DRVNA INDUSTRIJA

ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE • ZAGREB • VOLUMEN 68 • BROJ 2
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY • ZAGREB • VOLUME 68 • NUMBER 2

***Hura crepitans* L.**

2/17

UDK 674.031.677.7 CODEN: DRINAT ISSN 0012-6772

UDK 630*8+674 Coden: Drinat ISSN 0012-6772

DRVNA INDUSTRIJA

ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY

DRVNA INDUSTRIJA je časopis koji objavljuje znanstvene i stručne radove te ostale priloge iz cjelokupnog područja iskorištavanja šuma, istraživanja svojstava i primjene drva, mehaničke i kemijske prerade drva, svih proizvodnih grana te trgovine drvom i drvnim proizvodima.

Časopis izlazi četiri puta u godini.

DRVNA INDUSTRIJA contains research contributions and reviews covering the entire field of forest exploitation, wood properties and application, mechanical and chemical conversion and modification of wood, and all aspects of manufacturing and trade of wood and wood products.

The journal is published quarterly.

OVAJ BROJ ČASOPISA POTPOMAŽE:

Sadržaj
Contents

NAKLADA (Circulation): *700 komada* · **ČASOPIS JE REFERIRAN U (Indexed in):** *CA search, CAB Abstracts, Compendex, Crossref, EBSCO, Forestry abstracts, Forest products abstracts, Geobase, Paperchem, SCI-Expanded, SCOPUS* · **PRILOGE** *treba slati na adresu Uredništva. Znanstveni i stručni članci se recenziraju. Rukopisi se ne vraćaju.* · **MANUSCRIPTS** *are to be submitted to the editor's office. Scientific and professional papers are reviewed. Manuscripts will not be returned.* · **KONTAKTI s uredništvom (Contacts with the Editor) e-mail:** *editordi@sumfak.hr* · **PRETPLATA (Subscription):** *godišnja pretplata (annual subscription) za sve pretplatnike 55 EUR. Pretplata u Hrvatskoj za sve pretplatnike iznosi 300 kn, a za đake, studente i umirovljenike 100 kn, plativo na žiro račun 2360000 – 1101340148 s naznakom "Drvna industrija"* · **ČASOPIS SUFINANCIRA** *Ministarstvo znanosti, obrazovanja i sporta Republike Hrvatske.* · **TISAK (Printed by)** *– DENONA d.o.o., Getaldićeva 1, Zagreb, tel. 01/2361777, fax. 01/2332753, E-mail: denona@denona.hr; URL: www.denona.hr* · **DESIGN** Aljoša Brajdić · **ČASOPIS JE DOSTUPAN NA INTERNETU:** *http://drvnaindustrija.sumfak.hr* · **NASLOVNICA** *Presjek drva* Hura crepitans *L., ksiloteka Zavoda za znanost o drvu, Šumarski fakultet Sveučilišta u Zagrebu*

DRVNA INDUSTRIJA · Vol. 68, 2 · str. 97-182 · ljeto 2016. · Zagreb
REDAKCIJA DOVRŠENA 2.06.2017.

ORIGINAL SCIENTIFIC PAPERS
Izvorni znanstveni radovi **99-152**

PHYSICAL, MECHANICAL AND BONDING PERFORMANCE OF CALABRIAN PINE (*PINUS BRUTIA* TEN.) AS INFLUENCED BY HEAT TREATMENT
Utjecaj toplinske obrade na fizikalna i mehanička svojstva te na svojstva lijepljenih spojeva drva kalabrijskog bora (*Pinus brutia* Ten.)
Ergün Güntekin, Tuğba Yilmaz Aydin, Birol Üner **99**

CHEMICAL CHARACTERIZATION OF LEBONAN CEDAR TAR
Analiza kemijskog sastava katrana od libanonskog cedra
Ayben Kılıç Pekgözlü, Süleyman Kuştaş, Burak Mercan, Aziz Biçer **107**

CHEMICAL CHARACTERIZATION OF BIO-OIL FROM PYROLYSIS OF UNDECAYED AND DECAYED FAGUS ORIENTALIS WOOD
Kemijska karakterizacija biološkog ulja dobivenoga pirolizom zdravoga i natrulog drva bukve (*Fagus orientalis*)
Seyyed Khalil Hosseinihashemi, Saeed Hassani, Ahmad Jahan Latibari, Günay Özbay **113**

WOOD-CEMENT BOARD REINFORCED WITH STEEL NETS AND WOVEN HEMP YARNS: PHYSICAL AND MECHANICAL PROPERTIES
Drvno-cementna ploča ojačana čeličnom mrežom i tkanom konopljom: fizikalna i mehanička svojstva
Hossein Rangavar **121**

MICRO-TENSILE AND COMPRESSION STRENGTH OF SCOTS PINE WOOD AND COMPARISON WITH STANDARD-SIZE TEST RESULTS
Mikrovlačna i mikrotlačna čvrstoća škotske borovine i usporedba s rezultatima ispitivanja čvrstoće na uzorcima standardne veličine
Ümit Büyüksarı, Nusret As, Türker Dündar, Ezel Sayan **129**

AN EVALUATION OF MODULUS OF ELASTICITY, DIMENSIONAL STABILITY AND BONDING STRENGTH OF BONDED HEAT-TREATED WOOD
Procjena modula elastičnosti, dimenzijske stabilnosti i čvrstoće lijepljenja toplinski obrađenog drva
Darius Albrektas, Povilas Navickas **137**

SIMULATION MODEL FOR PREDICTION OF TIMBER ASSORTMENT PRICE TRENDS IN CROATIA - A CASE STUDY OF BRINJE FOREST OFFICE
Simulacija trendova cijena šumskih sortimenata u Hrvatskoj na primjeru Šumarije Brinje
Karlo Beljan, Stjepan Posavec, Silvije Orsag, Krunoslav Teslak **145**

PRELIMINARY PAPER
Prethodno priopćenje **153-161**

IMPACT OF VENEER LAYOUTS ON PLYWOOD TENSILE STRENGTH
Utjecaj položaja furnira u strukturi furnirskih ploča na njihovu vlačnu čvrstoću
Violeta Jakimovska Popovska, Borche Iliev, Goran Zlateski **153**

REVIEW PAPER
Pregledni rad **163-172**

OPERATIONAL VS. EMBODIED ENERGY: A CASE FOR WOOD CONSTRUCTION
Analiza operativne i ugrađene energije drvenih građevina
Laszlo Bejo **163**

PROFESSIONAL PAPER
Stručni rad **173-178**

MEASURING THE FORMALDEHYDE CONTENT FROM DIFFERENT TYPES OF ORIENTED STRAND BOARD MANUFACTURED WITH DIFFERENT THICKNESSES AND GLUED WITH DIFFERENT RESINS
Mjerenje sadržaja formaldehida u pločama s orijentiranim iverjem različite debljine i proizvedenih upotrebom različitih ljepila
Mohamed Z. M. Salem, Martin Böhm, Ramadan A. Nasser **173**

UZ SLIKU S NASLOVNICE / Species on the cover **179-180**

Ergün Güntekin[1], Tuğba Yilmaz Aydin[1], Birol Üner[1]

Physical, Mechanical and Bonding Performance of Calabrian Pine (*Pinus brutia* Ten.) as Influenced by Heat Treatment

Utjecaj toplinske obrade na fizikalna i mehanička svojstva te na svojstva lijepljenih spojeva drva kalabrijskog bora (*Pinus brutia* Ten.)

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 8. 9. 2015.
Accepted – prihvaćeno: 15. 11. 2016.
*UDK: 630*812.463; 630*812.7; 674.032.475.44; 630*824.44*
doi:10.5552/drind.2017.1533

ABSTRACT • *In this study, the effects of heat treatment on some physical, mechanical, wettability and bonding properties of Calabrian pine (Pinus brutia Ten.) were investigated. Specimens were exposed to heat under atmospheric pressure at four different temperatures (120, 150, 180, 210 °C) and three different time levels (2, 5, 8 hours). Weight loss, bending strength (MOR), modulus of elasticity (MOE) in bending, Young's modulus in compression, compression strength parallel to grain, contact angle, and bonding performance using shear tests were evaluated. All of the properties of the specimens tested were affected by heat treatment of different intensity. As a result, softer treatments yielded some increase in mechanical properties, but increase of time and temperature resulted in significant decrease in mechanical properties with decreasing mass loss. Contact angle measurements before and after treatment indicated a significant increase in wood hydrophobicity. Shear strength of the specimens were diminished when time and temperature of heat treatment were increased.*

Key words: *Calabrian pine, heat treatment, mechanical properties, bonding*

SAŽETAK • *U radu su prikazani rezultati istraživanja učinaka toplinske obrade na neka fizikalna i mehanička svojstva, sposobnost kvašenja i svojstva lijepljenih spojeva drva kalabrijskog bora (Pinus brutia Ten.). Uzorci su izloženi utjecaju topline pod atmosferskim tlakom pri četiri različite temperature (120, 150, 180 i 210 °C) i tri različita vremena izlaganja (2, 5 i 8 sati). Primjenom smičnih testova određeni su gubitak mase, čvrstoća na savijanje (MOR), modul elastičnosti (MOE) pri savijanju, Youngov modul pri tlačnom opterećenju, tlačna čvrstoća paralelno s vlakancima, kontaktni kut i svojstva lijepljenog spoja. Toplinska obrada drva utjecala je na sva istraživana svojstva uzoraka kalabrijskog bora, ali je taj utjecaj bio različitog intenziteta. Rezultati su pokazali da blaži uvjeti toplinske obrade neznatno pridonose povećanju vrijednosti mehaničkih svojstava, a porast vremena i temperature toplinske obrade*

[1] Authors are associate professor, research assistant and associate professor at Department of Forest Products Engineering, Faculty of Forestry, Suleyman Demirel University, Isparta, Turkey.
[1] Autori su izvanredni profesor, asistent i izvanredni profesor Odjela za inženjerstvo drvnih proizvoda, Šumarski fakultet, Sveučilište *Suleyman Demirel*, Isparta, Turska.

rezultirali su značajnim smanjenjem vrijednosti mehaničkih svojstava i smanjenjem gubitka mase. Mjerenje kontaktnog kuta na površini uzoraka prije i nakon toplinske obrade pokazalo je značajan porast hidrofobnosti drva. Pri povećanju vremena i temperature toplinske obrade smanjila se smična čvrstoća uzoraka.

Ključne riječi: *kalabrijski bor, toplinska obrada, mehanička svojstva, lijepljenje*

1 INTRODUCTION
1. UVOD

Preservation of wood using heat-treatment process is one of the modification processes that alter the physical, chemical and mechanical properties of wood. Studies on heat treatment of wood are not new. They started in the 1920s by Tiemann and gained interest in the last two decades leading to commercialization (Esteves and Pereira, 2009). According to Boonstra (2008), the reasons for this interest may include decreasing of durable timber, increasing demand of sustainable building materials, deforestation of sub-tropical forests and restrictive regulations. In the heat-treatment process, wood is exposed to temperatures up to 160-250 °C, usually above 200 °C depending on the species used and the desired material properties (Kocaefe *et al*., 2008).

While thermal treatment of wood results in darkened color, decreased moisture performance, improved biological durability and improved dimensional stability, most of its mechanical properties will decrease depending upon species tested, temperature and duration of exposure (Esteves and Pereira, 2009). During the process, hemicelluloses are the first to decompose, then lignin softens and finally cellulose and hydrophilic groups are modified (Bekhta and Niemz, 2003). Since hardwoods contain higher proportion of hemicelluloses than softwoods, the degradation is more severe (Esteves *et al.*, 2007).

Different commercial treatments appeared due to the increase of demand for heat treated wood in different countries during the last two decades. Increase in demand also resulted in the number of investigations conducted on different wood species. Some selected properties of heat treated wood species can be found in Esteves and Pereira (2009), but in general, color change, equilibrium moisture content (EMC), dimensional stability, bending properties and compression strength were studied in most investigations.

The purpose of this study was to investigate the influence of the heat treatment on some physical, mechanical, wettability as well as bonding performance of Calabrian pine wood. The effect of heat treatment on physical and mechanical properties of wood is well-understood, but investigations on wettability and bonding behavior are scarce. Calabrian pine covers the largest area (3 096 064 ha) among conifers grown in Turkey, which corresponds to approximately 15 % of the total forest area. Calabrian pine is a fast-growing tree; its wood is an important raw material for various fields, including construction (Bektas *et al*. 2003).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Small clear wood samples were prepared from Calabrian pine (*Pinus brutia* Ten.) logs harvested from Bucak Forest District in Turkey. They were approximately 50 cm in diameter. The logs were transferred and sawn to lumber. Only sapwood lumbers were used in order to prepare small clear specimens.

Three pieces (2, 5, 8 hours) of lumber, free of visible defects, were used in preparation of each individual test. Five matched heat treatment samples (0, 120, 150, 180, 210 °C), with the dimensions 20 x 80 x 480 mm, were cut from each lumber. Specimens were exposed to heat under atmospheric pressure. For shear tests, PVA adhesive was used. After heat treatment, small samples were cut for testing. At least 6 replicates were prepared for each test group.

Before testing and after heat treatment process, specimens were conditioned in climatic chambers at 65 % relative humidity (RH) at a temperature of 20 °C. To minimize the influence of the MC change, specimens were tested immediately after removal from the climatic chamber. Wood MC was determined by the oven-drying method. Apparent densities of the samples were calculated according to TS 2472 (2005) using stereometric method, which is based on measurement of the sample volume and mass. The properties of wood samples investigated include mass loss (ML, %), bending modulus of elasticity (MOE), bending strength (MOR), compression strength (CS), Young's modulus in compression (YM), contact angle using water (CAW), contact angle using hexane (CAH) and shear strength (SS).

Weight loss was measured by the difference of dry weight before and after thermal treatments. Mechanical tests were performed using UTM with the capacity of 50 kN. Static bending tests were performed in a three-point bending apparatus with a span length of 360 mm and a loading speed of 6 mm/min, according to TS 2474 (1976) and 2478 (1976). Compression tests were conducted using an extensometer with a loading speed of 2 mm/minute according to TS 2595 (1997). Shear tests were performed according to TS 3459 (2012). After the mechanical tests, the load-deflection curves were analyzed in order to calculate the mechanical properties. The contact angles of water and hexane droplets on untreated and heat-treated samples were measured by the sessile drop method in the grain of sapwood cut in tangential surfaces using KSV-CAM 101 tensiometer. Hexane was chosen as non-polar test liquid to avoid problems due to polarity of wood. All measurements were performed at 20 °C and 65 % relative humidity.

Analysis of variance (ANOVA) general linear model procedure was run for data with SAS statistical analysis software to interpret effects of temperature and duration of exposure on the properties of clear wood samples.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Average values for ML, MOE, MOR, CS, YM, CAW, CAH and SS of the specimens tested are pre-

sented in Table 1. The average density of the control samples were 0.54 g/cm^3 with a correlation coefficient of 11 %. There was a good match among the density values in the various treatment groups. With respect to available literature references for similar MC, the measured density values were comparable.

ML values (%) of the specimens tested are presented in Figure 1 and ranged between 0.80 % and 15.97 %, depending on the temperature and duration of exposure. The values of ML (%) are accumulated with increasing temperature and duration of exposure. The values found in this study are similar to those reported by Esteves and Pereira (2009). ML is mainly due to the degradation of the hemicelluloses, which are the most heat sensitive polymers of the wood (Bourgois and Guyonnet, 1988). Mass loss is also one of the most important aspects of heat treatment and is accepted as indication of quality (Esteves and Pereira, 2009).

In general, the change of mechanical properties depends on the tree species and on conditions of the heat treatment. Bending properties of the samples tested in this study were significantly affected by heat treatment. MOE seemed to increase for softer treatments (%) and decrease for more severe treatments as shown in Figure 2. Results indicate that 2-hour heat treatment of samples increased the MOE values of the samples by 6 %, while 8-hour treatment decreased the MOE values by 7.8 %. There is no significant difference between the MOE values of control samples and 5-hour treatments.

There is no significant difference between the MOR values of the control samples and 2-hour treatments. For the 5 hour treatments, the MOR values of the samples were increased by 5 % and 3 % when the temperature was raised to 120 and 150 °C, while 180 and 210 °C exposures decreased the MOR values by 5 % and 7 %, respectively. After 8-hour heat treatment, the MOR values of the samples were increased by 5 % and 8 % when the temperature was raised to 120 and 150 °C, while 180 and 210 °C exposures decreased the MOR values by 7 % and 55 %, respectively. Influence of heat treatments on the MOR values is shown in Figure 3.

The effect of heat treatment on the MOR values of the wood is greater than on the MOE values (Esteves and Pereira, 2009; and Ross, 2010). According to Esteves and Pereira (2009), softer heat treatments yield

Table 1 Average values of ML, MOE, MOR, YM, CS, SS, CAW and CAH
Tablica 1. Prosječne vrijednosti veličina ML, MOE, MOR, YM, CS, SS, CAW i CAH

Temp °C	Hour	ML %	MOE N/mm^2	MOR MPa	YM MPa	CS MPa	SS MPa	CAW °	CAH °
Control	2*	0	8181 (9.93)**	102 (7.41)	10111 (14.46)	52 (5.39)	8.45 (10.48)	60.49 (23.14)	13.87 (48.22)
	5*	0	12365 (9.16)	136 (7.37)	17093 (9.03)	74 (2.51)	8.45 (10.48)	45.66 (20.52)	13.65 (40.24)
	8*	0	10519 (13.54)	114 (9.99)	13022 (13.07)	53 (10.31)	8.45 (10.48)	31.20 (35.11)	13.48 (50.63)
120	2	0.8 (4.75)	9012 (7.79)	105 (10.17)	13595 (23.78)	57 (10.09)	6.87 (8.81)	68.96 (35.11)	13.16 (35.07)
150		1.5 (4.2)	8537 (10.53)	101 (5.57)	11242 (13.74)	54 (7.81)	9.96 (6.96)	66.54 (7.06)	11.62 (39.44)
180		1.81 (7.1)	8034 (9.48)	103 (11.02)	11114 (8.86)	57 (3.69)	6.99 (8.59)	79.13 (20.42)	12.46 (51.58)
210		9.42 (2.12)	9296 (9.71)	103 (9.10)	16659 (12.15)	67 (8.79)	2.75 (13.00)	100 (5.12)	8.89 (30.24)
120	5	2.05 (5.85)	13584 (7.39)	165 (7.37)	20104 (10.39)	75 (14.33)	5.96 (44.22)	71 (33.53)	12.19 (52.43)
150		2.13 (3.4)	11779 (10.96)	160 (6.26)	16233 (12.53)	77 (8.21)	8.07 (14.80)	89.29 (11.19)	11.18 (57.32)
180		3.04 (4.5)	11786 (10.70)	122 (4.10)	15819 (14.54)	74 (6.30)	6.57 (19.06)	93.26 (5.59)	9.84 (48.43)
210		11.53 (3.5)	10939 (11.59)	105 (6.88)	12630 (14.18)	65 (12.57)	3.15 (18.60)	111.15 (5.57)	9.82 (27.29)
120	8	2.85 (6.5)	10433 (9.81)	115 (6.41)	14156 (10.47)	59 (5.22)	12.28 (16.13)	83.88 (18.51)	11.39 (37.13)
150		3.49 (5.15)	10182 (12.09)	113 (14.31)	13337 (12.74)	58 (11.24)	7.68 (17.90)	114.91 (11.76)	10.23 (47.18)
180		7.56 (3.0)	9964 (9.25)	104 (7.57)	12414 (9.32)	61 (6.47)	4.92 (19.28)	104.28 (3.58)	9.50 (39.62)
210		15.97 (15)	9099 (5.79)	51 (10.12)	11145 (11.70)	52 (9.88)	2.38 (10.43)	87.50 (5.12)	9.79 (20.08)

ML - mass loss, % / *gubitak mase,* %; MOE - bending modulus of elasticity / *modul elastičnosti pri savijanju*; MOR - bending strength / čvrstoća na savijanje; YM - Young's modulus in compression / *Youngov modul pri tlačnom opterećenju*; CS - compression strength / *tlačna čvrstoća*; SS - shear strength / *smična čvrstoća*; CAW - contact angle using water / *kontaktni kut primjenom vode*; CAH - contact angle using hexane / *kontaktni kut primjenom heksana*; * number indicates piece of lumber from which samples were made, not hours of treatment duration / *broj označava uzorak piljenice od koje su izrađeni uzorci, a ne vrijeme trajanja toplinske obrade*; **values in parenthesis are coefficient of variations / *vrijednosti u zagradama označuju koeficijent varijacije*

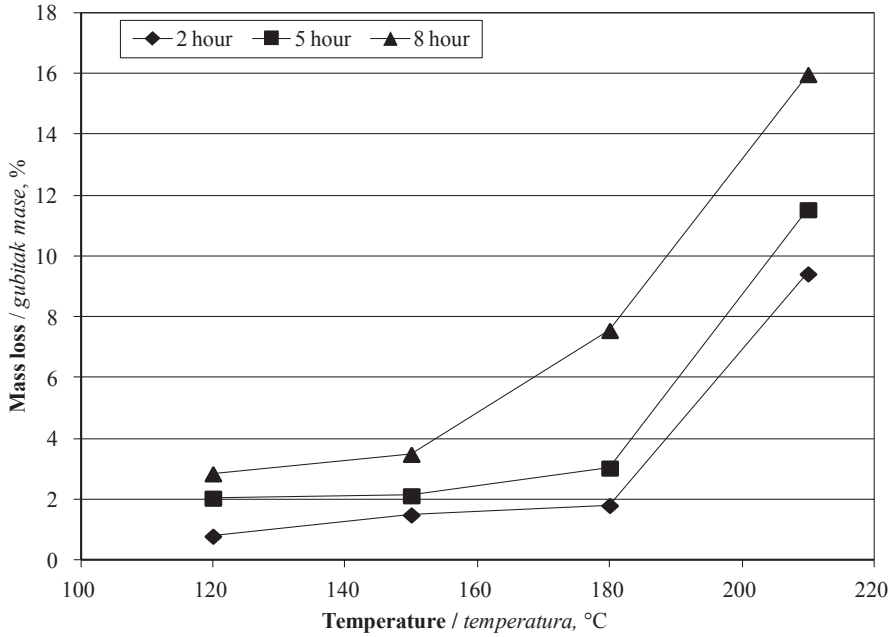


Figure 1 Effect of heat treatment on ML (%) of Calabrian pine
Slika 1. Utjecaj toplinske obrade drva kalabrijskog bora na gubitak mase

an increase in the MOE values, while severe treatments result in a decrease in the MOE values. The findings presented by Altınok *et al.* (2010) support this idea. Kubojima *et al.* (2000) state that the effects of heat treatment on the MOR are less in nitrogen than in air.

Figure 4 presents the effects of heat treatment on the YM values. Test results show that 2 hour-treatments increase the YM values by 20 %, while 5 hour-treatments decrease the YM values by 23 %. There is no significant difference between the values of control samples and 8-hour treatments. There is no significant difference between the values of control samples and 150-180 °C exposures. Kubojima *et al.* (1998) reported similar results for Sıtka spruce exposed to 120, 160, and 200 °C. According to Kubojima *et al*. (1998), the increase in the YM can be explained by the increase in the crystallinity index of cellulose, while the decrease is due to the degradation.

Figure 5 illustrates the effects of heat treatment on the CS values. Results indicate that 2 and 8-hour treatments increase the CS values by 10 % and 14 %, respectively, while 5-hour treatments decrease the CS values by 14 % in comparison to control samples.

There is a contradiction in the literature on whether the CS is decreased by heat treatment or not.

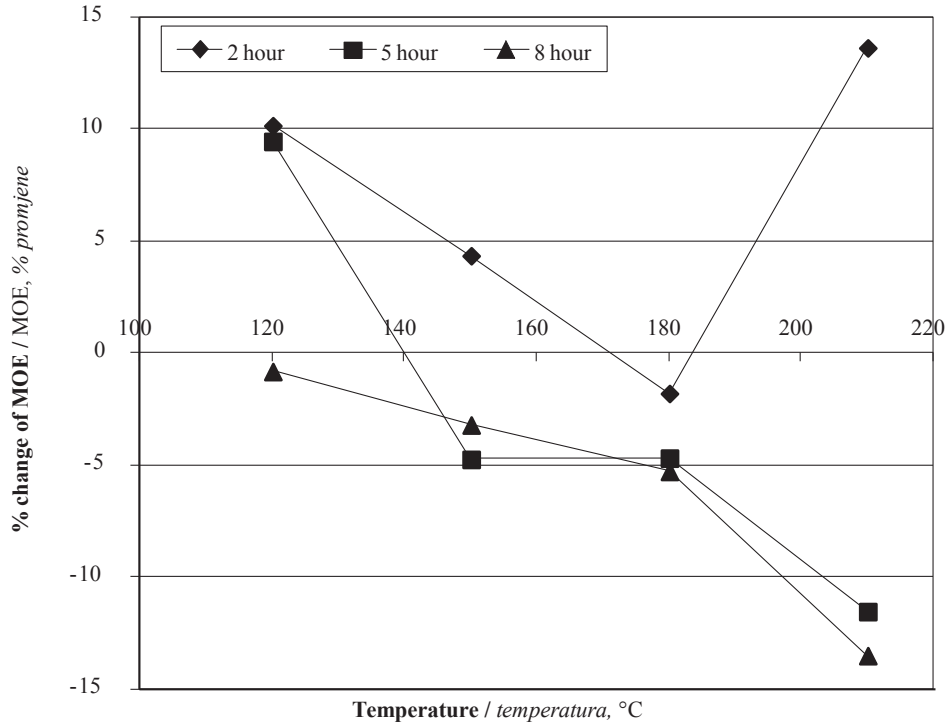


Figure 2 Effect of heat treatment on MOE values of Calabrian pine
Slika 2. Utjecaj toplinske obrade drva kalabrijskog bora na modul elastičnosti pri savijanju

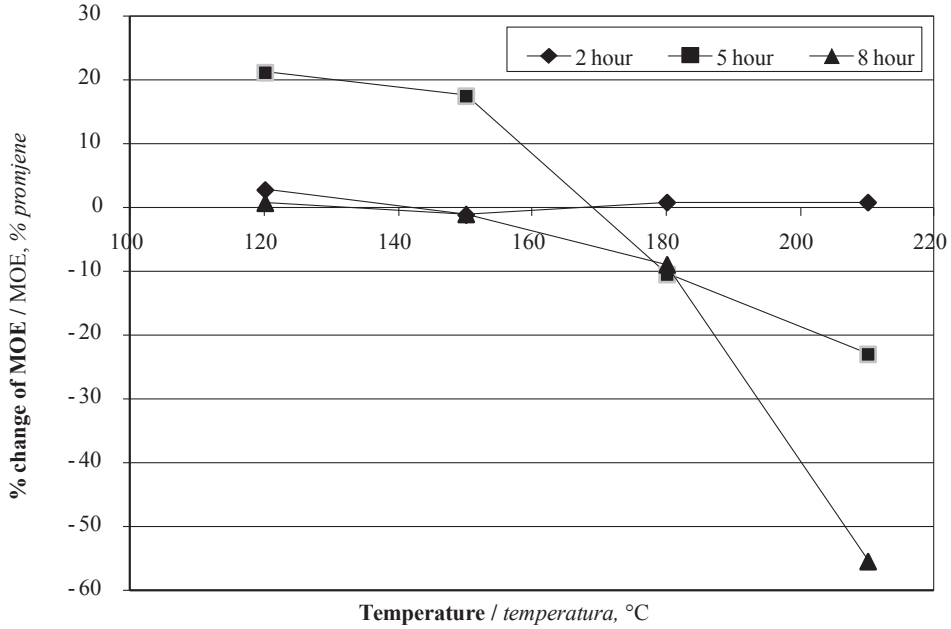


Figure 3 Effect of heat treatment on MOR values of Calabrian pine
Slika 3. Utjecaj toplinske obrade drva kalabrijskog bora na čvrstoću na savijanje

Some authors (Ünsal and Ayrılmış, 2005; Korkut *et al.*, 2008a; Korkut *et al.*, 2008b) found that the CS is decreased by heat treatment, while others (Boonstra and Blomberg, 2007; Altınok *et al.*, 2010) reported an increase with heat treatment.

The reduction of mechanical properties due to heat treatment can be explained by the degradation of hemicelluloses, as the main reason, followed by crystallization of amorphous cellulose. Cross-linking of lignin may contribute to the mechanical properties in the longitudinal direction. The lower equilibrium moisture content may have positive effects on strength properties, but degradation of chemical compounds ousts this effect (Esteves and Pereira, 2009).

While the influence of heat treatment on the physical and mechanical behavior of wood is relatively well known (Esteves and Pereira, 2009), investigations of the wettability and bonding performance are limited. So far, only a few studies have investigated the wettability and bonding performance of wood (Kocaefe *et al.,* 2008; Sernek *et al.*, 2008; Altınok *et al.,* 2010; Perçin and Uzun, 2014).

Heat-treated wood shows lower affinity to water and a strongly modified wettability leading to important changes of its behavior with most coating or gluing processes (Petrissans *et al.*, 2003). According to Hakkou *et al.* (2005), wood is totally hydrophilic with a contact angle value near zero for heat treatments below 120 °C; after this threshold value, contact angle suddenly changes to reach 90° for treatment temperature between 120 and 160 °C; for higher temperatures, it remains constant near 90°. Oliveira *et al.* (2010) state that contact angle also varies for sapwood and heartwood.

Results of this study show that the contact angle using both water and hexane was significantly changed for all treatments, but the change was drastic when hig-

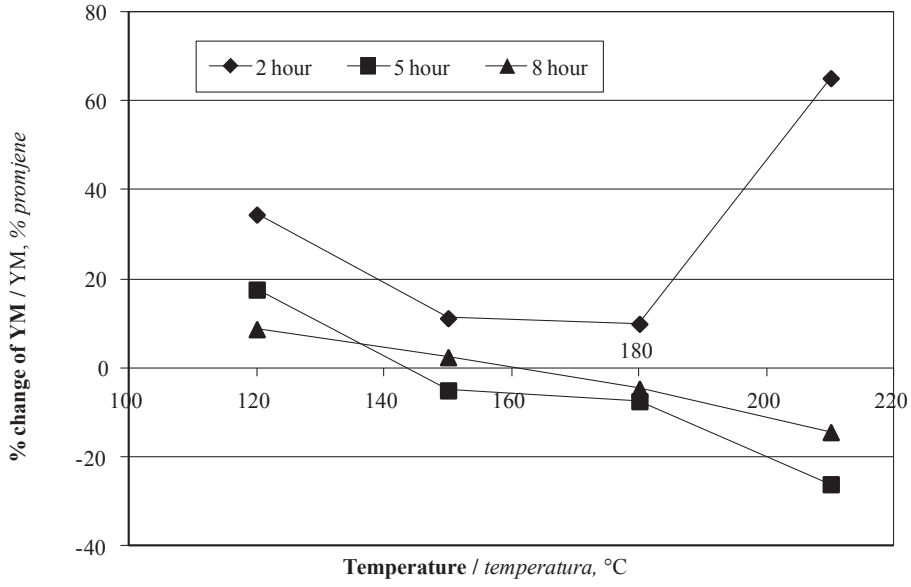


Figure 4 Effect of heat treatment on YM values of Calabrian pine
Slika 4. Utjecaj toplinske obrade drva kalabrijskog bora na Youngov modul pri tlačnom opterećenju

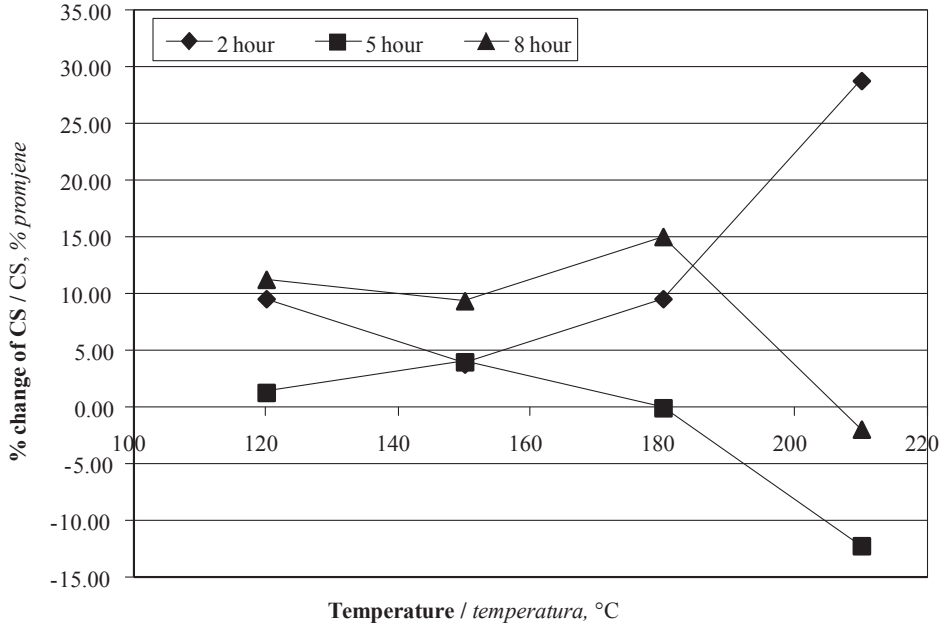


Figure 5 Effect of heat treatments on CS of Calabrian pine
Slika 5. Utjecaj toplinske obrade drva kalabrijskog bora na tlačnu čvrstoću

her temperatures were applied for a longer time (Figure 6 and 7). Generally, the contact angle using water drops is increasing from 120 to 210 °C due to a higher hydrophobic condition of the wood sample, when higher temperatures are applied for a longer time. The contact angle decreases after 150 °C, thus evidencing that the wood recovers its hydrophilic nature. Treatments between 200 and 260°C can cause significant degradation in hemicelluloses content of wood, which release a great content of acetic acid (Weiland *et al.*, 1998). The phenolic carboxylic acid and 4-O-methyl-glucuronic and galacturonic acids, produced as a result of the hydrolysis of wood, also contribute to wood acidity (Windeisen *et al.*, 2007). Chen *et al.* (2012) state that heat treatment in oxygen leads to lower pH values than in nitrogen. Production of acid groups in heat treated wood for longer durations and high temperatures may cause a decrease in the contact angle when polar water drops are used. Polar water may form new linkages with acidic functional groups on the surface of heat treated wood. Drying defects occurring on the surface of the samples may enhance water–surface interaction, resulting in a decrease of the contact angle (Oliveira *et al.* 2010).

Thermal decomposition of hemicelluloses and cellulose of wood with the thermal treatment may lead to reduce the wettability of wood. Decreasing effect of heat treatment on the wettability was also observed by Hakkou *et al.* (2005) and Kocaefe *et al.* (2008). Petrissans *et al.* (2003) suggested that one of the possible reasons for the decrease of wettability could be the increase of cellulose crystallinity.

