja signifikantnosti razlike volumena neokrajčenih piljenica nominalne debljine 50 mm
Table 3 Results of statistical significance analysis of differing volumes for 50 mm thick sawn boards

Izvor varijacije *Source of variation*	**Zbroj kvadrata** *Sum of squares*	**Stupnjevi slobode** *Degrees of freedom*	**Sredina kvadrata** *Mean square*	***F*-omjer** *F ratio*	***p*-vrijednost** *p value*
Protumačen (između grupa) *Interpreted (between groups)*	543,01	4	135,75	0,38899	0,81627
Neprotumačen (unutar grupa) *Unexplained (within groups)*	50 602,82	145	348,98		
Ukupno / *Total*	51 145,82	149	-	-	-

različitim načinima mjerenja njihove širine primijenjena analiza varijance (ANOVA).

Testiranje razlika između prosječnih vrijednosti volumena neokrajčenih piljenica debljine 50 mm izračunanih na pet različitih načina (HRN2, HRN1, EN, P1, P2) provedeno je analizom varijance. Opisna statistika i rezultati testiranja prikazani su u tablicama 2. i 3.

F-omjer za analizirane varijable pripada *F- distribuciji* (stupanj slobode – 4, 145), a uz razinu značajnosti α = 5 % kritična vrijednost iznosi 2,43407. Empirijski je *F-omjer* za prosječne vrijednosti volumena neokrajčenih piljenica debljine 50 mm manji od kritične vrijednosti, te se zaključuje da razlika koja postoji među izračunanim volumenima nije statistički značajna. Uz pomoć *p-vrijednosti* dolazi se do istog zaključka (p > 0,05). Usporedba volumena neokrajčenih piljenica debljine 50 mm prikazana je na slici 5.



Slika 5. Grafički prikaz distribucije volumena neokrajčenih piljenica nominalne debljine 50 mm
Figure 5 Illustration of distribution of volumes of 50 mm thick sawn boards

Testiranje razlika između prosječnih vrijednosti volumena neokrajčenih piljenica debljine 60 mm izračunanih na pet različitih načina (HRN2, HRN1, EN, P1, P2) provedeno je analizom varijance. Opisna statistika i rezultati testiranja dani su u tablicama 4. i 5.

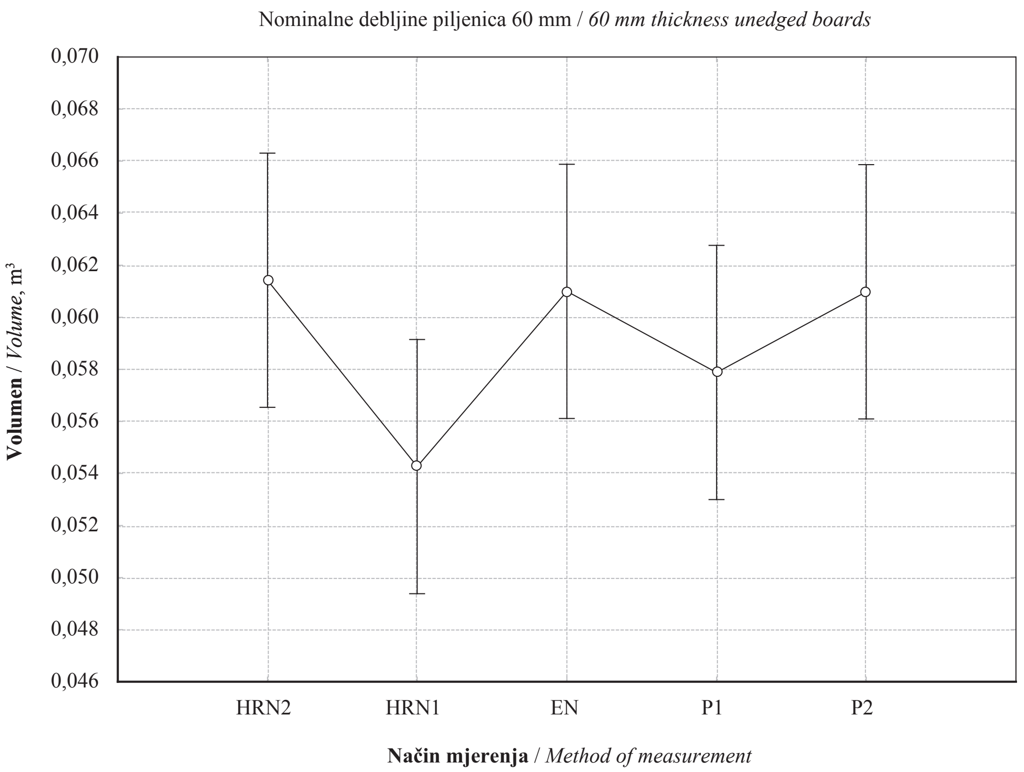
F-omjer za analizirane varijable pripada *F-distribuciji* (stupanj slobode – 4, 145), a uz razinu značajnosti α = 5 % kritična vrijednost iznosi 2,43407. Empirijski je *F-omjer* za prosječne vrijednosti volumena neokrajčenih piljenica debljine 60 mm manji od kritične vrijednosti, te se zaključuje da razlika koja postoji među izračunanim volumenima nije statistički značajna. Uz pomoć *p-vrijednosti* dolazi se do istog zaključka ($p > 0{,}05$). Usporedba volumena neokrajčenih piljenica debljine 60 mm prikazana je na slici 5.

Tablica 4. Deskriptivna statistička obrada izmjerenih dimenzija neokrajčenih piljenica nominalne debljine 60 mm
Table 4 Analysis of descriptive statistics of measured dimensions of 60 mm thick unedged boards

Način mjerenja *Method of measurement*	**Dimenzija** *Dimension*	**Veličina uzorka** *N*	**Minimum** *Minimum*	**Medijan** *Median*	**Maksimum** *Maximum*	**Aritmetička sredina** *Average*	**Standardna devijacija** *Stand. dev.*
HRN 2	*b*, cm	30	27	40	54	41	7
Croatian Standard 2	*V*, m³	30	0,041	0,062	0,090	0,061	0,013
HRN 1	*b*, cm	30	17	36	51	36	8
Croatian Standard 1	*V*, m³	30	0,026	0,054	0,085	0,054	0,015
EN	*b*, cm	30	28	40	53	40	6
European Standard	*V*, m³	30	0,042	0,061	0,090	0,061	0,013
Pilana 1	*b*, cm	30	24	38	52	38	7
Sawmill 1	*V*, m³	30	0,036	0,057	0,086	0,058	0,014
Pilana 2	*b*, cm	30	29	39	54	40	7
Sawmill 2	*V*, m³	30	0,041	0,061	0,088	0,061	0,013

Tablica 5. Rezultati testiranja signifikantnosti razlike volumena neokrajčenih piljenica nominalne debljine 60 mm
Table 5 Results of statistical significance analysis of differing volumes for 60 mm thick sawn boards

Izvor varijacije *Source of variation*	**Zbroj kvadrata** *Sum of squares*	**Stupnjevi slobode** *Degrees of freedom*	**Sredina kvadrata** *Mean square*	***F* omjer** *F ratio*	***p* vrijednost** *p value*
Protumačen (između grupa) *Interpreted (between groups)*	1121,57	4	280,39	1,53131	0,19615
Neprotumačen (unutar grupa) *Unexplained (within groups)*	26 550,46	145	183,11		
Ukupno / *Total*	27 672,04	149	-	-	-



Slika 6. Grafički prikaz distribucije volumena neokrajčenih piljenica nominalne debljine 60 mm
Figure 6 Illustration of distribution of volumes of 60 mm thick sawn boards

Testiranje razlika između prosječnih vrijednosti volumena neokrajčenih piljenica debljine 80 mm izračunanih na pet različitih načina (HRN2, HRN1, EN, P1, P2) provedeno je analizom varijance. Opisna statistika i rezultati testiranja navedeni su u tablicama 6. i 7.

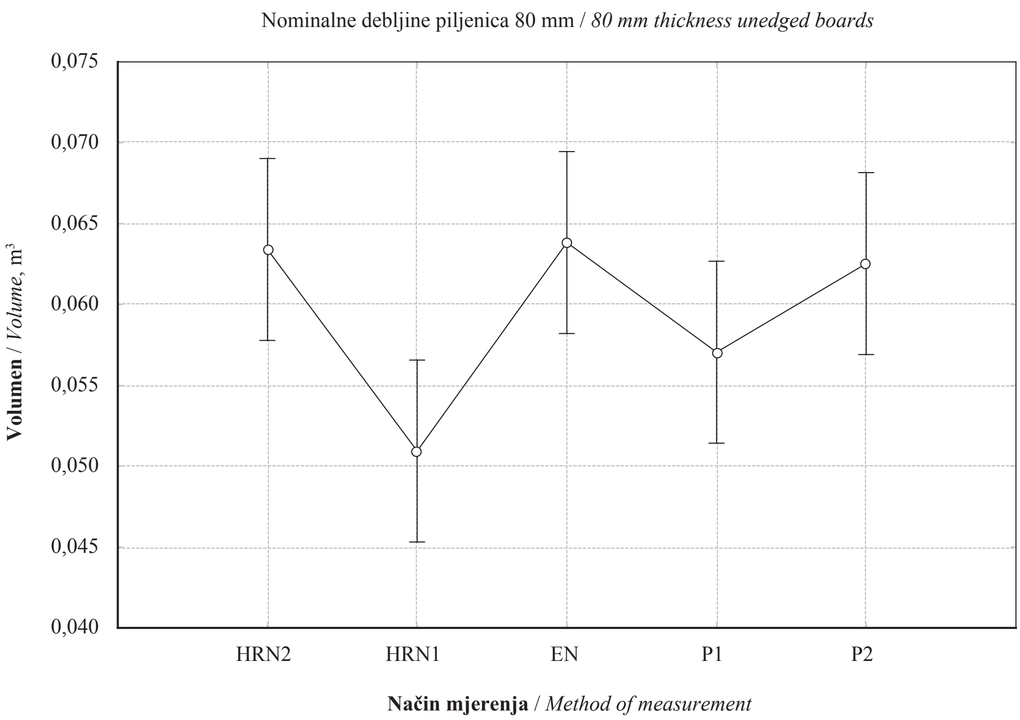
F-omjer za analizirane varijable pripada *F-distribuciji* (stupanj slobode – 4, 145), a uz razinu značajnosti α = 5 % kritična vrijednost iznosi 2,43407. Empirijski je *F-omjer* za prosječne vrijednosti volumena neokrajčenih piljenica debljine 80 mm veći od kritične vrijednosti, te se zaključuje da je razlika koja postoji među izračunani volumenima statistički značajna. Uz pomoć *p-vrijednosti* dolazi se do istog zaključka ($p < 0,05$). Usporedba volumena neokrajčenih piljenica debljine 80 mm predočena je na slici 6.

Tablica 6. Deskriptivna statistička obrada izmjerenih dimenzija neokrajčenih piljenica nominalne debljine 80 mm
Table 6 Analysis of descriptive statistics of measured dimensions of 80 mm thick unedged boards

Način mjerenja *Method of measurement*	**Dimenzija** *Dimension*	**Veličina uzorka** *N*	**Minimum** *Minimum*	**Medijan** *Median*	**Maksimum** *Maximum*	**Aritmetička sredina** *Average*	**Standardna devijacija** *Stand. dev.*
HRN 2	*b*, cm	30	24	31	43	32	5
Croatian Standard 2	*V*, m³	30	0,046	0,060	0,100	0,063	0,015
HRN 1	*b*, cm	30	16	24	40	25	7
Croatian Standard 1	*V*, m³	30	0,030	0,047	0,087	0,051	0,016
EN	*b*, cm	30	25	32	43	32	5
European Standard	*V*, m³	30	0,048	0,060	0,103	0,064	0,015
Pilana 1	*b*, cm	30	20	27	41	29	6
Sawmill 1	*V*, m³	30	0,038	0,053	0,094	0,057	0,016
Pilana 2	*b*, cm	30	23	30	43	31	6
Sawmill 2	*V*, m³	30	0,044	0,060	0,102	0,063	0,016

Tablica 7. Rezultati testiranja signifikantnosti razlike volumena neokrajčenih piljenica nominalne debljine 80 mm
Table 7 Results of statistical significance analysis of differing volumes for 80 mm thick sawn boards

Izvor varijacije *Source of variation*	**Zbroj kvadrata** *Sum of squares*	**Stupnjevi slobode** *Degrees of freedom*	**Sredina kvadrata** *Mean square*	***F*-omjer** *F ratio*	***p*-vrijednost** *p value*
Protumačen (između grupa) *Interpreted (between groups)*	3671,95	4	917,99	3,77812	0,00593
Neprotumačen (unutar grupa) *Unexplained (within groups)*	35 231,39	145	242,98		
Ukupno / *Total*	38 903,34	149	-	-	-



Slika 7. Grafički prikaz distribucije volumena neokrajčenih piljenica nominalne debljine 80 mm
Figure 7 Illustration of distribution of volumes of 80 mm thick sawn boards

Tablica 8. Rezultati testiranja signifikantnosti razlike volumena neokrajčenih piljenica nominalne debljine 80 mm (Bonferroni post-hoc test)
Table 8 Results of statistical significance analysis of differing volumes for 80 mm thick sawn boards (Bonferronijev *post-hoc test*)

Način mjerenja *Method of measurement*	$HRN2_{80}$ (63, 408)	$HRN1_{80}$ (50, 944)	EN_{80} (63, 032)	$P1_{80}$ (57, 056)	$P2_{80}$ (62, 536)
$HRN2_{80}$	-	0,02354	1,00000	1,00000	1,00000
$HRN1_{80}$	0,02354	-	0,01676	1,00000	0,04577
EN_{80}	1,00000	0,01676	-	0,94411	1,00000
$P1_{80}$	1,00000	1,00000	0,94411	-	1,00000
$P2_{80}$	1,00000	0,04577	1,00000	1,00000	-

Razlike u procjeni vrijednosti volumena neokrajčenih piljenica debljine 80 mm pokazale su se statistički značajnima [ANOVA: $F(4,145) = 3,77812$; $p = 0,00593$]. Naknadnim (*post-hoc*) testiranjem, primjenom Bonferronijeva testa, potvrđeno je da vrijednosti volumena neokrajčenih piljenica debljine 80 mm izračunane načinom HRN1 značajno odstupaju od vrijednosti volumena izračunanih načinima HRN2, EN i P2, dok se razlika u odnosu prema vrijednosti volumena izračunanog načinom P1 nije pokazala statistički značajnom. Rezultati naknadnog testiranja uvršteni su u tablicu 8.

4. RASPRAVA
4 DISCUSSION

U ovom su istraživanju dobiveni rezultati koji upućuju na to da se različitim načinima mjerenja širina, koji su zadani različitim normama, mogu dobiti i značajno različite vrijednosti volumena. Razčike u vrijednostima volumena u nekim su slučajevima veće, a u nekima su gotovo zanemarive za krajnji rezultat.

Najmanje vrijednosti za sve tri istraživane debljine piljenica dobivene su mjerenjem širine prema HRN1 normi, što je logično s obzirom na to da se mjeri samo uža plošna stranica piljenice. Treba napomenuti da se upravo zato načinom mjerenja prema HRN1 propisuje mjerenje neokrajčenih piljenice do najveće debljine od 47 mm.

Zatim je provedeno mjerenje prema načinu mjerenja u pilani označenoj sa P1, u kojoj se piljenica mjeri od početka zaobljenja bočnog brida uže plošne stranice do sredine zaobljenja bočnog brida na drugoj strani piljenice.

S porastom debljine piljenica povećava se razlika izmjerenih vrijednosti dobivenih tim dvama načinima mjerenja u odnosu prema ostalim istraživanim načinima. Rezultati testiranja signifikantnosti razlike pokazuju da se statistički značajna razlika pojavljuje pri mjerenju piljenica debljine 80 mm načinom što ga propisuje HRN1 i načinom mjerenja prema HRN2 te između načina prema EN i načina mjerenja u pilani označenoj sa P2.

Za piljenice debljine 50 mm najveće su vrijednosti dobivene prema načinu mjerenja kakav se provodi u pilani označenoj sa P2. Za piljenice debljine 60 i 80 mm najveće su vrijednosti dobivene načinom mjerenja prema EN.

Za sve istraživane debljine načini mjerenja prema HRN2, EN i pilani označenoj sa P2 pokazuju međusobno znatno manja odstupanja. Ta manja odstupanja proizlaze iz, općenito, sličnog načina mjerenja koji kao rezultat daje vrijednost širine približno jednake aritmetičkoj sredini zbroja širina uže i šire plohe piljenice.

Primarne piljenice ispiljene od trupaca nose i sve njihove nepravilnosti vidljive na plohama, ali i na bočnim bridovima, što također otežava njihovu mjerljivost. Navedene nepravilnosti odnosno deformacije na bočnim bridovima piljenica problem su mjeriteljima pri radu čija sposobnost i snalažljivost uvelike utječe na točnost mjerenja. Greške drva na piljenicama često zahtijevaju i promjenu položaja mjeritelja i/ili piljenice te mjesta mjerenja.

Pri mjerenju neokrajčenih piljenica nastaju problemi zbog nepravilnog oblika bočnih bridova koji su u svake pojedine piljenice drugačiji i ne može se odrediti neki zajednički oblik po kojemu bi se točno mogla izmjeriti svaka piljenica. Bočni brid najčešće ima oblik luka koji je u piljenica napravljenih od perifernog dijela trupca položeniji, a u piljenica od središnjeg dijela trupca okomitiji. S obzirom na tu pretpostavku, različita je i duljina tog luka, koja je veća u perifernih nego u piljenica bližih središnjem dijelu trupca. Uzmemo li u obzir da se iz središnjeg dijela trupca obično pile deblje piljenice nego iz periferna, na rezultate neće utjecati samo položaj s kojega piljenica potječe nego i njezina debljina.

U nekim su normama zadani načini mjerenja širine koji se temelje na izračunu aritmetičke sredine širina uže i šire plošne strane piljenice. Tada se u proračunu ne uzima u obzir da se bočne stranice prostiru u obliku luka nego u obliku ravnih crta te stoga dolazi do određenih odstupanja u dimenzijama.

U hrvatskim se pilanama za izmjeru piljenica najčešće primjenjuje ručna metoda mjerenja. Pri ručnom mjerenju rabe se analogni ili digitalni mjerni uređaji. Jedan od ključnih činitelja pri ručnom mjerenju, uz ispravne i umjerene mjerne uređaje, jest ljudski faktor.

Razmatrajući razlike koje prizlaze iz rezultata mjerenja širine piljenica tim načinima izmjere, možemo pretpostaviti da su one, osim greškom mjeritelja, nastale i zbog nepravilnosti oblika trupca koji se prenosi na bočni brid piljenice, odnosno zbog asimetričnosti bočnih bridova. U takvim slučajevima pri načinu mjerenja kakav se provodi u pilanama označenima sa P1 i P2 vrijednost izmjere ovisi i o tome koji brid određujemo kao početak mjerenja, a koji kao završetak.

Kako bi se točnije utvrdile te razlike i zakonitosti, u idućim će istraživanjima biti provedena simulacija mjerenja širine piljenica utemeljena na njihovim grafičkim modelima.

5. ZAKLJUČAK
5 CONCLUSION

Analizom dobivenih rezultata istraživanja može se zaključiti sljedeće:

- način mjerenja širine piljenica debelih 50 mm kakav se provodi u pilani označenoj sa P2 daje najveće vrijednosti volumena, a zatim slijede načini mjerenja prema HRN2, EN, u pilani označenoj sa P1 i HRN1
- način mjerenja širine piljenica debelih 60 i 80 mm daje najveće vrijednosti volumena mjerenjem prema EN, a zatim prema HRN2, u pilanama označenima sa P2 i P1 te prema HRN1
- način mjerenja širine prema EN, HRN2 i mjerenju u pilani označenoj sa P2 rezultira manjim međusobnim odstupanjima
- uočena je razlika u razmatranim načinima mjerenja širine neokrajčenih piljenica koji utječu na izračun njihova volumena, no u ovom istraživanju oni su se pokazali statistički značajnima samo pri izmjeri piljenica debljine 80 mm
- razlike koje proizlaze iz rezultata mjerenja širine piljenica trima opisanim načinima izmjere nastale su i zbog nepravilnosti oblika trupca koje se prenose i na bočni brid piljenice, odnosno zbog asimetričnosti bočnih bridova.