Results of this study reveal that bonding performance of 2-5-8 hour treated samples were decreased by 20-34 % comparing to control samples. When 120 °C exposure was applied, the bonding strength of the samples did not change significantly. 150 °C exposure seems to increase the bonding strength, but 180 °C and 210 °C exposures drastically reduced the bonding

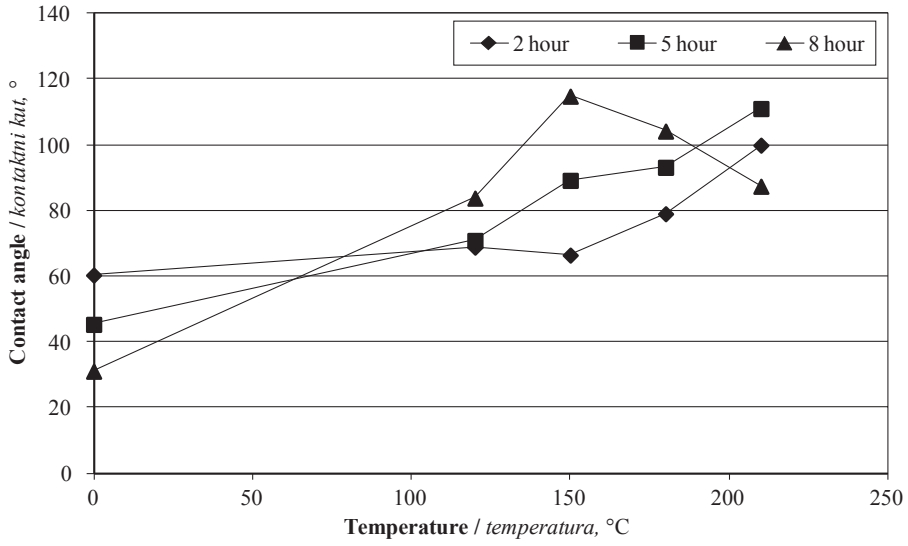


Figure 6 Effects of heat treatment on contact angle measured by water drops
Slika 6. Utjecaj toplinske obrade drva kalabrijskog bora na kontaktni kut izmjeren kapljicama vode

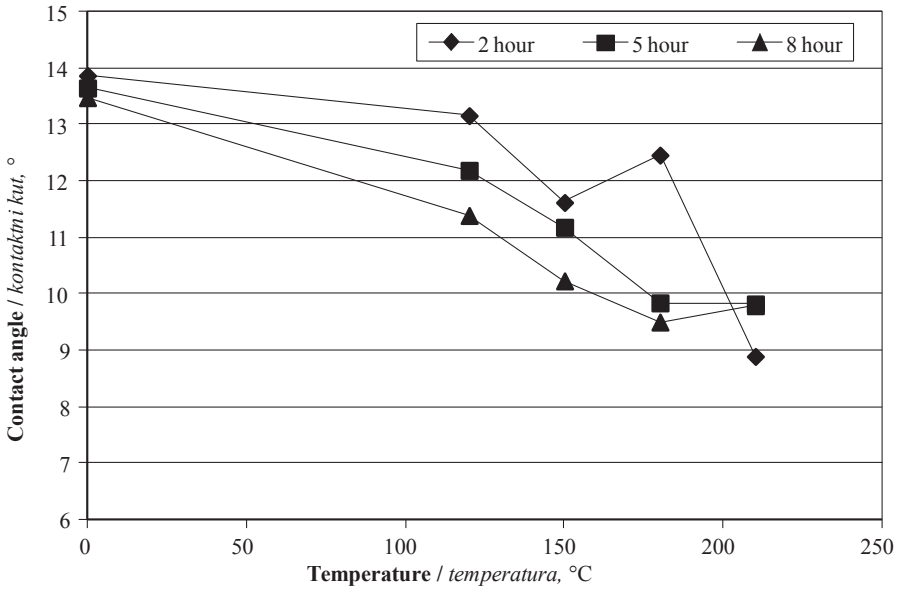


Figure 7 Effects of heat treatment on contact angle measured by hexane drops
Slika 7. Utjecaj toplinske obrade drva kalabrijskog bora na kontaktni kut izmjeren kapljicama heksana

strength (30 % and 67 %). Figure 8 shows the change in bonding strength depending upon heat treatment duration and temperatures.

Decrease in shear strength was reported by several studies including Šernek *et al*. (2007), who reported a decline of 13 % for spruce bonded with PF and UF, each by heat treatment at 210 °C for 2 hours. Another study by Šernek *et al.* (2008) reported that shear strength was decreased by 23 % for heat treated spruce. Kol *et al.* (2009) also presented lower shear strength for heat treated Tali and Iroko woods at 180 °C for 2 hours. Perçin and Uzun (2014) reported similar reduction of bonding strength after heat treatment for wood species of pine, beech, scots pine and poplar using PVAc-D4 type adhesives. Esen and Özcan (2012) presented similar reduction of bonding strength after heat treatment for wood species of oak using several types of adhesives.

The only study that revealed an increase was reported by Altınok *et al.* (2010), who applied heat treatments at 100 and 150 °C for 4 hours on PVA and PU bonded samples.

4 CONCLUSIONS
4. ZAKLJUČAK

Increase of duration and temperature during heat treatment results in a significant weight loss, which is one of the quality parameters of the process. Softer treatments resulted in some improvement in mechanical properties, probably due to lower equilibrium moisture content. MOE and Young's modulus decreased significantly under treatment conditions of longer exposure and higher temperature. The effect of heat treatment on MOR is more severe. CS seems to be increasing with treatment severity. Heat treated samples become hydrophobic at the temperature ranging between 120 and 210 °C. Wettability was significantly reduced by heat treatment resulting in lower shear

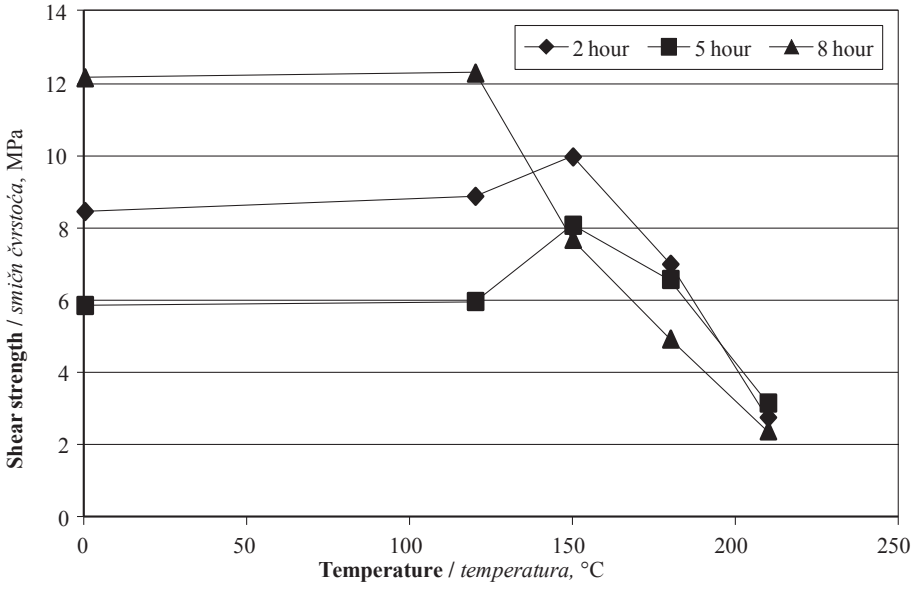


Figure 8 Effect of temperature and duration of exposure on shear strength of Calabrian pine
Slika 8. Utjecaj toplinske obrade drva kalabrijskog bora na smičnu čvrstoću

strength. Since mechanical properties were significantly reduced, heat treated wood of Calabrian pine may not be suitable for load carrying members.

5 REFERENCES
5. LITERATURA

1. Altınok, M.; Özalp, M.; Korkut, S., 2010: The effects of heat treatment on some mechanical properties of laminated beech (*Fagus Orıentalıs* L.) wood. Wood Research, 55 (3): 131-142.
2. Bekhta, P.; Niemz, P., 2003: Effect of high temperature on the changes in color, dimensional stability and mechanical properties of spruce wood. Holzforschung, (57):539-546. http://dx.doi.org/10.1515/HF.2003.080.
3. Bektas, I.; Alma, M. H.; As, N.; Gundogan, R., 2003: Relationship between site index and several mechanical properties of Turkish calabrian pine (*Pinus brutia* Ten.). Forest Products Journal, 53 (2): 27-31.
4. Boonstra, M., 2008: A two-stage thermal modification of wood. Ph.D. Thesis in Applied Biological Sciences: Soil and Forest management, Henry Poincaré University-Nancy, France.
5. Boonstra, M.; Blomberg, J., 2007: Semi-isostatic densification of heat-treated radiata pine. Wood Sci. Technol., 41: 607-617. http://dx.doi.org/10.1007/s00226-007-0140-y.
6. Bourgois, J.; Guyonnet, R., 1988: Characterisation and analysis of torrefied wood. Wood Sci. Technol., 22: 143-155. http://dx.doi.org/10.1007/BF00355850.
7. Chen, Y.; Fan, Y.; Gao, J.; Stark, N. M., 2012: The effect of heat treatment on the chemical and color change of black locust (*Robinia pseudoacacia*) wood flour. BioResources, 7 (1): 1157-1170.
8. Esen, R.; Özcan, C., 2012: The effects of heat treatment on shear strength of oak (*Quercus petraea* L.) wood. SDU Faculty of Forestry Journal, 13: 150-154.
9. Esteves, B.; Domingos, I.; Pereira, H., 2007: Improvement of technological quality of eucalypt wood by heat treatment in air at 170-200 ºC. For. Prod. J., 57 (1/2): 47-52.
10. Esteves, B. M.; Pereira, H. M., 2009: Wood modification by heat treatment: A review. BioResources, 48 (1): 370-404.
11. Hakkou, M.; Petrissans, M.; Zoulalian, A.; Gerardin, P., 2005: Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. Polymer Degradation and Stability, 89: 1-5. http://dx.doi.org/10.1016/j.polymdegradstab.2004.10.017.
12. Kocaefe, D.; Poncsak, S.; Dore, G.; Younsi, R., 2008: Effect of heat treatment on the wettability of white ash and soft maple by water. Holz Roh Werkst, 66: 355-361. http://dx.doi.org/10.1007/s00107-008-0233-9.
13. Kol, H. S.; Özbay, G.; Altun, S., 2009: Shear strength of heat-treated Tali (*Erythrophleum ivorense*) and Iroko (*Chlorophora excelsa*) woods, bonded with various adhesives. BioResources, 4 (4): 1545-1554.
14. Korkut, S.; Akgül, M.; Dündar, T., 2008a: The effects of heat treatment on some technological properties of Scots pine (*Pinus sylvestris* L.) wood. Bioresour. Technol., 99: 1861-1868. http://dx.doi.org/10.1016/j.biortech.2007.03.038.
15. Korkut, S.; Kök, M.; Korkut, D.; Gürleyen T., 2008b: The effects of heat treatment on technological properties in Red-bud maple (*Acer trautvetteri* Medw.) wood. Bioresour. Technol., 99: 1538-1543. http://dx.doi.org/10.1016/j.biortech.2007.04.021.
16. Kubojima, Y.; Okano, T.; Ohta, M., 2000: Bending strength of heat-treated wood. J. Wood Sci., 46: 8-15.
17. Kubojima, Y.; Okano, T.; Ohta, M., 1998: Vibrational properties of Sitka spruce heat-treated in nitrogen gas. J. Wood Sci., 44: 73-77. https://doi.org/10.1007/BF00521878.
18. Oliveira, R. M.; Brisolari, A.; Sales, A.; Gonçalves, D., 2010: Wettability, Shrinkage and Color Changes of *Araucaria angustifolia* After Heating Treatment. Materials Research, 13 (3): 351-354. https://doi.org/10.1590/S1516-14392010000300012.
19. Perçin, O.; Uzun, O., 2014: Determination of bonding strength in heat treated some wood materials, SDU Faculty of Forestry Journal, 15: 72-76.
20. Petrissans, M.; Gerardin, P.; Elbakali, D.; Serraj, M., 2003: Wettability of heat treated wood. Holzforschung, 57: 301-307. http://dx.doi.org/10.1515/HF.2003.045.
21. Ross, R. J. (ed.), 2010: Wood handbook: Wood as an engineering material, General Technical Report FPL-GTR 190. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI.
22. Šernek, M.; Humar, H.; Kumer, M.; Pohleven, F. 2007: Bonding of thermally modified spruce with PF and UF adhesives. In: Proceedings of the 5th COST E34 International Workshop. Bled-Slovenia, pp. 31-39.
23. Šernek, M.; Boonstra, M.; Pizzi, A.; Despres, A.; Gerardin, P., 2008: Bonding performance of heat-treated wood with structural adhesives. Holz Roh-Werkst., 66 (3): 173-180. http://dx.doi.org/10.1007/s00107-007-0218-0.
24. Unsal, O.; Ayrilmis, N., 2005: Variations in compression strength and surface roughness of heat-treated Turkish river red gum. J. Wood Sci., 51: 405-409. http://dx.doi.org/10.1007/s10086-004-0655-x.
25. Weiland, J. J.; Guyonnet, R.; Gibert, R., 1998: Analysis of controlled wood burning by combination of TA, DSC and FTIR spectroscopy. Journal of Thermal Analysis and Calorimetry, 51 (1): 265-274. https://doi.org/10.1007/BF02719028.
26. Windeisen, E.; Strobel, C.; Wegener, G., 2007: Chemical changes during the production of thermotreated beech wood. Wood Sci Technol, 41 (6): 523-536. http://dx.doi.org/ 10.1007/s00226-007-0146-5.
27. ***TS 2472, 2005: Wood – Determination of density for physical and mechanical tests. Turkish Standards Institute, Ankara, Turkey (in Turkish).
28. ***TS 2474, 1976: Wood – Determination of Ultimate Strength in Static Bending. Turkish Standards Institute, Ankara, Turkey (in Turkish).
29. ***TS 2478, 1976: Wood-Determination of Modulus of Elasticity in Static Bending. Turkish Standards Institute, Ankara, Turkey (in Turkish).
30. ***TS 2595, 1997: Wood-Determination of Ultimate Stress in Compression Parallel to Grain. Turkish Standards Institute, Ankara, Turkey (in Turkish).
31. ***TS 3459, 2012: Wood-Determination of ultimate shearing stress parallel to grain. Turkish Standards Institute, Ankara, Turkey (in Turkish).

Corresponding address:

Assoc. Prof. ERGÜN GÜNTEKİN, Ph. D.

Department of Forest Products Engineering
Faculty of Forestry
Suleyman Demirel University
Isparta, TURKEY
e-mail: ergunguntekin@sdu.edu.tr

Ayben Kılıç Pekgözlü[1], Süleyman Kuştaş[2], Burak Mercan[3], Aziz Biçer[4]

Chemical Characterization of Lebonan Cedar Tar

Analiza kemijskog sastava katrana od libanonskog cedra

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 4. 2. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*813.4; 630*872.64; 674.032.475.842*
doi:10.5552/drind.2017.1607

ABSTRACT • *Chemical characterization of Cedrus libani A. Rich tar, obtained by the traditional method and Jenkner Retort, was studied. Roots and fallen branches were used and analyzed separately. FID-GC and GC-MS were used for the characterization. The tar yield of Jenkner Retort was 60 %, while it is 30-40 % in the traditional method. 41 compounds were identified. β-himachalane (22-28 %) was found to be the main compound in all tars. α-himachalane (6-10%) and longifolene (7-9 %) were the other important compounds. Some compounds, which have antifungal and insecticides effects like deodarone and E-(α)-atlantone, were determined only in tars of roots. Phenolic compounds were not determined by the traditional method.*

Key words: *Cedrus libani, himachalane, pyrolysis, GC-MS, Jenkner Retort*

SAŽETAK • *U radu je prikazana analiza kemijskog sastava katrana od libanonskog cedra (Cedrus libani A. Rich) dobivenoga tradicionalnim postupkom i uz pomoć Jenknerove retorte. Napravljena je zasebna analiza za staro korijenje i za otpale grane libanonskog cedra. Za kemijsku karakterizaciju primijenjene su metode FID-GC i GC-MS. Prinos katrana uz pomoć Jenknerove retorte bio je 60 %, a prinos tradicionalnom metodom iznosio je 30 – 40 %. Pritom je identificiran 41 kemijski spoj. Ustanovljeno je da je β-himakalan (22 – 28 %) glavni spoj svih analiziranih katrana. Drugi po važnosti bili su A-himakalan (6 – 10 %) i longifolen (7 – 9 %). Neki spojevi koji imaju antifungalne i insekticidne učinke kao što su deodaron i E-(α)-atlanton pronađeni su samo u korijenju. U katranu dobivenom tradicionalnim postupkom nisu pronađeni fenolni spojevi.*

Ključne riječi: *libanonski cedar, himakalan, piroliza, GC-MS, Jenknerova retorta*

1 INTRODUCTION
1. UVOD

Pyrolysis is a thermal method converting biomass into gas, liquid and char product in the absence of oxygen. Sort of biomass and thermal conditions affect the yield of these products. Slow pyrolysis (low temperature, long residence time) enhances the charcoal yield, where in fast pyrolysis (moderate temperature, short residence time) liquid-tar yield is high (Bridgwater, 2003; Li *et al.*, 2008; Wang *et al.*, 2009)

Tar is a complex mixture which has a distinctive smoky smell and mainly dark brown color. Generally, *Pinus* sp., *Juniperus* sp., *Fagus* sp., *Betula* sp., *Picea* sp., and *Cedrus* sp. tree species are used for tar production. This liquid product has been used in wood preser-

[1] Author is associate professor at Bartin University, Forestry Faculty, Department of Forest Industry Engineering, Bartin, Turkey. [2]Author is assistant at Karadeniz Technical University, Faculty of Forestry, Department of Forest Industry Engineering, Tarbzon, Turkey. [3]Author is an employee of the company AHSAPSAN A.Ş, İstanbul, Turkey. [4]Author is research & development engineer in Kastamonu Entegre Ağaç San. ve Tic. A.Ş., Istanbul, Turkey.

[1] Autor je izvanredni profesor Sveučilišta u Bartinu, Šumarski fakultet, Odjel za inženjerstvo industrije na bazi drva, Bartin, Turska. [2]Autor je profesor Tehničkog sveučilišta u Karadenizu, Šumarski fakultet, Odjel za inženjerstvo industrije na bazi drva, Tarbzon, Turska. [3]Autor je zaposlenik tvrtke AHSAPSAN A. Ş., İstanbul, Turkey. [4]Autor je inženjer za istraživanje i razvoj u tvrtki Kastamonu Entegre Ağaç San. ve Tic. A. Ş., Istanbul, Turkey.

vation since ancient times specially in the impregnation of ships and boats (Reunanen *et al.*, 1989; Reunanen *et al.*, 1990; Reunanen *et al.*, 1993).

It was also widely used in veterinary as an antiseptic that is applied to wounds and scratches, treatment for intestinal parasites by adding some drops to drinking water and as repellent against insects and snakes. There are also some applications for the human health care eg. ulcers, dandruff, eczema (Kurt *et al.*, 2008). Despite its distinctive smell and some toxic effect, inhaling of tar helps asthma and, especially in Marrakesh, it is believed to keep away Satan from small babies (Julin, 2008). Tars can be burned as fuel, too (Bridgwater, 2003).

Lebanon Cedar (*Cedrus libani* A. Rich) is a native Mediterranean species with a pleasant odor and valuable wood. In the ancient times, it had a religious meaning and was used as a medicine (Hafizoglu, 1987a). Today there is a legal restriction to cut these trees. Nonetheless, villagers use the fallen branches and old roots to produce cedar tar.

In the last decade, pyrolysis of woody plants has been studied by modern methods from different aspects because of its advantage in storage and variable use (Chiodo *et al.*, 2015; Das and Sarmah, 2015; Hagner *et al.*, 2015; Niu and Liu, 2015; Lij *et al.*, 2015; St Pierre *et al.*, 2015). However, traditional tar production has been used for several millennia. From this point of view, the aim was to compare the tar composition obtained by traditional and modern pyrolysis methods and also to determine the difference between root and branch wood of a tree.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

In this study, Lebanon Cedar (*Cedrus libani* A. Rich), a native species in Turkey, was used for tar production. Due to the legal restrictions of Cedar wood production, fallen branches and old roots were used. Samples were taken at the altitude of 1400 m from Büyüknacar-Pazarcık, Kahramanmaraş, Turkey. The moisture content of branches and roots were 5.83 % and 7.5 %, respectively. Traditionally obtained tar was taken from the same location and parts of tree.

2.2 Method
2.2. Metoda

2.2.1 Sample preparation
2.2.1. Priprema uzoraka

Two different methods, Traditional and Jenkner Retort, were used for tar production in this study. Traditional method, which is in principle a kind of distillation, was applied by the local people. 400-500 kg sample was used in this method. Two holes with different dimensions, depending on the amount of wood material used, were dug nearby and generally the smaller, where tar is collected, was located down-slope from the larger. A pipe was placed between two holes for the tar flow. Inner and upper part of the hole, where ignition occurs, were plastered with mud and clay. If required, small holes were opened on the top to keep the burning process active. For a better tar yield, wood samples were inserted vertically in the hole (Hjulstrom *et al.*, 2006; Kurt *et al.*, 2008). Jenkner Retort was used for the pyrolysis of cedar samples. A cylindrical stainless steel reactor with 12 cm internal diameter and 26 cm height was used. The temperature of retort was measured by Pt-Rh-Pt thermocouple. Branches and roots were applied separately. For each sample, approximately 600 g was placed in the reactor and heated by electric furnace. With the rate of 4 °C/min, temperature raised to max. 400 °C. Bio-char, end-product, was weighted after the experiment and gas yield was calculated by taking the difference (Sutcu *et al.*, 2004). Three repetitions were done for each experiment.

2.2.2 Characterization
2.2.2. Karakterizacija

For the chemical analysis, three different solvents, n-hexane, diethyl ether and dichloromethane, were used for the liquid-liquid extraction. 5 ml tar was extacted with 30 ml solvent and diluted to 100 ml. 1 ml aliquot was taken from the diluted sample and evaporated under the nitrogen before silylation (Ekman and Holmbom, 1989). Silylated samples were analyzed by FID-GC (Flame Ionization Detector – Gas Chromatography) (Shimadzu GC-2010) and GC-MS (Gas Chromatography - Mass Spectrometry) (Shimadzu GCMS-2010 Plus) equipped with TRB-5 type column 30 m x 0.25 mm (0.25 µm film thickness). Helium was used as carrier gas with 1.03 ml/min flow. Temperature program was 60 °C (1 min.) raised to 120 °C with the rate of 4°C/min and held for 10 min. with the same rate raised to 200 °C (held 10 min.) and then to 300 °C (held 10 min.). Detector temperature was 300 °C. Split ratio was 1:10. Three injections were done for each sample.

3 RESULTS AND DISCUSSION
3. REZUTATI I RASPRAVA

3.1 Product yields
3.1. Prinos proizvoda

In the traditional method, the yield was 30-40 % (150 – 200 kg tar/400 – 500 kg wood material), while with Jenkner Retort system it was 60 %. When modern closed systems are used, it is possible to control and apply high temperatures, which affect the yield. The temperature is an important parameter affecting the yield of pyrolysis products (Duman *et al.*, 2011; Ozciftci and Özbay, 2013). Table 1 presents the yield of Jenkner Retort products. As seen, tar is the main product. Tar was obtained at 230 °C from branches and at 300 °C from roots. No significant difference was observed between the yield of roots and branches.

According to Koch P. (1972), with destructive distillation, the yield of char was found as 15-20 % and 6-12 % of tar in southern pine stump wood.

During the process, two different colors of tar were observed. Dark black color was from resinous roots and

Table 1 Yield of Jenkner Retort products, %
Tablica 1. Prinos proizvoda Jenknerovom retortom, %

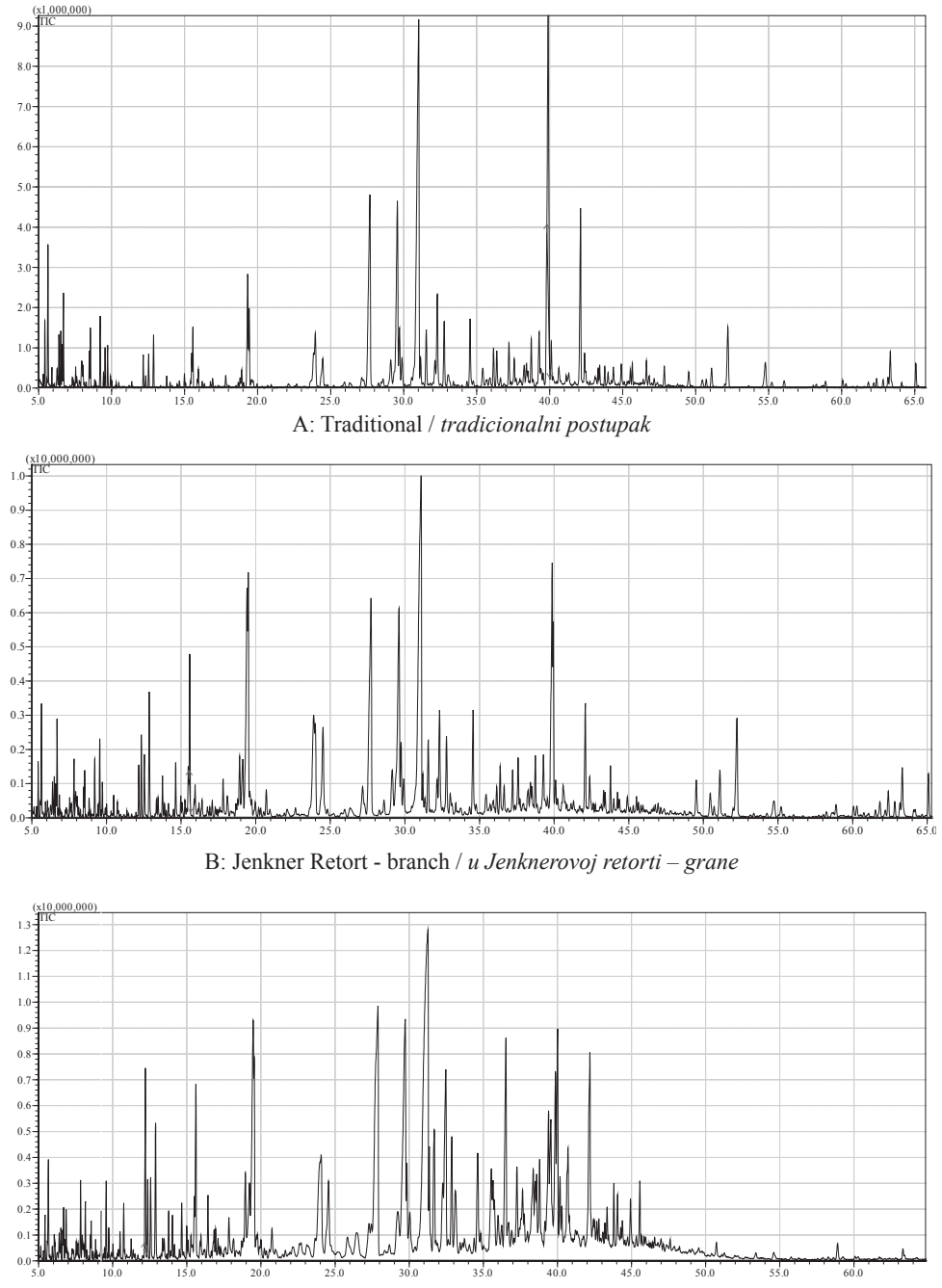
	Gas *Plin*	**Liquid (Tar)** *Tekućina (katran)*	**Char** *Ugljen*
Root / *Korijen*	12.2	62.1	25.6
Branch / *Grane*	11	64.5	24.4

yellow color from branches. Unfortunately, the gas product cannot be used as in the closed Jenkner Retort system.

3.2 Analysis of tars
3.2. Analiza katrana

Cedar tar, obtained with different methods and from different parts of wood, was analyzed by GC-MS and FID-GC. Chemical composition of tars is shown in Table 2. Phenols, alcohols, acids, sesquiterpenoids and fatty-resin acids are the constituents of tars with different ratios. Almost 70 % of tar produced by Jenkner Retort was identified; however, this ratio was 50 % in the traditional method.

β-himachalane (22-28 %), a sesquiterpene, is the most abundant compound in all tars. It is found to be higher in the branches. α-himachalane (6-10 %) and longifolene (7-9 %) are the other important compounds. As known, β-himachalane and its derivates obtained from cedrus have antifungal and insecticidal effects (Daoubi *et al.*, 2005; Derwich *et al.*, 2010; Singh and Agarwal, 1988). Although the results showed similarities with literature, himachalol, which was found in the essential oil of cedar wood obtained by



A: Traditional / *tradicionalni postupak*

B: Jenkner Retort - branch / *u Jenknerovoj retorti – grane*

C: Jenkner Retort - root / *u Jenknerovoj retorti – grane*

Figure 1 GC-MS Chromatograms of cedrus tar diluted in dichloromethane
Slika 1. GC-MS kromatogrami katrana od cedra razrijeđenoga u diklormetanu

Table 2 Chemical composition of *Cedrus libani* tar obtained by different methods, %
Tablica 2. Kemijski sastav katrana od libanonskog cedra proizvedenoga različitim metodama, %

Compound *Kemijski spoj*	**RT**	**Root (Jenkner Retort)** *Korijen (u Jenknerovoj retorti)*			**Branch (Jenkner Retort)** *Grane (u Jenknerovoj retorti)*			**Traditional** *Tradicionalni postupak*		
		A	B	C	A	B	C	A	B	C
3-methyl-3-butanoic acid / *3-metil-3-maslačna kiselina*	10.32	0.31	0.13	0.34	0.47	0.80	0.54	-	0.84	1.28
Phenol / *fenol*	13.67	0.31	0.25	0.11	-	0.16	0.44	0.13	-	-
Propanoic acid / *propanoična kiselina*	14.02	-	-	0.11	-	-	-	-	-	-
Acetic acid / *octena kiselina*	14.56	-	0.05	0.37	-	0.36	-	-	-	-
2,6-Dimethyl styrene / *2,6-dimetil stiren*	15.07	0.31	0.24	-	-	-	-	-	-	-
p-Cresol-1 / p-krezol-1	17.02	0.23	0.31	-	0.21	0.29	0.34	-	-	-
p-Cresol-2 / *p-krezol-2*	17.44	0.47	0.75	0.64	0.34	0.38	0.65	-	-	-
1,3-methyl phenyl ethanone / *1,3-metil fenil etanon*	19.06	0.27	0.32	-	-	-	-	-	-	-
2,4-dimethyl phenol / *2,4-dimetil fenol*	21.06	0.25	0.29	0.28	0.28	0.30	0.28	-	-	-
Guaiacol / *gvajakol*	21.23	0.99	1.23	0.44	0.68	0.19	1.61	-	-	-
2,6-dimethylphenoxy / *2,6-dimetilfenoksi*	23.46	0.05	-	-	-	-	-	-	-	-
4-methyl-guaiacol / *4-metil-gvajakol*	27.70	-	-	2.97	2.89	2.95	5.79	0.29	2.63	1.11
4-methyl-guaiacol+catechol* *4-metil-gvajakol+katehol**	27.75	3.04	5.13	-	-	-	-	-	-	-
Catechol / *katehol*	27.79	-	-	1.57	-	4.96	2.22	0.36	0.94	1.34
4-methyl-catechol / *4-metil-katehol*	32.43	0.38	1.41	1.78	-	6.70	3.76	0.84	1.87	2.09
3-methyl-catechol / *4-metil-katehol*	33.20	-	-	-	0.48	-	-	-	-	-
α-Himachalane / *α-himakalan*	35.70	9.41	8.78	7.48	10.1	6.01	9.22	6.57	10.1	7.29
Longifolene / *longifolen*	37.07	8.75	7.73	7.22	9.70	7.11	8.75	7.69	9.40	7.80
Cedren / *cedren*	37.16	-	0.63	0.64	1.24	1.02	1.24	1.25	1.39	1.16
β-Himachalane / *β-himakalan*	38.30	25.1	22.5	21.9	28.1	23.1	25.8	23.7	25.8	23.0
(+)-Cuparane / *(+)-kuparan*	38.59	2.26	1.99	2.33	1.61	1.11	1.49	-	-	-
iso-longifolene / *izo-longifolen*	39.10	1.05	1.05	1.13	0.64	-	-	0.59	0.53	0.59
iso-Eugenol / *izo-eugenol*	40.79	1.26	1.23	1.57	2.05	2.44	1.84	1.56	1.39	1.50
Dihydro-Ar-Tumerone / *dihidro-ar-tumeron*	42.12	0.87	1.55	1.52	-	-	-	-	-	-
β-Himachalenoxide / *β-himakalenoksid*	42.55	-	-	-	-	-	-	1.22	1.00	1.11
Ar-tumerone / *Ar-tumeron*	44.39	1.98	1.74	2.05	0.61	0.99	0.36	-	-	-
β-Atlantone / *β-atlanton*	44.56	0.85	1.43	1.05	-	-	-	-	-	-
Tumerone / *tumeron*	45.35	1.82	1.53	1.82	0.98	0.99	0.86	1.73	1.23	1.50
Deodarone / *deodaron*	45.67	2.40	2.06	2.31	-	-	-	-	-	-
E-(α)-Atlantone / *E-(α)-atlanton*	48.29	3.55	3.46	4.21	-	-	-	-	-	-
16:0 acid / *16:0 kiselina*	60.23	tr	tr	tr	tr	tr	tr	tr	tr	tr
Dehydroabietan *dehidroabietan*	61.33	-	-	-	1.87	2.86	1.84	-	-	-
9-18:1 acid / *9-18:1 kiselina*	66.94	tr	tr	tr	tr	tr	tr	tr	-	tr
Pimaric acid / *pimarinska kiselina*	70.74	-	-	-	0.58	0.35	-	-	-	-
Sandrocopimaric acid / *sandrokopimarna kiselina*	71.11	tr	tr	tr	-	0.28	0.16	tr	tr	-
iso-Pimaric acid / *izo-pimarinska kiselina*	71.22	tr	tr	tr	1.62	1.50	1.36	1.70	1.27	1.58
Dehydroabietic acid / *dehidroabietična kiselina*	72.53	tr	tr	tr	1.09	1.28	1.04	1.01	0.74	0.90
Abietic acid / *abietična kiselina*	73.36	-	-	-	-	-	-	0.70	0.52	0.64
22:0 acid / *22:0 kiselina*	78.33	tr	tr	tr	tr	tr	tr	tr	tr	tr
24:0 alcohol / *24:0 alkohol*	80.67	tr	tr	tr	tr	tr	tr	tr	tr	tr
24: acid / *24:0 kiselina*	81.53	tr	tr	tr	tr	tr	tr	tr	tr	tr
Total non-identified compounds *Ukupno neidentificirani spojevi*		33.1	32.4	35.3	33.5	28.1	33.1	50.6	40.3	47.1

tr: trace (< % 0.1) A: n-Hexane, B:Diethylether, C:Dichloromethane, RT: TRB-5 type column,*:were not seperated. *tr: u tragovima (<0,1 %) A: n-heksan, B: dietileter, C: diklormetan, RT: TRB-5 kolona, *: nisu izdvojeni.*

Clevenger apparatus at 100 °C (Hafizoglu, 1987b; Fleisher and Fleisher, 2000; Saab *et al.*, 2005), was not detected in our samples. β-himachalenoxide was only determined by the traditional method.

Likewise the yield, the composition of tar also differs with thermal conditions (Wang *et al.*, 2009). Phenols, guaicol, creosol and 2.4-dimethyl phenol, were clearly observed only in the Jenkner Retort system. These compounds indicated that temperature applied in the traditional method was not sufficient for lignin degradation. Another compound iso-eugenol, precursors of lignin biosynthesis, was determined almost more than 2% in the branches. As known, in the softwood branches, the lignin content was higher (Fengel and Wegener, 2003). Phenols, obtained from biomass pyrolysis oils are valuable chemicals. They have disinfectant and antidiarrheal characteristics. They are also used as intermediates in synthesis of pharmaceutical products, adhesives and special polymers (Amen-Chen *et al.*, 1997; Ozbay, 2015).

Resin and fatty acids were found in all samples, while in roots they were less than 0.01 % (trace). Catechol, used in the production of pesticides, was found in higher amounts (2.2-6.7 %) in the tars obtained from branches.

Deodarone, E-(α)-atlantone, dihydro-Ar-tumore, which have an antifungal and insecticides effect, were found only in roots (Satrani *et al.*, 2006; Chaudhary *et al.*, 2012). Another compound, tumorene, used as a repellent against mosquito larvae, was identified in all tars (Champakaew *et al.*, 2007).

Three solvents with different polarities were used to dissolve tars for the analysis (Fig. 1). Although no significant difference was observed, dichloromethane gave the highest yield (59.6-71.8 %) of solubility among the identified compounds. However, β-himachalane, the main compound, was found to be higher in the hexane extract.

4 CONCLUSION
4. ZAKLJUČAK

In this study, chemical characterization of *Cedrus libani* A. Rich tar obtained by pyrolysis with Jenkner Retort system and traditional method was studied. Roots and fallen branches were used and analyzed separately. The tar yield of Jenkner Retort was 60 %, while it is 30-40 % in the traditional method, which revealed the effect of temperature. 41 compounds were identified. Phenols, alcohols, acids, sesquiterpenoids and fatty-resin acids are the main constituents. Phenols and methoxy groups were seen only in Jenkner Retort system. However, sesquiterpenoids (β-himachalane, α- himachalane), used for veterinary purposes, were determined in all samples. Traditional method can be used by the local veterinary, if compounds that have antifungal and insecticides are determined in these samples.

Acknowledgments - Zahvala

The authors would like to thank to Prof. Dr. Ihsan TOROGLU, Bülent Ecevit University, for using Jenkner Retort System and to local people of Pazarcik, Kahramanmaraş, Turkey for performing traditional method.