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Vasiliki Dimou[1]

Noise Measurements in Timber Industries

Mjerenje buke u drvnoj industriji

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ABSTRACT • *The intensification of industrial production and the concurrent increase in machine operation speeds has led to the rise in the intensity of noise generated in most workplaces. The purpose of the present paper is to investigate occupational noise exposure in timber processing units. For this reason, a number of measurements were carried out in various parts of three sawmills. Maximum allowable exposure limits (permissible levels) were set at 85 dB(A) for the production area and warehouses, and 55 dB(A) for offices. According to the results of the study, the production area in a sawmill gives rise to higher levels of noise compared to warehouses and offices, which significantly exceed maximum permissible levels. More specifically, the highest noise levels recorded were found to be produced by cutting machinery. In such cases it is imperative that employees be protected either with the use of personal hearing protectors or with the implementation of a regular break scheme. In addition, substantial reduction in noise levels can be achieved with the use of other protective measures such as control of noise at its source or in its path.*

Keywords: *noise pollution, hearing loss, occupational disease, sawmills*

SAŽETAK • *Intenziviranje industrijske proizvodnje i istodoban porast brzine rada strojeva dovelo je do porasta intenziteta buke kojom je opterećena većina radnih mjesta u drvnoj industriji. Cilj ovog rada bio je istražiti izloženost buci na radnim mjestima u pogonima za industrijsku preradu drva. Stoga su provedena mjerenja buke na različitim radnim mjestima u tri pilane. Granična vrijednost buke (dopuštena razina) kojoj mogu biti izloženi radnici iznosi 85 dB (A) za područje proizvodnje i skladišta te 55 dB(A) za uredske prostore. Prema rezultatima studije, u proizvodnim pogonima pilane izmjerene su više razine buke nego u skladištima i uredskim prostorima, a izmjerene razine buke znatno premašuju najveću dopuštenu razinu. Najviše razine buke izmjerene su na radnim mjestima uz strojeve za mehaničku obradu drva. U takvim uvjetima zaposlenici moraju biti zaštićeni od prekomjerne izloženosti buci upotrebom osobnih zaštitnih sredstava ili skraćivanjem vremena provedenog na radnome mjestu uvođenjem redovitih stanki tijekom radnog vremena. Osim toga, znatno se smanjenje razine buke može postići i primjenom drugih zaštitnih mjera kao što su kontrola i smanjenje buke na izvoru ili na putu njezina širenja.*

Ključne riječi: *buka, gubitak sluha, profesionalne bolesti, pilana*

1 INTRODUCTION
1. UVOD

Nowadays, noise is one of the main sources of annoyance (Skenberg and Öhrström, 2002). Consequently, it is considered as a form of "invisible pollution", called *noise-pollution* (Dafis, 1998). At the beginning of the 20th century, one of the fathers of modern hygienology, Robert Koch, wrote that "the day will come when man will have to fight noise as inexorably as cholera and the plague" (in Grivas, 2007). Noise is defined as every kind of unwanted and disturbing sound that threatens our physical, psychological and social well-being (Peippo *et al*., 2000; Ouis, 2001).

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The methods used to assess noise levels that are emitted from various types of machinery are described in ISO 3740 (2001), which also includes all the basic ISO standards related to noise. Besides, ISO TC 43 is a point of reference for issues of noise (Laios and Giannakourou-Sioutari, 2003).

Noise pollution can be the cause of a multitude of problems that modern man is affected by, the most significant being: damage to hearing resulting in hearing loss, cardiac disorders, various health problems like high blood pressure, migraines, ulcer, asthma, pregnancy disorders, learning disabilities in children, loss of efficiency and concentration at work, sleep disturbance, etc. (Arana and Garcia, 1997; Stansfeld, 1992; Ouis, 2001; Skenberk and Öhrström, 2002; Job *et al*., 1996).

At the workplace, exposure to high-level noise can seriously impair communication between employees and, depending on the level, frequency and duration of exposure, it can adversely affect workers' physical and psychological health (Shaikh, 1999; Kryter, 1970; Donald-Siu, 2001). One of the most serious consequences of high-level noise is the irreparable damage to human hearing (Irle *et al*., 1998; Niu-Canlon, 2002). Exposure to high noise levels at work has been associated with a significant increase in work-related accidents; in addition, the so-called "occupational noise-induced hearing loss" is considered the most frequent work-related disease.

According to the 2nd European Survey on Working Conditions (ESWC), the workplaces that are most exposed to noise are (HSE, 1998):

- Metal Industries
- Timber Industries
- Base metal industries
- Paper industries
- Construction
- Fiber Industries.

Out of the above listed workplaces, Metal and Timber Industries are the most hazardous noise-generating environments, on the grounds that they use a series of processes and a great number of machines for the shaping and handling of materials (HSE, 1998). These processes produce extremely high and protracted volumes of noise at the workplace. For this reason, the European law sets certain limits to the exposure of workers to noise, according to which noise should, under no circumstances, exceed an average of 87 dB(A) on one hand and on the other for levels exceeding 80 dB(A), proper hearing protection (earplugs or earmuffs) is compulsory (MSFC-STD-267).

Hearing loss is listed among the occupational diseases included in Article 40 of Disease Regulations issued by the Greek Social Security Organization - *IKA* (published in Government Gazette No. 132/12.2.1979). The same document specifies that a minimum of 5 years of employment is required to officially recognize a hearing loss and establish it as an occupational disease. Table 1 shows the percentage of workers suffering from hearing loss in relation to years of exposure and noise levels over an eight-hour working day.

Table 1 Probability of hearing loss among workers in relation to years of exposure and noise levels for an eight-hour day (Grandjean, 1997)
Tablica 1. Vjerojatnost gubitka sluha radnika u ovisnosti o razini buke i godinama izloženosti buci tijekom osamsatnoga radnog dana

Noise level *Razina buke* dB(A)	**5 years** *5 godina*	**10 years** *10 godina*	**20 years** *20 godina*
80	0 %	0 %	0 %
90	4 %	10 %	16 %
100	12 %	29 %	42 %
110	26 %	55 %	78 %

Under the Control of Noise at Work Presidential Decree 85/91, the health of the workers receiving high noise doses should be protected. More specifically, the Decree makes it imperative that employers take certain technical and organizational precautions, should levels reach 85 dB(A); in addition, maximum exposure limit for an 8-hour day is set at 90 dB(A) (Marhavilas, 2010).

Physicists use a logarithmic scale for measuring sound pressure (Sound Pressure Level - SPL), namely the decibel (dB) scale. The decibel is a number that represents the logarithm of a ratio between a given sound pressure and a reference value:

$$SPL = 20 \cdot \log (P/P_O) \quad (1)$$

where P is the square root of the mean square value of the sound pressure of a stimulus and P_0 the reference pressure (usually a barely perceptible sound, called *the threshold of human hearing*) (Laios and Giannakourou-Sioutari, 2003).

The decibel as a logarithmic unit has a very significant role in determining sound levels at workplaces: every increase of sound intensity equal to 3 dB(A) doubles the energy that the human ear receives, meaning that the double of 85 dB(A) is not 170 but 88 dB(A) (Grivas, 2007).

Most sound measuring instruments take into account the variations in the sensitivity of the human ear as far as the frequency of the sounds is concerned. For this reason, various frequency weighting methods have been developed to approximate the way the human ear responds to noise levels. The most widely used method of measurement is called "A-weighting" and the equivalent unit of pressure is dB(A) (Laios and Giannakourou-Sioutari, 2003).

Sustained exposure to 80 dB(A) throughout the working day is considered to be the safety limit under which a worker does not run the risk of developing occupational noise-induced hearing loss (HSE, 1998).

Noises equal to or exceeding 85 dB(A) with continuous distribution in the range of acoustic frequencies (from 15 to 20.000Hz) are considered dangerous, regardless of exposure duration, necessitating the use of hearing protectors. Maximum permissible noise exposure is set at 115 dB(A) for a period that does not exceed 2 min per 24 hours (Laios and Giannakourou-Sioutari, 2003). Presidential Decree 85/1991, in accordance with the European Union Directive, requires the reduction of noise at its source so that a worker's daily exposure does not exceed 90 dB(A). For this reason, when exposures exceed 85 dB(A), employers are obliged to supply workers with *Personal Protective Equipment (PPE)*. Table 2 shows the recommended use of PPE in relation to noise levels.

Table 2 Use of Personal Protective Equipment (PPE) in relation to noise levels (Presidential Decree 85/1991)
Tablica 2. Uporaba osobnih zaštitnih sredstava ovisno o razini buke (Presidential Decree 85/1991)

Noise levels, dB(A) *Razina buke, dB(A)*	**Description** *Opis*	**Use of PPE** *Uporaba osobnih zaštitnih sredstava*
< 74	Good conditions *dobri uvjeti*	Use not required *ne zahtijeva se*
75-80	Tolerable conditions *podnošljivi uvjeti*	Use not required *ne zahtijeva se*
81-84	Noisy conditions *bučni uvjeti*	Use not required *ne zahtijeva se*
85-87	Very noisy conditions *vrlo bučni uvjeti*	Use required *zahtijeva se*
>88	Intolerable conditions *nepodnošljivi uvjeti*	Use required *zahtijeva se*

In the USA, under the Occupational Safety & Health Administration, workers with daily exposures to an average noise level of 85 dB(A) or higher must be protected with the implementation of proper preventive measures (reduction of noise emissions, removal of noise sources, etc) or with proper personal protective equipment. The maximum permissible exposure levels are shown in Table 3 (Laios and Giannakourou-Sioutari, 2003).

Table 3 Maximum Permissible Exposure Levels (OSHA 1910.95/1998)
Tablica 3. Maksimalno dopuštena razina izloženosti buci (OSHA 1910.95/1998)

Daily exposure (hours) *Dnevna izloženost (sati)*	**Noise level** *Razina buke* dB(A)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25	115

Workers who live in environments with high-level noise have reduced opportunities for communication, the consequences of which are far-reaching since it is difficult for signals or warnings of danger to be heard.

Systematic research on occupational noise-induced hearing loss has never been carried out in Greece. There are certain publications, of course, but they do not contain epidemiological data and consequently the extent of the problem is not fully known. The Greek law is in accordance with the European law; however we do not know if it is thoroughly applied. For this reason, it is considered crucial to carry out the present research in order to highlight all the aspects of the problem so that protective measures may be taken for employees.

The aim of the present study is to investigate the noise levels to which timber industry workers are exposed on a daily basis.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

Research was conducted in timber industries. Three typical sawmills, located in Drama, Northern Greece, were chosen, in which numerous measurements were carried out. The aim of the study was to assess noise generated by various timber processing machines, both at individual workstations and in its totality, as well as the extent of its impact on the staff, consisting of machine operators and the rest of the employees.

At the beginning, the machines were classified into groups depending on the kind of processing they performed. As a result, the following groups were formed:

- Cutting machinery (multi-rip saw, band saw, log cutter, edger, circular saw, planer – moulder, wood profile cutter, etc);
- Planing machinery;
- Other machines (absorption machines, boilers, etc).

Measurements were carried out while machines processed timber coming from spruce (*Picea excelsa)*, beech (*Fagus silvatica)*, black pine (*Pinus nigra)* and poplar sp. *(Populus sp.)* Subsequently, it was deemed equally necessary to conduct measurements in areas located outside the productive process, such as warehouses and offices, so as to acquire a complete picture of the problem and its effects.

All noise monitoring was conducted with a digital, portable sound level meter designed in compliance with DIN 45633, JIS 1502, IEC 651 specifications.

During the sampling process, two kinds of measurements were performed: a) measurement of the overall noise pollution generated in the place, and b) measurement of the noise pollution recorded in each operator workstation. In total, 7 locations were chosen in the general area and their selection was made on the basis of the layout of the place. Finally, it was decided that the individual workstations of the operators should be of the same number as the machines.

In each assessment site in the general area a total of 40 measurements were carried out (1 every 15 seconds), whereas in each machine area 80 measurements were performed (40 with the machine in operation and another 40 with the machine in idling mode.) The processed timber was classified into two groups: the first contained logs of small dimensions, whose diameter in the middle was below 30 cm, whereas the second contained thick logs, with a diameter in the middle of over 30 cm.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of noise monitoring are shown in Table 4 to 8. Table 4 illustrates noise levels produced in three sawmills, with Sawmill A consisting of two production places, Room 1 and Room 2. It can be observed here that noise levels are on average high (in excess of 90 dB(A)) in all sawmills and on certain occasions they reach almost 99 dB(A).

Table 4 Noise levels produced in the sawmills
Tablica 4. Rezultati mjerenja razine buke u tri pilane

Noise intensity, dB(A) *Intenzitet buke, dB(A)*	Sawmill A *Pilana A*		Sawmill B *Pilana B*	Sawmill C *Pilana C*
	Room 1 *pogon 1.*	Room *pogon 2.*		
Mean	90.1	88.46	96.14	96.59
MAX	91.6	89.67	97.56	97.8
MIN	89.5	87.56	94.56	95
Number of measurements *Broj mjerenja*	240	840	520	360

Table 5 provides a comprehensive picture of the volume of noise produced by different machine groups. Cutting machinery produces the highest level of noise reaching approximately 97.46 dB(A), whereas planing machinery generates the lowest noise levels (an average of 88.76 dB(A)). The rest of the machines produce levels falling between these two extremes. It is noteworthy that all groups of machinery cause noise that is higher than the 85 dB(A) permissible level.

Table 5 Intensity of noise generated by various types of machinery in timber processing units
Tablica 5. Intenzitet buke što ju emitiraju različiti strojevi u pogonima za preradu drva

Type of machinery *Vrsta stroja*	Number of machines *Broj strojeva*	Noise intensity, dB(A) *Intenzitet buke, dB(A)*		
		Mean *Srednja vrijednost*	Max *Maks.*	Min *Min.*
Cutting machinery *Strojevi za rezanje*	20	95.35	97.46	94.47
Planing machinery *Strojevi za blanjanje*	2	88.76	91	87
Other machines *Ostali strojevi*	2	92.54	93.5	90.5

Total number of measurements: 1680

Table 6 presents noise levels corresponding to each machine. The noisiest machines (producing almost 100 dB(A)) were found to be the wood profile

Table 6 Noise levels generated by various machines in timber processing units
Tablica 6. Razina buke koju emitiraju različiti strojevi u pogonima za preradu drva

Machine *Naziv stroja*	Number of machines *Broj strojeva*	Mean *Srednja vrijednost*		Max *Maks.*		Min *Min.*		Type of machinery *Vrsta stroja*
		in operation *pod opterećenjem*	in idling mode *u praznom hodu*	in operation / *pod opterećenjem*	in idling mode *u praznom hodu*	in operation *pod opterećenjem*	in idling mode *u praznom hodu*	
Multi-rip saw *višelisna pila*	1	95	94.28	97	95	95	93	1
Total / *ukupno*		94.64		96		93.5		
Band saw *tračna pila*	8	92.1	91.55	94.25	92,83	92,83	92,16	1
Total / *ukupno*		91.83		93.54		91.37		
Log cutter *iverači za trupce*	2	99.33	96.88	100	100	100	96,5	1
Total / *ukupno*		98.105		100		95.5		
Edger / *stroj za okrajčivanje*	3	96.08	94.33	97.67	95,67	95,67	95	1
Total / *ukupno*		95.21		96.67		94.17		
Circular saw *kružna pila*	4	95.42	93.95	96.83	98,17	95,17	94,5	1
Total / *ukupno*		94.68		96		92.75		
Absorption *odsisni uređaj*	1	99.75		100		97		3
Planer – moulder *Blanjalica - glodalica*	1	95.92		100		95		1
Wood profile cutter *profilni centar*	1	99.77		100		99		1
Boiler / *kotao*	1	85.32		87		84		3
Sharpening machines *strojevi za oštrenje*	2	88.76		91		87		2

Total number of measurements: 1680

cutter, log cutter and absorption machine, followed by multi-rip saw, planer and edger (around 95dB(A)). Less annoyance is produced by the boiler, whose noise level is at an average of 85.32 dB(A). In other words, it can be seen that only the boiler is within the 85 dB(A) permissible noise limit.

The results also reveal that the noise produced is higher in large width logs (with a mean diameter of over 30 cm). This is true for most cutting machines (such as the band saw).

It is noteworthy that in the general area, and not only in the proximity of a machine operator (Table 7), noise levels are clearly in excess of 85 dB(A), reaching an average of approximately 90 dB(A). At an operator's workstation, the difference between levels produced by a machine in operation and in idling mode is on average 1.5 dB(A). This difference is considered significant bearing in mind that a 3 dB difference in actuality means that the ear receives double energy.

The majority of the employees participating in the present study were between 35 and 45 years of age. When asked if noise was a nuisance during work, most of them answered that it was quite annoying but they have become used to it and, generally speaking, they had no hearing complaints. They also said that they made no use of earmuffs or plugs. Their tolerance toward an everyday problem such as noise pollution can be accounted for only by their short period of employment since most of them said that they had been working in sawmills for less than 5 years.

Table 7 Noise generated in various assessment sites
Tablica 7. Razina buke na različitim radnim mjestima

Measurement site *Mjesto mjerenja*	**Noise intensity, dB(A)** *Intenzitet buke, dB(A)*		
	Mean *Srednja vrijednost*	Max *Maks.*	Min *Min.*
Production area *Proizvodni pogon*	89.2	91.3	88.6
Operator site (machine in operation) / *Radno mjesto operatera stroja (stroj je pod opterećenjem)*	95.6	97.1	95.7
Operator site (machine in idling mode) / *Radno mjesto operatera stroja (stroj je u praznom hodu)*	94.2	96.3	92.2

Total number of measurements: 1720

As illustrated in Table 8, in the rest of the work areas noise levels are tolerable since they often drop below 55 dB(A) (e.g. in offices).

As far as offices are concerned, as well as places where employee concentration is essential, international standards require that maximum noise exposure be set at 55 dB(A). Under Norwegian law, in jobs where critical communication is involved, noise levels must not exceed 55 dB(A) (Koukoulaki, 2008).

Figure 1 gives a comparative picture of noise generated by the machines monitored in the study, in relation to the 85dB(A) permissible level for an 8-hour work day.

Table 8 Noise levels generated in various parts of the timber factory
Tablica 8. Razina buke u različitim prostorima tvrtke za preradu drva

Measurement site *Mjesto mjerenja*	**Noise intensity, dB(A)** *Intenzitet buke, dB(A)*		
	Mean *Srednja vrijednost*	Max *Maks.*	Min *Min.*
Warehouse / *Skladište*	67.7	69	67
Office / *Uredski prostori*	21.15	25	18

Total number of measurements: 80

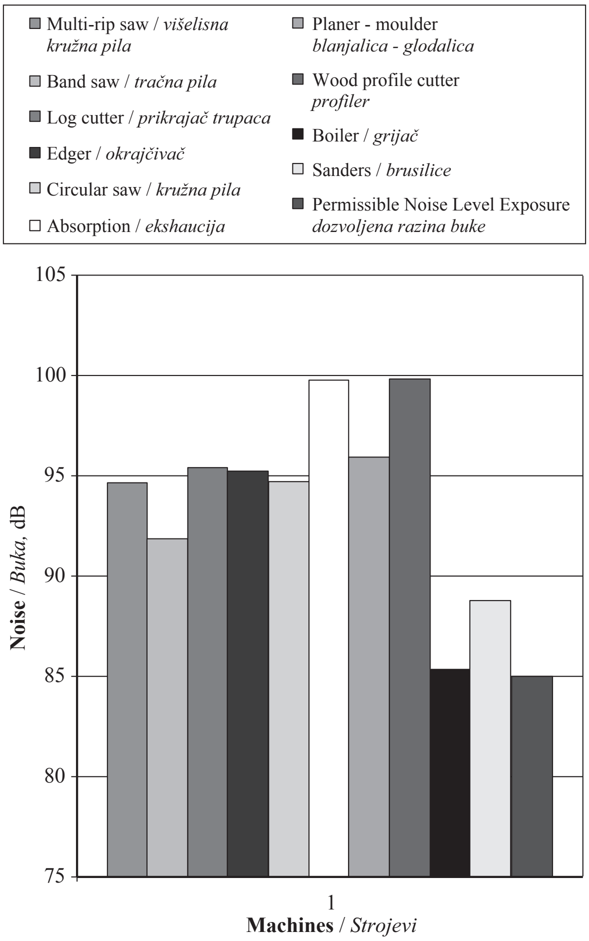

Figure 1 Noise generated by different machines in various parts of the timber factory in relation to the 85 dB(A) permissible level
Slika 1. Izmjerena razina buke različitih strojeva i u različitim prostorijama pogona za preradu drva u usporedbi s graničnom razinom buke od 85 dB(A)

4 CONCLUSIONS
4. ZAKLJUČAK

According to the findings of the present study, noise levels generated in sawmills are generally above the rationally accepted exposure standards in all parts of the sawmill with the exception of the offices.

The highest volume of noise is emitted from the cutting machinery, especially the multi-rip saw, log cutter and wood profile cutter. The boiler is the only machine that does not exceed the 85 dB(A) permissible level.

The extent of annoyance is also in close relation with the dimensions of the material that is cut and the type of timber.

The production area generally gives rise to high-level noise, above the acceptable threshold, whereas in the offices and warehouses noise levels are comparatively low.

Workers and especially operators of most machines are exposed to such noise levels that it is quite possible that their health will be adversely affected on a temporary or permanent basis. The precautions that are necessary to be taken so as to reduce the amount and impact of noise are, first of all, the proper marking by the organization of noise generating zones with suitable notices. In addition, it is imperative that a special program of hearing protection be implemented. In the attempt to improve the noise environment at the workplace, crucial preventive actions to be taken include control of noise at its source; this can be done with measures such as the design of the whole productive process in a specific area aimed at minimizing the amount of noise-pollution.

Other measures that organizations can take include:

- Improve the design of machines (e.g. by supplying them with shock absorbers and anti-vibration mounting, installing protective Plexiglas enclosures, etc). Where possible, use special covers, silencers and generally materials with strong anti-vibration capacity.
- When technically feasible, reduce emission of noise by placing a barrier between the noise source and the employee (e.g. a sound-proof cabin).
- Increase the distance between the noise source and the worker.
- Use special sound absorbing materials on the walls, ceilings and floor of noisy areas. Provide workers with personal protective devices such as suitable earmuffs and plugs.
- Use tools and equipment with anti-noise design. Choose electrical tools instead of compressed air tools. Fit rubber pads that are specially designed to absorb vibration. Maintain equipment properly since poorly maintained machinery can increase sound emissions. Reduce the speed of cutting, sawing and spinning (Facts)
- Limit the amount of time an employee spends at a noise source. This can be implemented when workers take it in turns to spend time at very noisy areas.
- Provide quiet areas where workers can spend time in order to gain relief from hazardous noisy environments.