5 REFERENCES
5. LITERATURA

1. Amen-Chen, C.; Padel, H.; Roy, C., 1997: Separation of phenols from Eucalyptus wood tar. Biomass and Bioenergy, 13(1/2): 25-37. https://doi.org/10.1016/S0961-9534(97)00021-4.
2. Bridgwater, A. V., 2003: Renewable fuels and chemicals by thermal processing of biomass. Chemical Engineering Journal, 91(2-3): 87-102. https://doi.org/10.1016/S1385-8947(02)00142-0.
3. Champakaew, D.; Choochote, W.; Pongpaibul, Y.; Chaithong, U.; Jitpakdi, A.; Tuetun, B.; Pitasawat, B., 2007: Larvicidal efficacy and biological stability of a botanical natural product zedoary oil-impregnated sand granules against Aedes aegypti (*Diptera, Culicidae*). Parasitology Research, 100(4): 729-737. https://doi.org/10.1007/s00436-006-0350-5.
4. Chaudhary, A.; Sood, S.; Kaur, P.; Kumar, N.; Thakur, A.; Gulati, A.; Singh, B., 2012: Antifungal sesquiterpenes from *Cedrus deodara*.Planta Medica, 78(2): 186-188. https://doi.org/10.1055/s-0031-1280264.
5. Chiodo, V.; Zafarana, G.; Maisano, S.; Freni, S.; Urbani, F., 2015: Pyrolysis of different biomass: Direct comparisonamong Posidonia Oceanicai Lacustrine Alga and White-Pine. Fuel, 164: 220-227. https://doi.org/10.1016/j.fuel.2015.09.093.
6. Das, O.; Sarmah, A. K., 2015: Mechanism of waste biomass pyrolysis: Effcet of pysical and chemical pre-treatments. Science of the Total Enviroment, 537: 323-334. https://doi.org/10.1016/j.scitotenv.2015.07.076.
7. Daoubı, M.; Hernaandez-Galaa, R.; Benharref, A.; Collado, I., 2005: Screening Study of Lead Compounds for Natural Product-Based Fungicides: Antifungal Activity and Biotransformation of 6r,7r-Dihydroxy-*â*-himachalene by Botrytis cinerea. J. Agric. Food Chem, 53: 6673-6677. https://doi.org/10.1021/jf050697d.
8. Derwich, E.; Benziane, Z.; Boukir., A., 2010: Chemical composition and In vitro antibacterial activity of the essential oil of *Cedrus atlantica*. Int. J. Agric. Biol., 12: 381-385.
9. Duman, G.; Okutucu, C.; Uçar, S.; Stahl, R.; Yanık, J., 2011: The slow and fast pyrolysis of cherry seed. Bioresource Technology, 102: 1869-1878. https://doi.org/10.1016/j.biortech.2010.07.051.
10. Ekman, R.; Holmbom, B., 1989: Analysis by gas chromatography of wood extractives in wood and pulp samples from mechanical pulping of spruce. Nordic Pulp Paper Res J, 41:16-24. https://doi.org/10.3183/NPPRJ-1989-04-01-p016-024.
11. Fengel, D.; Wegener, G., 2003: Wood Chemistry, Ultrastructure, Reactions. Verlag Kessel.
12. Fleisher, A.; Fleisher, Z., 2000. The volatiles of the leaves and wood of Lebanon Cedar (*Cedrus libani* A.Rich) aromatic plants of the Holy Land and the Sinai.Part XIV. Journal of Essential oil Research, 12(6): 763-765. https://doi.org/10.1080/10412905.2000.9712210.
13. Hafızoğlu, H., 1987a: Extractive constituents of *Cedrus libani*. Karadeniz Teknik University Forestry Faculty Journal, 10(1-2): 91-97.
14. Hafızoğlu, H., 1987b. Studies on the chemistry of *Cedrus libani* A. Rich. I. Wood extractives of *Cedrus libani*. Holzforschung, 41 (1): 27-38. https://doi.org/10.1515/hfsg.1987.41.1.27.

15. Hagner, M.; Hallman, S.; Jauhiainen, L.; Kemppainen, R.; Ramo, S.; Tiilikkala, K.; Setala, H., 2015: Birch (*Betula* spp.) wood biochar is a potential soil amendment to reduce glyphose leaching in agricultural soils. Journal of Environment Management, 164: 46-52. http://dx.doi.org/10.1016/j.envman.2015.08.039.
16. Hjulstrom, B.; Isaksson, S.; Hennius, A., 2006: Organic geochemical evidence for pine tar production in Middle Eastern Sweden during the Roman iron Age. J. Archaeol Sci., 33: 283-294. https://doi.org/10.1016/j.jas.2005.06.017.
17. Julin, M., 2008: Tar production-traditional medicine and potential threat to biodiversity in the Marrakesh region. An ethnobotanical study. Uppsala University. Degree Project in biology, Sweden.
18. Koch, P., 1972: Utilization of The Southern Pines, Vol II: Processing, Agriculture Handbook, USA, No: 420, pp.1485.
19. Kurt, Y.; Kaçar, M. S.; Isık, K., 2008: Traditional Tar production from *Cedrus libani* A.Rich on the Taurus Mountains in Southern Turkey. Economic Botany, 62(4): 615-620. https://doi.org/10.1007/s12231-008-9023-x.
20. Li, J.; Yan, R.; Xiao, B.; Liang, T. D.; Lee, D. H., 2008: Preparation of Nano-NiO particles and evaluation of their catalytic activity in pyrolyzing biomass components. Energy&Fuels, 22(1): 16-23. https://doi.org/10.1021/ef700283j.
21. Li, J.; Paul, M. C.; Younger, P. L.; Watson, I.; Hossain, M.; Welch, S., 2015: Characterization of biomass combustion at high temperatures based on an upgraded single particle model. Applied Energy, 156: 749-755. https://doi.org/10.1016/j.apenergy.2015.04.027.
22. Niu, H. C.; Liu, N. A., 2015: Thermal decomposition of pine branch:Unified kinetic model on pyrolytic reactions in pyrolysis and combustion. Fuel, 160: 339-345. https://doi.org/10.1016/j.fuel.2015.07.108.
23. Reunanen, M.; Raine, E.; Markku, H., 1989: Analysis of Finnish Pine Tar and Tar from the Wreck of Frigate St. Nikolai. Holzforschung, 43: 33-39. https://doi.org/10.1515/hfsg.1989.43.1.33.
24. Reunanen, M.; Raine, E.; Markku, H., 1990: Long-term Alteration of Pine Tar in a Marine Enviroment. Holzforschung, 44: 277-278. https://doi.org/10.1515/hfsg.1990.44.4.277.
25. Reunanen, M.; Holmbom, B.; Edgren, T., 1993: Analysis of Archaeological Birch Bark Pitches. Holzforschung, 47: 175-177. https://doi.org/10.1515/hfsg.1993.47.2.175.
26. Ozbay, G., 2015: Pyrolysis of Firwood (Abies bornmüllerianaMattf.) Sawdust: Characterization of Bio-Oil and Bio-Char. Drvna industrija, 66(2): 105-114. https://doi.org/10.5552/drind.2015.1359.
27. Ozcifci, A.; Özbay, G., 2013: Bio-oil production from catalytic pyrolysis method of furniture industry sawdust. Journal of the Faculty of Engineering and Architecture of Gazi University, 28(3): 473-479.
28. Saab, A.M.; Harb, F.Y.; Koenig, W.A., 2005: Essential oil components in heart wood of *Cedrus libani* and *Cedrus atlantica* from Lebanon. Minerva Biotecnologica, 17(3): 159-161.
29. Satrani, B.; Aberchane, M.; Farah, A.; Chaouch, A.; Talbi, M., 2006: Composition chimique et activite antimicrobienne des huiles essentielles extraites par hydrodistillation fractionnee du bois de Cedrsu atlantica Manetti. Acta Botanica Gallica: Botany Letters, 153(1): 97-104. https://doi.org/10.1080/12538078.2006.10515524.
30. Singh, D.; Agarwal, S. K., 1988: Himachalol and β-himachalene: Insecticidal principles of himalayan cedarwood oil. J Chem Ecol., 14(4): 1145-1151. https://doi.org/10.1007/BF01019342.
31. Sutcu, H.; Toroglu, I.; Piskin, S., 2004: High Temperature Carbonization of Turkish Bituminous Coals in Jenkner Retort, Energy Sources, 26(7): 671-683. https://doi.org/10.1080/00908310490445544.
32. St Pierre, J.; Beis, S.; Van Heiningen, A., 2015: Pyrolysis of hardwood soda-anthraquinone spent pulping liquor. TAPPI Journal,14: 639-648. www.tappi.org
33. Wang, Z.; Cao, J.; Wang, J., 2009: Pyrolytic characteristics of pine wood in a slowly heating and gas sweeping fixed-bed reactor. Journal of Analytical and Applied Pyrolysis, 84 (2): 179-184. https://doi.org/10.1016/j.jaap.2009.02.001.

Corresponding address:

Assoc. Prof. AYBEN KILIÇ PEKGÖZLÜ, Ph.D.

Bartin University, Faculty of Forestry
Department of Forest Industry Engineering
74100, Bartin, TURKEY
e-mail: akilic@bartin.edu.tr

Seyyed Khalil Hosseinihashemi[1], Saeed Hassani[2], Ahmad Jahan Latibari[3], Günay Özbay[4]

Chemical Characterization of Bio-oil from Pyrolysis of Undecayed and Decayed *Fagus orientalis* Wood

Kemijska karakterizacija biološkog ulja dobivenoga pirolizom zdravoga i natrulog drva bukve (*Fagus orientalis*)

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 27. 4. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*813.4; 630*872.64; 674.031.632.22*
doi:10.5552/drind.2017.1626

ABSTRACT • *Among forest diseases, fungi are the most important agents that cause irreparable losses to the wood of standing trees and logs. In this study, pyrolysis of undecayed and decayed beech (Fagus orientalis) wood were carried out using a fixed-bed reactor at pyrolysis temperature of 500 °C in nitrogen atmosphere. The influence of Trametes versicolor fungal decay on the yield and chemical composition of products was investigated. The bio-oil yield was 62.5 wt% at a pyrolysis temperature of 500 °C for decayed wood, while the bio-oil yield was found to be about 58 wt% at the same temperature for undecayed wood. Bio-oils were characterized using some chromatographic and spectroscopic techniques, such as gas chromatography-mass spectrometry (GC/MS). It was found that Tetracosamethyl-cyclododecasiloxane (5.50 %), tetradecamethyl-hexasiloxane (4.85 %), 2,6-dimethoxy-phenol (4.21 %), and benzene acetic acid (3.16 %) were the main oil components present in decayed beech wood, while syringol (14.86%), methoxyeugenol (6.59 %), naphthalene (4.41 %), o-guaiacol (3.60 %), isoeugenol (3.17 %), and 2-methoxy-4-methyl-phenol (3.08 %) were present in undecayed beech wood. These results show that decayed wood can be used for the production of bio-oil.*

Key words: *beech wood, Trametes versicolor, pyrolysis, GC/MS, oil compound*

SAŽETAK • *Među šumskim štetnicima gljive su najopasniji činitelji koji uzrokuju nepovratne gubitke drva rastućih stabala i trupaca. U ovom je istraživanju provedena piroliza uzoraka od zdravoga i natrulog drva bukve (Fagus orientalis) u atmosferi dušika, uz pomoć fiksnog reaktora i pri temperaturi pirolize 500 °C. Istraživan je utjecaj gljiva truležnica (Trametes versicolor) na prinose i kemijski sastav produkata pirolize tretiranog drva. Prinos biološkog ulja od natrulog drva pri temperaturi pirolize 500 °C bio je 62,5 % (težinskog udjela), dok je prinos biološkog ulja od zdravog drva bio oko 58 % (težinskog udjela) pri jednakoj temperaturi pirolize. Biološkog ulja su karakterizirana uz pomoć određenih kromatografskih i spektroskopskih tehnika kao što je plinska kromatografija / masena spektrometrija (GC/MS). Utvrđeno je da su glavne uljne komponente zastupljene u natruloj bukovini*

[1] Author is associate professor at Department of Wood Science and Paper Technology, Karaj Branch, Islamic Azad University, Karaj, Iran. [2] Author is M.Sc. at Department of Wood Science and Paper Technology, Karaj Branch, Islamic Azad University, Karaj, Iran. [3] Author is professor at Department of Wood Science and Paper Technology, Karaj Branch, Islamic Azad University, Karaj, Iran. [4] Author is associate professor at Department of Industrial Engineering, Engineering Faculty, Karabük University, Karabük 78050, Turkey

[1] Autori su izvanredni profesori Odjela za znanost o drvu i tehnologiju papira, Islamsko sveučilište Azad, Karaj Branch, Karaj, Iran. [2] Autor je profesor Odjela šumarstva i drvne tehnologije, Agronomski fakultet (EL-Shatby), Sveučilište Alexandria, Alexandria, Egipat. [3]Autor je profesor Odjela za industrijsko inženjerstvo, Fakultet inženjerstva, Sveučilište Karabük, Karabük, Turska.

tetracosametil-ciklododekasiloksan (5,50 %), tetradekametil-heksasiloksan (4,85 %), 2,6-dimetoksi-fenol (4,21 %) i benzen octena kiselina (3,16 %), dok je u zdravom bukovu drvu bilo siringola (14,86 %), metoksieugenola (6,59 %), naftalena (4,41 %), o-gvajakola (3,60 %), izoeugenola (3,17 %) i 2-metoksi-4-metilfenola (3,08 %). Dobiveni rezultati pokazuju da se natrulo drvo može iskoristiti za proizvodnju biološkog ulja.

Ključne riječi: *bukovina, Trametes versicolor, piroliza, GC/MS, uljni spoj*

1 INTRODUCTION
1. UVOD

Growing population is followed by increasing demand for energy and chemical products and fossil fuel resources are not inexhaustible and their prices are increasing. Consequently, more attention is focused on wood as renewable raw material and its chemical components that lead to fuel. Pyrolysis technology has been investigated actively and has spread all over the world, to be utilized in bio-fuel production (Gardner and Schultz, 1985).

Wood is a natural polymer and a biological material having porous structure. Wood, like any other biological material, will be damaged by specific deteriorating agents. The most important deteriorating agents that cause irreparable losses to the wood of standing trees and logs are fungi (Hosoya *et al*., 2006).

Pyrolysis is a process in which materials are decomposed under heating condition in the presence of inert gas (without oxygen) or in the presence of an amount of controllable oxygen. Depending on the wood as raw material, the chemical products obtained from wood pyrolysis are turpentine, acetone, phenol, acetic acid, wood tar, syringol, resorsinol, etc (Faix *et al.*, 1988).

High-resolution capillary columns in GC system have been used as a very efficient method in the analysis of organic complex compounds such as products obtained from wood pyrolysis, oil derivatives cracking, and also chemical and extractive materials as a complex mixture (Faix *et al.*, 1988).

Pyrolysis compounds of white oak and lobbly pine woods determined by GC/MS technique have included lignin products such as guaiacol, 4-methyl guaiacol, 4- vinyl guaiacol, coniferaldehyde, coniferylaldehyde, vanillin, and also some products like guaiacol, 2-6-dimethoxy phenol, 4-methyl-2-6-methoxy phenol, syringaldehyde, and synapaldehyde (Dobele *et al*., 2007). Lignin, compared to other compounds in wood, is the most resistant. The highest rate of weight loss for lignin of milled spruce, beech and bamboo wood was obtained between 360 to 407 °C (Obst, 1983; Tiilikkala *et al*., 2010).

Separation and identification of compounds in common walnut (*Juglans regia)* wood pyrolytic oils in a fixed bed reactor and in nitrogen atmosphere at 350 °C was done using GC/MS, where 10 compounds were identified, and most of them were related to levoglucosan and α-L-galactopyranose that accounted for 49 %. These compounds were obtained by pyrolysis of cellulose and hemicellulose of wood structure (Schultz and Nicholas, 1977). Glycolaldehyde is not detectable in normal conditions and when GC is injected with pyrolytic wood, it was converted into other compounds; this compound was identified using silylation of oil compounds by N,O- bis (TMS) trifluoroacetamide (BSTFA); this method was introduced as one of the most appropriate techniques to investigate compounds obtained from wood pyrolysis (Hosoya *et al.*, 2006).

This work was conducted to investigate the efficiency of pyrolysis method in wood conversion into important chemical compounds with significant added value, especially using decayed wood that are not usable in other applications. Research reports on pyrolysis of decayed beech wood is not extensive in the literature and since the decayed wood in forests is the most important source of contamination in forest standing trees, it would be economically feasible to find any application for decayed wood pyrolysis products and oil compounds.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Preparation of samples
2.1. Priprema uzoraka

Beech wood (*Fagus orientalis* L.) samples were cut from a log harvested from Klardasht in the North of Iran. An unseasoned one meter long log was selected from a tree butt. The log averaged 500 mm in diameter. After being transferred to the laboratory, 1000×300×30 mm lumber was cut in the tangential direction of the log, and the moisture content (MC) was measured gravimetrically. The lumber was seasoned at 60 % relative humidity and 21 ºC for 24 days to reach equilibrium moisture content. Then, some lumber was chosen randomly and decay samples were cut from this section. The dry test beech blocks (50×25×15 mm) were extracted using ethanol/ toluene (1:2. v/v) mixture for 6-8 h. Then the extracted samples were dried at 60 ± 5 ºC to constant weight and the weight was determined.

2.2 Decay test
2.2. Test truljenja

In order to carry out the wood resistance test, white rot (*Trametes versicolor*) fungus was chosen as one of the three fungi sources to evaluate the natural resistance of wood. It was chosen according to BS 838:1961 standard test method. This fungus is considered fatal for hardwood species because it uses both cellulose and lignin (Farsi and Mirshokraei, 2011).

Samples were autoclaved at 120 ºC for 15 min and exposed to *T. versicolor* in Petri dishes containing 3 % malt extract agar, pre-inoculated 1 week prior to the test. Samples were supported on sterile plastic

mesh, and incubated at 25 ºC and 65 % relative humidity for 14 weeks. At 14-week intervals, six beech samples were removed. Mycelium was removed from their surfaces and oven-dried to constant weight. The weight losses (WL) of individual samples were calculated according to Kolleschale method. The following Equation (1) was used for the calculation;

$$WL\ (\%) = [(a\text{-}b)/a] \times 100 \quad (1)$$

Where *a* and *b* denote the oven dry weight of specimen prior to and after exposure to fungus, respectively.

After 14 weeks, some of the decayed samples were milled to produce wood flour. Decayed wood flour (DWF) was screened using a shaker prior to pyrolysis and chemical composition tests.

2.3 Measurement of chemical compounds
2.3. Mjerenje kemijskih spojeva

Measurement of chemical compounds of decayed wood flour (DWF) and undecayed wood flour (UDWF) was done according to relevant TAPPI standard test methods as follow: cellulose, T 264 om-88; extractives, T 207 om-97; Klason lignin, T 222 om-98; ash, T 211 om-93.

2.4 Determination of pyrolysis temperature
2.4. Određivanje temperature pirolize

A TGA-PL (Perkin Elmer, United Kingdom) microbalance from Iran Polymer and Petrochemical Research Institute was used for thermo-gravimetric tests. The DWF samples were heated from room temperature to 500 ºC, under a nitrogen flow of 150 mL/min and heating rate of 10 ºC/min. Milled samples of approximately 10 mg were used. All tests were carried out twice to ensure reproducibility, and the average of two tests was reported.

2.5 Pyrolysis tests
2.5. Postupak pirolize

The pyrolysis test operating conditions were as follow: the total pressure inside the fixed-bed reactor was lower than 0.4 kPa, the final pyrolysis temperature was 500 ºC and the heating rate was 10 ºC/min. The reactor has a steel cylinder with an internal diameter of 6 cm and a height of 21 cm. During the experiments, the heating rate and pyrolysis temperature were controlled with a PID (Proportional-Integral-Derivative) controller. The temperature was measured every minute in the reactor using a type K thermocouple. In the pyrolysis experiment, a sample was weighed and placed into the reactor, which was heated by an electric furnace. There were three step delays in heating; the first step was at 300 ºC, the second step at 400 ºC and the third at 500 ºC. In each step of pyrolysis, the temperature was held constant for at least 15 min. Pyrolysis temperature is known to influence pyrolysis yield. In pyrolysis studies found in literature, the pyrolytic oil reached a maximum value at 400-600 °C (Heo *et al.*, 2010; Fagbemi *et al,*. 2001; Ozcifci and Özbay, 2013). The obtained oil was stored at 4 ºC for future analysis.

2.6 Silylation and GC/MS analysis
2.6. Sililacija i GC/MS analiza

2.6.1 Trimethylsilylation
2.6.1. Trimetil sililacija

A 100 ml pyrolysis oil sample was mixed with 100 ml N, O-bis (trimethylsilyl) trifluoroacetamide (BSTFA, Merck, Darmstadt, Germany), and 1 ml diethyl ether was then added. The sample was then left for at least two hours (reaction time) at 70 ºC in the water bath prior to the analysis of GC/MS. Analyses were conducted with a GC (HP 6890) equipped with a quadrupole mass selective detector (HP-5973series) (Agilent Technologies, Belgium). For all the analyses, the El electron energy was 70 ev and the ion source temperature 250 ºC. The sample was analyzed with a 30 m × 0.25 µm capillary column (HP-SMS), and the injector temperature was 70 ºC. The time-temperature program for the samples was 3 minutes at 60 ºC, then the temperature was increased to 250 ºC at 6 ºC/min, then to 280 ºC at 20 ºC/min, and it was finally held at 280 ºC for 3 min.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Weight loss of samples
3.1. Gubitak mase uzoraka

After 14-week exposure of beech wood samples to *Trametes versicolor,* the average weight loss of samples was 23.7 %. However, Olfat (2014) indicated that the weight loss of beech wood was 47.5 % after 16 weeks and 13.2 % after 10 weeks.

3.2 Results of TG analysis
3.2. Rezultati TG analize

As observed in thermo gravimetric curves of decayed and control (undecayed) beech wood pyrolysis samples (Figure 1a, b), thermal decomposition of cellulose and lignin started at 325 ºC and 440 ºC, respectively.

The TGA and DTG curves of the decayed and undecayed beech wood samples are shown in Figure 1a, b. The maximum peak temperature of decayed beech wood was 325 °C and for undecyed wood 352 °C, which resulted in one or two prominent peaks that corresponded to the decomposition of hemicellulose and cellulose. Lignin decomposition was reached at 600 °C. The DTG curves revealed that the weight loss of undecayed samples started at 228 and continued up to 600 °C, while for decayed samples it started at 211 and continued up to 600 °C. Furthermore, increased weight loss was observed in decayed wood, resulting in increased volatile matters.

The results of experiments on the determination of pyrolysis temperature, time and products are summarized in Table 1.

It can be seen that the decayed wood had the highest yields of gas and tar, 26.2 % and 62.5 %, respectively, and undecayed wood 18.3 % and 58.2 %, respectively. On the other hand, the charcoal yield was lower in decayed wood (11.3 %) in comparison to undecayed wood (23.5 %).

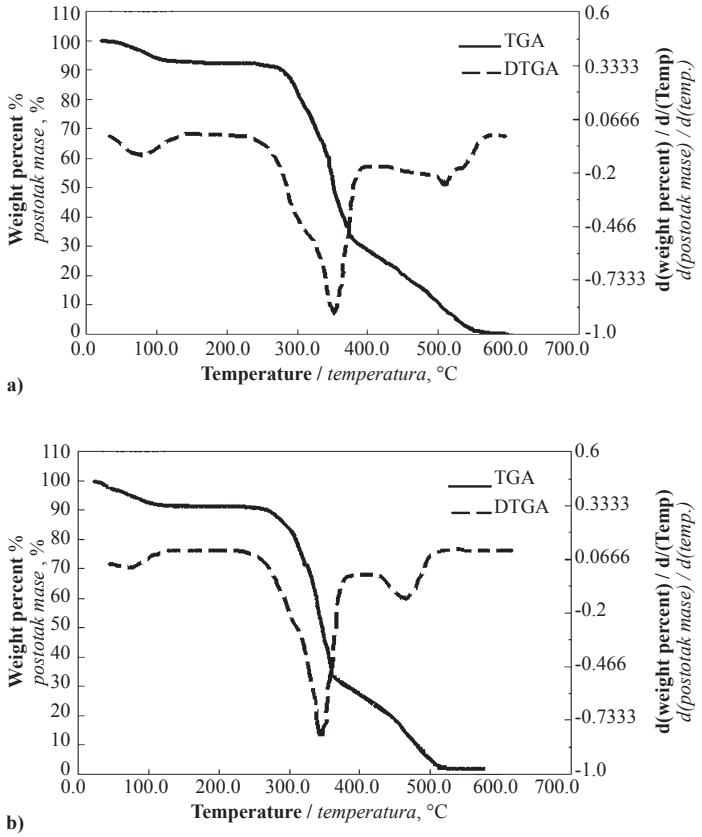


Figure 1 Thermal behavior of decayed and undecayed beech wood samples; TGA, DTGA of control (a) and decayed beech wood (b)
Slika 1. Toplinsko ponašanje uzoraka natruloga i zdravoga bukova drva: a) TGA, DTGA kontrolnog uzorka; b) TGA, DTGA natruloga bukova drva

Table 1 Charcoal, gas and tar yield of decayed and undecayed beech wood samples
Tablica 1. Udjeli ugljena, plina i katrana dobiveni pirolizom uzoraka natruloga i zdravog bukova drva

Treatment *Uzorak*	**Temperature** *Temperatura* ºC	**Time** *Vrijeme* min	**Initial weight of wood flour** / *Početna masa drvnog brašna* g	**Charcoal** *Ugljen* %	**Gas** *Plin* %	**Tar** *Katran* %
Decayed beech wood / *natrulo bukovo drvo*	500	30	5	11.3	26.2	62.5
Undecayed beech wood / *zdravo bukovo drvo*	500	30	5	23.5	18.3	58.2

3.3 Analysis of chemical compounds
3.3. Analiza kemijskih spojeva

The chemical components of the wood influence its application in the production of pyrolysis products. Each component produces different products with different properties and application. Therefore, the chemical composition of both decayed and uncedayed beech wood samples are determined and summarized in Table 2.

It was reported that thermal decomposition of hemicelluloses occurs at temperatures ranging from 150 to 350 °C, while cellulose decomposes in the range of 275 to 350 °C (Hindi *et al*., 2010) and lignin gradually decomposes at temperatures between 250 and 500 °C (Essabir *et al*., 2013). The initial degradation between 50 and 200 °C, obtained for decayed and undecayed beech wood, refers to the losses of volatile compounds and water.

The results indicate that the decayed wood contains more extractives (4.33 %) than the undecayed wood. In addition, both cellulose and lignin decreased in decayed wood (53.33 % and 28.5 %), which was

Table 2 Cellulose, Klason lignin, extractives and ash content of decayed and undecayed beech wood samples
Tablica 2. Sadržaj celuloze, Klason lignina, ekstraktiva i pepela u uzorcima od natruloga i zdravoga bukova drva

Compound *Spoj*	**Cellulose** *Celuloza* %	**Klason Lignin** *Klason lignin* %	**Extractives** *Ekstraktivi* %	**Ash** *Pepeo* %
Decayed beech wood / *natrulo bukovo drvo*	53.33	28.5	2.3	2.8
Undecayed beech wood / *zdravo bukovo drvo*	49.83	31	4.33	2

expected as this fungus has a negative effect on these compounds.

3.4 Analysis of GC/MS spectrums
3.4. GC/MS analiza spektra

In order to separate and identify the oils obtained from pyrolysis of decayed beech wood, the oil was injected into GC/MS device after purification and derivation by BSTFA at 500 ºC.

According to Table 3, tetracosamethyl-cyclododecasiloxane (5.50 %), tetradecamethyl–hexasiloxane (4.85 %), 2,6-dimethoxy-phenol (syringol) (4.21 %), and benzene acetic acid (3.16 %) were the main oil

Table 3 Main organic components of bio-oils [a]
Tablica 3. Glavni organski sastojci biološkog ulja [a]

R.T. (min)	Quality *Kvaliteta*	Name of compounds *Naziv spoja*	Area, % *Površina, %*	
			Control wood oil *Ulje od zdravog drva*	**Decayed wood oil** *Ulje od natrulog drva*
Aldehydes / *aldehidi*				
13.26	96	4-Hydroxy-3- methoxy –benzaldehyde *4-hidroksi-3-metoksi-benzaldehid*	1.19	0.85
Sum / *zbroj*			1.19	0.85
Acids / *kiseline*				
16.52	70	Benzeneacetic acid / *benzenoctena kiselina*	1.83	3.16
19.56	95	n-Hexadecanoic acid / *n-heksadekanska kiselina*	-	0.36
21.11	80	1,2-Benzenedicarboxylic acid / *1,2-benzendikarboksilna kiselina*	-	1.15
Sum / *zbroj*			1.83	4.67
Alcohols / *alkoholi*				
11.61	94	2-Methoxy benzenethanol / *2-metoksi benzenetanol*	1.23	-
Sum / *zbroj*			1.23	-
Ketones / *ketoni*				
7.65	96	2-Hydroxy-3-methyl-2-cyclopenten-1-one *2-hidroksi-3-metil-2-ciklopenten-1-jedan*	1.42	0.64
Sum / *zbroj*			1.42	0.64
Benzenes / *benzeni*				
6.59	91	1-Ethyl-3-methyl- benzene / *1-etil-3-metil-benzen*	-	0.90
7.15	92	1,2,4-trimethyl- benzene / *1,2,4-trimetil-benzen*	-	0.77
10.27	93	Naphthalene / *naftalen*	4.41	1.84
10.56	95	1-Pentene, 3-ethyl- 3-ethyl / *1-penten, 3-etil-3-etil*	-	0.79
13.39	93	Tetradecamethyl –hexasiloxane / *tetradekametil-heksasiloksan*	2.82	4.85
Sum / *zbroj*			7.23	9.15
Phenols / *fenoli*				
8.73	90	2-Methoxy-phenol / *2-metoksi-fenol*	3.60	1.26
10.34	96	2-Methoxy-4-methyl-phenol / *2-metoksi-4-metil-fenol*	3.08	1.32
10.47	96	2 -Trimethyl-phenol / *2-trimetil-fenol*	-	0.66
11.61	90	4-Ethyl-2-methoxy-phenol / *4-etil-2-metoksi-fenol*	-	0.69
12.10	96	2-Methoxy-4-vinyl-phenol / *2-metoksi-4-vinil-fenol*	1.88	-
12.58	93	2,6-Dimethoxy-phenol / *2,6-dimetoksi-fenol*	14.86	4.21
13.92	96	2-Methoxy-4-(1-propenyl)-phenol / *2-metoksi-4-(1-propenil)-fenol*	3.17	0.83
15.78	97	2,6-Dimethoxy-4-(2-propenyl)-phenol *2,6-dimetoksi-4-(2-propenil)-fenol*	6.59	1.67
Sum / *zbroj*			33.18	10.65
Alkanes / *alkani*				
9.92	91	Decamethyl-cyclopentasiloxane / *dekametil-ciklopentasiloksan*	1.73	1.28
10.55	94	3-Cyclopropylcarbonyloxydodecane *3-ciklopropilkarboniloksidodekan*	1.88	
12.04	91	Dodecamethyl-cyclohexasiloxane / *dodekametil-cikloheksasiloksan*	0.91	0.59
12.22	96	[1,2-Phenylenebis(oxy)] silane / *[1,2-fenilenebis(oksi)] silan*	-	1.39
12.30	93	Dodecamethyl-cyclohexasiloxane / *dodekametil-cikloheksasiloksan*	-	0.63
13.23	98	Tetradecane / *tetradekan*	2.88	1.81
15.21	99	[1,2,3-Benzenetriyltris(oxy)- silane / *[1,2,3-benzentriiltris(oksi)- silan*	-	1.77
15.71	98	Hexadecane / *heksadekan*	2.31	1.18
17.94	95	Octadecane / *oktadekan*	-	0.46
21.26	83	Tetracosamethylcyclododecasiloxane / *tetrakozametilciklododekasiloksan*	1.26	5.50
Sum / *zbroj*			10.97	14.61
TOTAL / *UKUPNO*			57.05	40.56

[a] Obtained at 500 °C. / *Dobiveno pri 500 °C.*

components present in decayed beech wood after pyrolysis at 500 °C.

Table 3 also presents the chemical components in undecayed beech wood after pyrolysis at 500 °C, where the main components are 2,6-dimethoxy-phenol or syringol (14.86 %), 2,6-dimethoxy-4-(2-propenyl)-phenol or methoxyeugenol (6.59 %), naphthalene (4.41 %), 2-methoxy-phenol or *o*-guaiacol (3.60 %), 2-methoxy-4-(1-propenyl)-phenol or isoeugenol (3.17 %), and 2-methoxy-4-methyl-phenol or 4-methylguaiacol (3.08 %).

The main chemical compounds obtained at this temperature are related to phenols and phenyls, derived from thermal degradation of lignin (Faix and Jakab, 1988; Zandersons *et al*., 1999; Ingram *et al*., 2008; Mohan *et al*., 2008; Özçimen and Ersoy-Meriçboyu, 2010). Lignin is the most resistant polymer in wood that can be degraded by heat (Faix and Jakab, 1988). Zandersons *et al*. (1999) reported that polysaccharides are degraded at low temperatures.

The bio-oils obtained from control and decayed wood, analyzed by GC/MS, were widely different. The determined products are divided into the following seven categories: aldehydes, acids, alcohols, ketones, benzenes phenols and alkanes. The analysis of decayed wood bio-oils indicated that the main wood components derived from these compounds, such as phenols, aldehydes and alcohols, were lower. Phenols were the most important compounds; phenols accounted for 10.65 % of the total peak areas detected in decayed wood bio-oil, while 33.18 % of the total peak areas were detected in control wood bio-oil. The identified products were similar to literature data on the chemical composition of bio-oils (Chum and Black, 1990; Branca *et al*., 2003; Bu *et al*., 2012; Kantarelis *et al*., 2013; Özbay, 2015a; Özbay, 2015b).

4 CONCLUSIONS
4. ZAKLJUČAK

In this work, decayed and undecayed beech woods were pyrolyzed at the temperature of 500 °C to produce bio-oils. The effects of decay on the yield and composition of pyrolysis products were investigated. The main conclusions of this work are as follows:

- Decayed wood showed the highest yield of gas and tar, in comparison with the undecayed wood, while the charcoal yield was lower in decayed wood.
- The results of the GC/MS analysis showed that bio-oils from decayed and undecayed wood contain various chemical compounds such as phenol and guaiacol.
- It should be pointed out that pyrolysis technique is an appropriate way to extract valuable chemicals from decayed and undecayed wood.

Acknowledgment – Zahvala

The authors are grateful for the support of the Department of Wood Science and Paper Technology, Karaj Branch, Islamic Azad University.