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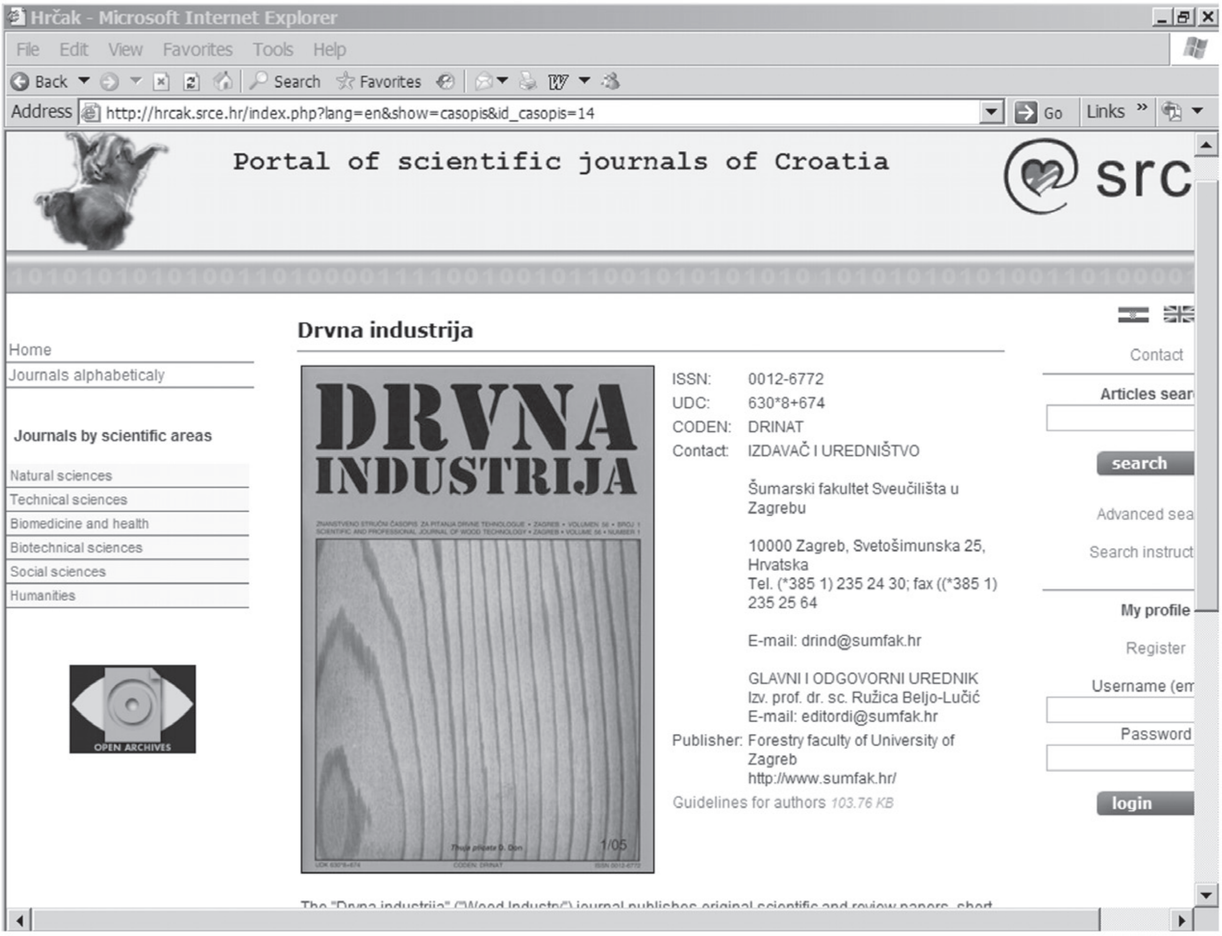

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Nikola Španić obranio doktorski rad

Nikola Španić, mag. ing. techn. lign. obranio je 21. veljače 2014. godine na Šumarskom fakultetu Sveučilišta u Zagrebu doktorski rad pod naslovom *Karakterizacija biokompozitnih drvnih materijala pripremljenih sintetiziranjem acetilirane celuloze i celuloznih polimorfa*, pred povjerenstvom u sastavu: prof. dr. sc. Mladen Brezović (Šumarski fakultet), doc. dr. sc. Alan Antonović (Šumarski fakultet) i doc. dr. sc. Sergej Medved (Biotehniška fakulteta, Univerza v Ljubljani), i time stekao akademski stupanj doktora znanosti s područja biotehničkih znanosti, znanstvenog polja drvne tehnologije. Mentor rada bio je prof. dr. sc. Vladimir Jambreković.

PODACI IZ ŽIVOTOPISA

Nikola Španić rođen je u Zagrebu 3. lipnja 1982. godine. Osnovnu školu pohađao je u Sesvetama, a srednju Drvodjeljsku u Zagrebu, gdje je 27. lipnja 2000. godine maturirao i stekao zvanje drvodjeljskog tehničara. Iste je godine upisao Šumarski fakultet a 21. rujna 2007. godine obranom diplomskog rada *Znanstvene metode određivanja konstrukcija na primjeru kutnih sastava* stekao je zvanje diplomiranog inženjera drvne tehnologije, što je kasnije izjednačeno sa zvanjem magistra inženjera drvne tehnologije. Nakon studija odslužio je vojni rok, a potom se zaposlio na Šumarskom fakultetu, gdje od 1. ožujka 2008. godine radi kao asistent na Zavodu za tehnologije materijala. Iste, 2008. godine upisao je poslijediplomski doktorski studij Drvna tehnologija.

Nastavni rad počinje kao asistent za kolegij Tehnologija ploča od usitnjenog drva (stari program), a prelaskom na Bolonjski proces postaje asistent za kolegije Ploče od usitnjenog drva, Tehnologija ploča od usitnjenog drva, Pločasti materijali i Tehnologija drvnih vlakana i papira na Šumarskom fakultetu, te Ploče od usitnjenog drva na Stručnom studiju drvne tehnologije u Virovitici. Pri tome je kao neposredni voditelj sudjelovao u izradi 44 završna i diplomska rada tematike usko vezane za sustave kompozitnih materijala od usitnjenog drva, odnosno za tehnologije drvnih vlakana i papira. Od 2008. godine kao istraživač sudjeluje u znanstvenom projektu MZOŠ-a broj 068-0680457-0562 pod nazivom *Tehnologije novih vrsta drvnih materijala od usitnjenog i utekućenog drva* voditelja prof. dr. sc. Vladimira Jambrekovića. Ukupno je kao autor ili suautor objavio 14 znanstvenih i dva stručna rada. Usto je kao autor ili suautor objavio i tri neindeksirana znanstvena rada u zbornicima skupova s međunarodnom recenzijom i jedan neindeksirani stručni rad u zborniku domaćeg skupa bez recenzije. Sudjelovao je na sedam međunarodnih znanstvenih skupova s ukupno 12 objavljenih radova i na jednom domaćem stručnom skupu (jedan objavljeni rad). U suautorstvu sa studentima objavio je četiri znanstvena i dva stručna rada.

Usporedno s nastavnim radom, od 2009. godine na Zavodu za tehnologije materijala kao istraživač-suradnik radi u Laboratoriju za drvne ploče, gdje obavlja poslove vezane za ispitivanje svojstava pločastih materijala i za izdavanje potvrda o njihovoj sukladnosti s normama. Član je Hrvatskoga mjeriteljskog društva, Tehničkog odbora Hrvatskog zavoda za norme TO 89 - Furniri i drvne ploče, Forest Products Societyja, a sudjeluje i u radu COST akcije FP 1105 *Understanding wood cell wall structure, biopolymer interaction and composition: implications for current products and new material innovation*, te akcije FP 1205 *Innovative applications of regenerated wood cellulose fibres*. Član je povjerenstva za znanstvenoistraživački rad Šumarskog fakulteta, a kao član Organizacijskog odbora pet je puta sudjelovao u organizaciji i provedbi osnovnoga i naprednog stupnja fitosanitarne izobrazbe (ISPM 15). Aktivno se služi engleskim jezikom u govoru i pismu te njemačkim jezikom.

PRIKAZ DOKTORSKOG RADA

Doktorski rad Nikole Španića, mag. ing. techn. lign., naslova *Karakterizacija biokompozitnih drvnih materijala pripremljenih sintetiziranjem acetilirane celuloze i celuloznih polimorfa* sastoji se od 189 stranica (I-IX + 180) teksta u koji su uključene 93 slike, 45 tablica i 176 navoda citirane literature. Doktorski rad podijeljen je na sedam osnovnih dijelova:

1. *Uvod* (uključujući predstavljanje problema, cilj i osnovnu hipotezu rada), 46 stranica,
2. *Materijali i metodika rada*, 16 stranica,
3. *Eksperimentalne metode*, 18 stranica,
4. *Rezultati i analiza rezultata istraživanja*, 75 stranica,
5. *Rasprava*, 4 stranice,
6. *Zaključak*, *1 stranica,*
7. *Literatura,* 10 stranica.

Eksperimentalni dio rada vezan za sintezu materijala proveden je na Šumarskom fakultetu, na Zavodu za tehnologije materijala, u Laboratoriju za kemiju i Laboratoriju za ploče. Karakterizacija kompozitnih materijala provedena je u laboratoriju Oddelka za lesarstvo, Biotehniške fakultete Univerze v Ljubljani, u SEM laboratoriju Tekstilno-tehnološkog fakulteta u Zagrebu te u već spomenutim laboratorijima Šumarskog fakulteta u Zagrebu.

1. Uvod

Uvodni dio rada podijeljen je na četiri potpoglavlja. U prvom potpoglavlju *Uvoda* predstavljen je koncept biokompozitnih materijala te problematika sinteze i uporabe prirodnih polimernih materijala kao alternative petrokemijskim produktima, s naglaskom na drvnoj celulozi i njezinim derivatima. Nadalje, u tom se dijelu doktorskog rada iznosi teorijska osnova o mogućnostima pripreme biokompozitnih materijala u potpunosti izrađenih s matricom i punilom jednakoga, drvnog podrijetla. Drugim potpoglavljem, naslovljenim *Drvo i njegov kemijski sastav*, detaljno je objašnjena interakcija pojedinih gradbenih jedinica drva, čime je objašnjena i mogućnost razvoja biokompozitnih materijala u potpunosti izrađenih od drva. Kao logičan nastavak tog potpoglavlja, u sljedećemu, naslovljenome *Biokompozitni materijali*, obavljena je analiza dostupne literature o svojstvima i sintezi potencijalnih sirovina za izradu biomatrica kao polimernih osnova biokompozitnih materijala. Pri tome su zasebno obrađeni biološki razgradivi i biološki nerazgradivi tipovi biomatrica, čime su međusobno komparirani, uz naglasak na usporedbi biomatrica od celuloze s ostalim tipovima biopolimernih materijala. U nastavku tog potpoglavlja dana je sustavna analiza dostupnih podataka o pripremi i karakterizaciji biokompozitnih materijala, čime je u potpunosti zaokružen teorijski koncept takvog tipa polimernog materijala. U četvrtom potpoglavlju *Uvoda* navedeni su cilj i osnovna hipoteza rada. Povećanje kvantitativnoga i kvalitativnog iskorištenja drva izradom celuloznih biokompozitnih materijala navedeni su kao cilj rada, a kao osnovna hipoteza postavljena je mogućnost aktivacije polimerizacijskog potencijala drva u obliku kemijske derivatizacije i acetilacije celuloze radi sinteze sustava biokompozitnih materijala u potpunosti izrađenih od drva, bez primjesa komercijalnih petrokemijskih produkata. Hipotezom i ciljevima rada obuhvaćena je i pretpostavka o povoljnijem kemijskom sastavu drva lošijih fizikalno-mehaničkih i morfoloških svojstava za sintezu biokompozitnih materijala zadovoljavajućih uporabnih svojstava. Rezultatima eksperimenta dobio bi se uvid u mehanizme reakcije i utjecaj kemijskih tretmana na drvo i njegove gradbene jedinice sa stajališta sinteze i karakterizacije biokompozitnih materijala s matricom i punilom jednakog podrijetla. Na taj bi se način ostvarila znanstveno utemeljena osnova za daljnju optimizaciju svojstava celuloznih biokompozitnih materijala od drva.