5 REFERENCES
5. LITERATURA

1. Branca, C.; Giudicianni, P.; Di Blasi, C., 2003: GC/MS characterization of liquids generated from low-temperature pyrolysis of wood. Industrial & Engineering Chemistry Research, 42(14): 3190-3202. https://doi.org/10.1021/ie030066d.
2. British Standard 838, 1961: Methods of tests for toxicity of wood preservatives to fungi. BSI, London.
3. Bu, Q.; Lei, H.; Wang, L.; Zhang, Q.; Tang, J.; Ruan, R., 2012: Production of phenols and biofuels by catalytic microwave pyrolysis of lignocellulosic biomass. Bioresources Technology, 108: 274-279. https://doi.org/10.1016/j.biortech.2011.12.125.
4. Chum, H. L.; Black, S. K., 1990: Process for fractionating fast-pyrolysis oils, and products derived therefrom. In: US Patent. Midwest Research Institute, Kansas City, MO, USA.
5. Dobele, G.; Urbanovich, I.; Volpert, A., 2007: Fast pyrolysis- Effect of wood drying on the yield and properties of bio-oil. BioResources, 2(4): 698-706.
6. Essabir, H.; Nekhlaoui, S.; Malta, M.; Bensalah, M. O.; Arrakhiz, F. Z.; Qaiss, A.; Bouhfid, R., 2013: Biocomposites based on polypropylene reinforced with almond shells particles: mechanical and thermal properties. Materials Design, 51(10): 225-230. https://doi.org/10.1016/j.matdes.2013.04.031.
7. Fagbemi, L.; Khezami, L.; Capart, R., 2001: Pyrolysis products from different biomasses: application to the thermal cracking of tar. Applied Energy, 69: 293-306. https://doi.org/10.1016/S0306-2619(01)00013-7.
8. Faix, O.; Jakab, E.; Till, F., 1988: Study on low mass thermal degradation products of mill wood lignin by thermogravimetry-mass spectrometry. Wood Science and Technology, 22(4): 323-334. https://doi.org/10.1007/BF00353322.
9. Farsi, R.; Mirshokraei, S. A., 2011: Identification of compounds obtained from pyrolysis of *Juglans regia* wood at 350 °C by using GC/MS. Journal of Wood & Forest Science and Technology, 18(2): 117-128.
10. Freel, B.; Graham, R. G., 2002: Bio-oil Preservatives; Ensyn Technologies, Inc., Greely (CA), USA.
11. Gardner, D. J.; Schultz, T. P.; Meginnis, G. D., 1985: The pyrolitic behavior of selected lignin preparation. Journal of Wood chemistry and Technology, 5(1): 85-110. https://doi.org/10.1080/02773818508085182.
12. Goktas, O.; Ozen, E.; Baysal, E.; Mammadov, R.; Alma, M. H., 2010: A research on the usage of extracts from two poisonous plants (*Muscari neglectum* Guss. and *Gynandriris sisyrinchium* (L.) Parl.) as a wood preservative. Wood Research, 55(2): 53-62.
13. Heo, S. H.; Park, H. J.; Park, Y.-K.; Ryu, C.; Suh, D. J.; Suh, Y.-W.; Yim, J.-H. Kim, S.-S., 2010: Bio-oil production from fast pyrolysis of waste furniture sawdust in a fluidized bed. Bioresource Technology, 101(1): 91-96. https://doi.org/10.1016/j.biortech.2009.06.003.
14. Hindi, S. S.; Bakhashwin, A. A.; El-Feel, A., 2010: Physico-chemical characterization of some Saudi lignocellulosic natural resources and their suitability for fiber production. Meteorology, Environment and Arid Land Agriculture Sciences, 21(2): 45-55. https://doi.org/10.4197/met.21-2.4.
15. Hosoya, T.; Kawamoto, H.; Saka, S., 2006: Oxime-trimethylsilylation method for analysis of wood pyrolysate. Journal of Analytical and Applied Pyrolysis, 77(2): 121-126. https://doi.org/10.1016/j.jaap.2006.02.009.
16. Ingram, L.; Mohan, D.; Bricka, M.; Steele, P.; Strobel, D.; Crocker, D.; Mitchell, B.; Mohammad, J.; Cantrell,

K.; Charles, U. P., 2008: Pyrolysis of wood and bark in an auger reactor: physical properties and chemical analysis. Energy & Fuels, 22(1): 614-625. https://doi.org/10.1021/ef700335k.
17. Kantarelis, E.; Yang, W.; Blasiak, W., 2013: Production of liquid feedstock from biomass via steam pyrolysis in a fluidized bed reactor. Energy & Fuels, 27(8): 4748-4759. https://doi.org/10.1021/ef400580x.
18. Mohan, D.; Shi, J.; Nicholas, D. D.; Pittman Jr., C. U.; Steele, P. H.; Cooper, J. E., 2008: Fungicidal values of bio-oils and their lignin-rich fractions obtained from wood/bark fast pyrolysis. Chemosphere, 71(3): 456-465. https://doi.org/10.1016/j.chemosphere.2007.10.049.
19. Obst, R. J., 1983: Analytical Pyrolysis of hardwood and softwood lignin and its use in lignin type determination of hardwood vessel elements. Journal of Wood Chemistry and Technology, 3(4): 377-397. https://doi.org/10.1080/02773818308085170.
20. Olfat, A. M., 2014: Natural durability ratings in *Fagus orientalis* degraded by wood-rotting Basidiomycetes, *Coriolus versicolor*. Advances in Environmental Biology, 8(4): 985-989.
21. Özbay, G., 2015a: Catalytic Pyrolysis of Pine Wood Sawdust to Produce Bio-oil: Effect of Temperature and Catalyst Additives. Journal of Wood Chemistry and Technology, 35(4): 302-313. https://doi.org/10.1080/02773813.2014.958240.
22. Özbay, G., 2015b: Pyrolysis of firwood (*Abies bornmülleriana* Mattf.) sawdust: characterization ofb-oil and biochar. Drvna industrija, 66(2): 105-114. https://doi.org/10.5552/drind.2015.1359.
23. Özçifçi, A.; Özbay, G., 2013: Bio-oil production from catalytic pyrolysis method of furniture industry sawdust. Journal of the Faculty of Engineering and Architecture of Gazi University, 28(3): 473-479.
24. Özçimen, D.; Ersoy-Meriçboyu, A.-E., 2010: Characterization of biochar and bio-oil samples obtained from carbonization of various biomass materials. Renewable Energy, 35(6): 1319-1324. https://doi.org/10.1016/j.renene.2009.11.042.
25. Schultz, T. P.; Nicholas, D. D., 1977: Susceptibility of angiosperm sapwood to white-rot fungal colonization and subsequent degradation. International Research Group on Wood Preservation. IRG/WP97-10211.
26. Tiilikkala, K.; Fagernas, L.; Tiilikkala, J., 2010: History and use of wood pyrolysis liquids as biocide and plant protection product. The Open Agriculture Journal, 4(1): 111-118. https://doi.org/10.2174/187433150100401011.
27. Zandersons, J.; Gravitisb, J.; Kokorevicsa, A.; Zhurinsha, A.; Bikovensa, B.; Tardenakaa, A.; Spincea, B., 1999: Studies of the Brazilian sugarcane bagasse carbonization process and products properties. Biomass and Bioenergy, 17(3): 209-219. https://doi.org/10.1016/S0961-9534(99)00042-2.

Corresponding address:

Assoc. Prof. SEYYED KHALIL HOSSEINIHASHEMI, Ph.D.

Department of Wood Science and Paper Technology
Karaj Branch, Islamic Azad University
Karaj, IRAN
e-mail: hashemi@kiau.ac.ir

Hossein Rangavar[1]

Wood-Cement Board Reinforced with Steel Nets and Woven Hemp Yarns: Physical and Mechanical Properties

Drvno-cementna ploča ojačana čeličnom mrežom i tkanom konopljom: fizikalna i mehanička svojstva

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 1. 6. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
UDK: 630 861.232; 630*812*
doi:10.5552/drind.2017.1631

ABSTRACT • *The aim of this study was to improve physical and mechanical properties of wood-cement boards and to determine optimum content of cement in the formulation. Hence, boards were reinforced with steel nets and woven hemp yarns adding cement to the dry mass of wood in the ratio of 2.5:1, 2.75:1 and 3:1. Physical and mechanical properties of wood-cement boards, such as water absorption (WA) and thickness swelling (TS) after 2 and 24 hour immersion in water, bending strength (MOR), modulus of elasticity (MOE) and internal bond strength (IB), were determined according to EN Standards. Results showed that reinforcement of boards with steel nets and 3 parts of cement added to the dry mass of wood improved all physical and mechanical properties. Properties of these boards showed a similar trend to the values of EN 634-2:2007 standard (specifications of cement bonded particleboards), except for modulus of elasticity, which was lower than minimum requirement.*

Key words: *wood-cement board, cement content, steel nets, hemp yarns, physical and mechanical properties.*

SAŽETAK • *Cilj istraživanja bio je poboljšati fizikalna i mehanička svojstva drvno-cementnih ploča i odrediti optimalan sadržaj cementa u njima. Ploče su ojačane čeličnim mrežama i tkanom konopljom. Sadržaj cementa u proizvedenim pločama bio je u omjeru 2,5:1; 2,75:1 i 3:1 u odnosu prema suhoj masi drvnog materijala. Fizikalna i mehanička svojstva drvno-cementnih ploča kao što su apsorpcija vode (WA) i bubrenje po debljini (TS) nakon 2 i 24 sata namakanja uzoraka u vodu, čvrstoća na savijanje (MOR), modul elastičnosti (MOE) i unutarnja čvrstoća vezanja (IB) određeni su prema europskim normama. Rezultati su pokazali da su ojačanjem ploča čeličnim mrežama i dodatkom trostruko veće količine cementa od suhe mase drvnog materijala poboljšana sva fizikalna i mehanička svojstva ploča. Svojstva tih ploča imaju vrijednosti slične vrijednostima što ih propisuje norma EN 634-2: 2007 (obilježja iverica s cementom), osim za modul elastičnosti, koji je za istraživane ploče bio manji od minimalno zahtijevanoga u normi.*

Ključne riječi: *drvno-cementna ploča, sadržaj cementa, čelične mreže, konoplja, fizikalna i mehanička svojstva*

[1] Author is associate professor at Shahid Rajaee Teacher Training University, Faculty of Civil Engineering, Department of Wood Science and Technology, Tehran, Iran.
[1] Autor je izvanredni profesor Učiteljskog sveučilišta Shahid Rajaee, Građevinski fakultet, Odjel za znanost o drvu i drvnu tehnologiju, Tehran, Iran.

1 INTRODUCTION
1. UVOD

Due to increasing population and environmental awareness, demand for light, cheap and more eco-friendly materials is increasing. Because of heaviness and low bending strength of concrete, building materials could not be used as large panels and prefabricated panels in construction. Furthermore, the use of cement boards reinforced with asbestos, which is still produced in some countries, cannot meet the environmental requirements. In this regard, cement-bonded composites reinforced with natural fibers or wood particles are presented as a valuable construction material. One of the problems in producing wood cement boards is the decrement in speed of cement hydration after the addition of wood particles. Consequently the alkali-soluble compounds, water-soluble hemicellulose and wood extractives limit and postpone cement curing, therefore reducing the resistance of wood-cement panels (Catarina *et al.*, 2006; Miller and Moslemi, 1991; Nazerian and Sadeghiipanah, 2013; Wei *et al.*, 2000). Due to embrittlement characteristics of cement and low tensile strength, these boards are susceptible to fail under different loadings. So reinforcing these panels with different materials seems necessary for improving their physical and mechanical properties.

Nazerian and Sadeghipanah evaluated cement-bonded particleboards manufactured from a mixture of wheat straw and poplar. They reported that cement composites, with bending strength of around 12.5 MPa and internal bond strength of about 0.28 MPa, can be made by using wheat straw as a reinforcing material. According to the results, the use of straw particles in the panels of up to 11.5 % satisfied the minimum requirements of EN 312 (2003) for IB and MOR. Also, it was determined that the amount of 4.95 % of calcium chloride (by cement weight) could improve mechanical properties of the panels meeting the minimum requirements of EN 312 (Nazerian and Sadeghipanah, 2013). Investigation of properties of cement-bonded wood–wool boards made from a mixture of eucalyptus and poplar showed that the addition of wood to cement clearly reduced the maximum hydration temperature and increased the time to reach the maximum temperature. Test results showed that boards made of poplar wood–wools had superior properties compared to those made of eucalyptus and mixed wood–wools. The presence of eucalyptus in the wood mixture typically resulted in a decrease of mechanical properties. It has been noted that the amount of 5 % of $CaCl_2$ by cement weight can be beneficial for cement curing (Ashori *et al.*, 2011).

Three-layered cement-bonded boards (CBBs) produced from wastepaper and sawdust at cement/particle ratios of 3.0:1 and 3.5:1 was suitable for building construction such as paneling, ceiling and partitioning (Fuwape *et al.*, 2007).

According to Aggarwal *et al.* (2008), agro-based cement composites, with bending strength >9.0 MPa and internal bond strength >0.6 MPa, could be made using arhar stalks as reinforcing material and were found to satisfy the minimum requirements of the International Standard, ISO: 8335-1987 (Aggarwal *et al.*, 2008).

The aim of all these studies was to improve physical and mechanical properties by use of lignocellulosic materials. Another way to improve physical and mechanical properties of wood cement boards is to reinforce them by steel nets and hemp yarns but no research has yet been done in this field. In the study related to medium density fiberboard (MDF) panels reinforced by metal (stainless steel with a mesh size of 25 mm) and woven polymeric nets, it has been determined that boards reinforced by thin metal nets (with string diameter of 0.7 mm) showed the highest MOR with a 105 % increase; while the highest MOE and impact strength were determined in the boards reinforced by thick metal nets (with string diameter of 1.12 mm), which were primarily embedded in 112 % and 79 % epoxy resin. The highest tensile strength was also determined in boards reinforced by thick metal nets. Boards reinforced by woven polymeric nets showed lower strength than those reinforced by metal nets (Mohebbi *et al*., 2011).

Xiong et al. studied ribbed roof panels made of high-density wood shaving-cement boards reinforced with steel strips. They reported that employing wood shavings increased flexural strength, load-carrying capacity, stiffness, and plastic property of cement based panels compared to panels without wood shavings (Xiong, 1996).

According to Dimakis *et al.* (2006), using reinforcing strings of metal, rubber, plastic, glass fibers, carbon fiber and even graphite in wood based composites increased significantly impact load resistance, toughness, and also tensile strength (Dimakis *et al*., 2006).

The aim of this research was to investigate the issue of reinforcement of wood cement boards. As it is well known, when a board is under bending load, the highest tensile stress occurs at the bottom side of the board and the highest compression stress occurs at the top side of the board. If the reinforcement is placed on the sides where high stress occurs, the strength of the board should increase. Therefore, reinforcement of wood cement boards was studied by placing two types of steel and woven hemp yarn nets as reinforcement at the critical points of the board, on top and bottom sides.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Wood particles used in this study were obtained by planing poplar wood. Wood particles were dried to 3 % moisture content and packed in plastic bags, to be ready for laboratory tests. The cement used in manufacturing the boards was Portland type II produced by the Abic factory in Qazvin. In order to accelerate curing of the cement in the mixture of cement and wood particles, 5 % of calcium chloride was used to dry the cement mass. The diameter of steel wires was 0.5 mm and net dimensions were 25 mm. The diameter of hemp yarns was 0.75 mm and the net had the same dimension as steel nets (Figure 1).

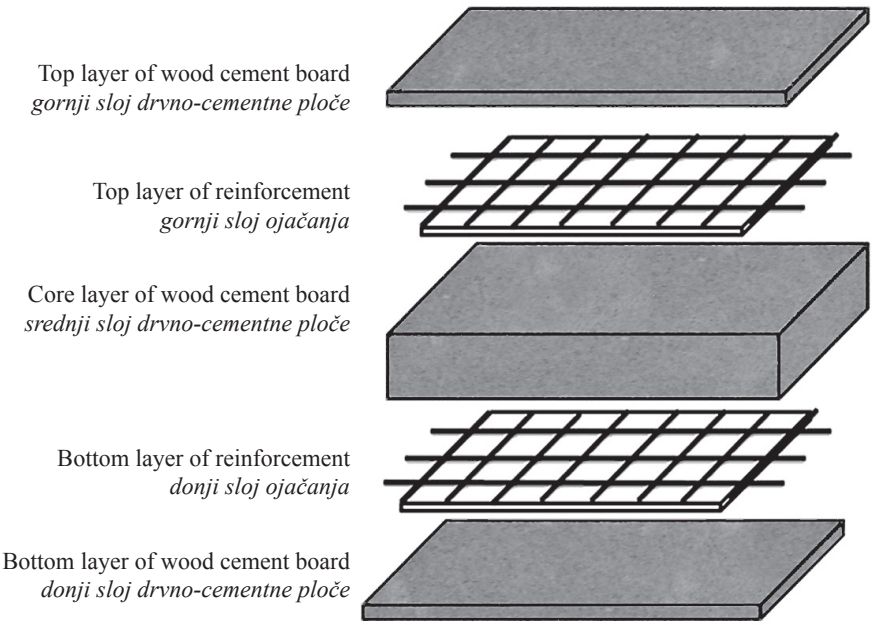


Figure 1 Configuration of the reinforcement location in the panels; the reinforcements were placed at 1/4 of the board thickness
Slika 1. Konfiguracija mjesta ojačanja u pločama; ojačanja su postavljena na 1/4 debljine ploče

Thickness and density of the boards were 16 mm and 1 g/cm^3, respectively. Three types of boards were produced: reinforced with steel nets, reinforced with hemp yarns and non-reinforced boards (control). Three weight ratios of cement to wood particles were selected as the second variable: 2.5:1, 2.75:1 and 3:1. To minimize the influence of different factors affecting the formation of different mixtures of cement and wood particles, a steel frame with the dimension 400×400 mm was used to produce the mat. Steel and hemp nets were placed at ¼ from the top and bottom surface of the boards (Figure 1). The prepared mat was pressed to 16 mm with the laboratory hydraulic press. Then, for curing and hardening the cement, steel-mould was placed in steel jaws and the press was set up. The cement panels were produced in accordance with Ashori *et al.* (2011).

Considering all factors, 9 treatments with 3 replicates were made, resulting in 27 wood cement boards. After removing the boards from the press, samples were conditioned in a climate chamber for at least 28 days for best curing of cement.

Samples were prepared for investigating physical and mechanical properties according to EN standard. To determine the physical properties (water absorption and thickness swelling) of wood cement boards (50×50 mm), samples were immersed in the distilled water for 2 and 24 hours according to EN 317 standard (EN 317, 1998). For the determination of *MOR* and *MOE* according to EN 310, samples were prepared with the dimension 325×50 mm (EN 310, 1999). The internal bond strength was determined on samples with the dimension 50×50 mm according to EN 319 (EN 319, 1998).

Physical and mechanical results obtained in this study were compared with wood-cement board standard (EN 634-2, 2007).

Statistical analysis was conducted using SAS software program. Two-way analysis of variance (ANOVA) was performed to determine significant differences at the 99 % confidence level. Duncan Test was used to determine the significant difference among the groups.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results obtained from variance analysis of physical and mechanical properties of manufactured boards are shown in Table 1.

Table 1 Variance analysis of direct and joint impact of factors on physical and mechanical properties of wood cement board
Tablica 1. Analiza varijance izravnoga i zajedničkog utjecaja čimbenika na fizikalna i mehanička svojstva drvno-cementnih ploča

Factor / *Čimbenik*	***MOR***	***MOE***	***IB***	TS_2	TS_{24}	WA_2	WA_{24}
Cement / *Cement*	303.48**	43.67**	308.51**	34.00**	1347.07**	24.39**	71.18**
Board type / *Vrsta ploče*	2041.2**	935.77**	44.27**	24.91**	81.06**	17.81**	27.35**
Cement× board type / *Cement × vrsta ploče*	16.52**	6.56**	4.27**	0.57^{ns}	5.60**	0.69^{ns}	6.62**

MOR – bending strength / *čvrstoća na savijanje*; *MOE* – modulus of elasticity / *modul elastičnosti*; *IB* – internal bond strength / *unutarnja čvrstoća vezanja*; TS_2 – thickness swelling after 2 hours immersion in water / *debljinsko bubrenje nakon 2 sata namakanja uzoraka u vodi*; TS_{24} – thickness swelling after 24 hours immersion in water / *debljinsko bubrenje nakon 24 sata namakanja uzoraka u vodi*, WA_2 – water absorption after 2 hours immersion in water / *apsorpcija vode nakon 2 sata namakanja uzoraka u vod*i; WA_{24} – water absorption after 24 hours immersion in water / *apsorpcija vode nakon 2 sata namakanja uzoraka u vodi.*
**: significant at 99 % confidence level /*signifikantno pri razini pouzdanosti 99 %*; ^{ns}: not significant / *nije signifikantno.*

Table 2 Direct effect of board type on mechanical properties and Duncan grouping
Tablica 2. Utjecaj vrste ploče na mehanička svojstva i grupiranje prema Duncanovu testu

Type board / *Vrsta ploče*	**Reinforced with steel nets** *Ploča ojačana čeličnom mrežom*	**Reinforced with hemp yarns** *Ploča ojačana tkanom konopljom*	**Non-reinforced (control)** *Ploča koja nije ojačana*
Internal bond strength, MPa / *Unutarnja čvrstoća vezanja, MPa*	0.402^{A}	0.367^{B}	0.363^{B}
Bending strength, MPa / *Čvrstoća na savijanje*, MPa	13.150^{A}	10.35^{B}	9.66^{C}
Modulus of elasticity, MPa / *Modul elastičnosti, MPa*	2895.27^{A}	2506.80^{B}	2313.25^{C}

As shown, two variables (board type and cement content) had a significant direct effect (P <0.01) on physical and mechanical properties.

Table 2 shows the direct effect of board type (reinforced with steel nets, reinforced with hemp yarns and non-reinforced) on mechanical properties, as well as their Duncan grouping.

As shown in Table 2, reinforcing the boards improved all mechanical properties (bending strength, modulus of elasticity and internal bond strength) and the highest strength was found in boards reinforced with steel nets compared to boards reinforced with hemp yarns and non-reinforced boards.

Table 3 shows direct effect of board type on physical properties, as well as their Duncan grouping.

According to the results shown in Table 3, the highest thickness swelling and water absorption after 2 and 24 hours immersion in water was observed in boards reinforced with hemp yarns and non-reinforced boards (control), while the lowest values were observed in boards reinforced with steel nets (grouping A). The results related to boards reinforced with steel nets, in comparison with control samples for *TS* and *WA* after 24 hours immersion, had a lower value, 6.2 and 4.4 %, respectively.

Direct effect of cement content on mechanical properties of manufactured boards as well as Duncan grouping is presented in Table 4.

By increasing the cement content from 2.5 to 3 times, the bending strength and internal bond in-

Table 3 Direct effect of board type on physical properties and Duncan grouping
Tablica 3. Utjecaj vrste ploče na fizikalna svojstva i grupiranje prema Duncanovu testu

Type board / *Vrsta ploče*	**Reinforced with steel nets** *Ploča ojačana čeličnom mrežom*	**Reinforced with hemp yarns** *Ploča ojačana tkanom konopljom*	**Non-reinforced (control)** *Ploča koja nije ojačana*
TS 2h %	1.5^{A}	1.82^{C}	1.7^{B}
TS 24h, %	2.42^{A}	2.60^{AB}	2.58^{B}
WA 2h, %	7.86^{A}	8.99^{B}	8.99^{B}
WA 24h, %	15.59^{A}	16.41^{B}	16.3^{B}

TS 2h – thickness swelling after 2 hours immersion in water / *debljinsko bubrenje nakon 2 sata namakanja uzoraka u vodi*; *TS* 24h – thickness swelling after 24 hours immersion in water / *debljinsko bubrenje nakon 24 sata namakanja uzoraka u vodi*, *WA* 2h – water absorption after 2 hours immersion in water / *apsorpcija vode nakon 2 sata namakanja uzoraka u vodi*; *WA* 24h – water absorption after 24 hours immersion in water / *apsorpcija vode nakon 2 sata namakanja uzoraka u vodi*.

Table 4 Direct effect of cement content on mechanical properties and Duncan grouping
Tablica 4. Utjecaj sadržaja cementa na mehanička svojstva i grupiranje prema Duncanovu testu

Cement content (to dried wood mass) *Sadržaj cementa (u odnosu prema suhoj masi drvnog materijala)*	**2.5 times** *2,5 puta*	**2.75 times** *2,75 puta*	**3 times** *3 puta*
Internal bond strength, MPa / *Unutarnja čvrstoća vezanja, MPa*	0.32^{C}	0.38^{B}	0.43^{A}
Bending strength, MPa / *Čvrstoća na savijanje, MPa*	10.23^{C}	11.38^{B}	11.54^{A}
Modulus of elasticity, MPa / *Modul elastičnosti, MPa*	2508.30^{C}	2638.94^{A}	2568.07^{B}

Table 5 Direct effect of cement content on physical properties and Duncan grouping
Tablica 5. Utjecaj sadržaja cementa na fizikalna svojstva i grupiranje prema Duncanovu testu

Cement content (to dried wood mass) *Sadržaj cementa (u odnosu prema suhoj masi drvnog materijala)*	**2.5 times** *2,5 puta*	**2.75 times** *2,75 puta*	**3 times** *3 puta*
TS 2h %	1.88^{C}	1.65^{B}	1.49^{A}
TS 24h, %	3.21^{C}	2.15^{AB}	1.88^{A}
WA 2h, %	8.29^{B}	8.56^{B}	7.79^{A}
WA 24h, %	17.18^{C}	15.73^{B}	14.95^{A}

TS 2h – thickness swelling after 2 hours immersion in water / *debljinsko bubrenje nakon 2 sata namakanja uzoraka u vodi*; *TS* 24h - thickness swelling after 24 hours immersion in water / *debljinsko bubrenje nakon 24 sata namakanja uzoraka u vodi*, *WA* 2h – water absorption after 2 hours immersion in water / *apsorpcija vode nakon 2 sata namakanja uzoraka u vodi*; *WA* 24h – water absorption after 24 hours immersion in water / *apsorpcija vode nakon 2 sata namakanja uzoraka u vodi*.

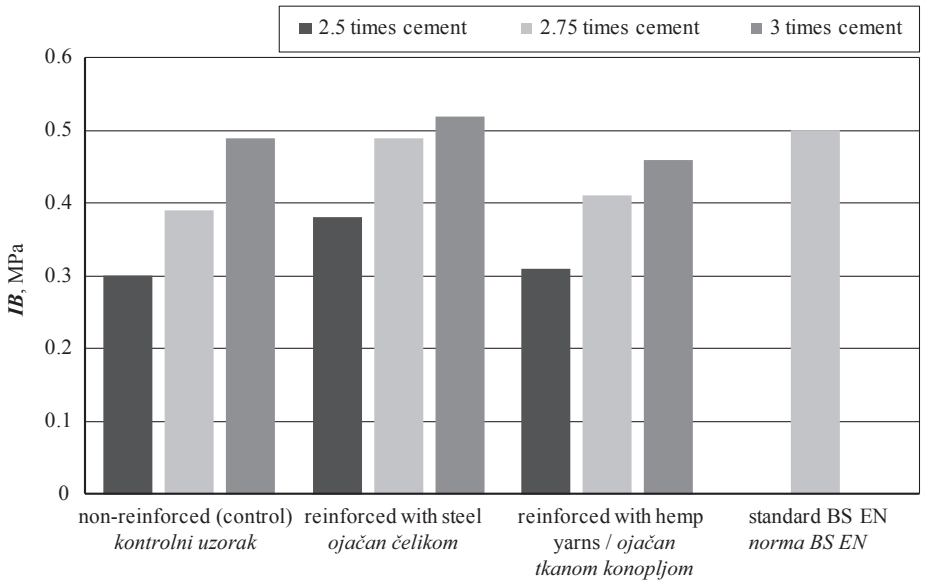


Figure 2 Joint effect of board type and cement content on internal bond strength
Slika 2. Zajednički utjecaj vrste ploče i sadržaja cementa na unutarnju čvrstoću vezanja ploča

creased. Modulus of elasticity only increased by increasing cement content to 2.75 times; the values decreased when the cement content exceeded 2.75.

Direct effect of cement content on physical properties of boards is presented in Table 5.

The analysis of the effect of cement content on physical properties of boards showed that by increasing the cement content from 2.5 to 3 times to the dry wood mass caused improving water absorption and thickness swelling after 2 and 24 hours immersion in water. Board manufactured with 3:1 cement/wood ratio, in comparison with 2.5:1, caused decreasing thickness swelling after 2 and 24 hours immersion in water, 20.7 and 41.4 %, respectively. Furthermore, after 2 and 24 hours immersion in water, water absorption decreased by 6 and 13 %, respectively.

Table of variance analysis (Table 1) showed that the joint effect of board type and cement content had a significant effect ($P < 0.01$) on mechanical properties (bending strength, modulus of elasticity and internal bond strength).

Figure 2 shows the joint effect of board type and cement content on internal bond strength.

The highest value of internal bond strength was found in boards manufactured with steel nets and 3:1 cement/wood ratio, and it was about 0.52 MPa. In comparison with non-reinforced (control) and reinforced with hemp yarns, these boards showed an increased

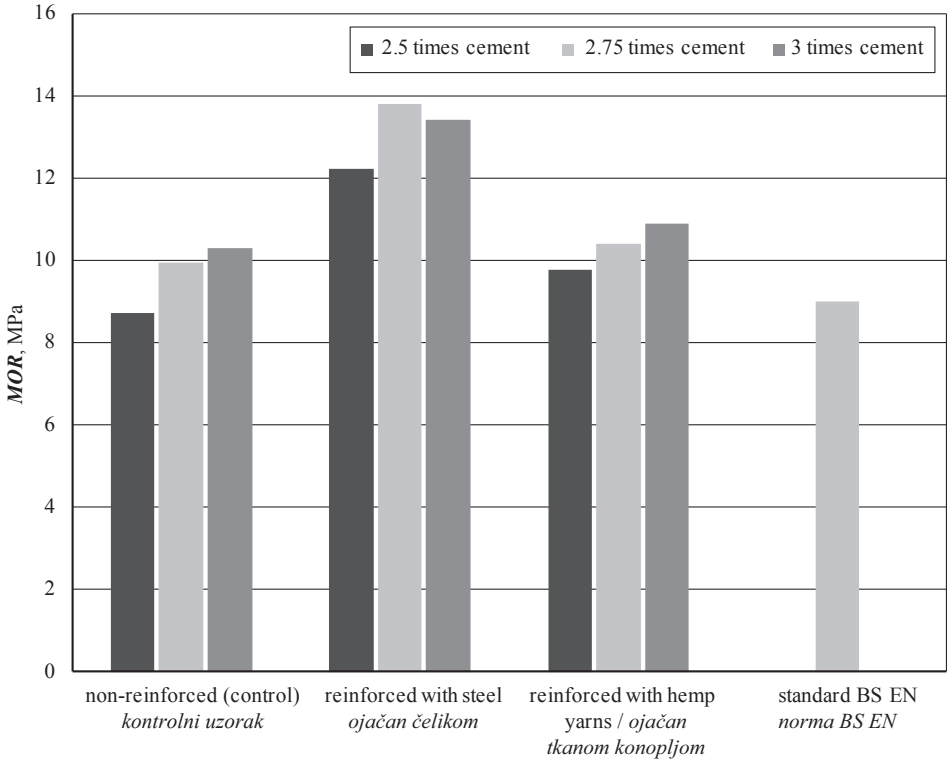


Figure 3 Joint effect of board type and cement content on bending strength
Slika 3. Zajednički utjecaj vrste ploče i sadržaja cementa na čvrstoću ploča na savijanje

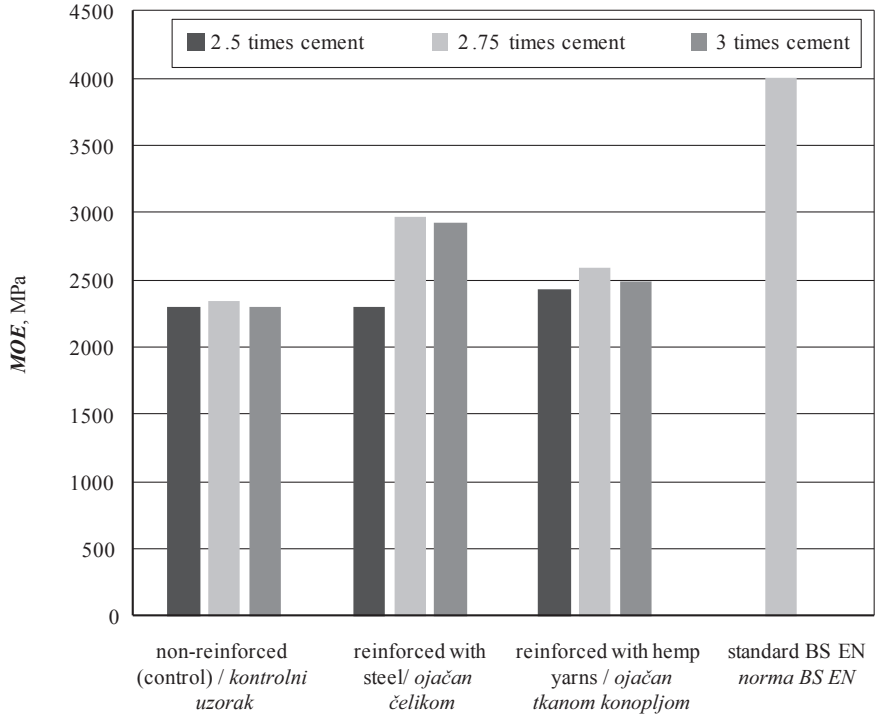


Figure 4 Joint effect of board type and cement content on modulus of elasticity of boards
Slika 4. Zajednički utjecaj vrste ploče i sadržaja cementa na modul elastičnosti ploča

internal bond strength with the same cement content (13 %). The internal bond values of these boards met minimum requirements of wood cement boards of EN 634-2:2007 standard (Figure 2). When the cement content was increased from 2.5 to 3 parts in the cement/wood ratio, wood particles were closed with cement and the voids between wood particles were filled, resulting in increased internal bond strength of the boards. On the other hand, as hemp yarns have an organic-base, they cannot achieve a good bonding with cement, which causes lower internal bond strength in boards reinforced with hemp yarns than in boards reinforced with steel nets.

The joint effect of board type and cement content on bending strength and modulus of elasticity of boards is presented in Figures 3 and 4, respectively.

Boards manufactured with steel nets and 3:1 cement/wood ratio had the highest values of bending strength and modulus of elasticity, 13.81 and 2977 MPa, respectively. In comparison with non-reinforced boards (control), the bending strength of these boards increased by 34 % and modulus of elasticity by 27 %, and the bending strength and modulus of elasticity increased by 26.7 and 14.32 %, respectively, in comparison with boards reinforced with hemp yarns. The results conducted in this study correspond to the results of reinforcing MDF by Mohebbi *et al*. (2011).

EN634-2 standard of wood cement boards indicated that the minimum bending strength is about 9 MPa and of modulus of elasticity 4000 MPa. The bending strength of boards reinforced with steel nets was by 53.3 % higher than the standard value, while the modulus of elasticity was by 25 % lower than the standard value.

When a board is under a bending force, the maximum tensile stress occurs on the top surface and the

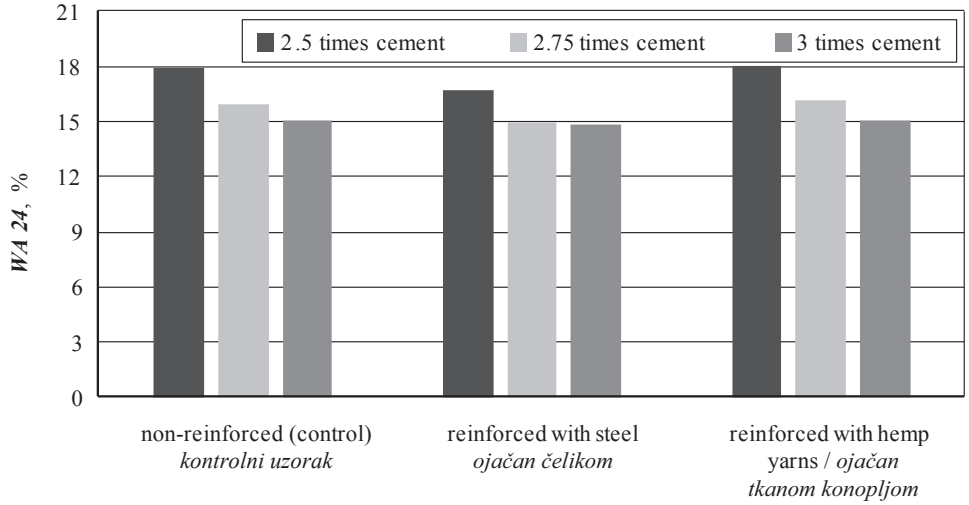


Figure 5 Joint effect of board type and cement content on water absorption
Slika 5. Zajednički utjecaj vrste ploče i sadržaja cementa na apsorpciju vode

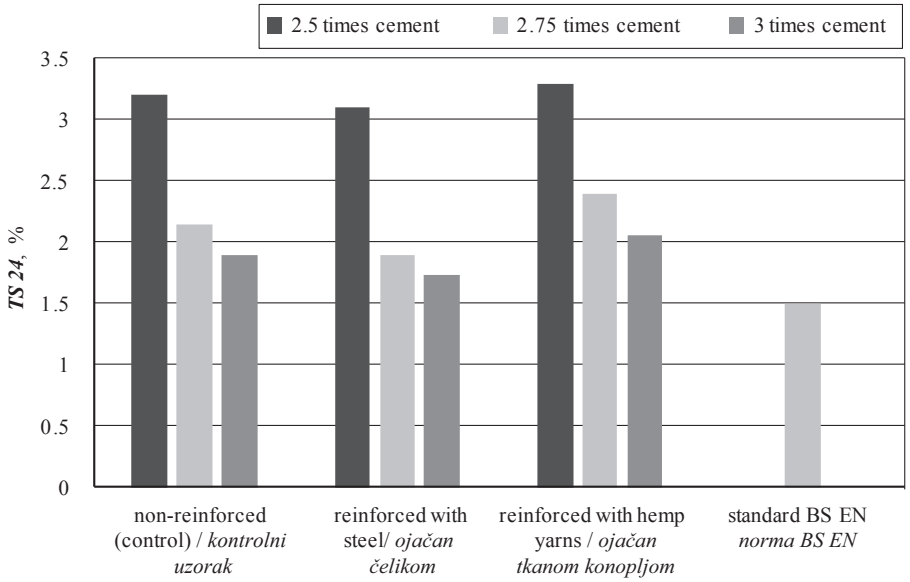


Figure 6 Joint effect of board type and cement content on thickness swelling
Slika 6. Zajednički utjecaj vrste ploče i sadržaja cementa na debljinsko bubrenje ploča

highest compression stress occurs on the bottom surface. Reinforcing boards with steel nets and hemp yarns near the board surfaces increased tensile and compression stresses, and consequently the bending strength and modulus of elasticity increased. Since hardness and stiffness of steel wires and their bonding with cement is higher than that of hemp yarns, boards manufactured with steel nets had higher mechanical strength. When the cement content increased from 2.5 to 3 times in the cement/wood ratio, the voids between wood particles were filled resulting in a strong bond between particles and in the increase of the mechanical strength of boards. The joint effect of board type and cement content on water absorption and thickness swelling after 24 hours immersion in water was significant (Table 1).