2. Materijali i metodika rada

U poglavlju *Materijali i metodika rada*, podijeljenom na pet potpoglavlja, opisani su načini pripreme uzoraka, postupci izolacije i određivanja udjela pojedinih gradbenih jedinica drva (komponenti kemijskog sastava), metoda acetilacije celuloze, odnosno iznesena je metodika rada. U prvom potpoglavlju s naslovom *Priprema uzoraka* navedene su vrste drva na kojima je provedeno inicijalno ispitivanje kemijskog sastava, odnosno metodika njihova uzorkovanja u šumskim sastojinama te načini pripreme drvnog brašna kao osnove za utvrđivanje kemijskog sastava. Drugim potpoglavljem – *Izolacija i određivanje učešća pojedinih komponenti kemijskog sastava* – prikazane su metode izolacije pojedine gradbene jedinice drva, a objašnjeno je i zašto je za pravilan odabir dviju vrsta drva za pripremu biokompozitnih materijala važno poznavati udio lignina, ekstraktivnih tvari, celuloze i celuloznog polimorfa I. Proces acetilacije celuloze i određivanje karakterističnih parametara kojima se on definira navedeni su u sljedećem potpoglavlju s naslovom *Acetilacija celuloze*. Pojedine faze pripreme matrica i biokompozitnih materijala, s naglaskom na utjecaj dodatka i zadaću plastifikatora u strukturi materijala, objašnjeni su u četvrtom potpoglavlju, naslovljenome *Priprema matrica i kompozitnih materijala*. Metodika rada objašnjena je u posljednjem potpoglavlju istog naslova. Metodikom rada definiran je broj kompozitnih smjesa pripremljenih u sklopu eksperimentalnog dijela rada, a opisana je i metoda izrade uzoraka potrebnih za pojedina mjerenja. Sam rad podijeljen je na četiri faze, pri čemu su rezultati prethodne faze bili osnova za pripremu materijala iduće faze. Tako je u prvoj fazi određen kemijski sastav, a u drugoj je lijevanjem i ispitivanjem svojstava četiriju kompozitnih smjesa po vrsti određen utjecaj plastifikatora na svojstva čistih matrica. U trećoj je fazi na osnovi ispitivanja triju kompozitnih smjesa po vrsti određen utjecaj konstantnog udjela različitih tipova punila na svojstva biokompozitnih materijala. U posljednjoj, četvrtoj fazi ispitivanjem dviju kompozitnih smjesa određen je utjecaj varijabilnog udjela pojedine vrste punila na svojstva biokompozitnih materijala.

3. Eksperimentalne metode

U tom su poglavlju detaljno opisane pojedine eksperimentalne metode primijenjene pri karakterizaciji biokompozitnih materijala. Točnije, opisana je FTIR spektroskopijska metoda kojom su na osnovi promjene određenih funkcionalnih skupina potvrđene razlike u kemijskom sastavu drva i celuloze, odnosno holoceluloze, a upotrebom iste analitičke metode potvrđena je izolacija polimorfa I, odnosno transfer iz celuloze u celulozni acetat. Uz navedenu, opisane su i metode određivanja toplinskih svojstava matrica i biokompozitnih materijala koje uključuju analizu diferencijalnim pretražnim kalorimetrom (DSC), odnosno termogravimetrijskim analizatorom (TGA), rezultati kojih se međusobno dopunjuju i olakšavaju objašnjenje morfoloških svojstava materijala. U poglavlju je objašnjena i metoda utvrđivanja morfoloških svojstava površine matrica i biokompozitnih materijala pretražnim elektronskim mikroskopom (SEM). Nadalje, objašnjen je i postupak utvrđivanja mehaničkih svojstava matrica i biokompozitnih materijala. Uz načela rada pojedinih uređaja, autor je u ovom poglavlju sustavno povezao važnost rezultata dobivenih navedenim analitičkim tehnikama, čime je potvrdio njihov opravdan izbor za karakterizaciju sustava biokompozitnih materijala.

4. Rezultati i analiza rezultata istraživanja

Poglavlje *Rezultati i analiza rezultata istraživanja* podijeljeno je na četiri međusobno odvojene, a istodobno povezane cjeline. U prvom potpoglavlju – *Određivanje kemijskog sastava i prikladnosti pojedine vrste drva za izradu biokompozitnih materijala* – navedeni su rezultati određivanja kemijskog sastava 20 domaćih vrsta drva, definiran je ključ izbora i odabrane su vrste drva za daljnji laboratorijski rad. Drugim potpoglavljem, naslovljenim *Utvrđivanje svojstava celuloznog acetata i utjecaja dodatka plastifikatora na svojstva biomatrica*, kvantitativno je i kvalitativno analiziran proces acetilacije, u kojemu su logički obrađeni rezultati ispitivanja i utvrđen utjecaj plastifikatora na svojstva biomatrica. Potpoglavlje s naslovom *Utvr-*

đivanje utjecaja konstantnog učešća različitih tipova punila na svojstva biokompozitnih materijala logični je slijed prethodnoga, a u njemu su analizirana svojstva biokompozitnih materijala te je na osnovi rezultata odabran tip punila upotrijebljenoga u četvrtom potpoglavlju – *Utvrđivanje utjecaja varijabilnog učešća određenog tipa punila na svojstva biokompozitnih materijala*. Navedena potpoglavlja sustavno prate predviđeni slijed pokusa, pri čemu su dobiveni rezultati analizirani sa stajališta hipoteze i ciljeva rada, uz statističku obradu podataka ispitivanja mehaničkih svojstava.

5. Rasprava

U poglavlju *Rasprava* iznesen je sukus cjelokupnog istraživanja te su navedeni svi problemi i opažanja uočeni u eksperimentalnom dijelu rada. Uz navedeno je dan i kritički osvrt na opažene probleme, kao i opcije njihova rješavanja, uz poveznice na relevantna svojstva biokompozitnih materijala. Slijed tog poglavlja analogan je rezultatima navedenima u prethodnom poglavlju (*Rezultati i analiza rezultata istraživanja*), čime je omogućeno sustavno i logično praćenje cjelokupnog istraživanja.

6. Zaključak

Poglavlje *Zaključak* posljednje je poglavlje doktorskog rada u kojemu se navode dostignuća rada izvedena neposredno iz rezultata istraživanja i rasprave o njihovu značaju. Nedvojbeno, iz zaključaka proizlazi da su novostečena znanja osnova za daljnju optimizaciju sustava biokompozitnih materijala izrađenih s matricom i punilom jednakoga, točnije, drvnog podrijetla. Na osnovi rezultata pojedinih faza eksperimentalnog rada i u radu navedenih činjenica doneseni su sljedeći zaključci.

- Kemijski sastav drva iznimno je važan činitelj odabira sirovina za pripremu biokompozitnih materijala koji dodatno naglašava značenje pravilnog vođenja procesa sinteze i acetilacije celuloze te pripreme punila (dokazano FTIR analizom).
- Uspješnost procesa sinteze biomatrica i biokompozitnih materijala ovisi o individualnome kemijskom sastavu pojedinih vrsta drva, o čemu u konačnici ovise i svojstva biokompozitnih materijala.
- Rezultat postupka acetilacije celuloze ovisi o sadržaju vode, čije povećanje rezultira višim iznosima zaostalih acetilnih skupina u strukturi acetata, što utječe i na svojstva biomatrica i biokompozitnih materijala.
- Biomatrice izrađene bez dodatka kemijskog plastifikatora optimalna su polimerna osnova biokompozitnih materijala jer njihova svojstva ovise samo o sadržaju vode kao plastifikatoru manje molarne mase.
- Povećanje udjela plastifikatora intenzivira efekt antiplastifikacije smanjujući time vrijednosti mehaničkih i toplinskih svojstava, uz izostanak znatnijih promjena morfoloških svojstava.
- Dodatkom čestica punila biomatricama moguće je proizvesti biokompozitni materijal u potpunosti na bazi od drva pripremljenih sirovina, što potvrđuju rezultati određivanja mehaničkih svojstava, DSC analize i SEM analize morfologije površine.
- Duljina i broj koraka kemijskog tretmana izolacije uvelike utječu na svojstva punila, čineći time polimorf I punilom najlošijih svojstava, uz izuzetak toplinske stabilnosti, znatno povećane izdvajanjem ekstraktivnih tvari i lignina iz njegove strukture.
- Usporedba rezultata TGA i DSC analize pokazuje kako lignin u strukturi punila ima najveći utjecaj na toplinska svojstva biokompozitnih materijala, što potvrđuje važnost kemijske čistoće pojedinog tipa punila.
- Povećanje udjela holoceluloznog punila rezultira znatnim padom vrijednosti svojstava biokompozitnih materijala, dok smanjenje udjela nema znatnijeg utjecaja.
- Usporedba vrijednosti ispitivanja svojstava dviju promatranih vrsta drva upućuje na važnost njihova individualnoga kemijskog sastava, koji uvjetuje različitost iznosa vrijednosti ispitivanih svojstava i tendencije njihove promjene.

OCJENA DOKTORSKOG RADA

Doktorski rad Nikole Španića, mag. ing. techn. lign., pod naslovom *Karakterizacija biokompozitnih drvnih materijala pripremljenih sintetiziranjem acetilirane celuloze i celuloznih polimorfa*, obrađuje dosad neistražene sustave biokompozitnih materijala u kojima su i matrica i punilo drvnog podrijetla. Specifičnost provedenih istraživanja očituje se u tome što je sinteza materijala u potpunosti provedena u kontroliranim laboratorijskim uvjetima, od drvne sirovine poznatih svojstava, pri čemu je doslovno svaki parametar pomno kontroliran i, s obzirom na rezultate istraživanja, neminovno pravilno odabran. Neovisno o opsegu istraživanja i činjenici kako priprema i karakterizacija u radu opisanog tipa materijala zahtijevaju mnogo interdisciplinarnoga znanstvenog, ali i stručnog znanja, rezultati ispitivanja jasno su i nedvosmisleno objašnjeni. Pri tome je osobita pozornost pridana povezivanju rezultata pojedinih faza rada dobivenih specifičnim analitičkim metodama s ciljem sveobuhvatne karakterizacije sustava biokompozitnih materijala. Iako literaturni podaci gotovo i ne spominju mogućnost pripreme biokompozitnih materijala u potpunosti izrađenih od drva, pravilnom metodologijom rada i pomnim povezivanjem činjenica odnosno rezultata ispitivanja autor je u potpunosti potvrdio postavljenu hipotezu i realizirao postavljeni cilj.