Figures 5 and 6 show the joint effect of board type and cement content on water absorption and thickness swelling of boards.

Boards reinforced with steel nets and 3:1 cement/wood ratio had a minimum thickness swelling and water absorption after 24 hours immersion in water. Results indicated that, when the cement content was increased, wood particles were more effectively covered with cement, and consequently wood particles absorbed less water, so that water absorption and thickness swelling of boards decreased. Good bonding between cement particles and steel wires resulted in improving internal bonding of boards. Consequently, permeability of water into internal layers of boards reinforced with steel nets decreased, meaning that physical properties of boards were improved. Since hemp yarns have a great ability to absorb water, water absorption and thickness swelling of boards reinforced with hemp yarns was slightly higher than that of control boards (non-reinforced). As observed in Figure 5, thickness swelling in these boards after 24 hours immersion in water was slightly higher than required by BS EN standard.

4 CONCLUSION
4. ZAKLJUČAK

Results of the analysis of the effect of cement content on physical and mechanical properties of wood cement boards showed that the increase of the cement/wood ratio from 2.5 to 3 times caused the decrease of water absorption and thickness swelling after 2 and 24 hours immersion in water and increase of mechanical strength. Results of the analysis of the effect of board type (non-reinforced, reinforced with steel nets and reinforced with hemp yarns) on physical and mechanical properties of wood cement boards showed that reinforcing boards with steel nets and hemp yarns caused the increase of their mechanical strength, while boards reinforced with steel nets had a lower water absorption and thickness swelling in comparison with the others. Based on the results of this research, it can be concluded that reinforcing wood cement boards with steel nets and using 2.5 cement/wood ratio could improve physical and mechanical properties for internal use, all in accordance with EN 634-2:2007 standard. In this case, only the modulus of elasticity was lower than the standard value.

Acknowledgement

This work was supported by Shahid Rajaee Teacher Training University under contract No. 18630".

5 REFERENCES
5. LITERATURA

1. Aggarwal, L. K.; Agrawal, S. P.; Thapliyal, P. C.; Karade, S. R., 2008: Cement-bonded composite boards with arhar stalks. Cement and Concrete Composites, 30: 44-51. https://doi.org/10.1016/j.cemconcomp.2007.07.004.
2. Ashori, A.; Tabarsa, T.; Azizi, Kh.; Mirzabeygi, R., 2011: Wood-wool cement board using mixture of eucalyptus and poplar. Industrial Crops and Products, 34: 1146-1149. https://doi.org/10.1016/j.indcrop.2011.03.033.

3. BS EN634-2, 2007: Cement-bonded Particleboards-Specifications. Part 2: Requirements for OPC bonded particleboards for use in dry, humid and external conditions.
4. Catarina, P.; Fernando, C. J.; Mark, L.; Jose Maria, F., 2006: Characterizing the setting of cement when mixed with cork, blue gum, or maritime pine, grown in Portugal II: X-ray diffraction and differential thermal analyzes. Journal of Wood Science, 52: 318-324. https://doi.org/10.1007/s10086-005-0775-y.
5. Dimakis, A.; Brightwell, L.; Kerns, J.; Neogi, A.; Robak, G.; Schulner, T.; Smith, J. E., 2006: Reinforced wood product and methods for reinforcing a wood product. United States patent. NO: 20060127633.
6. EN 310, 1999: Wood-based panels – Determination of modulus of elasticity in bending and of bending strength. European committee for standardization.
7. EN 317, 1998: Particleboards and fiberboards – Determination of swelling in thickness after immersion in water. European committee for standardization.
8. EN 319, 1998: Particleboards and fiberboards – Determination of tensile strength perpendicular to the plane of the board. European committee for standardization.
9. Fuwape, J. A.; Fabiyi, J. S.; Osuntuyi. E. O., 2007: Technical assessment of three layered cement-bonded boards produced from wastepaper and sawdust. Waste Management, 27: 1611-1616. https://doi.org/10.1016/j.wasman.2006.09.005.
10. Miller, D. P.; Moslemi, A. A., 1991: Wood-cement composites: Species and heartwood-sapwood effects on hydration and tensile strength. Forest products journal, 41(3): 9-14.
11. Mohebbi, B.; Tavassoli, F.; Kazemi, S., 2011: Mechanical properties medium density fiberboard reinforced with metal and woven synthetic nets. Eur. J. Wood Prod, 69: 199-206. https://doi.org/10.1007/s00107-010-0412-3.
12. Nazerian M.; Sadeghiipanah, V., 2013: Cement-bonded particleboard with a mixture of wheat straw and poplar wood. Journal of Forestry Research, 24(2): 381-390. https://doi.org/10.1007/s11676-013-0363-8.
13. Vaickelionis, G.; Vaickelioniene, R., 2006: Cement hydration in the presence of wood extractives and pozzolan mineral additives. Ceramics Silikaty, 50(2): 115-122.
14. Xiong, G., 1996: Steel strip reinforced high-density wood shaving-cement board ribbed roof panel. Cement and Concrete Composites, 18(6): 429-436. https://doi.org/10.1016/S0958-9465(96)00035-2.
15. Wei, Y. M., Guang Zhou, Y.; Tomita, B. J., 2000: Hydration behavior of wood cement-based composite I: evaluation of wood species effects on compatibility and strength with ordinary portland cement. Journal of Wood Science, 46: 296-302. https://doi.org/10.1007/BF00766220.

Corresponding address:

Assoc. Prof. HOSSEIN RANGAVAR, Ph.D.

Shahid Rajaee Teacher Training University
Faculty of Civil Engineering,
Department of Wood Science and Technology
Tehran, IRAN
e-mail: hrangavar@yahoo.com, rangavar@srttu.edu

Ümit Büyüksarı[1], Nusret As[2], Türker Dündar[2], Ezel Sayan[1]

Micro-Tensile and Compression Strength of Scots Pine Wood and Comparison with Standard-Size Test Results

Mikrovlačna i mikrotlačna čvrstoća škotske borovine i usporedba s rezultatima ispitivanja čvrstoće na uzorcima standardne veličine

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 22. 8. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*812.72; 630*812.76; 674.032.475.442*
doi:10.5552/drind.2017.1639

ABSTRACT • *The goal of this study was to investigate the tensile and compression strength of Scots pine wood (Pinus sylvestris L.) using micro- and standard-sized test specimens. In the standard- and micro-sized specimens, tensile strength was evaluated as 76.9 MPa and 91.5 MPa and compression strength as 43.8 MPa and 36.3 MPa, respectively. The results showed that the compression strength of the micro-sized specimens was lower compared to the standard-sized specimens, while the tensile strength was higher in the micro-sized specimens. With the exception of the effect of specimen size and individual tree interaction on tensile strength, statistically significant effects were found for specimen size, individual trees and the interactions of the size and trees on the tensile and compression strength. Moreover, regression analyses indicated a positive linear regression between the strength of micro- and standard-sized specimens. Micro-sized specimens can be used to estimate the tensile and compression strength of Scots pine wood, when it is not possible to obtain standard-size specimens.*

Key words: *micro-sized specimens, standard-sized specimens, tensile strength, compression strength*

SAŽETAK • *Cilj istraživanja bio je usporediti vlačnu i tlačnu čvrstoću borovine (Pinus sylvestris L.) određenu na mikrouzorcima i na ispitnim uzorcima standardne veličine. Vlačna čvrstoća borovine određena na ispitnim uzorcima standardne veličine iznosila je 76,9 MPa, a na mikrouzorcima 91,5 MPa, dok je tlačna čvrstoća borovine izmjerena na standardnim ispitnim uzorcima bila 43,8 MPa, a na mikrouzorcima 36,3 MPa. Rezultati su pokazali da je tlačna čvrstoća borovine određena na mikrouzorcima manja od tlačne čvrstoće izmjerene na ispitnim uzorcima standardne veličine, dok je vlačna čvrstoća borovine izmjerena na mikrouzorcima veća od vlačne čvrstoće standardnih uzoraka. Uz izuzetak interakcijskog utjecaja veličine ispitnog uzorka i pojedinačnog stabla od kojega su uzorci izrađeni na vlačnu čvrstoću, statistička analiza dobivenih podataka pokazala je signifikantan utjecaj veličine ispitnog uzorka, pojedinačnog stabla od kojega je izrađen ispitni uzorak i interakcije veličine uzorka i*

[1] Authors are associate professor and master student at Duzce University, Faculty of Forestry, Forest Product Engineering Department, Duzce, Turkey. [2]Authors are professor and associate professor at Istanbul University, Faculty of Forestry, Forest Product Engineering Department, Istanbul, Turkey.
[1] Autori su izvanredni profesor i student diplomskog studija Sveučilišta u Duzceu, Šumarski fakultet, Odjel za inženjerstvo drvnih proizvoda, Duzce, Turska. [2]Autori su profesor i izvanredni profesor Sveučilišta u Istanbulu, Šumarski fakultet, Odjel za inženjerstvo drvnih proizvoda, Istanbul, Turska.

stabla od kojega je uzorak izrađen na vlačnu i tlačnu čvrstoću borovine. Usto, regresijska je analiza podataka pokazala pozitivnu linearnu regresiju između čvrstoće mikrouzoraka i čvrstoće ispitnih uzoraka standardne veličine. Iz toga se može zaključiti da se za procjenu vlačne i tlačne čvrstoće škotske borovine mogu upotrijebiti mikrouzorci kad god izrada ispitnih uzoraka standardne veličine nije moguća.

Ključne riječi: *mikrouzorci, ispitni uzorci standardne veličine, vlačna čvrstoća, tlačna čvrstoća*

1 INTRODUCTION
1. UVOD

Scots pine is an important tree species native to Eurasia. In Turkey, it covers about 5 % (738 000 ha) of the total Turkish forestland. Moreover, it exhibits superior technological properties and a high potential for utilization. In order to determine the mechanical properties of wood, the approach has been to use structural-size and small-size clear specimens. In recent years, micro-size specimens have been used to evaluate the mechanical properties of earlywood and latewood sections, wood strands, and fibers (Plagemann, 1982; Hunt *et al.*, 1989; Groom *et al.*, 2002; Mott *et al.*, 2002; Deomano and Zink-Sharp 2004; Cai *et al.*, 2007; Hindman and Lee 2007; Jeong 2008; Jeong *et al.*, 2009).

In previous studies on micro-sized testing, researchers used various specimen dimensions and loading rates according to the purpose of the study. Deomano and Zink-Sharp (2004) investigated the bending properties of southern yellow pine (*Pinus* spp.), sweet gum (*Liquidambar styraciflua* L.), and yellow poplar (*Liriodendron tulipifera* L.) wood. Samples of 25 × 5.0 × 0.6 mm flakes were used to calculate the modulus of rupture (MOR) and modulus of elasticity (MOE) of these wood species, with the loading rate of 2.54 mm/min. Hindman and Lee (2007) measured the bending and tensile properties of both earlywood and latewood sections of loblolly pine (*Pinus taeda*) strands. The dimensions of the bending test samples were 33.0 × 11.0 × 0.68 mm and of the tensile test samples 60 × 0.66 × 4.58 mm for earlywood, and 60 × 0.66 × 3.3 mm for latewood. The loading rate was 0.127 mm/min.

The tensile properties of willow (*Salix* spp.), yellow poplar (*Liriodendron tulipifera* L.), red oak (*Quercus* spp.) and loblolly pine (*Pinus taeda*) wood strands were investigated by Cai *et al.*, (2007). Hunt *et al.*, (1989) conducted tensile testing to determine the tensile strength and tensile modulus of yellow poplar strands (*Liriodendron tulipifera* L.) with a 2224 N load cell at a test speed of 1.9 mm/min. Their study revealed that the average tensile strength and tensile modulus was 70.3 MPa and 11.8 GPa, respectively.

Zink-Sharp and Price (2006) determined the compression strength of sweetgum (*Liquidambar styraciflua* L.), yellow poplar (*Liriodendron tulipifera* L.), and red maple (*Acer rubrum*) wood species using 1 × 1 × 4 mm specimens. The test was conducted at 12 % moisture content (MC) with a loading speed of 0.029 mm/min. They found that the compression strength of sweetgum, yellow poplar and red maple wood were 39.2, 33.5 and 41.6 MPa, respectively.

Micro-size specimens can be used to determine the mechanical properties of wood, when it is not possible to obtain standard-size test specimens. In order to avoid damaging the wood in various applications, the mechanical properties can be determined by using micro-size test specimens. Furthermore, the test specimens of structural wood material can be taken periodically and their mechanical properties can be determined. In this way changes in the mechanical properties of wood can be observed over time. With the development of micro-size tests, the strength losses due to exposure time can be determined for structural wood applications. This information can provide a solid base for a true assessment of the necessity of wooden structure renewal.

The mechanical properties of specimens are dependent on the specimen dimensions. This phenomenon is called size effect (Weibull, 1939). According to the theory of size effect (weakest link theory), the strength is dependent on the size of highly stressed volume. The basis for this theory is that there is a greater probability that a region of low strength will occur in a member of large volume than in a member of small volume. This region of low strength is assumed to cause complete failure of the member (Weibull, 1939).

The analysis of the factors influencing the size effect of strength and elastic properties is very complex and a number of hypotheses have been developed in the last 100 years. To simplify the matter, it is helpful to consider different species and different mechanical tests separately (Schotzhauer *et al*., 2015). Madsen and Buchanan (1986) also stated that the size effect is dependent on wood species.

There is limited information concerning the comparison of tensile and compression strength of micro- and standard-size specimens. In previous studies, researchers compared their findings of micro-size test with values published in Wood Handbook for standard-size specimens (Zink-Sharp and Price, 2006; Cai *et al.*, 2007). Cai *et al.*, (2007) found that the tensile strength of willow, yellow poplar, red oak and loblolly pine strands, was, respectively, 31.1 %, 44.2 %, 36.2 % and 73.4 % lower than that of standard-size specimens. Zink-Sharp and Price (2006) stated that the compression strength of the micro-size specimens was close to but lower than handbook values for sweet gum, yellow poplar and maple wood species. This approach of comparing the values obtained from different trees is not valid for obtaining information about the presence of a correlation between micro-size and standard-size specimens. It is recognized that the tree age and growth conditions, such as the climate, soil characteristics, slope, and altitude, affect the annual ring width and the mechanical properties of wood. The goal of this paper is, therefore, to evaluate the tensile and compression strength of micro-size Scots pine (*Pinus sylvestris* L.) wood and investigate the

correlation between micro- and standard-size specimens that are taken from the same tree.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Sample trees were harvested from the Bolu Forest Enterprises in the northwestern part of Turkey. Eight trees with straight stems were selected as sample trees. Table 1 shows the properties of the sample trees and sampling area.

Logs of 3 m in length were cut from each tree at a height of 0.30 m, and then 6-cm-thick planks, including the central pith, were cut from these logs. The micro- and standard-size test specimens were prepared from these planks. The cutting plan of the test specimens is shown in Figures 1a and 1b. All of the specimens were conditioned in a climate chamber at a temperature of 20 °C and a relative humidity of 65 % for three weeks to reach the target moisture content of 12 % prior to testing.

2.2 Methods
2.2. Metode

Specimens were cut according to International Organization for Standardization (ISO) in order to determine the tensile strength parallel to grain (ISO 13061-6, 2014) and compression strength parallel to grain (ISO/DIS 13061-17, 2014). The standard-size test specimens were prepared in dimensions of 15 mm × 50 mm × 400 mm for tensile and 20 mm × 20 mm × 30 mm for compression test. A Lloyd universal test machine with a 10 kN load cell was used for the standard-size tests.

Micro-size tests were performed with a Zwick universal test machine using a 100 N load cell for compression test and a 1kN load cell for tensile test. The same ISO standards were used as a guide for the micro-size specimens. The micro-size tensile test specimens were approximately 50 mm × 5.0 mm × 1.3 mm and the width of the specimen was reduced to 0.8 mm with a sanding drum. The gauge lengths were 3 mm for the micro-size tensile specimens and 280 mm for the standard-size specimens. Figure 2 shows the micro-size tensile test specimens and the preparation process. The dimensions of micro-size compression test specimens were 3 mm × 3 mm × 5 mm. The micro- and standard-size tensile and compression test specimens are shown in Figure 3.

2.3 Data analyses and statistical methods
2.3. Analiza podataka i statističke metode

For the tensile and compression strength, all multiple comparisons were first subjected to an analysis of

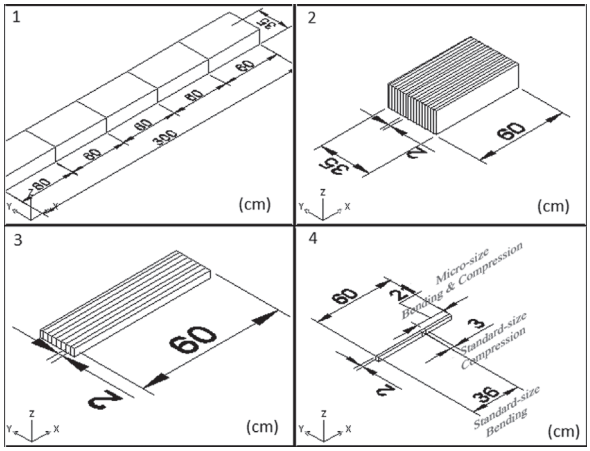


Figure 1a Cutting plan of compression test specimens at standard- and micro-size
Slika 1.a) Plan izrezivanja ispitnih uzoraka standardne veličine i mikrouzoraka za ispitivanje tlačne čvrstoće

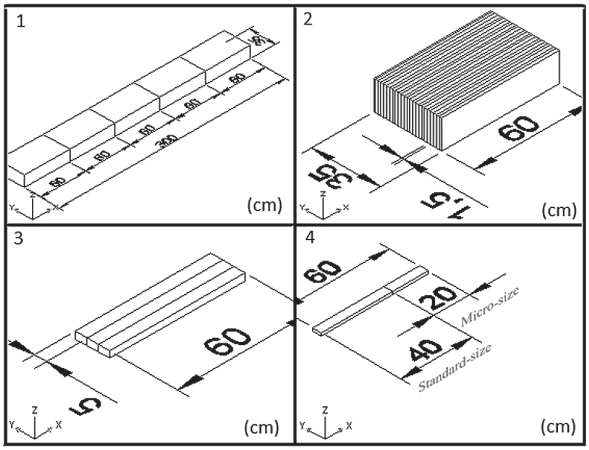


Figure 1b Cutting plan of tensile test specimens at standard- and micro-size
Slika 1.b) Plan izrezivanja ispitnih uzoraka standardne veličine i mikrouzoraka za ispitivanje vlačne čvrstoće

Table 1 Properties of the sample trees and sampling area
Tablica 1. Obilježja stabala od kojih su izrađeni uzorci i lokacije stabala

Tree No. *Broj stabla*	**Diameter of tree at 1.30 m** *Promjer stabla na visini 1,30* m cm	**Tree age** *Starost stabla* Year / *god.*	**Altitude** *Nadmorska visina* m	**Aspect** *Položaj*	**Slope** *Nagib terena* %
1	33	137	1540	Northeast *sjeveroistok*	40
2	34	135			
3	34	144			
4	37	127			
5	34	94			
6	32	135			
7	36	123			
8	35	130			

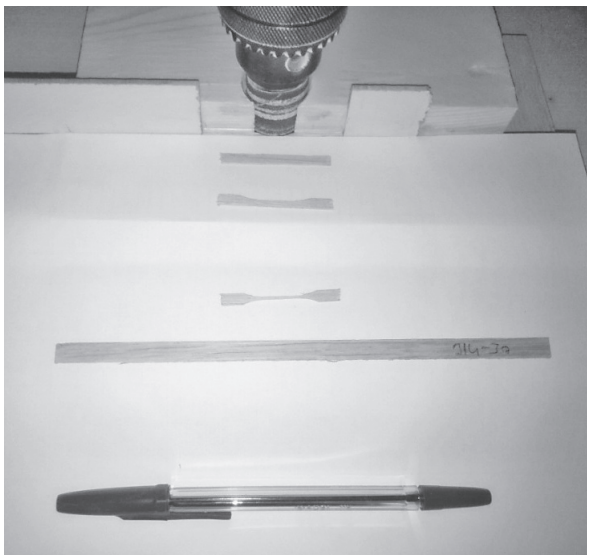


Figure 2 Micro-size tensile test specimens and preparation process
Slika 2. Mikrouzorci za ispitivanje vlačne čvrstoće i proces njihove pripreme

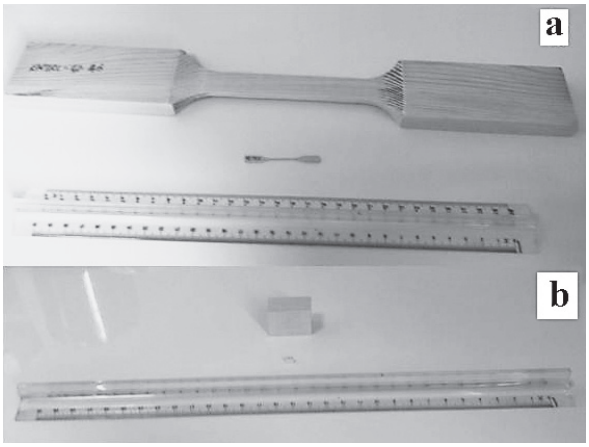


Figure 3 Micro- and standard-size test specimens for (a) tensile and (b) compression
Slika 3. Mikrouzorci i ispitni uzorci standardne veličine za ispitivanje: a) vlačne čvrstoće, b) tlačne čvrstoće

variance (ANOVA) at $p < 0.05$ considering two factors (specimen size and individual tree) and interactions. Post-hoc comparisons were conducted using Duncan's multiple range tests. Regression analysis was used to determine the relationship between standard- and micro-size specimens.

3 RESULTS
3. REZULTATI

The average tensile strength values and Duncan test results of the standard- and micro-size Scots pine wood specimens are shown in Table 2. The tensile strength values of the standard- and micro-size specimens were determined as 76.9 MPa and 91.5 MPa, respectively. The results showed that the tensile strength values of the micro-size specimens were 19.0 % higher compared to the standard-size specimens. For individual trees, the tensile strength values ranged from 75.7 MPa (tree 2) to 111.8 MPa (tree 6) in the micro-size specimens and from 66.6 MPa (tree 5) to 89.9 MPa (tree 6) in the standard-size specimens. The highest tensile strength values were observed for tree 6 in both the micro- and standard-size specimens.

The average compression strength values and Duncan test results of the standard- and micro-size Scots pine wood specimens are shown in Table 3.

The compression strength values of standard- and micro-size specimens were found to be 43.8 MPa and 36.3 MPa, respectively. The results showed that the compression strength of the micro-size specimens were 17.1 % lower compared to the standard-size specimens. For individual trees, the compression strength values ranged from 31.9 MPa (tree 2) to 40.9 MPa (tree 6) in the micro-size specimens and from 36.3 MPa (tree 2) to 51.9 MPa (tree 6) in the standard-size specimens. The highest compression strength values were observed for tree 6 in both the micro- and standard-size specimens.

Table 2 The average tensile strength values and Duncan test results of standard- and micro-size Scots pine wood
Tablica 2. Prosječne vrijednosti vlačne čvrstoće i rezultati Duncanova testa za podatke dobivene na mikrouzorcima i ispitnim uzorcima standardne veličine

Tree No. *Broj stabla*	**Tensile strength, MPa /** *Vlačna čvrstoća, MPa*					
	Standard-size / *Uzorci standardne veličine*			**Micro-size /** *Mikrouzorci*		
	N	Mean	Std. Deviation	*N*	Mean	Std. Deviation
1	32	66.9^{a}	22.4	31	83.1^{de}	31.2
2	15	74.0^{ab}	22.6	15	75.7^{d}	25.1
3	23	85.1^{bc}	26.9	23	94.7^{def}	33.2
4	35	83.1^{bc}	17.5	35	98.2^{ef}	36.2
5	25	66.6^{a}	14.7	23	80.4^{de}	21.5
6	28	89.9^{c}	24.7	27	111.8^{f}	35.0
7	30	77.8^{ab}	19.3	28	89.9^{de}	31.8
8	31	70.9^{a}	12.4	29	89.4^{de}	33.9
Total	219	76.9	21.5	211	91.5	33.1

N – Number of specimens; Groups with same letters in column indicate that there is no statistical difference ($p < 0.05$) between the samples according to Duncan's multiply range test.
N – broj uzoraka; među prosječnim vrijednostima označenim istim slovom u stupcu nije utvrđena statistički signifikantna razlika ($p < 0,05$) prema Duncanovu višestrukom usporednom testu

Table 3 The average compression strength values and Duncan test results of standard- and micro-size Scots pine wood
Tablica 3. Prosječne vrijednosti tlačne čvrstoće i rezultati Duncanova testa za podatke dobivene na mikrouzorcima i ispitnim uzorcima standardne veličine

Tree No. *Broj stabla*	**Compression strength, MPa /** *Tlačna čvrstoća, MPa*					
	Standard-size / *Uzorci standardne veličine*			**Micro-size /** *Mikrouzorci*		
	N	Mean	Std. Deviation	*N*	Mean	Std. Deviation
1	51	40.3^{g}	6.1	47	32.5^{n}	5.8
2	43	36.3^{h}	5.4	42	31.9^{n}	5.7
3	47	48.6^{k}	5.9	44	39.6^{r}	6.3
4	61	44.9^{i}	7.0	59	35.8^{pr}	6.6
5	46	40.6^{g}	6.1	45	35.2^{o}	6.4
6	57	51.9^{m}	7.2	55	40.4^{r}	7.0
7	41	41.3^{g}	5.1	40	34.1^{no}	5.0
8	58	43.7^{i}	4.2	53	36.3^{op}	6.1
Total	404	43.8	7.5	385	36.3	6.8

N – Number of specimens; Groups with same letters in column indicate that there is no statistical difference ($p < 0.05$) between the samples according to Duncan's multiply range test.
N – broj uzoraka; među prosječnim vrijednostima označenim istim slovom u stupcu nije utvrđena statistički signifikantna razlika ($p < 0,05$) prema Duncanovu višestrukom usporednom testu

The factors of the specimen size (standard- and micro-size), individual trees (eight trees) and their interactions on the tensile and compression strength are shown in Table 4. For the tensile strength, specimen size and individual tree were significantly different ($p < 0.000$), while the interaction of specimen size and individual tree was not ($p = 0.811$). For the compression strength, all factors were significantly different.

Table 4 The interactions of specimen size and individual tree on tensile strength and compression strength (ANOVA)
Tablica 4. Interakcije veličine uzorka i pojedinačnog stabla na vlačnu i tlačnu čvrstoću (ANOVA)

Source *Izvor*		**Type III sum of squares** *Zbroj kvadrata – tip III.*	***df***	**Mean square** *Kvadrat srednje vrijednosti*	***F***	***P***
Tensile Strength *vlačna čvrstoća*	Specimen size / *veličina ispitnog uzorka*	18692.1	1	18692.1	26.28	0.000
	Individual tree /*pojedinačno stablo*	34072.4	7	4867.5	6.84	0.000
	Specimen size * individual tree *veličina ispitnog uzorka * pojedinačno stablo*	2644.8	7	377.8	0.53	0.811
Compression strength *tlačna čvrstoća*	Specimen size / *veličina ispitnog uzorka*	10571.7	1	10571.7	284.1	0.000
	Individual tree / *pojedinačno stablo*	11217.9	7	1602.6	43.1	0.000
	Specimen size * individual tree *veličina ispitnog uzorka * pojedinačno stablo*	829.1	7	118.4	3.2	0.003

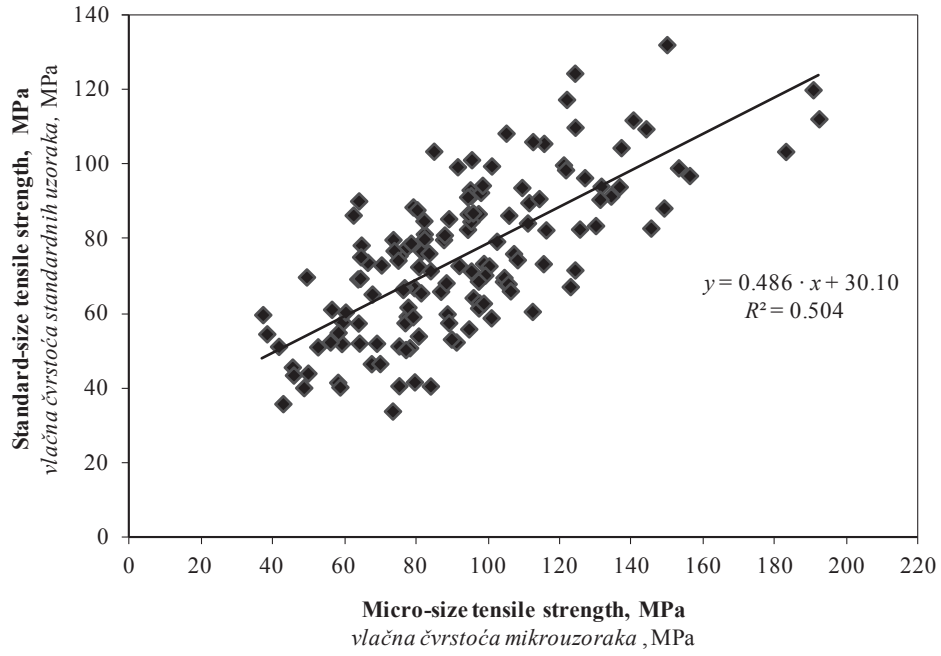


Figure 4 Regression analysis results for tensile strength of micro- and standard-size wood specimens
Slika 4. Regresijska analiza rezultata vlačne čvrstoće mikrouzoraka drva i ispitnih uzoraka standardne veličine

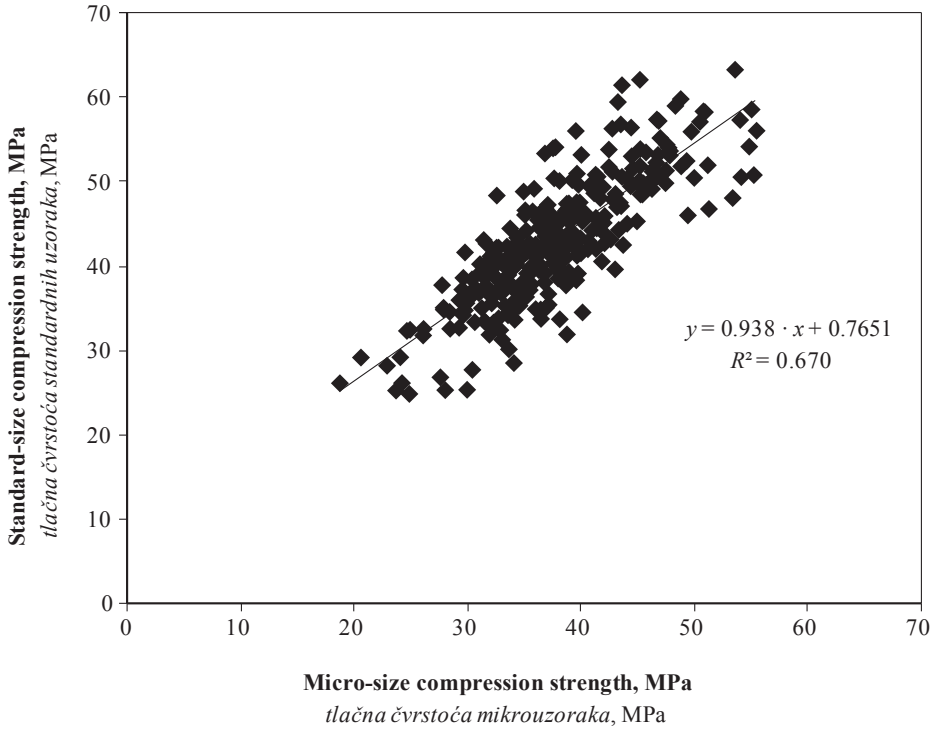


Figure 5 Regression analysis results for compression strength of micro- and standard-size wood specimens
Slika 5. Regresijska analizira rezultata tlačne čvrstoće mikrouzoraka drva i ispitnih uzoraka standardne veličine

Regression analysis graphics for the tensile and compression strength of the micro- and standard-size wood specimens are shown in Figures 4 and 5, respectively. The regression analysis indicated that all measured properties of the micro-size specimens were significantly correlated with the standard-size specimens ($p < 0.000$). The tensile and compression strength values of the standard- and micro-size specimens showed a positive linear dependency, presenting coefficients of correlation of 71.0 and 81.9 percent, respectively, in linear regression models.

4 DISCUSSION
4. RASPRAVA

In previous studies about the tensile strength of micro-size test specimens, researchers determined the tensile strength value of some wood species. Cai *et al.*, (2007) determined that the tensile strength values of yellow poplar, loblolly pine, willow and red oak wood strands were 48.5 MPa, 58.7 MPa, 22.7 MPa and 40.7 MPa, respectively. Additionally, the tensile strength of southern pine strands was determined as 50.0 MPa (Wu *et al.*, 2005), of loblolly pine strands as 43.3 MPa (Hindman and Lee 2007) and of yellow poplar strands as 70.3 MPa (Hunt *et al.*, 1989). The gage length, sample thickness, loading rate and sample shape (dog-bone or rectangle shape) affect tensile strength of micro-size samples. Unlike previous studies, in the current study, micro-size tensile strength specimens were prepared in the dog-bone shape. Kohan *et al.*, (2012) compared the tensile strength and modulus of elasticity of rectangular and tapered (dog-bone) wood strands. They concluded that the dog-bone shaped specimens had 16 % and 27 % higher tensile strength and modulus of elasticity, respectively, than the rectangular specimens, and that the variation in mechanical properties was not statistically different for the two shapes. The higher tensile strength value in the micro-size specimens could be attributed to the dimensions of the specimens, loading rate, ratio of earlywood and latewood or gauge length. Jeong (2008) pointed out that the results of previous studies are not directly comparable because of different loading conditions and different wood species. In his study, he indicated that the tensile strength of micro-size loblolly pine wood specimens reported by Hindman and Lee (2007) was 36 % higher compared to the work of Cai *et al.*, (2007). This comparison clearly shows the effect of specimen dimensions and loading rate on the strength properties of micro-size specimens. Price (1976) concluded that tensile strength increased as gauge length increased. Jeong *et al.*, (2008) concluded that tensile strength and MOE generally increased as the thickness increased, and the thickness of the specimen wood strands significantly affected the tensile strength and MOE of southern pine wood. In order to decrease the variability of test results, they recommended a 0.254 mm/min loading rate and a strand thickness of between 0.794 and 1.91 mm.

The results showed that the tensile strength value of the micro-size specimens was higher than that of the standard-size specimens. This is compatible to Weibull's theory, which states that with increasing volume, the strength decreases. Schneeweiß and Felber (2013) mentioned a strong decrease in tensile strength when increasing the length of the specimens. Conversely, previous studies have stated that the tensile strength of micro-size specimens was lower than that of standard-

size specimens (Price 1976; Cai *et al.*, 2007). Cai *et al.*, (2007) reported that the tensile properties of willow, yellow poplar, red oak, and loblolly pine wood strands were significantly lower than those of standard-size. When compared to the tensile strength of standard-size specimens in Wood Handbook, those of wood strands from willow, yellow poplar, red oak, and loblolly pine were lower by 31.1 %, 44.2 %, 36.2 % and 73.4 %, respectively. Price (1976) observed similar results for micro-size sweet gum specimens. In previous studies researchers compared their findings with published values in Wood Handbook (Green *et al.*, 1999) for the same wood species. This approach of comparing the values obtained from different trees is not valid for obtaining information about the presence of a correlation between micro-size and standard-size samples. It is recognized that tree age and growth conditions such as climate, soil characteristics, slope and altitude affect the annual ring width and the mechanical properties of wood.

The results of the present study showed that the compression strength value of the micro-size specimens was lower compared to the standard-size specimens. Similar results were seen by Zink-Sharp and Price (2006) in sweet gum (*Liquidambar styraciflua* L.), yellow poplar (*Liriodendron tulipifera*) and maple (*Acer rubrum*) wood. They found that the compression strength of the micro-size specimens was close to but lower than handbook values for all studied species. They explained that the exact cause of this difference was unknown, but that there were at least two probable explanations. The size effect was one possibility and the second was that damage created by specimen preparation had a more significant impact on the intra-ring specimens than on the standard-size specimens. Another reason of the differences between the compression strength of micro- and standard size samples can be the failure mode. Schlotzhauer *et al.*, (2015) concluded that the mode of failure is also affected by the specimen dimensions.

The compression strength results of the present study are contradictory to Weibull theory. Schneeweiß (1964) concluded that the volume strength dependence is a function of absolute specimen volume. He established three different categories. At volumes below 10 cm^3 (Category 1) and above 1000 cm^3 (Category 3), Weibull's theory applies. In between (Category 2), the volume is considered an influencing factor of low importance. Schneeweiß (1964) stated that the compression strength of Spruce wood first decreased with increasing specimen volume then increased slightly to maximum and finally decreased again. Madsen and Buchanan (1986) stated that the size effect is dependent on wood species. Schlotzhauer *et al.*, (2015) observed that the compression strength increased as specimen volume increased in beech, oak and lime wood, while the specimen dimensions did not influence the compression strength of maple, birch and ash wood.

5 CONCLUSIONS
5. ZAKLJUČAK

Based on this study, the following conclusions can be drawn:

1. The compression strength of the micro-size specimens were 17.1 % lower compared to the standard-size specimens, while tensile strength was 19.0 % higher in micro-size specimens.
2. The effects of specimen size, individual trees and the interactions between size and trees on tensile and compression strength were statistically significant, except for the effect of the interaction of specimen size and individual trees on tensile strength.
3. The regression analysis indicated that tensile and compression strength of the micro-size specimens was significantly correlated with the standard-size specimens. A positive linear regression between the micro- and standard-size specimens was found for tensile and compression strength.
4. Micro-size test specimens can be used to estimate the standard-size test results for the tensile and compression strength of Scots pine wood.
5. Dog-bone shape micro-size tensile strength samples at given dimensions can be used to determine tensile strength of wood. For the loading rate, ISO standards can be used as a guide for the micro-size specimens.

Acknowledgement – Zahvala

This work was supported by the Scientific and Technological Research Council of Turkey (TUBITAK Project Number: 112O815).

6 REFERENCE
6. LITERATURA

1. Cai, Z.; Wu, Q.; Han, G.; Lee, J. N., 2007: Tensile and thickness swelling properties of strands from Southern hardwoods and Southern pine: Effect of hot-pressing and resin application. Forest Products Journal, 57(5): 36-40.
2. Deomano, E. C.; Zink-Sharp, A., 2004: Bending properties of wood flakes of three southern species. Wood Fiber Sci., 36(4): 493-499.
3. Groom, L.; Shaler, S.; Mott, L., 2002: Mechanical properties of individual southern pine fibers. Part III. Global relationships between fiber properties and fiber location within an individual tree. Wood Fiber Sci., 34(2): 238-250.
4. Hindman, D. P.; Lee, J. N., 2007: Modeling wood strands as multi-layer composites: bending and tension loads. Wood Fiber Sci., 39(4): 516-526.
5. Hunt, M. O.; Triche, M. H.; McCabe, G. P.; Hoover, W. L., 1989: Tensile properties of yellow-poplar veneer strands. Forest Products Journal, 39(9): 31-33.
6. Jeong, G. Y., 2008: Tensile properties of loblolly pine strands using digital image correlation and stochastic finite element method. Doctoral dissertation, Virginia Polytechnic Institute & State University, Blacksburg, VA.
7. Jeong, G. Y.; Zink-Sharp, A.; Hindman, D. P., 2009: Tensile properties of earlywood and latewood from loblolly pine (*Pinus taeda*) using digital image correlation. Wood Fiber Sci., 41(1): 51-63.
8. Kohan, N.; Via, B. K.; Taylor, S., 2012: A comparison of geometry effect on tensile testing of wood strands. Forest Products Journal, 62(3): 167-170. https://doi.org/10.13073/0015-7473-62.3.167.
9. Madsen, B.; Buchanan, A. H., 1986: Size effects in timber explained by a modified weakest link theory. Can. J. Civil Eng., 13(2), 218-232. https://doi.org/10.1139/l86-030.

10. Mott, L.; Groom, L.; Shaler, S., 2002: Mechanical properties of individual southern pine fibers. Part II. Comparison of earlywood and latewood fibers with respect to tree height and juvenility. Wood Fiber Sci., 34(2): 221-237.
11. Plagemann, W. L., 1982: The response of hardwood flakes and flakeboard to high temperature drying. Master's thesis, Washington State University, Pullman, WA.
12. Price, E. W., 1976: Determining tensile properties of Sweetgum veneer flakes. Forest Products Journal, 26(10): 50-53.
13. Schlotzhauer, P.; Nelis, P. A.; Bollmus, S.; Gellerich, A.; Militz, H.; Seim, W., 2015: Effect of size and geometry on strength values and MOE of selected hardwood species. Wood Material Science & Engineering. https://doi.org/10.1080/17480272.2015.1073175.
14. Schneeweiß, G., 1964: Compressive strength and Hoeffgen Hardness. Holz als Roh-und Werkstoff, 22 (7), 258-264. https://doi.org/10.1007/BF02608291.
15. Schneeweiß, G.; Felber, S., 2013: Review on the bending strength of wood and influencing factors. American Journal of Materials Science, 3(3), 41-45.
16. Weibull, W., 1939: A statistical theory of the strength of material. Proc. Roy. Swedish Inst. Eng. Res., 45 p.
17. Wu, Q.; Cai, Z.; Lee, J. N., 2005: Tensile and dimensional properties of wood strands made from plantation southern pine lumber. Forest Products Journal, 52(2): 1-6.
18. Zink-Sharp, A.; Price, C., 2006: Compression strength parallel to the grain within growth rings of low density hardwoods. Maderas: Ciencia y Technologia, 8(2): 117-126. https://doi.org/10.4067/S0718-221X2006000200005.
19. ISO 13061-6: 2014: Physical and mechanical properties of wood: Test methods for small clear wood specimens. Part 6: Determination of ultimate tensile stress parallel to grain. International Organization for Standardization, Geneva, Switzerland.
20. ISO/DIS 13061-17: 2014: Physical and mechanical properties of wood: Test methods for small clear wood specimens. Part 17: Determination of ultimate stress in compression parallel to grain. International Organization for Standardization, Geneva, Switzerland.

Corresponding address:

Assoc. Prof. ÜMIT BÜYÜKSARI, Ph. D.

Duzce University
Faculty of Forestry, Forest Industrial Engineering
81620, Düzce, TURKEY
e-mail: umitbuyuksari@duzce.edu.tr

Darius Albrektas, Povilas Navickas[1]

An Evaluation of Modulus of Elasticity, Dimensional Stability and Bonding Strength of Bonded Heat-Treated Wood

Procjena modula elastičnosti, dimenzijske stabilnosti i čvrstoće lijepljenja toplinski obrađenog drva

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 14. 9. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*812.701; 630*812.23; 630*824.324; 630*844.53*
doi:10.5552/drind.2017.1641

ABSTRACT • *In this study, the effects of heating on the mechanical and sorption properties of pine and spruce wood were investigated. The study was carried out using wood heated in laboratory. Specimens were divided into the following three groups: specimens of one group were not exposed to heating, whereas specimens of two other groups were subjected to heating at the temperature of 190 °C and 215 °C, in the air under atmospheric pressure. Specimens were then bonded together using a cold press and four different systems of not heated and heated (at different temperatures) samples were formed: two not heated samples and two samples heated at different temperatures. After that, newly formed systems were moistened and dried in a climatic chamber and measurements of dimensional changes were carried out. Then the mechanical properties were observed again using two different methods - method of transverse vibrations and method of three point static bending. A positive and strong correlation coefficient was determined between static and dynamic MOE values, however, dynamically determined MOE was up to 16 % higher. None of the bonded specimens became loosened during soaking and drying, which means that wood, heated at the different temperatures, could be bonded together thereby obtaining a system of heat-treated wood that may have better mechanical or sorption properties than solid wood.*

Key words: *heat-treated wood, pine, spruce, mechanical properties, nondestructive evaluation method, three point static bending, bonding*

SAŽETAK • *U radu je prikazano istraživanje utjecaja toplinske obrade drva na mehanička i sorpcijska svojstva borovine i smrekovine. Istraživanje je provedeno na drvu koje je toplinski obrađeno u laboratoriju. Uzorci su podijeljeni u sljedeće tri skupine: uzorci koji nisu bili izloženi toplinskoj obradi, uzorci toplinski obrađeni u zraku – pri atmosferskom tlaku i temperaturi 190 °C, te na uzorke obrađene na temperaturi 215 °C. Zatim su uzorci slijepljeni u hladnoj preši tako da su izrađena četiri slijepljena spoja: od uzoraka toplinski neobrađenog drva i top-*

[1] Authors are associate professor and PhD student at Kaunas University of Technology, Faculty of Mechanical Engineering and Design, Department of Materials engineering, Kaunas, Lithuania.
[1] Autori su izvanredni profesor i doktorand Tehnološkog sveučilišta u Kaunasu, Fakultet strojarstva i dizajna, Odjel inženjerstva materijala, Kaunas, Litva.

linski obrađenog drva pri 190 °C, od uzoraka toplinski neobrađenog drva i toplinski obrađenog drva pri 215 °C, od dva uzorka toplinski neobrađenog drva i od uzoraka drva toplinski obrađenoga pri dvije različite temperature. Nakon toga novonastali su spojevi navlaženi i osušeni u klimatskoj komori te su provedena mjerenja dimenzijskih promjena. Zatim su dvjema različitim metodama – metodom transverzalnih vibracija i metodom trotočkastoga statičkog savijanja – ispitana njihova mehanička svojstva. Utvrđen je pozitivan i visok koeficijent korelacije između vrijednosti statičkoga i dinamičkog modula elastičnosti, pri čemu je dinamički modul elastičnosti bio do 16 % veći od statičkoga. Nijedan od slijepljenih spojeva pri navlaživanju i sušenju nije izgubio čvrstoću, što znači da se drvo toplinski obrađeno pri različitim temperaturama može lijepiti. Tako dobiven slijepljeni spoj toplinski obrađenog drva može imati bolja mehanička ili sorpcijska svojstva od masivnog drva.

Ključne riječi: *toplinski obrađena drvo, borovina, smrekovina, mehanička svojstva, nerazorne metode ispitivanja, trotočkasto statičko savijanje, lijepljenje*

1 INTRODUCTION
1. UVOD

Wood is a natural, renewable and environmentally friendly material, which consists mainly of cellulose, hemicellulose, lignin and extractive substances. It is one of the strongest and most widely used organic materials in furniture and construction industry. Although wood is an excellent renewable building material, it has some disadvantages, such as its degradation under outdoor conditions and hygroscopicity. Wood based materials absorb and desorb moisture from the surrounding environment resulting in dimensional instability. Numerous methods have been tested in order to improve the durability and stability of wood dimensions avoiding the use of chemicals. One of the most effective methods used to enhance wood dimensional stability is thermal treatment. (Rowell *et al.,* 2009; Priadi and Hiziroglu, 2013; Akyildiz and Ates, 2008; Bekhta and Niemz, 2003)

Thermal wood processing involves the use of only three components - water, steam and high temperature, and, therefore, makes heated wood an ecofriendly alternative to chemically impregnated wood. During heat treatment, a large number of chemical changes occur, including the esterification of hydroxyl groups and reduction of hemicellulose and the number of accessible OH groups within wood. Consequently, heat treatment can improve the natural quality and properties of wood, such as resistance to biological deterioration. Nevertheless, the level of modification depends on temperature and time of treatment, atmosphere, wood species and its properties, wood initial humidity and dimension of the samples. It is also indicated that heat treated wood is more resistant to natural weathering. Surface damages such as cracking and mould growing on coated heat treated wood were found to be less than on the painted control wood. Although resulting in improved dimensional stability and biological durability, the main drawback of this method is the poor mechanical performance of the final wood product (Korkut and Hiziroglu, 2014; Li *et al.,* 2011; Missio *et al.,* 2015; Tomak *et al.,* 2014).

Heat treatment generally results in an apparent reduction of mechanical properties of the members due to material losses in the cell wall, hemicellulose degradation and modification of long chain molecules. The strength properties begin to deteriorate at temperatures over 150 °C. The wood becomes more brittle, and bending and tensile strength decrease by 10 – 30 %. Therefore, in general heat treated wood would not be an ideal product where high strength properties for constructional applications are desired. However, heat treated wood can be used for aesthetic places such as garden, kitchen, and sauna furniture, cladding on wooden buildings, bathroom cabinets, floor material, musical instruments, ceilings, inner and outer bricks, doors and window joinery, and a variety of other outdoor and indoor wood applications (Korkut *et al.,* 2008; Ozcan, *et al.,* 2012; Korkut 2008).

Some earlier experiments demonstrated that heat treatment did not cause any significant changes in the values of modulus of elasticity. In addition, it was observed that the modulus of elasticity of heat treated specimens was slightly higher than the one of untreated wood and it was determined that the transverse tensile strength of the specimens decreased by 26 % (Santos, 2000; Bal, 2014).

Wood is a biological material with a heterogeneous structure. Therefore, during the analysis of its mechanical properties, the extensive spread of data is obtained. One of the possible solutions is to use a large quantity of specimens and to subject data to statistical processing. Another solution is to apply non-destructive testing methods for the evaluation of mechanical properties. The main advantage provided by this method is that specimens remain intact and there is no need to cut out specimens with certain dimensions. In addition, the use of dynamic methods for the analysis of specimens allows quite accurate determination of their modulus of elasticity (Baltrušaitis, *et al.,* 2010; Santos, 2000).

Currently, there is a lack of information on strength properties of bonded heat treated wood. Therefore, the objective of this study is to develop different systems by bonding natural and thermally modified wood and to evaluate their mechanical and sorption properties.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

Studies were carried out using specimens of spruce and pine wood cut out of planed beams with the following measurements: 250x20x6 mm. Each group contained 20 pieces of specimens. The average density of pine specimens was 595 kg/m^3, and of spruce - 417

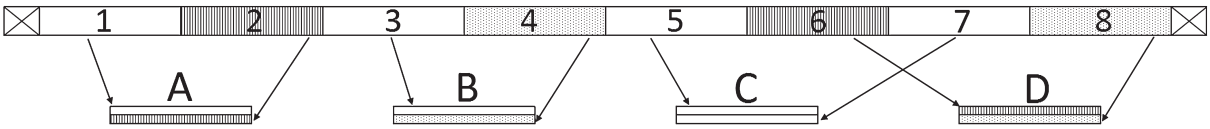


Figure 1 Specimens cutting and bonding scheme. 1, 3, 5, 7 – non heat-treated; 2, 6 – for treatment at the temperature of 190 °C; 4, 8 - for treatment at the temperature of 215 °C; x – cutout edges; A, B, C, D – systems of bonded specimens
Slika 1. Shema rezanja i lijepljenja uzoraka: 1, 3, 5, 7 – toplinski neobrađeni uzorci; 2, 6 – uzorci za toplinsku obradu pri temperaturi 190 °C; 4, 8 – uzorci za toplinsku obradu pri temperaturi 215 °C; x – rubovi za izrezivanje; A, B, C, D – sustavi slijepljenih uzoraka

kg/m^3. Specimens were heated in the air under atmospheric pressure for 2 hours. When specimens have an excessive moisture content (>10 %), wood can develop cracks during the heating process and uneven color after the heating (Akyildiz *et al.,* 2009). In order to prevent this before the beginning of the heating process specimens underwent conditioning at the temperature of 25 ± 2 °C and 35 ± relative humidity of 5 % for 10 days and after that their moisture content was about 8 %. Before the determination of mechanical properties, conditioning was carried out at the temperature of 20 ± 2 °C and relative humidity of 65 ± 5 %.

Subsequently, using a cold press, specimens were bonded with a polyurethane adhesive and the following four different systems, with the following dimensions 250x20x12 mm, were formed: A – unheated specimens and specimens heated at 190 °C, B – unheated specimens and specimens heated at 215 °C, C – unheated specimens and unheated specimens, and D – specimens heated at 190 °C and 215 °C (Figure 1). Bonding conditions were applied according to the specifications of the adhesive manufacturer: the minimum pressure of 0.6 N/mm^2 and bonding time of 60 minutes at the temperature of 20 °C. Specimens moisture content before bonding was as follows: unheated specimens – from 9 % to 9.5 %, heated at 190 °C – about 6 %, heated at 215 °C – about 4 %.

After completing the adhesive bonding process, specimens were moistened at the temperature of 23 °C ± 1 °C and relative humidity of 80 % ± 5 %, and dried at the temperature of 23 °C ± 1 °C and relative humidity of 40 % ± 5 % in a climatic chamber. It took 10 days to complete each cycle, and after then measurements of dimensional changes and weight were carried out. The width of different bonded parts of specimens were measured in order to estimate dimensional stability, to determine how un-heated and heated, at different temperatures, parts of specimens affected each other to establish their mutual dimensional changes.

Then the mechanical properties of newly formed heated wood systems were established, using two different methods: non-destructive method of transverse vibrations and three point static bending test, according to standard EN310. The special test stand (Vobolis and Albrektas, 2007) was used to determine the modulus of elasticity (MOE) on the basis of the non-destructive testing method, which also allowed assessing the mechanical properties of specimens (Figure 2).

For three point static bending test, a universal tensile/bending testing machine was used. During the determination of three point static bending and non-destructive MOE, the load was applied and the sensor was fastened on the unheated side of the specimen.

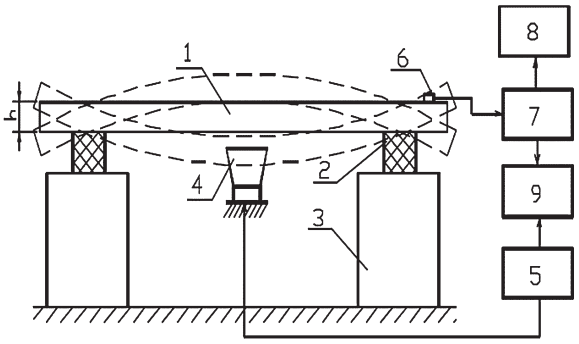


Figure 2 The scheme of the non-destructive MOE test stand: 1 – specimen; 2 – vibration damping material (foam rubber); 3 – massive supports; 4 – loudspeaker; 5 – vibration generator; 6 – sensor; 7 – measuring instrument; 8 – oscillograph; 9 – phase meter
Slika 2. Shema uređaja za nerazorno ispitivanje modula elastičnosti: 1 – uzorak; 2 – materijal za prigušenje vibracija (pjenasta guma); 3 – masivni nosači; 4 – zvučnik; 5 – generator vibracija; 6 – senzor; 7 – mjerni instrument; 8 – osciloograf; 9 – fazni mjerač

Other specimens were prepared to establish the bonding strength: fracture zone was removed and from the remaining two parts, samples of 100 mm length were formed (Figure 3).

One part of the specimen was placed in a dry place, while other underwent moistening and drying cycles. Moistening was carried out in a water bath and drying was performed in a kiln at the temperature of 45 °C ± 2 °C and relative humidity of 10 % ± 2 %. It took 7

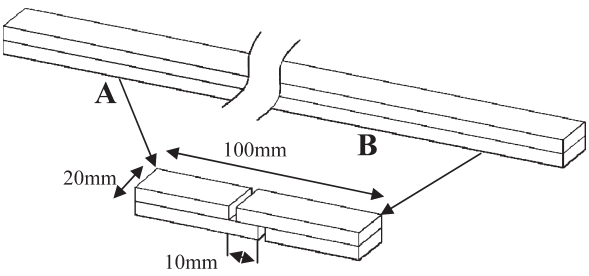


Figure 3 The scheme of preparation of specimens for bonding strength. A – group for moistening and drying, B – control group
Slika 3. Shema pripreme uzoraka za ispitivanje čvrstoće slijepljenog spoja. A – skupina za navlaživanje i sušenje, B – kontrolna skupina

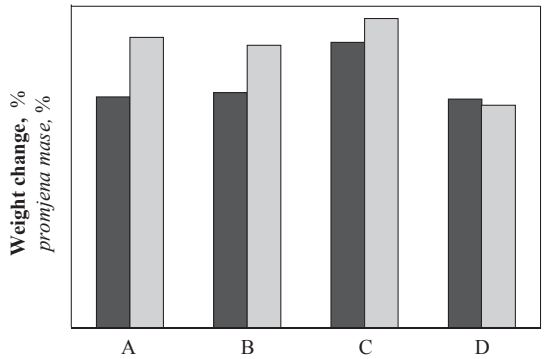
days for each cycle. The shear test of the bond line was performed on the basis of the standard EN205 using a universal tensile/bending testing machine.

Finally, statistical analysis of data (Pekarskas, 2007) was performed.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The obtained results demonstrate that thermal modification influenced the sorption properties and dimensional stability of specimens. It was also established that thermal modification had a greater impact on pine specimens. This is related to wood density - higher density wood is known to be less resistant to the effect of heat. The obtained data are in line with the literature data (Chaouch *et al*., 2010). Figure 2 shows a change in the weight of specimens during the moistening and drying cycles.

It was determined that, during the moistening and drying cycle, the greatest shift in weight occurred in the case of spruce specimens of group C. There was an almost identical change in the weight of the spruce specimens of groups A, B and D. Such result may have been influenced by the density of specimens: higher density wood contains more cellulose, which is a hydrophilic wood component. This means that higher density wood contains more free OH groups to which water molecules are connected when wood undergoes moistening (Jakimavičius, 2008). The density of the section of group D specimens, which was heated at temperatures of 190 °C and 215 °C, was only 0.3 % and 0.7 % lower, respectively, than the density of the unheated section of group B specimens. The density of the section of group B specimens, which was heated at a temperature of 215 °C, was 5.4 % lower than the density of the section of group D specimens, which was heated at the same temperature.



	A	B	C	D
Spruce	4.1	4.2	5.1	4.1
Pine	5.2	5.1	5.5	4.0

Figure 4 The average change in the weight of specimens, %: A – unheated and heated at 190 °C, B – unheated and heated at 215 °C, C – unheated and unheated, D – heated at 190 °C and 215 °C

Slika 4. Prosječna promjena mase uzoraka, %: A – toplinski neobrađen i toplinski obrađen uzorak drva pri 190 °C, B – toplinski neobrađen i toplinski obrađen uzorak drva pri 215 °C, C – dva toplinski neobrađena uzorka drva, D – toplinski obrađeni uzorci drva pri 190 °C i 215 °C

When analyzing a change in the weight of pine specimens, one can observe that the largest and smallest shift in weight occurred in the case of the specimens of groups C and D, respectively (Figure 4). Meanwhile, the changes were almost identical in the weight of the specimens of groups A and B. It can be stated that the section of the specimen, which was heated at a temperature of 215 °C and included in system B, did not have any significant impact on sorption properties in comparison to system A. Tables 1 and 2 provide data about a shift in the width measurement of the different sections of bonded specimens.

When comparing the change in the measurements of the unheated section, it was found that the smallest shift in width occurred in the case of specimens of unheated group A. The change in the width of the unheated sections of group A of specimens of spruce and pine was ~1.3 and 1.06 - 1.18 times smaller, respectively, than that of groups B and C. The smallest shift in the width of the section heated at a temperature of 190 °C was also recorded in the case of system A. The change in the width of the section of this system, heated at a temperature of 190 °C, was 1.43 and 1.16 times smaller, respectively, in the case of spruce and pine specimens. In the case of specimens of spruce and pine, the most stable section of the specimen heated at a temperature of 215 °C was in systems B and D, respectively. However, in terms of width change, the difference in the sections of spruce specimens heated at a temperature of 215 °C (1.4-fold) was greater than the one of pine specimens (1.1-fold). In summary, it can be concluded that the lowest and highest dimensional stability was recorded in the case of groups C and A of both types of wood specimens, respectively

Having established the MOE of specimens, it was determined that values obtained by means of the

Table 1 The average shift in the measurement of spruce specimens, %

Tablica 1. Prosječna promjena dimenzija smrekovih uzoraka, %

System *Spoj*	**Non-heated part** *Toplinski neobrađeni dio*	**190 °C part** *Toplinski obrađeni dio pri 190 °C*	**215 °C part** *Toplinski obrađeni dio pri 215 °C*
A	0.82	0.67	
B	1.09		0.61
C	1.10		
D		0.96	0.85

Table 2 The average shift in the measurement of pine specimens, %

Tablica 2. Prosječna promjena dimenzija borovih uzoraka, %

System Spoj	**Non-heated part** *Toplinski neobrađeni dio*	**190 °C part** *Toplinski obrađeni dio pri 190 °C*	**215 °C part** *Toplinski obrađeni dio pri 215 °C*
A	1.06	0.86	
B	1.12		1.05
C	1.25		
D		1.00	0.94

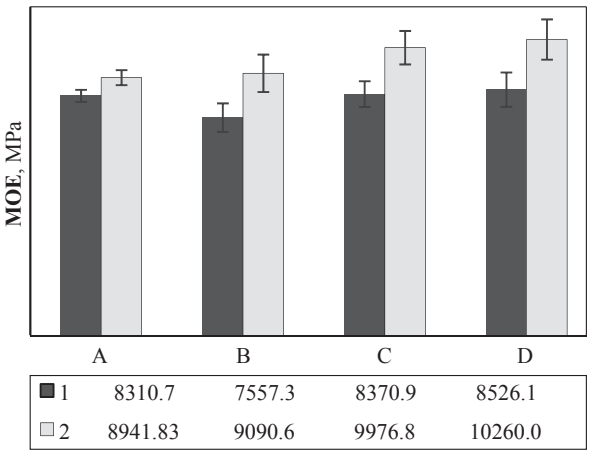


Figure 5 MOE of spruce specimens, MPa: 1 – static MOE, 2 – dynamic MOE. A – unheated and heated at 190 °C, B – unheated and heated at 215 °C, C – unheated and unheated, D – heated at 190 °C and 215 °C

Slika 5. Modul elastičnosti smrekovine, MPa: 1 – statički modul elastičnosti, 2 – dinamički modul elastičnosti; A – toplinski neobrađen i toplinski obrađen uzorak drva pri 190 °C, B – toplinski neobrađen i toplinski obrađen uzorak drva pri 215 °C, C – dva toplinski neobrađena uzorka drva, D – toplinski obrađeni uzorci drva pri 190 °C i 215 °C

dynamic method are 7 – 16 % higher than the values obtained by means of the static method. This was expected, because it is well know that the dynamic MOE values are higher than the static MOE values. Other researches (Shan-qing and Feng, 2007; Divos and Tanaka, 2005; Nzokou *et al.,* 2006) also obtained similar results. Figures 5 and 6 present the values of the MOE of spruce and pine specimens, which were obtained using the static and dynamic methods.

The obtained data reveal that, when spruce specimens were researched by means of both the static and dynamic methods, the highest values of the MOE were obtained in the case of specimens of group D. The lowest dynamic and static values of the MOE were established in the case of specimens of group A and B, respectively. However, the dynamic values of the MOE of specimens of group A and B differ insignificantly - only by 1.7 %. In addition, when the statistical analysis of data was performed, two values were excluded as statistically unreliable from the calculations of the MOE of specimens of group A and such value was removed from specimens of group B. This also may have influenced such result. The highest value of the MOE, obtained in the case of specimens of group D, can be explained by the fact that prior to heating, the MOE of the unbonded specimens of this group, which was measured using the dynamic method, was 1 % higher in comparison to specimens of group C. When the MOE is measured by means of the dynamic method after heating and bonding, a similar result is obtained - the MOE of group D specimens is 2.8 % higher in comparison to group C specimens. Denser and dryer wood is known to have better mechanical properties in most cases (Spatz et al., 2013). The equilibrium moisture content of heated wood is lower in comparison to unheated wood, thus this also may have had an impact on such results.

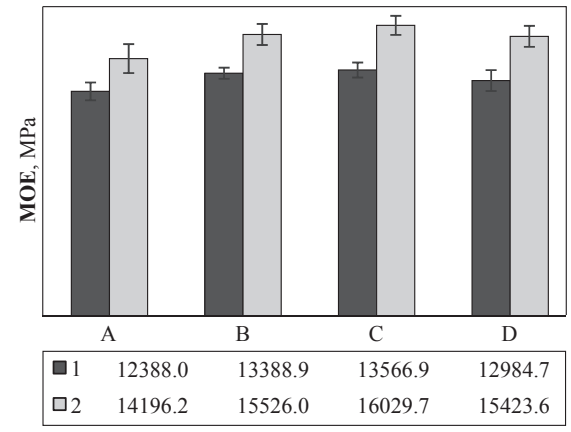


Figure 6 MOE of pine specimens, MPa: 1 – static MOE, 2 – dynamic MOE. A – unheated and heated at 190 °C, B – unheated and heated at 215 °C, C – unheated and unheated, D – heated at 190 °C and 215 °C

Slika 6. Modul elastičnosti borovine, MPa: 1 – statički modul elastičnosti, 2 – dinamički modul elastičnosti; A – toplinski neobrađen i toplinski obrađen uzorak drva pri 190 °C, B – toplinski neobrađen i toplinski obrađen uzorak drva pri 215 °C, C – dva toplinski neobrađena uzorka drva, D – toplinski obrađeni uzorci drva pri 190 °C i 215 °C

When pine specimens were analyzed, it was found that there was a coincidence between the highest and lowest values of the MOE, which was determined using both the static and dynamic method. The highest value of the MOE was recorded in the case of specimens of group C and the lowest value of the MOE was registered in the case of specimens of group A. The values of the MOE of these groups, which were established by means of the static and dynamic method, differed by 8.7 % and 11.4 %, respectively. The lowest value of the MOE of specimens of group A can be explained by the fact that, before the heating and bonding, this group of specimens had the lowest value of the MOE, which was determined by the dynamic method, in all specimens of pine: in comparison to specimens of group C, the MOE of specimens of group A was ~8.1 % lower.

In order to evaluate the reliability of the MOE data, the coefficient of variation was calculated. The obtained data demonstrate that the results are reliable and that their dissemination is insignificant. In the case of the values of the MOE of spruce and pine specimens, which were established by means of the static method, the coefficient of variation was 6.5 - 12.5 % and 3.9 - 7.9 %, respectively. In the case of the values of the MOE of spruce and pine specimens, which were established using the dynamic method, the coefficient of variation was 4.5 - 10.9 % and 5.0 - 9.1 %, respectively.

In order to compare the statically and dynamically obtained values of the MOE of specimens, a correlation coefficient was determined (Table 3). Although, there is a 7 – 16 % difference between the statically and dynamically obtained values of the MOE of specimens, the correlation coefficients obtained between them display a strong relationship. Only the correlation coefficient of specimens of group D spruce was ~12 % lower in comparison to the correlation coefficients of other specimens. However, it is still included in the concept of a

Table 3 Correlation coefficient between static and dynamic MOE values
Tablica 3. Koeficijent korelacije između vrijednosti statičkoga i dinamičkog modula elastičnosti

Correlation coefficient / *Koeficijent korelacije*				
Group / *Skupina*	A	B	C	D
Spruce / *Smrekovina*	0.85	0.86	0.88	0.76
Pine / *Borovina*	0.84	0.88	0.88	0.83

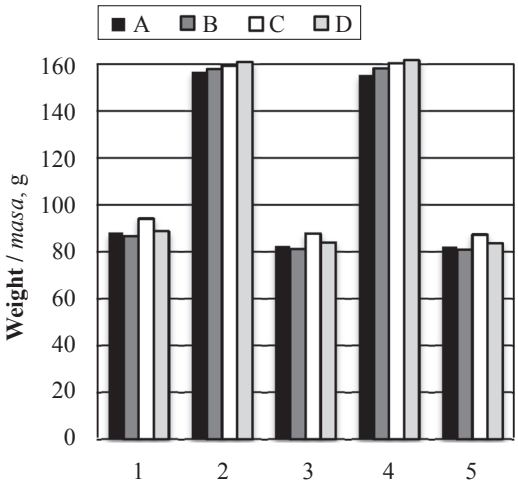


Figure 7 Spruce weight after moistening–drying cycles, g: 1 – primary, 2, 4 – after moistening, 3, 5 – after drying. A – unheated and heated at 190 °C, B – unheated and heated at 215 °C, C – unheated and unheated, D – heated at 190 °C and 215 °C
Slika 7. Masa smrekovih uzoraka nakon ciklusa navlaživanja i sušenja, g: 1 – prije navlaživanja; 2, 4 – nakon navlaživanja; 3, 5 – nakon sušenja; A – toplinski neobrađen i toplinski obrađen uzorak drva pri 190 °C, B – toplinski neobrađen i toplinski obrađen uzorak drva pri 215 °C, C – dva toplinski neobrađena uzorka drva, D – toplinski obrađeni uzorci drva pri 190 °C i 215 °C

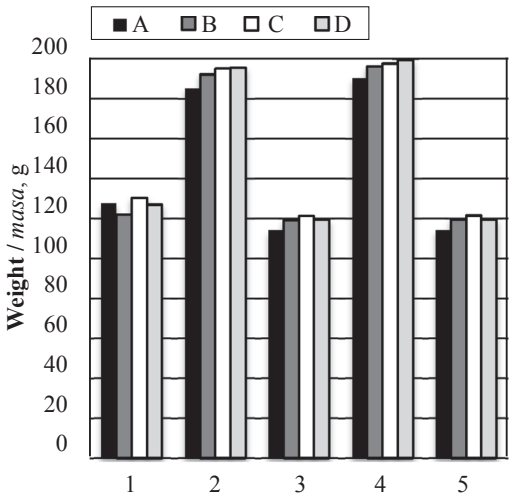


Figure 8 Pine weight after moistening – drying cycles, g: 1 – primary, 2, 4 – after moistening, 3, 5 – after drying. A – unheated and heated at 190 °C, B – unheated and heated at 215 °C, C – unheated and unheated, D – heated at 190 °C and 215 °C
Slika 8. Masa borovih uzoraka nakon ciklusa navlaživanja i sušenja, g: 1 – prije navlaživanja; 2, 4 – nakon navlaživanja; 3, 5 – nakon sušenja; A – toplinski neobrađen i toplinski obrađen uzorak drva pri 190 °C, B – toplinski neobrađen i toplinski obrađen uzorak drva pri 215 ° C, C – dva toplinski neobrađena uzorka drva, D – toplinski obrađeni uzorci drva pri 190 °C i 215 °C

strong correlation relationship. The correlation between static and dynamic MOE values were compared by several authors and strong correlation was also established between these two MOE values (Perstorper 1994; Jugo and Ozarska 1996).