Rad donosi nove, znanstveno utemeljene spoznaje kojima se ostvaruje realna opcija razvoja tih ekološki prihvatljivih materijala iskorištenjem manje vrijedne drvne sirovine, što će nužno imati pozitivan utjecaj na razvoj kemijske tehnologije drva i tehnologije drvnih kompozitnih materijala. Pri tome naznake budućih istraživanja podrazumijevaju angažman autora na tom vrlo zanimljivom, ali i slabo istraženom interdisciplinarnom području. Stoga se rad može smatrati osnovom za buduća istraživanja na području biokompozitnih drvnih materijala.

prof. dr. sc. Vladimir Jambreković

Final Cost Action FP0904 Conference Recent Advances in the field of TH and THM Wood Treatment

May 19-21, 2014, Skellefteå, Sweden

The Final International Cost Action Conference was held in Skellefteå, Sweden, from May 19th to May 21st. The conference provided a forum and an opportunity for experts and young researchers from worldwide academia and industry to present their latest research, exchanging and developing new ideas within the field of Thermo-Hydrous (TH) and Thermo-Hydro-Mechanical (THM) wood treatment.

The final International Cost-Action Conference was dedicated to upholding and furthering the objectives and achievements of the previous seminars in the series. Cost-Action has been of particular interest to all people who wished to learn about and discuss the latest developments in Thermo-Hydrous (TH) and Thermo-Hydro-Mechanical (THM) wood treatment by leading researchers and engineers from around the world.

The objectives of this conference have been to present and discuss the state-of–the-art of Thermo-Hydrous (TH) and Thermo-Hydro-Mechanical (THM) wood treatment in open and closed systems and the challenges faced in wood characterization for scaling-up from laboratory to full industrial production.

The key objective of this Final Action FP0904 Conference has been to present the main results of the Action, to summarise the scientific progress achieved and formulate open questions and further challenges.

The seminar consisted of two and half days of oral and poster presentations, combined with local laboratory tours. The abstracts have been published in the ”Book of Abstracts” and are ready for download on conference website.

COST Action FP0904 www.cost-fp0904.ahb.bfh.ch

Thermo-Hydrous (TH) and Thermo-Hydro-Mechanical (THM) treatments are increasing in popularity not only at a research level but also at a commercial level across Europe and worldwide. The range of applications associated with these processing tools is considerable, including heat treatment, welding of wood, wood moulding, densification, bending, profil-

Figure 1. Participants in front of the conference hall

ing, artificial ageing surface densification and composite wood panel construction.

The main topics of the conference were:

- Thermo-Hydro-Mechanical (THM) and Thermo-Hydrous (TH) wood treatment in open and closed systems.
- Innovation and development of new products.
- Improvements in the scaling-up of research findings to full industrial production, and market applications of TH-and THM-treated wood.

The following papers were presented:

Session 1: Chemical degradation of wood under thermo-hydrous treatments

Callum Hill: Thermally Modified Wood – the Role of Hemicelluloses

Wim Willems: Characterisation of Thermally Modified Wood by a Novel Means of Moisture Sorption Isotherm Analysis

Wieslaw Olek, Patrick Perré, Jerzy Weres, Romain Rémond: Water Diffusivity of Thermally Modified Beech Wood

Michael Altgen, Jukka Ala-Viikari, Timo Tetri, Antti Hukka, Holger Militz: The Impact of Elevated Steam Pressure during the Thermal Modification of Scots Pine and Norway Spruce

Iris Brémaud, Sandrine Bardet, Joseph Gril, Patrick Perré: Effects of Water Re-Saturation Conditions and Associated Extractives Leaching on Thermal Softening of Wet Wood

Lukas Brösel, Lothar Clauder, Alexander Pfriem: Flammability Tests on Thermally Modified and Untreated Timber

Mohamed Tahar Elaieb, Kevin Candelier, Anélie Petrissans, Stéphane Dumarcay, Philip Gerardin, Mathieu Petrissans: Chemical Modification during Heat Treatment of Tunisian Soft Wood Species

Lorenzo Barnini, Giacomo Goli, Marco Fioravanti: Effect of Steam Saturated Atmosphere on Some Physical and Mechanical Properties of Poplar Wood

Olov Karlsson, Ola Dagbro, Kurt Granlund: Soluble Degradation Products in Thermally Modified Wood

Maria-Cristina Popescu, Carmen-Mihaela Popescu: An NIR and XPS Study of the Lime Wood Samples Modified for Different Periods at Lower Temperature and Relative Humidity

M. Hakki Alma, Eyyup Karaogula, Tufan Salanb, Nasir Narlioglua, H. İbrahim Şahinc, Cengiz Güler: Effect of Thermal Treatment on XRD, ATR-FTIR AND SEM Analysis of Several Wood Species

Session 2: Modeling of THM processing and predicting the behavior of THM

Eiichi Obataya: Recoverable Effects of Heat Treatment

Sung-Lam Nguyen, Omar Saifouni, Jean-François Destrebecq, Rostand Moutou Pitti: An Incremental Model for Wood Behaviour Including Hydro-Lock Effect

Andreja Kutnar, Frederick A. Kamke, William Gacitúa: Elastic Cell Wall Modulus and Hardness of S2 Layer and Middle Lamella in Viscoelastic Thermal Compressed Wood

Giacomo Goli, Bertrand Marcon, Marco Fioravanti: Wood Heat Treatment Modifications: Effects of Initial Moisture and Air Exchange Rate on Kinetic and Final Product Characteristics

Patrick Perre, Romain Remond: A Comprehensive Dual-Scale Computational Model Able to Simulate the Heat-Treatment of a Thick-Bed of Particles or Boards

Hassen Riahi, Rostand Moutou Pitti, Frédéric Dubois: Numerical Analysis of Timber Fracture Due to Mechanical and Thermal Loads: an Approach Based on Invariant Integral A

Hassen Riahi, Rostand Moutou Pitti, Alaa Chateauneuf, Frédéric Dubois: Stochastic Analysis of Mixed Mode Fracture in Timber Material Using Polynomial Chaos Expansion

Dang Djily, Rostand Moutou Pitti, Evelyne Toussaint, Michel Grédiac: Experimental Evidence of Water Diffusion Gradient in Wood Using the Grid Method

Emilia-Adela Salca, Salim Hiziroglu: Evaluation of Roughness and Hardness of Heat Treated Wood Species

Bogdan Bedelean, Daniela Sova: Influence of Air Parameters on Drying Time and Energy Consumption during Thermo-Hydro Processing of Wood

Alexey Vorobyev, Nico van Dijk, Ingela Bjurhager, E. Kristofer Gamstedt: Determination of Elastic Behaviour of Precious Samples from Large Wooden Structures of Cultural Heritage Including Screening Potential in Process Treatment

Cécilia Gauvin, Kaoru Endo, Delphine Jullien, Eiichi Obataya, Joseph Gril: Effect of Hygrothermal Treatments on the Physical Properties of Wood

Mojgan Vaziri, Sven Berg, Dick Sandberg: Three-Dimensional Finite Element Modelling of Heat Transfer for Linear Friction Welding of Scots Pine

Session 3: Innovation and new products in THM treatments

Otto Th. Eggert, Solid Wood Bending – a Stunning Production System

Jörg Wehsener, Jens Hartig, Peer Haller: Investigations on the Recovery Behaviour of Beech (Fagus Sylvatica) Wood Densified Transverse to the Grain

Lars Blomqvist, Jimmy Johansson, Dick Sandberg: Modification of Surface Veneer to Reduce Damage in Laminated Veneer Products during Manufacturing

Róbert Németh, József Ábrahám, Mátyás Báder: Effect of High Temperature Treatment on Selected Properties of Beech, Hornbeam and Turkey Oak Wood

Alexander Pfriem: Thermally Modified Wood for Use in Musical Instruments – a Review

Nozomi Takemura, Aoi Hirano, Eiichi Obataya, Koji Adachi: Compressive Elasticity of Compressed Wood and its Application to Flexible Wooden Beam

Figure 2. Poster presentation

Aleš Straže, Miljenko Klarić, Stjepan Pervan, Silvana Prekrat, Željko Gorišek: Accelerated Artificial Ageing of Thermally Treated Ash Wood

Lothar Clauder, Alexander Pfriem: Comparative Durability Tests on TMT Beech – Preliminary Results

Veikko Möttönen, Juhani Marttila, Jukka Antikainen, Henrik Heräjärvi, Erkki Verkasalo: Colour, MOE and MOR of Silver Birch and European Aspen Wood after Compression and Thermal Modification in an Industrial Scale Modification Chamber

Ali Akbar Enayati, Fatemeh Taheri, Razieh Mosayyebi: Effect of Heat Treatment Conditions (Heat-Temperature and Initial (Moisture Content) on the pH Value and Buffer Capacity of Poplar Wood (Populous Alba)

Marek Grześkiewicz: Effect of Thermal Modification of Beech Wood on its MOE and other Mechanical Properties

Session 4: Environmental impact assessment of THM products & STSM presentations

Kévin Candelier, Characterization of Physical and Chemical Changes Occurring during Wood Thermal Degradation. Influence of Treatment Intensity, Wood Species and Inert Atmosphere

Michael Burnard, Andreja Kutnar: Restorative Environmental Design: a Design Paradigm for Thermally Modified Wood

José Sánchez del Pulgar, Illaria Santoni, Luca Cappellin, Anrea Romano, Cuccui Ignazia, Franco Biasioli, Ottaviano Allegretti: Rapid Assessment by PTR-ToF-MS of the Effect on Volatile Compound Emission of Different Heat Treatments on Larch and Spruce

Carmen-Mihaela Popescu, Maria-Cristina Popescu, Petronela Gradinariu: Soft and White Rot Degradation Resistance of Thermo-Hydro-Mechanical Processed Hardwood Evaluated by Infrared Spectroscopy

Ekaterina Sidorova, Sheikh A. Ahmed, Diego Elustondo: Wood Thermal-Modification at Luleå University of Technology

Carmen Cristescu, Dick Sandberg: Self-Bonding of Veneers with Heat and Pressure– a Full Scale Test

Nebojša Todorović, Goran Milić, Zdravko Popović: Estimation of Heat-Treated Beech Wood Properties by FT-NIR Spectroscopy: Effect of Radial and Cross Sectional Surface

Jonaz Nilsson, Jimmy Johansson, Dick Sandberg: Densified and Thermally Modified Wood as Outer Layers in Light-Weight panels for Furniture and Joinery

Sandak Jakub, Riggio Mariapaola, Pauliny Dusan, Sandak Anna: Densified Wood as a Resource for Novel Nail-Like Connectors

Wim Willems, Joël Hamada, Mathieu Pétrissans, Philippe Gérardin, Characterization of Thermally Modified Wood by Oxygen Bomb Calorimetry

Mirko Kariz, Manja Kitek Kuzman, Milan Sernek, Mark Hughes, Lauri Rautkari, Frederick A. Kamke, Andreja Kutnar: Influence of Temperature of Thermal Modification on Compressive Densification of Spruce

Lothar Clauder, Alexander Pfriem, Maria Rådemar, Lars Rosell, Marcus Vestergren: Emissions from TMT Products

Kristiina Laine, Lauri Rautkari, Mark Hughes, Kristoffer Segerholm, Magnus Wålinder: Set-Recovery and Micromorphology of Surface Densified Wood

Susanna Källbom, Lauri Rautkari, Magnus Wålinder, Dennis Jones, Kristoffer Segerholm: Water Vapour Sorption Properties and Surface Chemical Analysis of Thermally Modified Wood Particles

Professor Stjepan Pervan, Ph.D.
Associate Professor Silvana Prekrat, Ph.D.