After the cycle of soaking and drying, none of the bonded specimens became loosened, though the weights of some groups of specimens changed nearly twice (Figure 7 and 8). The obtained data reveal that the weights of spruce specimens shifted 1.3 – 1.5 times

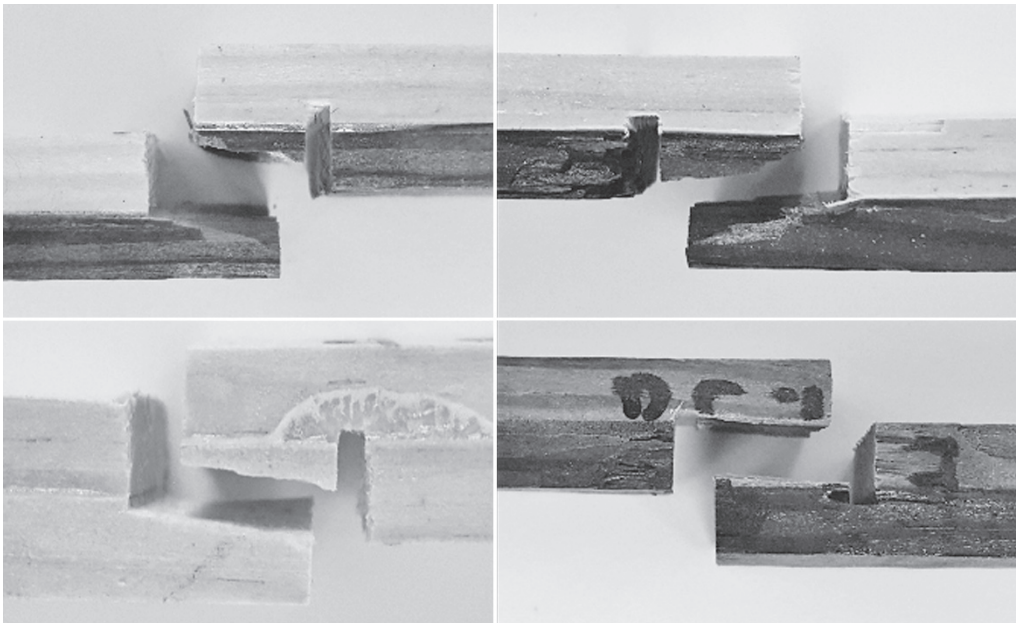


Figure 9 Specimens after bond line test
Slika 9. Uzorci nakon ispitivanja čvrstoće slijepljenog spoja

Table 4 Part which failed, %: A – unheated and heated at 190 °C, B – unheated and heated at 215 °C, C – unheated and unheated, D – heated at 190 °C and 215 °C
Tablica 4. Udjel uzoraka na kojima je nastao lom, %: A – toplinski neobrađen i toplinski obrađen uzorak drva pri 190 °C, B – toplinski neobrađen i toplinski obrađen uzorak drva pri 215 ° C, C – dva toplinski neobrađena uzorka drva, D – toplinski obrađeni uzorci drva pri 190 °C i 215 °C

	Spruce / *Smrekovina*				**Pine** / *Borovina*			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Unheated / *Toplinski neobrađeno*	7.5 %	0 %	100 %		5 %	0 %	100 %	
Heated at 190 °C / *Toplinski obrađeno pri 190 °C*	92.5 %			40 %	95 %			22.5 %
Heated at 215 °C / *Toplinski obrađeno pri 215 °C*		100 %		60 %		100 %		77.5 %

more than the ones of pine. This is related to wood density. Similar results were obtained in previous research (Navickas and Albrektas, 2013).

Having performed the testing of the strength of the bond line of specimens, it was established that the specimens of all groups cracked through the wood (figure 9). None of the specimens cracked through the bond line, therefore it can be claimed that a polyurethane adhesive is suitable for the bonding of both natural and thermally modified wood.

Spruce and pine specimens of group A and B mostly failed in the heat treated part, while specimens of group D mostly failed in the part heated at 215 °C (Table 4).

4 CONCLUSIONS
4. ZAKLJUČAK

1. During the cycle of moistening and drying, the highest and lowest dimensional stability was established in the case of groups A and C of both types of wood, respectively.
2. The dynamically determined MOE was up to 16 % higher than the statically determined MOE. However, the correlation coefficient between these values was 0.76 - 0.88.
3. The highest value of the MOE was statically and dynamically established in the case of spruce specimens of group D and pine specimens of group C.
4. During the cycle of soaking and drying, the weights of spruce and pine specimens changed by 69 – 96 % and 45 – 67 %, respectively. However, none of the bonded specimens became loosened.
5. When performing the testing of the strength of the bond line of specimens, 100 % of specimens cracked through the wood, which implies that the bond line was stronger.
6. PUR adhesives are suitable for ensuring reliable bonding of wood subjected to thermal modification at different temperatures.

5 REFERENCES
5. LITERATURA

1. Akyildiz, M. H.; Ates, S., 2008: Effect of Heat Treatment on Equilibrium Moisture Content (EMC) of Some Wood Species in Turkey. Research Journal of Agriculture and Biological Sciences, 4(6): 660-665.
2. Akyildiz, M. H., Ates, S., Ozdemir, H., 2009: Technological and chemical properties of heat-treated Anatolian black pine wood. African Journal of Biotechnology, 8(11): 2565-2572.
3. Bal, C. B., 2014: Some physical and mechanical properties of thermally modified juvenile and mature black pine wood. European Journal of Wood and Wood Products, 72(1): 61-66. https://doi.org/10.1007/s00107-013-0753-9.
4. Baltrušaitis, A.; Ukvalbergienė, K.; Pranckevičienė, V., 2010: Nondestructive evaluation of viscous-elastic changes in ammonia-modified wood using ultrasonic and vibrant techniques. Wood Research, 55(4): 39-50.
5. Bekhta, P.; Niemz, P., 2003: Effect of high temperature on the change in color, dimensional stability and mechanical properties of spruce wood. Holzforschung, 57: 539-546. https://doi.org/10.1515/HF.2003.080.
6. Broch, J. T., 1984: Mechanical Vibrations and Shock Measurements. Grostrum, K. Larsen and Son.
7. Chaouch, M.; Petrissans, M.; Petrissans, A.; Gerardin, P., 2010: Use of wood elemental composition to predict heat treatment intensity and decay resistance of different softwood and hardwood species. Polymer Degradation and Stability, 95: 2255-2259. https://doi.org/10.1016/j.polymdegradstab.2010.09.010.
8. Divos, F.; Tanaka, T., 2005: Relation between static and dynamic modulus of elasticity of wood. Acta Silvatica & Lignaria Hungarica, 1: 105-110.
9. Jakimavičius, Č., 2008: Medienotyra. Kaunas (in Lithuanian).
10. Jugo, I.; Ozarska, B., 1996: Nondestructive evaluation of properties of reconstituted wood products used in Australia. 10th International Symposium on Nondestructive Testing of Wood. Swiss Federal Institute of Technology, Lausanne, Switzerland.
11. Korkut, S., 2008: The effects of heat treatment on some technological properties in Uludağ fir (Abies bornmuellerinana Mattf.) wood. Building and environment, 43: 422-428. https://doi.org/10.1080/07373930903530162.
12. Korkut, S. D.; Hiziroglu, S., 2014: Experimental Test of Heat Treatment Effect on Physical Properties of Red Oak (*Quercus falcate* Michx.) and Southern Pine (*Pinus taeda* L.). Materials, 7: 7314-7323. https://doi.org/10.3390/ma7117314.
13. Korkut, S. D.; Korkut, S.; Dilik, T., 2008: Effect of Heat Treatment on Some Mechanical Properties of Laminated Window Profiles Manufactured Using Two Types of Adhesives. International Journal of Molecular Sciences, 9: 454-463. https://doi.org/10.3390/ijms9040454.
14. Li, X. J.; Cai, Z. Y.; Mou, Q. Y.; Wu, Y. Q.; Liu, Y., 2011: Effects of heat treatment on some physical properties of Douglas Fir (*Pseudotsuga Menziesii*) wood. Advanced Materials Research, 197-198: 90-95. https://doi.org/10.4028/www.scientific.net/AMR.197-198.90.
15. Missio, L. A.; Mattos, D. B.; de Cademartori, H. G. P.; Pertuzzatti, A.; Conte, B.; Gatto, A. D., 2015: Thermo-

chemical and physical properties of two fast-growing eucalypt woods subjected to two-step freeze–heat treatments. Thermochimica Acta, 615: 15-22. https://doi.org/10.1016/j.tca.2015.07.005.
16. Navickas, P.; Albrektas, D., 2013: Effect of Heat Treatment on Sorption Properties and Dimensional Stabillity of Wood. Materials Science, 9(3): 291-294. https://doi.org/10.5755/j01.ms.19.3.5239.
17. Nzokou, P.; Freed, J.; Kamden, D. P., 2006: Relationship between non destructive and static modulus of elasticity of commercial wood plastic composites. Holz als Roh- und Werkstoff, 64: 90-93. https://doi.org/10.1007/s00107-005-0080-x.
18. Ozcan, S.; Ozcifci, A.; Hiziroglu, S.; Toker, H., 2012: Effects of heat treatment and surface roughness on bonding strength. Construction and Building Materials, 33: 7-13. https://doi.org/10.1016/j.conbuildmat.2012.01.008.
19. Pekarskas, V., 2007: Matematinė inžinerinio eksperimento teorija (Mathematical theory of engineering experiment). Šiauliai (in Lithuanian).
20. Perstorper, M., 1994: Strength and stiffness prediction of timber using conventional and dynamic methodes. Proceedings First European Symposium on Nondestructive evaluation of Wood. University of Sopron, Sopron, Hungary.
21. Priadi, T.; Hiziroglu, S., 2013: Characterization of heat treated wood species. Materials and Design, 49: 575-582. https://doi.org/10.1016/j.matdes.2012.12.067.
22. Rowell, M. R.; Ibach, E. R.; McSweeny, J.; Nilsson, T., 2009: Understanding decay resistance, dimensional stability and strength changes in heat-treated and acetylated wood. Wood Material Science & Engineering, 1(2): 14-22. https://doi.org/10.1080/17480270903261339.
23. Santos, J. A., 2000: Mechanical behavior of Eucalyptus wood modified by heat. Wood Science and Technology, 34: 39-43. https://doi.org/10.1007/s002260050006.
24. Shan-qing, L.; Feng, F., 2007: Comparative study on three dynamic modulus of elasticity and static modulus of elasticity for Lodgepole pine lumber. Journal of Forestry Research, 18(4): 309-312. https://doi.org/10.1007/s11676-007-0062-4.
25. Spatz, C. H.; Pfisterer, J., 2013: Mechanical Properties of Green Wood and Their Relevance for Tree Risk Assessment. Arboriculture & Urban Forestry, 39(5): 218-225.
26. Timoshenko, S., 1985: Vibration problems in engineering. Mashinostrienie, Moscow.
27. Tomak, D. E.; Ustaomer, D.; Yildiz, S.; Pesman, E., 2014: Changes in surface and mechanical properties of heat treated wood during natural weathering. Measurement, 53: 30-39. https://doi.org/10.1016/j.measurement.2014.03.018.
28. Vobolis, J.; Albrektas, D., 2007: Comparison of Viscous Elastic Properties in Wood of Leaf and Coniferous Tree. Material Science, 13(2): 147-151.

Corresponding address:

Assoc. Prof. DARIUS ALBREKTAS, Ph.D.

Kaunas University of Technology
Faculty of Mechanical Engineering and Design
Department of Materials engineering
Studentu st. 56, LT – 51424 Kaunas, LITHUANIA
e-mail: Darius.Albrektas@ktu.lt

Karlo Beljan[1], Stjepan Posavec[1], Silvije Orsag[2], Krunoslav Teslak[1]

Simulation Model for Prediction of Timber Assortment Price Trends in Croatia - a Case Study of Brinje Forest Office

Simulacija trendova cijena šumskih sortimenata u Hrvatskoj na primjeru Šumarije Brinje

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 4. 10. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*79*
doi:10.5552/drind.2017.1643

ABSTRACT • *This paper presents the results of a simulation model for the prediction of sale prices of common beech (Fagus sylvatica L.) and silver fir (Abies alba Mill.) assortments in the case study of Brinje Forest Office in Croatia. The survey covers the future time frame of 140 years (starting from the year 2013). The database of realized selling prices of assortments in the period from 1997 to 2013 was used in this research. On the basis of statistical analysis of realized selling prices in the past and using the Monte Carlo method, a simulation of future prices with 500, 100, 50 and 30 simulation repetitions was made. The result of this research is the methodological basis for future forest management economic planning in the case study of Brinje Forest Office, as well as in other case studies with similar forest management characteristics. Although, in this research, timber prices applicable in Croatia have been used, the same methods could be applied in other countries, too.*

Key words: *timber assortment price, price fluctuations, Monte Carlo simulation*

SAŽETAK • *Članak se bavi prognoziranjem prodajnih cijena sortimenata obične bukve (Fagus sylvatica L.) i obične jele (Abies alba Mill.). Istraživanje se odnosi na studij slučaja Šumarije Brinje u Republici Hrvatskoj i obuhvaća buduće vremensko razdoblje od 140 godina (počevši od 2013.). U istraživanju je prikupljena baza podataka o ostvarenim prodajnim cijenama sortimenata drva u razdoblju 1997. – 2013. Na temelju statističke analize ostvarenih prodajnih cijena u prošlosti te primjenom metode Monte Carlo, napravljena je simulacija budućih cijena s 500, 100, 50 i 30 simulacijskih ponavljanja. Rezultat ovog istraživanja svojevrsna je metodološka podloga za buduće ekonomsko planiranje gospodarenja šumama Šumarije Brinje, kao i za ostale studije slučaja sličnih šumskogospodarskih obilježja. Iako se cijene sortimenata drva odnose na Republiku Hrvatsku, prikazana se metodologija može primijeniti i u ostalim državama.*

Ključne riječi: *cijene sortimenata drva, prognoziranje cijena, simulacija Monte Carlo*

[1] Authors are as listed postdoctoral researcher, associate professor, assistant professor at University of Zagreb, Faculty of Forestry, Department of Forest Inventory and Management, Zagreb, Republic of Croatia. [2]Author is full professor tenure at University of Zagreb, Faculty of Economics and Business, Department of Managerial Economics, Zagreb, Republic of Croatia.

[1] Autori su, redom, poslijedoktorand, izvanredni profesor i docent Šumarskog fakulteta Sveučilišta u Zagrebu, Zavod za izmjeru i uređivanje šuma, Zagreb, Hrvatska. [2]Autor je redoviti profesor Ekonomskog fakulteta Sveučilišta u Zagrebu, Katedra za ekonomiku poduzeća, Zagreb, Hrvatska.

1 INTRODUCTION
1. UVOD

The knowledge, i.e. a more precise estimate of possible future prices of goods and services is very important for the economics of forest management planning (Gong *et al.*, 2005, Linehan and Jacobson, 2005, Pukkala, 2015), similarly as for other economic branches. Adequate investment analysis is not possible without the involvement of elements of risk and uncertainty during the planning of a business process. Investing in the present is necessarily associated with a certain degree of risk and uncertainty that the expected effect of the project will not be achieved in the future or will be achieved with a certain degree of variability of results (Knoke *et al.*, 2001; Kangas *et al.*, 2008; Klemperer, 2003; Klemperer, 2001; Linehan and Jacobson, 2005; Gong *et al.*, 2005). Forest management plans, whose finances are based on the future price fluctuations, are more realistic than those with fixed future prices of products. Therefore, Knoke and Wurm (2006) and Hildebrandt and Knoke (2011) recommend using only this kind of planning. Price fluctuation of timber assortments in the future makes a specific background in studies dealing with long-term economic forest management planning, e. g. (Knoke *et al.*; 2001, Knoke and Plusczyk; 2001, Haight, 1990; Brazee and Mendelsohn, 1988; Knoke and Wurm, 2006; Beljan, 2015; Leskinen and Kangas, 1998). However, Knoke *et al.* (2001) and Knoke *et al.* (2005) emphasize that most of the research in forest economics do not take into account the risk of future price changes.

Under ideal conditions (market competition), the price of a product primarily depends on the relationship between supply and demand on the market (market-based approach). In most cases, the price changes are the result of a large number of other interactions on the market (Haight, 1990; Leefers and Ghani, 2014). In planned economy, prices will not fluctuate at all, while in market economy this is not the case. The forecast of future price of timber assortments is not a deterministic model and it is prone to certain deviations from the estimated value, while it depends on a large number of factors (Leefers and Ghani, 2014; Leskinen and Kangas, 1998). Based on the changes (fluctuations) of unit-prices of assortments in the past, it is possible, with certain degree of certainty, to assume the fluctuations of these prices in future (Knoke *et al.*, 2005; Knoke *et al.*, 2001; Clasen *et al.*, 2011; Beljan, 2015; Orsag and Dedi, 2011; Linehan and Jacobson, 2005; Pukkala, 2015). The risk of price changes is reflected in the standard deviation of past price fluctuations and it is a generally accepted measure of financial risk (Clasen *et al.*, 2011; Knoke and Wurm, 2006; Klemperer, 2003). The smaller the standard deviation, the lesser is the investment risk, and, therefore, the lower is the risk of price changes (fluctuations). For adequate analysis, it is first necessary to take into account a longer time series of timber sale prices from the past sorted by assortments. For this purpose, the Monte Carlo method is widely used to describe the future stochastic processes including the prediction of future timber assortment prices (Knoke *et al.*, 2001; Knoke and Plusczyk, 2001; Knoke *et al.*, 2005; Waller *et al.*, 2003).

The aim of this paper is the forecast of future selling prices of assortments of common beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) based on the example of Brinje Forest Office in the Republic of Croatia. The study includes the future time frame of 140 years (starting from the year 2013) and can serve as the basis for the long-term planning of forest management with the emphasis on economics.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Research site
2.1. Objekt istraživanja

The research site is located in the hilly area of Croatia (Brinje Forest Office) and covers an area of 18 019.36 ha divided into 7 Management Units. The forest is state owned and managed as selective beech-fir forest with average allowable cut of 45 016 $m^3 \cdot year^{-1}$ (the average in 1997-2013).

Table 1 shows descriptive statistical analyses of the data on selling prices for timber assortments of common beech and silver fir of Brinje Forest Office (Croatia) for the period 1997-2013. These data are owned by Croatian Forests Ltd. and are not shown in this research. It must be mentioned that in the research period the realized selling prices had notably small fluctuations with a tendency not to change. The most valuable timber assortments, according to the pricelist of Croatian Forests Ltd. (HŠ, 1997-2013), achieved the highest selling price. The analyzed time series of selling prices was limited to 17 years (data available for the 17-year period), but part of the data for individual assortments were made of 'shorter' time series because in certain years some assortments were not produced.

In the observed period (1997-2013), silver fir veneer logs achieved the highest selling price (114.55 $EUR \cdot m^{-3}$), while the lowest selling price was achieved for common beech firewood (OM) (12.61 $EUR \cdot m^{-3}$). The standard deviation for beech assortments (V, PV) is 19.18 $EUR \cdot m^{-3}$, while for silver fir assortments (TR) it totals 12.87 $EUR \cdot m^{-3}$. In total, standard deviation for common beech and silver fir assortments amounts to approx 3.75 $EUR \cdot m^{-3}$ (Table 1).

2.2 Applied methods
2.2. Metoda rada

The simulation of future price fluctuations is based on the assumption of normal distribution, where the variability of results, described with standard deviation and the average price in the past, are observed (Clasen *et al.*, 2011; Knoke *et al.*, 2001; Beljan, 2015; Orsag and Dedi, 2011). Past price fluctuations for every assortment separately are linked with feedback connections that have to be respected in future simulations (Knoke *et al.*, 2001; Knoke *et al.*, 2005; Beljan, 2015; Pukkala, 2015; Leskinen and Kangas, 1998). In other words, if the prices of certain assortments were simu-

Table 1 Results of descriptive statistics of selling prices of silver fir and common beech (1997-2013) for Brinje Forest Office (middle exchange rate of Croatian National Bank on 7/10/2015 1 EUR=7.62 HRK)
Tablica 1. Rezultati deskriptivne statistike ostvarenih prodajnih cijena jelovine i bukovine (1997. – 2013.) za Šumariju Brinje (srednji tečaj HNB-a 7, listopada 2015 : 1 EUR = 7,62 HRK)

Species *Vrsta drva*	**Assortment*** *Sortiment*	**Time series** *Vremenska serija* years / *god.*	**Average** *Prosječna vrijednost* EUR·m^{-3}	**Minimum** *Najmanja vrijednost* EUR·m^{-3}	**Maximum** *Najveća vrijednost* EUR·m^{-3}	**Standard deviation** *Standardna devijacija* EUR·m^{-3}
Fagus sylvatica L. Common Beech *bukva*	*V*	15	104.13	80.31	154.66	19.09
	PV	17	81.28	53.41	117.71	19.18
	I	17	55.12	51.97	58.66	1.75
	II	17	40.67	40.01	41.73	0.53
	III	17	28.88	25.98	30.10	1.08
	TR	17	29.31	17.99	33.07	4.91
	LM	17	21.23	12.61	30.97	4.85
	OM	10	20.80	12.34	29.66	5.09
	altogether	17	30.85	24.92	39.07	3.76
Abies alba Mill. Silver Fir / *jela*	V	7	114.55	109.58	117.05	2.49
	I	17	67.66	57.52	74.67	4.18
	II	17	48.87	43.17	52.49	2.69
	III	17	31.17	29.17	32.81	1.32
	TR	8	23.74	14.57	54.47	12.87
	LM	11	18.30	10.70	25.07	4.01
	OM	6	22.57	13.65	27.69	6.18
	altogether	17	35.31	26.25	40.81	3.75

*V – Veneer / *furnirski trupci*, PV – Peeled veneer (beech) / *trupci za ljušteni furnir*, I – 1st class sawlogs / *pilanski trupci I. klase*, II – 2nd class sawlogs / *pilanski trupci II. klase*, III – 3rd class sawlogs / *pilanski trupci III. klase*, TR – Thin roundwood / *tanka oblovina*, LM – Long-meter firewood / *višemetarsko ogrjevno drvo*, OM – One-meter firewood / *jednometarsko ogrjevno drvo*

lated in the future independently of each other, in their ultimate sum (at some point in the future), wrong values would be obtained. Therefore, first it is necessary to mathematically describe feedback connections (univariate linear regression) between one type of assortment of one tree species in relation to all other assortments of both tree species (Knoke *et al.*, 2001; Knoke *et al.*, 2005; Beljan, 2015). The assortment that is taken as standard (independent variable) is, in principle, one of the most produced, and its distribution of achieved selling prices is described by normal distribution (Knoke *et al.*, 2001; Knoke *et al.*, 2005; Clasen *et al.*, 2011). Shapiro-Wilks test (Shapiro and Wilk, 1965) was used for a test of normality and Durbin-Watson (Durbin and Watson, 1971) test for a test of autocorrelation. After the definition of the independent variable, a univariate linear regression analysis was made in relation to other types of assortments of both tree species.

Univariate linear regression analysis was done with *Statistica 8* software (StatSoft, 2007) using the expression according to Knoke *et al.* (2005):

$$p_{assort} = a + b \cdot p_{indep.\ variable} \quad (1)$$

p_{assort} – achieved selling price of assortment
$p_{independent\ variable}$ – achieved selling price of beech long-meter firewood (LM) assortment
a,b – univariate linear regression analysis coefficient

In this way, the feedback connections between the independent variable and other common beech and silver fir assortments (dependent variables) were determined.

Future simulated price fluctuation was made by using Monte Carlo simulation in Excel 2007. This method used an assumed normal distribution, a series of random numbers, the arithmetic mean and standard deviation from past data (Knoke *et al.*, 2005; Waller *et al.*, 2003; Hildebrandt and Knoke, 2011; Nana and Lu, 2013). The expression according to Clasen *et al.* (2011) was used:

$$p_{independent\ variable} = NORMINV\ (probability;\ mean;\ SD) \quad (2)$$

$p_{independent\ variable}$ – simulated price of beech long-meter firewood (LM) assortment
NORMINV –function name
probability --> RAND( ) – function that generates random numbers
mean - arithmetic mean
SD - standard deviation

Part of the function *probability* is replaced with function *RAND( )* to generate random numbers. The arithmetic mean and standard deviation refer to past prices, and Monte Carlo simulations assume their future values.

The process was first completed for the beech long-meter firewood (LM) assortment (Equation 2). In the same way, in the second step the simulation of prices for other assortments was made, but the feedback connections (the results of univariate linear regression analysis) were included in the Monte Carlo simulation using the expression according to (Clasen *et al.*, 2011):

$$p_{assort} = NORMINV\ (RAND(\ );\ a + b \cdot p_{indep.\ variable};\ SD) \quad (3)$$

p_{assort} – simulated price of assortment
RAND( ) – function that generates random numbers
$p_{independent\ variable}$ – simulated selling price of beech long-meter firewood (LM) assortment

a,b – univariate linear regression analysis coefficient
SD – standard deviation

The process of price simulation of each assortment was repeated 500, 100, 50 and 30 times and, on this basis, an adequate number of simulations were selected. Using the described method, the expected selling price of each assortment in every future period (for each year) was obtained.

Investigation time frame was 140 years since, according to Beljan (2015), this is the minimum time needed to establish a normal (theoretical) forest and to economically and adequately compare two basic forest management practices (even aged and selective) in the case study of Brinje Forestry Office.

3 RESULTS
3. REZULTATI

The normal distribution (Gauss, 1809) was compared with the distribution of the past selling prices of all assortments of common beech and silver fir. The distribution of selling prices of common beech long-meter firewood (LM) is closest to the normal distribution, which can be seen from *p* values (significance level $p<0.05$) (Figure 1). Also, Durbin-Watson two-sided test showed that there was no first-order autocorrelation problem for common beech long-meter firewood (DW=1.7595, $p= 0.4505$).

Figure 1*a* shows the LM assortment of common beech as the best representative of the normal distribution and its deviation from the normal distribution using *Normal P-Plot* (Figure 1*b*). The price values are expressed in Kunas, and not in Euros, for the purpose of a more detailed sorting in price classes. The distribution of the above mentioned common beech LM assortment is "closer" to the normal distribution than that of any other assortment. The assortment of one tree species, superior in production quantity to all others and with the distribution of selling prices nearest to the normal distribution, was used as an independent variable for univariate linear regression analyses for comparison with other assortments of the respective species (common beech) and all assortments of the other species (silver fir). Therefore, the assortment of common beech long-meter firewood (LM) is used for this purpose (independent variable). In gross production share for the period 1997-2013, this assortment accounts for 54.71 % to 63.69 %.

Coefficients (a, b) were obtained by univariate linear regression analyses between LM of common beech (independent variable) and all other assortments of common beech and silver fir (dependent variable) (Table 2). Although the LM price data set is not equal to other assortments in terms of quantity, the "missing value" option was used, which uses only data with given independent and dependent variable in regression analyses. Coefficient of determination r^2 varies between 0.34 and 0.79 depending on the assortment (Table 2). By goodness of fit ($Pr> F$), it is evident that only few assortments do not satisfy predefined null hypothesis (Table 2). The same table shows that some of *b* coefficients are negative. Those assortments are in negative correlation with common beech long-meter firewood. In this sense, Monte Carlo simulation is not limited. For future timber price simulation, Monte Carlo can be used with positive and/or negative correlation as well, e.g. Knoke *et al.* (2005).

The coefficients of univariate linear regression pre-testing were then defined. The aim of pre-testing was to define the appropriate number of simulation processes (repetitions). Pre-testing was made for beech long-meter firewood (Figure 2). Pre-testing includes four groups of simulation processes, which are defined by the number of repeated simulations. The larger the number of repetitions of simulation results, the lower is the variability of prices, and vice versa (Figure 2). Therefore, the simulation process of 500 repetitions resulted in noticeably little variability of arithmetic mean of prices (Figure 2), so there was no need to repeat the process with 1000 repetition in pre-testing, because its variability would be negligible. In Figure 2 and Figure 3, darker area shows higher frequency of overlapping and, therefore, greater probability, i.e. the value of the

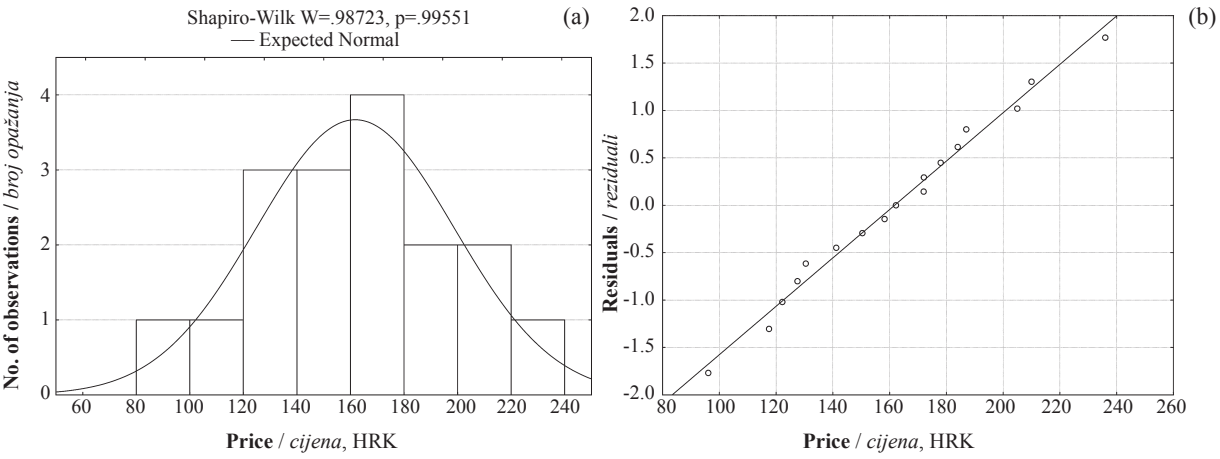


Figure 1 Results of Shapiro-Wilks test for common beech long-meter firewood (a). Deviations from normal distribution are shown by P-Plot chart (b)
Slika 1. a) Rezultati Shapiro-Wilkova testa za višemetricu bukve; b) odstupanja od normalne distribucije prikazana P-Plot grafikonom

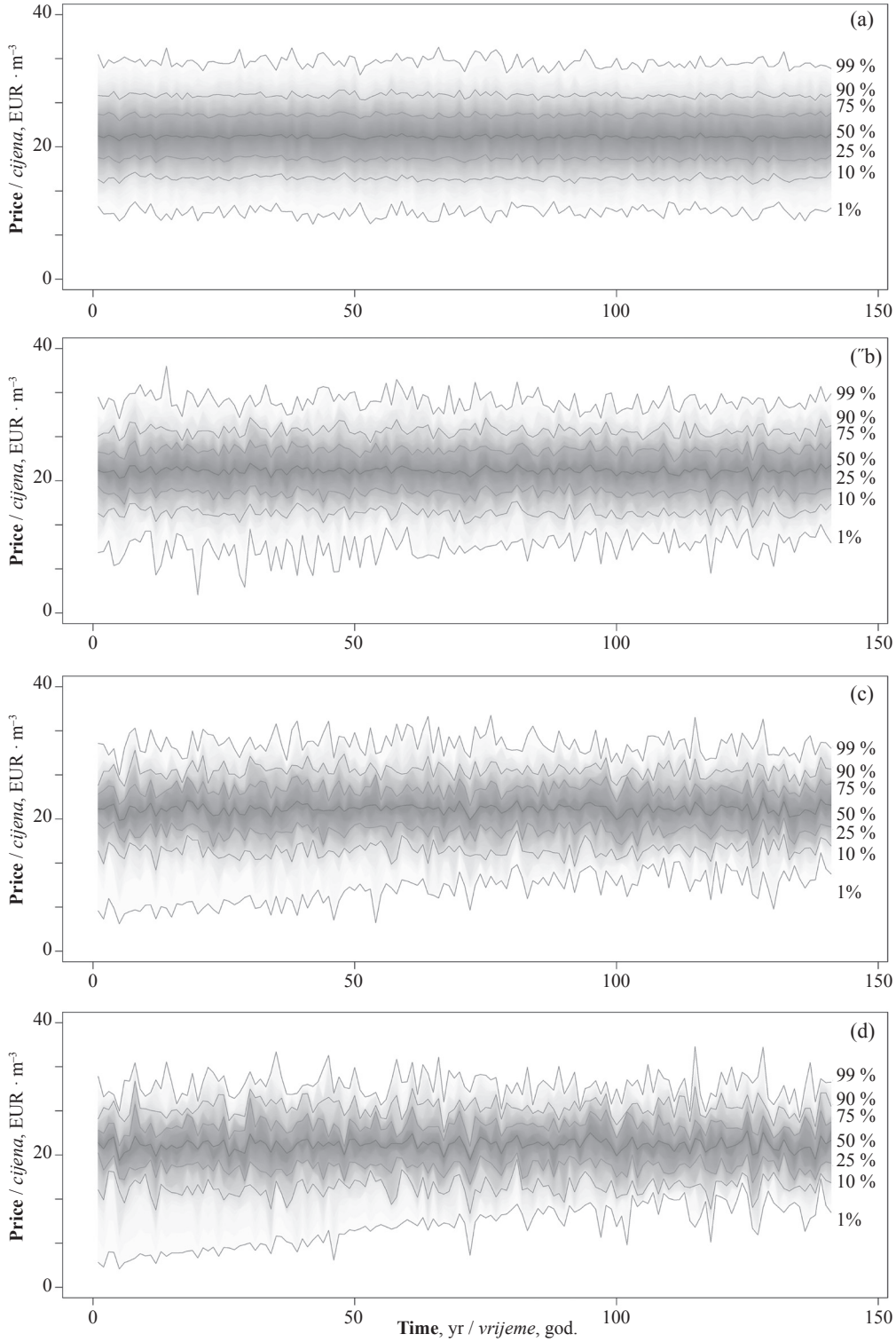


Figure 2 Pre-testing simulation of future prices repeated 500 (a), 100 (b), 50 (c) and 30 (d) times on the example of common beech long-meter firewood with average price of 21.23 EUR·m^{-3} and standard deviation 4.85 EUR·m^{-3} for the period of 140 years (darker area shows a higher frequency of overlapping)

Slika 2. Predtestiranje simulacije budućih cijena ponovljenih 500 (a), 100 (b), 50 (c) i 30 puta (d) na primjeru višemetrice obične bukve prosječne cijene 21,23 EUR·m^{-3} i standardne devijacije od 4,85 EUR·m^{-3} za razdoblje od 140 godina (tamnije područje prikazuje veću frekvenciju preklapanja)

most frequent overlapping of repeated simulations is shown in thick solid line.

The variability of prices over time is not regular and it varies depending on average selling price and standard deviation of each assortment in the past. The comparison of one simulation of achieved selling prices (Figure 3) shows that the Monte Carlo process drastically deviates from the arithmetic mean of thirty simulation repetitions.

The reason is that one Monte Carlo simulation regularly generates marginal selling prices. Only one simulation creates sudden price changes in a relatively short period of time, which cannot be expected in the actual conditions. Simulation repetition of thirty times

Table 2 Results of univariate linear regression analyses between common beech long-meter firewood and all other assortments of silver fir and common beech
Tablica 2. Rezultati univarijatne linearne regresijske analize između višemetrice bukve i svih ostalih sortimenata jele i bukve

Species *Vrsta drva*	**Assortment*** *Sortiment*	**Time series** *Vremenska serija* year / *god.*	**Coefficient** *Koeficijent*		r^2	*Pr >F*
			a	*b*		
Fagus sylvatica L. Common Beech / *bukva*	V	15	1168.918	-2.38514	0.61	0.000001
	PV	17	1122.703	-3.11171	0.79	< 0.000001
	I	17	440.0068	-0.123691	0.34	< 0.000001
	II	17	316.0228	-0.037867	0.35	< 0.000001
	III	17	222.7339	-0.016533	0.74	< 0.000001
	TR	17	156.1193	0.415658	0.41	0.001275
	OM	10	106.6529	0.332205	0.37	0.053188
Abies alba Mill. Silver Fir / *jela*	V	7	1000.401	-0.865067	0.87	0.000001
	I	17	451.0274	0.399157	0.46	< 0.000001
	II	17	337.0305	0.218366	0.39	< 0.000001
	III	17	218.9987	0.114495	0.42	< 0.000001
	TR	8	-104.923	2.190761	0.44	0.067840
	LM	11	7.9517	0.726147	0.69	0.086863
	OM	6	143.0897	0.149279	0.75	0.050195

*V – Veneer / *furnirski trupci*, PV – Peeled veneer (beech) / *trupci za ljušteni furnir*, I – 1st class sawlogs / *pilanski trupci I. klase*, II – 2nd class sawlogs / *pilanski trupci II. klase*, III – 3rd class sawlogs / *pilanski trupci III. klase*, TR – Thin roundwood / *tanka oblovina*, LM – Long-meter firewood / *višemetarsko ogrjevno drvo*, OM – One-meter firewood / *jednometarsko ogrjevno drvo*

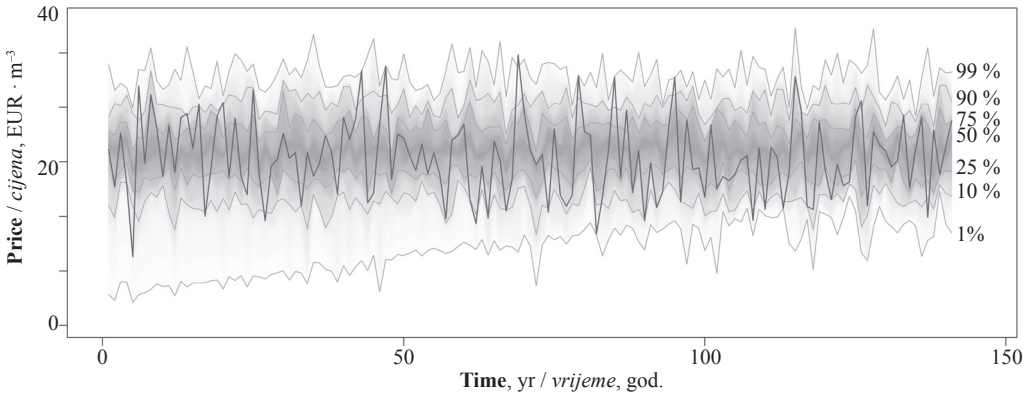


Figure 3 Comparison of one simulation (solid line) and arithmetic mean of 30 repetitions on the example of common beech long-meter firewood (grey area).
Slika 3. Usporedba jedne simulacije (debela linija) i aritmetičke sredine od 30 ponavljanja na primjeru višemetrice bukve (sivo područje)

was taken as a reference and used in simulations for all other assortments of common beech and silver fir. The end result of this research was the simulation of selling prices of all assortments of common beech and silver fir timber for the next 140 years (starting with the year 2013) including their mutual feedback connections. Because of the large quantity of simulations for other assortments (dependent variables), only the result of the simulation for common beech LM assortment was presented in this paper (Figure 2d).