KEMPAS

UDK: ???????????

NAZIVI I NALAZIŠTE

Drvo vrste *Koompassia malaccensis* Maing. iz botaničke porodice *Fabaceae* potječe iz Malezije i Indonezije. Moguće ga je pronaći na otocima Sumatri, Javi i Borneu. Lokalni su mu nazivi menggeris, toemaling (Indonezija), impas, mengris, kempas (Malajski otoci), kempas (Nova Gvineja), yuan (Tajland).

STABLO

Drvo vrste *Koompassia malaccensis* Maing. listača je srednje visine – naraste od 50 do 55 m visoko. Promjer debla kreće se između 60 i 210 cm. Visina do prve grane iznosi do 24 m.

DRVO

Makroskopska obilježja

Srž i bjeljika jasno se razlikuju po boji. Bjeljika je bijela do svjetložuta, a sirova je srž ružičastocrvena. Stajanjem poprima narančastocrvenu boju. Drvo ima grubu i ujednačenu teksturu. Žica drva je ravna, katkada i usukana. Granica goda je uočljiva. Pore i drvni traci povećalom su jasno i dobro vidljivi.

Mikroskopska obilježja

Drvo je rastresito porozno. Pore su mu pretežito pojedinačne ili se pojavljuju u obliku kratkih radijalnih nizova (po 2 – 3 pore). Promjer pora iznosi 196...255...314 mikrometara, a malobrojne su. Gustoća pora kreće se od 3 do 4 po mm^2 poprečnog presjeka. Pore mogu biti ispunjene smeđim sadržajem. Drvna vlakanca su libriformska vlakanca i vlaknaste traheide. Drvna vlakanca imaju srednje debelu do debelu stijenku. Nema septiranih vlakanaca. Aksijalni je parenhim vrpčast, paratrahealno aliforman do konfluentan. Staničje drvnih trakova je heterogeno. Drvni su traci difuzno raspoređeni. Široki su dvije stanice (katkad tri), heterocelularni su, s kvadratičastim i uspravnim parenhimskim stanicama koje nalazimo na rubnim dijelovima drvnog traka. U pojedinačnoj parenhimskoj stanici nalazi se jedan ili više kristala. U stanicama drvnih trakova nema silicija.

Fizikalna svojstva

Gustoća standardno suhog drva, ρ_o	oko 750 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	oko 880 kg/m^3
Gustoća sirovog drva, ρ_s	950...1000 kg/m^3
Totalno radijalno utezanje	oko 4,8 %
Totalno tangentno utezanje	oko 6,0 %
Totalno volumno utezanje	oko 11,2 %

Mehanička svojstva

Čvrstoća na tlak	oko 65 MPa
Čvrstoća na savijanje	oko 125 MPa
Modul elastičnosti	20,09 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Zbog svoje gustoće i tvrdoće drvo se teže obrađuje ručnim i strojnim alatima, a posebno ga pažljivo treba obrađivati ako mu je žica nepravilna. Obradom se postiže glatka i blago sjajna površina. Drvo dobro drži vijke i čavle, no potrebno ga je prethodno izbušiti. Dobro se brusi, ljušti i lijepi.

Sušenje

Drvo treba polako sušiti kako bi se izbjegle pukotine i iskrivljenost. Nema opasnosti od pojave skorjelosti ni kolapsa.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva otporna je na gljive truležnice (razred otpornosti 2) i srednje otporna na termite (razred otpornosti S). Otpornost srži na tercijarne kukce klasificirana je kao sredne trajna (razred otpornosti 3). Srž je slabo permeabilna (razred 3).

Prema normama, drvo se bez problema može koristiti u razredu opasnosti 3 (ne u dodiru sa zemljom ili vodom).

Uporaba

Drvo se upotrebljava za izradu teških drvenih konstrukcija (željezničkih pragova i mostova) te za proizvodnju namještaja i izradu parketa.

Sirovina

Drvo se na tržištu pojavljuje u obliku trupaca ili piljene građe. Trupci su obično većih dimenzija.

Napomena

Drvetu vrste *Koompassia malaccensis* Maing. zasad ne prijeti nestanak, tj. nije na popisu CITES –

Convention on International Trade in Endangered Species, niti na popisu IUCN – Red list of Threatened Species.

Literatura

1. ***HRN RN 350-2, 2005: Trajnost drva i proizvoda na osnovi drva – Prirodna trajnost masivnog drva, 2. dio.
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prof. dr. sc. Jelena Trajković
doc. dr. sc. Bogoslav Šefc

Upute autorima

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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.
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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:
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Upute

Predani radovi smiju sadržavati najviše 15 jednostrano pisanih A4 listova s dvostrukim proredom (30 redaka na stranici), uključujući i tablice, slike te popis literature, dodatke i ostale priloge. Dulje je članke preporučljivo podijeliti na dva ili više nastavaka. Tekst treba biti u *doc formatu*, u potpunosti napisan fontom *Times New Roman* (tekst, grafikoni i slike), normalnim stilom, bez dodatnog uređenja teksta.
Prva stranica poslanog rada treba sadržavati puni naslov, ime(na) i prezime(na) autora, podatke o zaposlenju autora (ustanova, grad i država) te sažetak s ključnim riječima (duljina sažetka približno 1/2 stranice A4).
Posljednja stranica treba sadržavati titule, zanimanje, zvanje i adresu (svakog) autora, s naznakom osobe s kojom će Uredništvo biti u vezi.
Znanstveni i stručni radovi moraju biti sažeti i precizni. Osnovna poglavlja trebaju biti označena odgovarajućim podnaslovima. Napomene se ispisuju na dnu pripadajuće stranice, a obrojčavaju se susljedno. One koje se odnose na naslov označuju se zvjezdicom, a ostale uzdignutim arapskim brojkama. Napomene koje se odnose na tablice pišu se ispod tablica, a označavaju se uzdignutim malim pisanim slovima, abecednim redom.
Latinska imena trebaju biti pisana kosim slovima (italicom), a ako je cijeli tekst pisan kosim slovima, latinska imena trebaju biti podcrtana.
U uvodu treba definirati problem i, koliko je moguće, predočiti granice postojećih spoznaja, tako da se čitateljima koji se ne bave područjem o kojemu je riječ omogući razumijevanje ciljeva rada.
Materijal i metode trebaju biti što preciznije opisane da omoguće drugim znanstvenicima ponavljanje pokusa. Glavni eksperimentalni podaci trebaju biti dvojezično navedeni.
Rezultati trebaju obuhvatiti samo materijal koji se izravno odnosi na predmet. Obvezatna je primjena metričkog sustava. Preporučuje se upotreba SI jedinica. Rjeđe rabljene fizikalne vrijednosti, simboli i jedinice trebaju biti objašnjeni pri njihovu prvom spominjanju u tekstu. Za pisanje formula valja se koristiti Equation Editorom (programom za pisanje formula u MS Wordu). Jedinice se pišu normalnim (uspravnim) slovima, a fizikalni simboli i faktori kosima (italicom). Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.
Broj slika mora biti ograničen samo na one koje su prijeko potrebne za objašnjenje teksta. Isti podaci ne smiju biti navedeni i u tablici i na slici. Slike i tablice trebaju biti zasebno obrojčane, arapskim brojkama, a u tekstu se na njih upućuje jasnim naznakama ("tablica 1" ili "slika 1"). Naslovi, zaglavlja, legende i sav ostali tekst u slikama i tablicama treba biti napisan hrvatskim i engleskim jezikom.
Slike je potrebno rasporediti na odgovarajuća mjesta u tekstu, trebaju biti izrađene u rezoluciji 600 dpi, crno-bijele (objavljivanje slika u koloru moguće je na zahtjev autora i uz posebno plaćanje), formata jpg ili tiff, potpune i jasno razumljive bez pozivanja na tekst priloga.
Svi grafikoni i tablice izrađuju se kao crno-bijeli prilozi (osim na zahtjev, uz plaćanje). Tablice i grafikoni trebaju biti na svojim mjestima u tekstu te originalnog formata u kojemu su izrađeni radi naknadnog ubacivanja hrvatskog prijevoda. Ako ne postoji mogućnost za to, potrebno je poslati originalne dokumente u formatu u kojemu su napravljeni (*excel* ili *statistica* format).
Naslovi slika i crteža ne pišu se velikim tiskanim slovima. Crteži i grafikoni trebaju odgovarati stilu časopisa (fontovima i izgledu). Slova i brojke moraju biti dovoljno veliki da budu lako čitljivi nakon smanjenja širine slike ili tablice. Fotomikrografije moraju imati naznaku uvećanja, poželjno u mikrometrima. Uvećanje može biti dodatno naznačeno na kraju naslova slike, npr. "uvećanje 7500 : l".
Diskusija i zaključak mogu, ako autori žele, biti spojeni u jedan odjeljak. U tom tekstu treba objasniti rezultate s obzirom na problem postavljen u uvodu i u odnosu prema odgovarajućim zapažanjima autora ili drugih istraživača. Valja izbjegavati ponavljanje podataka već iznesenih u odjeljku *Rezultati*. Mogu se razmotriti naznake za daljnja istraživanja ili primjenu. Ako su rezultati i diskusija spojeni u isti odjeljak, zaključke je nužno napisati izdvojeno. Zahvale se navode na kraju rukopisa. Odgovarajuću literaturu treba citirati u tekstu, i to prema harvardskom sustavu (*ime – godina*), npr. (Bađun, 1965). Nadalje, bibliografija mora biti navedena na kraju teksta, i to abecednim redom prezimena autora, s naslovima i potpunim navodima bibliografskih referenci. Popis literature mora biti selektivan, a svaka referenca na kraju mora imati naveden DOI broj, ako ga posjeduje (http://www.doi.org) (provjeriti na http://www.crossref.org).

Primjeri navođenja literature

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

Primjer

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

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

Primjeri

Krpan, J., 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb, Tehnička knjiga.
Wilson, J. W.; Wellwood, R. W., 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A. Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551- 559.
Ostale publikacije (brošure, studije itd.)
Müller, D., 1977: Beitrag zür Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanstalt für Forstund Holzvvirt schaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

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

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

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

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

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