4 DISCUSSION
4. RASPRAVA

It is normal for prices to increase over time at least for the money inflation rate. Based on the analysis of collected data on selling prices for the case study Brinje, it is obvious that the price of timber assortments did not increase in the period 1997-2013. Quite the contrary, the prices of some assortments were even reduced. The situation is similar on the entire market of timber assortments in the Republic of Croatia (Posavec and Beljan, 2013). The situation is also similar in other European countries, e.g. in Austria, where the prices showed the constancy (stability) in the period 2001-2008 (Statistik_ Austria, 2009) and 2008-2012 (Dundović, 2013), respectively. In many cases, the state governments regulate politically the prices of timber on the domestic market (Leefers and Ghani, 2014). This is also the case in Croatia, where an organized market, based on relationship between demand and supply, does not exist. Statistical data (CBS, 2015) show that, although the prices of other energy sources increased in the period 1997-2013, the price of timber remained the same. It can be assumed that the establishment of timber stock exchange would cause the change of timber prices with an

increasing tendency. The prices of timber assortments were not constant in Croatia. Nenadić (1922) described the increase of timber assortments prices that would be expected during the 20th century due to the population growth and greater demand for timber, which was also confirmed by Sabadi (1982). This can be confirmed by an almost triple increase in oak timber prices in the period 1881-1928, as stated by Nenadić (1929). The present situation (the last 25 years) on the timber assortment market in the Republic of Croatia has the characteristics of small fluctuations and this situation will probably remain the same due to the lack of changes in forest policies.

The overlapping of 30 simulation repetitions (Figure 2d) shows the most probable development trends of the future prices. Some authors, like Knoke and Wurm (2006) and Knoke *et al.* (2001), use simulations with 1000 repetitions for this purpose. It is clearly the responsibility of the decision maker or the investor to decide about an adequate number of simulation repetitions. If the market is more stable, it is possible to apply a greater number of repetitions and get fewer fluctuations. A similar procedure is applied when choosing the adequate forest interest rate for a certain area (Figure 2) and the comparison of single and thirtyfold repetition (Figure 3) show that referent simulation repetition (30 times) adequately describes the risk of future price changes. Although this research deals with price simulation for distant future, it is appropriate when calculating e.g. Net Present Value to use risk-adjusted discount rate (Klemperer, 2001; Klemperer, 2003; Price, 1997; Brukas *et al.*, 2001; Snowdon and Harou, 2013; Hahn *et al.*, 2014; Pukkala, 2015), which amounts to 2 % for the Croatian forestry (Beljan, 2015). However, some authors like Hahn *et al.* (2014) use for this purpose the fixed assortment price with a certain discount rate. Both methods are correct, but it is important to stress that higher discount rates should be used with fixed prices.

In this paper, only one of numerous available methods was used for the identification of price change risks. Univariate linear regression, which describes the feedback connections between the prices of timber assortments, can be replaced by a more complex mathematical function and thus increase the level of its explanation. Linehan and Jacobson (2005) stated that linear regression should be used for short and medium periods. The methodology of price definition in the future is a complex process prone to deviations from the forecasted value (Leskinen and Kangas, 1998; Linehan and Jacobson, 2005; Gong *et al.*, 2005, Pukkala, 2015). It is, however, indispensable for a more relevant economic analysis of forest management planning.

5 CONCLUSION
5. ZAKLJUČAK

For successful planning of management of forest resources, it is particularly important to predict the trends of timber assortment prices. The fluctuations of past prices of timber assortments can be simulated in the future for a time frame required by the forest management planning and provide opportunity for decision-makers to have insight into economic results of future scenarios of forest management. It is up to the decision-maker and investor to determine the risk level (the number of simulation repetitions) of price changes and select the interest rate and this decision depends on various factors. Simulation repetition of thirty times describes optimally the risk of price changes in the future for this case study.

In the last 20 years, the prices of timber assortments in Croatia have been stable and this is the result of help provided by the state to a powerful state company aimed at supporting the domestic wood industry. According to the results of predictions, stable prices can also be expected in the future especially for assortments of widely used timber species (common beech and silver fir).

Acknowledgment – Zahvala

The authors would like to thank Croatian Forests Ltd. for kindly providing data on selling prices.

6 REFERENCES
6. LITERATURA

1. Beljan, K., 2015: Ekonomska analiza gospodarenja šumama obične jele (*Abies alba* Mill.) jednodobne strukture [*Economic analysis of even-aged silver fir (Abies alba Mill.) forest management*] (in Croatian with English abstract). PhD thesis, University of Zagreb, Croatia.
2. Brazee, R.; Mendelsohn, R., 1988: Timber Harvesting with Fluctuating Prices. Forest Science, 34(2): 359-372.
3. Brukas, V.; Thorsen, B. J.; Helles, F.; Tarp, P., 2001: Discount rate and harvest policy: implications for Baltic forestry. Forest Policy and Economics, 2(2): 143-156. https://doi.org/10.1016/S1389-9341(01)00050-8.
4. Clasen, C.; Griess, V. C.; Knoke, T., 2011: Financial consequences of losing admixed tree species: A new approach to value increased financial risks by ungulate browsing. Forest Policy and Economics, 13(6): 503-511. https://doi.org/10.1016/j.forpol.2011.05.005.
5. Dundović, J., 2013: 17. Austrijski dani biomase [*17th days of Austrian biomass*] (in Croatian). Šumarski list, 137(3-4): 238-241.
6. Durbin, J.; Watson, G. S., 1971: Testing for Serial Correlation in Least Squares Regression. III. Biometrika, 58(1): 1-19. https://doi.org/10.2307/2334313.
7. Gauss, C. F., 1809: Theoria motus corporum coelestium in sectionibus conicis solem ambientium. Hamburg, Friedrich Perthes and I. H. Besser.
8. Gong, P. C.; Boman, M.; Mattsson, L., 2005: Non-timber benefits, price uncertainty and optimal harvest of an even-aged stand. Forest Policy and Economics, 7(3): 283-295. https://doi.org/10.1016/S1389-9341(03)00073-X.
9. Hahn, W. A.; Hatl, F.; Irland, L. C.; Kohler, C.; Moshammer, R.; Knoke, T., 2014: Financially optimized management planning under risk aversion results in even-flow sustained timber yield. Forest Policy and Economics, 42: 30-41. https://doi.org/10.1016/j.forpol.2014.02.002.
10. Haight, G. R., 1990: Feedback Thinning Policies of Uneven-Aged Stand Management with Stochastic Prices. Forest Science, 36(4): 1015-1031.
11. Hildebrandt, P.; Knoke, T., 2011: Investment decisions under uncertainty-A methodological review on forest sci-

ence studies. Forest Policy and Economics, 13(1): 1-15. https://doi.org/10.1016/j.forpol.2010.09.001.
12. Kangas, A.; Kangas, J.; Kurttila, M., 2008: Decision Support for Forest Management. Springer.
13. Klemperer, D. W., 2001. Incorporating risk into financial analysis of forest management investments. In: Gadow, K. (ed.). Risk analysis in forest management. Dordrecht: Kluwer Academic Publishers. https://doi.org/10.1007/978-94-017-2905-5_6.
14. Klemperer, D. W., 2003. Risk analysis. In: Klemperer, D. W. (ed.). Forest resource economics and finance. McGraw-Hill, Inc.
15. Knoke, T.; Moog, M.; Plusczyk, N., 2001: On the effect of volatile stumpage prices on the economic attractiveness of a silvicultural transformation strategy. Forest Policy and Economics, 2(3-4): 229-240. https://doi.org/10.1016/S1389-9341(01)00030-2.
16. Knoke, T.; Plusczyk, N., 2001: On economic consequences of transformation of a spruce (*Picea abies* (L.) Karst.) dominated stand from regular into irregular age structure. Forest Ecology and Management, 151(1-3): 163-179. https://doi.org/10.1016/S0378-1127(00)00706-4.
17. Knoke, T.; Stimm, B.; Ammer, C.; Moog, M., 2005: Mixed forests reconsidered: A forest economics contribution on an ecological concept. Forest Ecology and Management, 213(1-3): 102-116. https://doi.org/10.1016/j.foreco.2005.03.043.
18. Knoke, T.; Wurm, J., 2006: Mixed forests and a flexible harvest policy: a problem for conventional risk analysis? European Journal of Forest Research, 125(3): 303-315. https://doi.org/10.1007/s10342-006-0119-5.
19. Leefers, A. L.; Ghani, A. N. A., 2014. Timber pricing. In: Kant, S. & Alavalapati, J. (eds.). Handbook of Forest Resource Economics. Great Britain: Routledge. https://doi.org/10.4324/9780203105290.ch6.
20. Leskinen, P.; Kangas, J., 1998: Modelling and simulation of timber prices for forest planning calculations. Scandinavian Journal of Forest Research, 13(4): 469-476. https://doi.org/10.1080/02827589809383008.
21. Linehan, P. E.; Jacobson, M. G., 2005: Forecasting hardwood stumpage price trends in Pennsylvania. Forest Products Journal, 55(12): 47-52.
22. Nana, T. A.; Lu, F. D., 2013: Adaptive management decision of agroforestry under timber price risk. Journal of Forest Economics, 19(2): 162-173. https://doi.org/10.1016/j.jfe.2013.01.001.
23. Nenadić, Đ., 1922: Računanje vrijednosti šuma i šumska statika [*Calculating forests value and forest statics*] (in Croatian). Zagreb, Naklada Hrvatskog šumarskog društva.
24. Nenadić, Đ., 1929: Uređivanje šuma [*Forest management*] (in Croatian). Zagreb, Tisak zaklade tiskare Narodnih novina u Zagrebu.
25. Orsag, S.; Dedi, L., 2011: Budžetiranje kapitala-Procjena investicijskih projekata [*Budgeting Capital-Investment Projects Evaluation*] (in Croatian). Zagreb, Masmedia.
26. Posavec, S.; Beljan, K., 2013. Forest products production and sale trends in Croatia. In: Jelačić, D. (ed.) Markets for wood and wooden products. Chorzów, Poland: WoodEMA, i.a.
27. Price, C., 1997: A critical note on a long-running debate in forest economics. Forestry, 70(4): 389-397. https://doi.org/10.1093/forestry/70.4.389.
28. Pukkala, T., 2015: Optimizing continuous cover management of boreal forest when timber prices and tree growth are stochastic. Forest Ecosystems, 2(1): 1-13. https://doi.org/10.1186/s40663-015-0028-5.
29. Sabadi, R., 1982: World Timber Supply nad Demand up to Year 2000 (in Croatian with English abstract). Šumarski list, 106(9-10): 367-375.
30. Shapiro, S. S.; Wilk, M. B., 1965: An Analysis of Variance Test for Normality (Complete Samples). Biometrika, 52(3-4): 591-611. https://doi.org/10.1093/biomet/52.3-4.591.
31. Snowdon, P.; Harou, P., 2013: Guide to Economic Appraisal of Forestry Investments and Programmes in Europe. Forestry Commission.
32. Statistik_Austria, 2009: Land- und Forstwirtschaftliche Erzeugerpreise. Vienna.
33. Statsoft, 2007: Statistica (data analysis software system) version 8.0. www.statsoft.com.
34. Waller, L. A.; Smith, D.; Childs, J. E.; Real, L. A., 2003: Monte Carlo assessments of goodness-of-fit for ecological simulation models. Ecological Modelling, 164(1): 49-63. https://doi.org/10.1016/S0304-3800(03)00011-5.
35. ***HŠ. 1997 – 2013. Hrvatske šume. Ltd. Zagreb. Pricelist of Main Forest Products [Online]. (Date Accessed October 7. 2015.).
36. ***CBS, 2015. Croatain bureau of statistics http://www.dzs.hr/ (Date Accessed October 7. 2015.).

Corresponding address:

KARLO BELJAN, Ph.D.

University of Zagreb, Faculty of Forestry
Department of Forest Inventory and Management
Svetošimunska 25
10002 Zagreb, CROATIA
e-mail: kbeljan@sumfak.hr

Violeta Jakimovska Popovska, Borche Iliev, Goran Zlateski[1]

Impact of Veneer Layouts on Plywood Tensile Strength

Utjecaj položaja furnira u strukturi furnirskih ploča na njihovu vlačnu čvrstoću

Preliminary paper • Prethodno priopćenje
Received – prispjelo: 11. 7. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*832.281.2; 630*832.282.7*
doi:10.5552/drind.2017.1634

ABSTRACT • *The aim of the research presented in this paper is to study the plywood tensile strength through a change of the position of layers in the panel structure around the central axis, without changing the number and thickness of veneers. So far, it has been known that the veneer layout in plywood structure has a significant impact on plywood bending properties. Besides these mechanical properties, the tensile strength of plywood is also a property that can define the use of plywood as a structural or non-structural panel.*
For studying the impact of veneer layout on plywpood tensile strength, experimental models of nine-layer plywood were made. The models were made from peeled beech veneer with the thickness of 1.2, 1.5, 2.2 and 3.2 mm. The modelling was performed on the basis of changing the position of veneer, 3.2 mm thick, around the central axis. Pure water-soluble phenol-formaldehyde resin was used as plywood binder.
The tensile strength of plywood panels was tested in five directions: parallel and perpendicular to the face grain, as well as at the angle of 22.5°, 45° and 67.5° to the face grain of the plywood panel. On the basis of the obtained data for tensile strength in different directions of plywood panel, the coefficient of equality of tensile strength of plywood models was calculated (K_{er}). The coefficient of mass quality (K_{mq}) was calculated, too.
The research results showed that different veneer layouts in plywood structure have a significant impact on plyood tensile strength. All tested plywood models meet the defined values of tensile strength in accordance with the requirements of the national (MKC) standard for structural plywood for use in construction. Different layouts of veneer sheets in panel structure give opportunities for production of panels with different strength characteristics.

Key words: *plywood, veneers, tensile strength, changes, position, layers*

SAŽETAK • *U radu su opisana istraživanja čiji je cilj bio proučiti vlačnu čvrstoću furnirskih ploča s obzirom na promjenu položaja furnira u strukturi ploče oko središnje osi, bez promjene broja i debljine furnira. Do danas je poznato da položaj furnira u strukturi furnirskih ploča ima znatan utjecaj na savojna svojstva furnirskih ploča. Osim savojnih svojstava furnirskih ploča, važna je i njihova vlačna čvrstoća, koja može utjecati na to hoće li furnirske ploče biti primijenjene kao strukturni ili kao nestrukturni element. Za proučavanje utjecaja položaja furnira na vlačnu čvrstoću furnirske ploče izrađeni su eksperimentalni modeli devetoslojnih furnirskih ploča. Modeli su napravljeni od bukovih ljuštenih furnira debljine 1,2; 1,5; 2,2 i 3,2 mm. Modeliranje je obavljeno na temelju promjene položaja furnira debljine 3,2 mm oko središnje osi. Kao vezivo je upotrijebljena čista vodotopljiva fenol-formaldehidna smola. Vlačna čvrstoća furnirskih ploča ispitana je u pet smjerova: paralelno i okomito na smjer vlakanaca vanjskih furnira te pod kutom od 22,5°, 45° i 67,5° s obzirom na smjer vlakanaca vanjskih furnira*

[1] Authors are assistant professor and professors at the University of SS. Cyril and Methodius in Skopje, Faculty of Design and Technologies of Furniture and Interior, Skopje, Republic of Macedonia
[1] Autori su docentica i profesori Sveučilišta *Sv. Ćiril i Metodij* u Skoplju, Fakultet dizajna i tehnologije namještaja i enterijera, Skoplje, Republika Makedonija.

ploče. Na temelju dobivenih podataka o vlačnoj čvrstoći u različitim smjerovima ploče, izračunan je koeficijent jednakosti vlačne čvrstoće modela furnirskih ploča (K_{et}). Također je izračunan i koeficijent masene kvalitete (K_{mq}). Rezultati istraživanja pokazali su da različit položaj furnira u strukturi furnirskih ploča znatno utječe na njihovu vlačnu čvrstoću. Svi ispitani modeli furniskih ploča zadovoljavaju vrijednosti vlačne čvrstoće definirane u skladu s makedonskim normama za strukturne furnirske ploče namijenjene uporabi u graditeljstvu. Različit položaj furnira u strukturi ploče omogućuje proizvodnju ploča različitih svojstava čvrstoće.

Ključne riječi: *furnirske ploče, furniri, vlačna čvrstoća, promjena položaja furnira*

1 INTRODUCTION
1. UVOD

The wide range of wood-based composites includes materials for structural or non-structural use for indoor and outdoor application (Youngquist, 1999). Plywood is one of the major types of wood-based composite materials for structural use. It represents a flat panel made of odd number of layers made of veneer sheets, where the grain direction of the adjacent layers is at right angles.

The cross-laminated layup of veneer layers gives plywood excellent strength characteristics, stiffness and dimensional stability (Youngquist, 1999). Plywood is used in a variety of structural applications, such as flooring, siding, roofing, shear walls, formwork and engineered wood products (prefabricated I-joists, box beams, stressed-skin panels and panelized roofs) (Stark *et al*., 2010).

Plywood properties depend on the quality of the veneer, wood species, number and order of layers, as well as of the adhesive used for plywood bonding (Youngquist, 1999; Hráskỳ and Král, 2005; Stark *et al.,* 2010; Bal and Bektaş, 2014).

Dimensional uniformity and reliable, consistent structural properties make plywood an attractive choice of material from both a design and construction perspective. Because of its lightness, directional strength properties and inherent stiffness, plywood is an excellent material for fixing beam elements to timber so as to produce a composite construction (EWPAA, 2009).

The performance of wood composite materials is characterized by a wide range of engineering properties. The proper use of plywood requires a bigger understanding of mechanical properties of this material (Cai and Ross, 2010). These properties are some of the most important characteristics of plywood that are commonly considered (Kljak and Brezovic, 2007). Thensile strength of plywood is also an important property that shoud be taken into consideration when selecting materials for construction purposes.

The tensile strength of plywood is of a particular importance in stress-skin panels and sandwich-type structures, where plywood facings are the load-bearing members (ASTM Technical publication No. 194).

In order to produce stable panels that can meet the modern exploitation requirements, plywood is constantly subjected to research. Improving of mechanical properties of plywood can be done by changing the position of veneer in plywood structure (Jakimovska Popovska and Iliev, 2013), as well as by changing the thickness of the outer layers (Kljak *et al.*, 2006). Research on the influence of composition and number of plywood leayers on panel isotropy was carried on by Lovrić *et al.* (2015). By combining veneers of different thickness, plywood with adequate characteristics for the intended application can be obtained (Hráskỳ and Král, 2006).

The research of the characteristics of plywood properties in different directions is important for the proper application of these materials as load-bearing panels in different structures in construction (Jakimovska Popovska, 2011).

Previous research has shown that the veneer layouts in plywood structure have a significant impact on plywood bending properties (Jakimovska Popovska and Iliev, 2015). Plywood models, with more veneers in their structure, that run parallel to the span of the loaded panel have higher bending strength and modulus of elasticity in bending (Jakimovska Popovska and Iliev, 2015). The position and orientation of veneers in plywood also have a significant impact on plywood compressive strength (Jakimovska Popovska and Iliev, 2013). Besides these mechanical properties, the tensile strength of plywood is also a property that can define the use of plywood as a structural or non-structural panel.

The aim of the research presented in this paper is to study the impact of veneer layouts on plywood tensile strength, trough the change of the position of veneers in plywood structure around the central axis of the plywood panel, without changing the number and thickness of veneers.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

For the realization of the research, four experimental nine-layer plywood models were made. Each model had the same number of veneers of each thickness class: three veneer sheets with a thickness of 3.2 mm and two veneer sheets with a thickness of 2.2, 1.5 and 1.2 mm.

The modeling was made on the basis of changing the position of veneers with the thickness of 3.2 mm around the central axis of the panel. The central layer of each model represents a veneer sheet with the thickness of 3.2 mm, oriented parallel to the face grain of the panel.

In the first model, the veneers with the thickness of 3.2 mm were positioned next to the central veneer sheet. In the other models, their position moved towards the surface of the panel, so that in the fourth model these veneers built the surface layers of the panel (Figure 1).

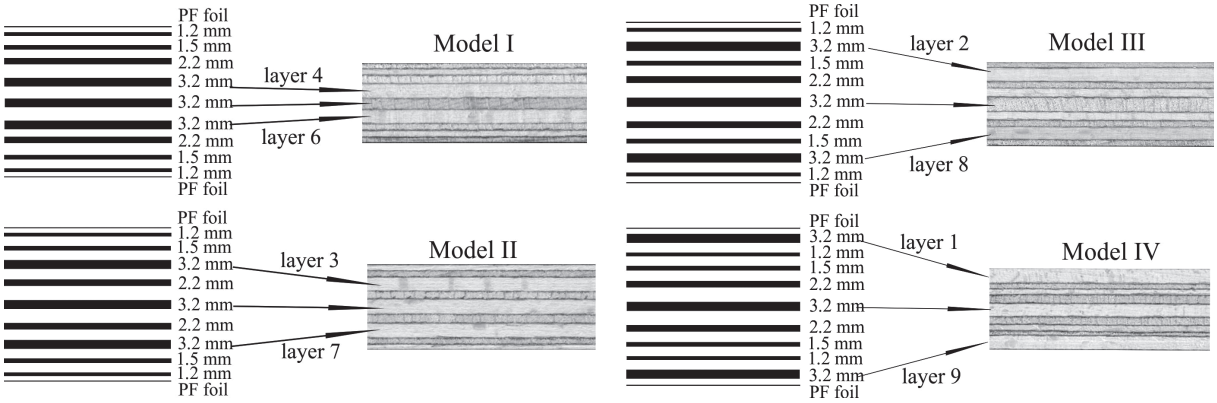


Figure 1 Pattern and cross-section of plywood models
Slika 1. Kompozicija i presjek modela furnirskih ploča

Table 1 Veneer arrangement and orientation in plywood compositions
Tablica 1. Raspored i orijentacija furnira u kompoziciji furnirskih modela

Layouts and orientation of veneers in plywood models *Raspored i orijentacija furnira u kompoziciji furnirskih modela*	
Model I	1.2_{0^o} / 1.5_{90^o} / 2.2_{0^o} / 3.2_{90^o} / 3.2_{0^o} / 3.2_{90^o} / 2.2_{0^o} / 1.5_{90^o} / 1.2_{0^o}
Model II	1.2_{0^o} / 1.5_{90^o} / 3.2_{0^o} / 2.2_{90^o} / 3.2_{0^o} / 2.2_{90^o} / 3.2_{0^o} / 1.5_{90^o} / 1.2_{0^o}
Model III	1.2_{0^o} / 3.2_{90^o} / 1.5_{0^o} / 2.2_{90^o} / 3.2_{0^o} / 2.2_{90^o} / 1.5_{0^o} / 3.2_{90^o} / 1.2_{0^o}
Model IV	3.2_{0^o} / 1.2_{90^o} / 1.5_{0^o} / 2.2_{90^o} / 3.2_{0^o} / 2.2_{90^o} / 1.5_{0^o} / 1.2_{90^o} / 3.2_{0^o}

The orientation of adjacent layers in plywood structure is at the right angle. In all models, the grain direction of the surface layers is parallel to the longitudinal axis of the panel.

The layots of plywood models and the orientation of the veneers in plywood compositions are described in Table 1.

Pure water-soluble phenol-formaldehyde resin with the concentration of 47.10 % was used as plywood binder, in the quantity of 180 g/m^2.

The panels were pressed in a hot press using the following parameters: specific pressure of 18 kg/cm^2, pressing temperature of 155 ºC and pressing time of 20 min.

The panels were overlaid with phenol formaldehyde-resin impregnated paper with a surface weight of 120 g/m^2. The paper was bonded during the hot pressing process. Plywood overlaying with this paper was made in order to improve the water resistance of plywood, having in mind the fact that these plywood panels were intended for construction purposes, where they can be exposed to high humidity conditions.

The plywood models were made with the following dimensions: 580×580×17 mm. The moisture content of the panels was 8 %.

The denotations of the experimental plywood models have the following meaning:

– model I – nine-layer plywood in which the veneers with the thickness of 3.2 mm are positioned in the fourth, fifth (central) and sixth layer of the panel (d=16.59 mm; γ=761.70 kg/m^3);
– model II – nine-layer plywood in which the veneers with the thickness of 3.2 mm are positioned in the third, fifth (central) and seventh layer of the panel (d=16.77 mm; γ=759.99 kg/m^3);
– model III – nine-layer plywood in which the veneers with the thickness of 3.2 mm are positioned in the second, fifth (central) and eighth layer of the panel (d=16.66 mm; γ=782.34 kg/m^3);
– model IV – nine-layer plywood in which the veneers with the thickness of 3.2 mm are positioned in the surface layers and in the central layer of the panel (first, fifth-central and ninth layer) (d=16.50 mm; γ=785.90 kg/m^3).

The plywood tensile strength was tested according to the national standard MKC D.A8.066/85. This property was tested in five directions, i.e., parallel and perpendicular to the face grain, and at the angles of 22.5º; 45º and 67.5º to the face grain of the panel. The dimensions and shape of the test specimens for the determination of plywood tensile strength are shown in Figure 2.

On the basis of the obtained data for tensile strength in different directions of plywood panel, the coefficient of equality of the tensile strength of plywood models was calculated (K_{et}). This coefficient was calculated by a graphical method, inputting the values of tensile strength in polar coordinate system (Figure 3) and using the equation (Krpan, 1971). A circle with the radius of the highest value of tensile strength was drawn in a polar coordinate system. The area under this circle was calculated. The values of tensile strength in all tested directions were input in the polar system and connected to each other so as to make a diagram with a certain area that was calculated, too. The ratio between the area under the diagram and the area under the circle represent the coefficient of equality of the tensile strength of plywood (Eq. 1).

The curves of the diagram obtained by this kind of tests are symmetrical in all four quadrants of the po-

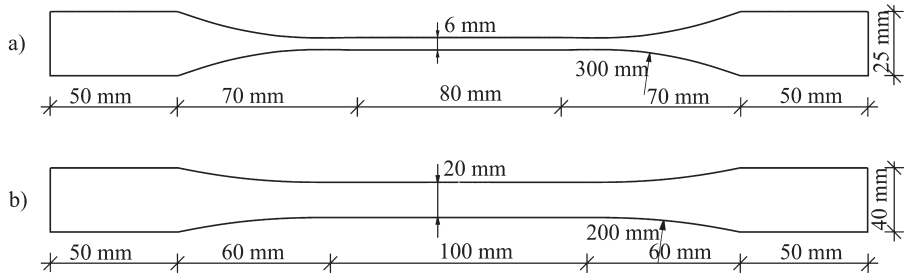


Figure 2 Dimensions and shape of the test specimens for the determination of plywood tensile strength: a) test specimens for the determination of tensile strength parallel and perpendicular to the face grain of plywood; b) test specimens for the determination of tensile strength at different angles to the face grain of plywood
Slika 2. Dimenzije i oblik epruveta za ispitivanje vlačne čvrstoće furnirske ploče: a) epruvete za ispitivanje vlačne čvrstoće paralelno i okomito na smjer vlakanaca vanjskih furnira ploče; b) epruvete za ispitivanje vlačne čvrstoće ploča pri različitim kutovima s obzirom na smjer vlakanaca vanjskih furnira ploče

lar coordinate system, so it is appropriate to test the tensile strength of plywood only in one quadrant and mirror it in the other three quadrants (Krpan, 1971).

$$K_{et} = \frac{A_d}{A_c} \quad (1)$$

Where, A_d – area under the diagram; A_c – area under the circle with the radius of the highest value of tensile strength.

The coefficient of equality of the tensile strength (K_{et}) and the coefficient of mass quality (K_{mq}) define the quality and usability of the plywood panel.

The coefficient of mass quality (K_{mq}) was calculated by the following equation:

$$K_{mq} = \frac{\sigma_{t\|+} + \sigma_{t\perp}}{\gamma} \quad (2)$$

Where, $\sigma_{t\|}$ – tensile strength parallel to the face grain of the plywood panel; $\sigma_{t\perp}$ – tensile strength perpendicular to the face grain of the plywood panel; γ – plywood density.

The obtained data were statistically analyzed. One way ANOVA (analysis of variance) was used to determine the significance of the effect of veneer layouts on plywood tensile strength. Shapiro-Wilk test for normality of the obtained data was applied as well as Levene's test for homogeneity of variances. Tukey's test was applied to evaluate the statistical significance between mean values of the tensile strength of plywood with different veneer layouts (different plywood models). The tests were conducted at 0.05 probability level.

Statistical software SPSS Statistic was used for the statistical analysis of the obtained data.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of tensile strength in all tested directions of plywood panel are shown in Table 2.

According to the test results of the tensile strength parallel to the face grain of the panel (Table 2), the following grouping can be done. The values of these properties of models I and III are within similar limits, as well as the values of models II and IV, while the difference in values between the two groups is obvious. The mean value of tensile strength in models II and IV are higher by 32.96 to 62.33 % compared to the mean

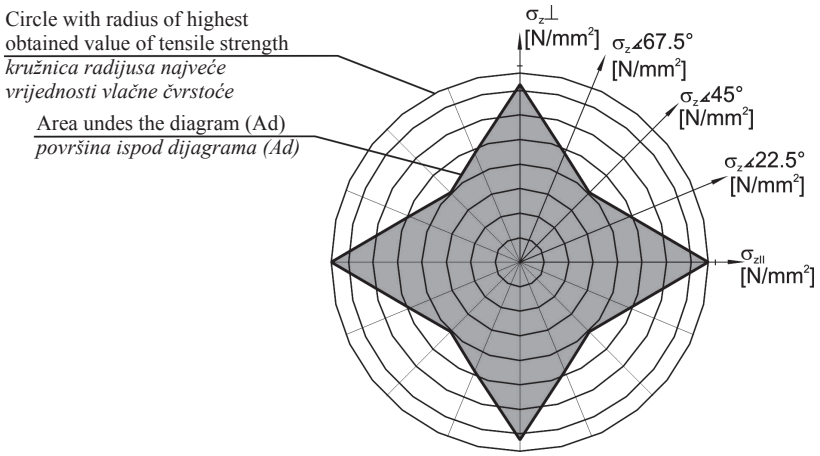


Figure 3 Graphical method for the determination of coefficient of equality of tensile strength of plywood
Slika 3. Grafička metoda za određivanje koeficijenta jednakosti vlačne čvrstoće furnirske ploče

Table 2 Statistical data for tensile strength of plywood in all tested directions
Tablica 2. Statistički podaci o vlačnoj čvrstoći furnirskih ploča u svim istraživanim smjerovima

Tensile strength *Vlačna* čvrstoća	**Model** *Model*	***N*** *Broj epruveta*	**Mean** *Srednja vrijednost*	**Std. Deviation** *Standardna devijacija*	**Std. Error** *Greška srednje vrijednosti*	**95 % Confidence Interval for Mean** *95-postotni interval pouzdanosti srednje vrijednosti*		**Min** *Min.*	**Max** *Maks.*
						Lower Bound *Donja granica*	**Upper Bound** *Gornja granica*		
Paralell to the face grain	I	5	60.55[a]	5.57	2.49	53.63	67.47	52.92	66.29
	II	5	80.51[b]	2.74	1.23	77.11	83.91	76.32	83.50
	III	5	54.10[a]	4.08	1.83	49.04	59.17	49.36	59.55
	IV	5	87.82[b]	9.01	4.03	76.64	99.00	73.40	97.65
Perpen-dicular to the face grain	I	5	73.17[a]	6.65	2.97	64.91	81.43	66.59	81.43
	II	5	57.73[b]	1.97	0.88	55.28	60.17	54.96	60.44
	III	5	74.63[a]	8.03	3.59	64.66	84.60	63.53	84.11
	IV	5	46.98[c]	5.08	2.27	40.67	53.28	39.18	52.26
At the angle of 22.5° to the face grain	I	5	34.16[a]	2.32	1.04	31.28	37.04	31.54	36.86
	II	5	35.38[a]	1.01	0.45	34.13	36.64	34.21	36.64
	III	5	36.53[a]	2.39	1.07	33.56	39.50	33.92	38.78
	IV	5	33.69[a]	2.61	1.17	30.45	36.93	29.76	36.37
At the angle of 45° to the face grain	I	5	27.18[a,b]	1.39	0.62	25.45	28.90	25.58	28.93
	II	5	25.90[a]	1.28	0.57	24.31	27.49	24.67	27.51
	III	5	27.49[a,b]	0.42	0.19	26.97	28.01	26.93	27.97
	IV	5	27.97[b]	0.99	0.44	26.74	29.20	27.06	29.45
At the angle of 67.5° to the face grain	I	5	35.47[a]	2.08	0.93	32.89	38.05	33.66	37.86
	II	5	36.04[a]	0.97	0.43	34.83	37.24	35.01	37.09
	III	5	35.96[a]	2.47	1.10	32.90	39.03	32.85	39.26
	IV	5	28.50[b]	2.25	1.00	25.71	31.29	26.34	31.98

Note: The mean values marked with the same letters are not significantly different at 0.05 probability level.
Napomena: Srednje vrijednosti označene istim slovom nisu signifikantno različite pri razini signifikantnosti 0,05.

value in models I and III. The highest value of tensile strength parallel to the face grain of the panel is achieved in model IV.

The analysis of variance of data obtained for tensile strength parallel to the face grain (ANOVA: F (3, 16) = 37.551; p = 0.000) showed that the differences between the mean values of these properties of (at least) two plywood models are statistically significant. The conducted post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences in the mean values of this property of models I and III compared to models II and IV. The difference in the values of tensile strength parallel to the face grain between the two groups of models results from the orientation of the veneers in the plywood structure, particularly of the veneers with the thickness of 3.2 mm, as they account for the highest percentage of the panel thickness. In models I and III, two of the three veneer sheets with the thickness of 3.2 mm are oriented perpendicular to the length of the test specimen (perpendicular to the direction of tensile force), while in models II and IV all three veneers with the thickness of 3.2 mm are oriented parallel to the direction of tension load. The reason for the higher values of tensile strength parallel to the face grain in models II and IV compared to models I and III lies in a higher number of longitudinally oriented veneers with the thickness of 3.2 mm. In models II and IV, the veneers oriented parallel to the direction of tensile force account for a higher percentage of panel thickness. Having in mind the fact that the total number of veneers, oriented in the same direction, has the main influence on tensile strength, it is clear why this property is higher in models II and IV. In fact, the highest thickness ratio of the veneers that run parallel to the panel length (the veneers that run parallel to the panel length account for 64.9 % of panel thickness) is found in model IV, and this contributes in the acchievemnt of the highest value of tensile strength parallel to the face grain of the panel. In model II, the veneers that run parallel to the direction of tensile force account for 61.9 % of panel thickness. In models I and III veneers that run parallel to the direction of tensile force account for 48.5 % and 44.3 % of the plywood nominal thickness, respectively.

The differences in the mean values of tensile strength between model I and model III, as well as between model II and model IV, are small and they are not statistically significant.

According to the results of tensile strength perpendicular to the face grain of plywood (Table 2), models I and III have higher values of tensile strength in cross-grain direction compared to the models II and IV. The highest value of this property is achieved in model III, which is higher for 29.27 % compared to model II and for 58.85 % compared to model IV. The analysis of variance of the obtained data (ANOVA: F (3, 16) = 25.223; p = 0.000) and post-hoc Tukey's test showed that these differences are statistically significant. Models I and III have similar values of tensile strength in

cross-grain direction, whereas the differences between them are not statistically significant. The lowest value of this property is achieved in model IV and this value statistically differs from the values of all other plywood models.

The differences in the values of tensile strength in cross-grain direction in different models are also a result of the orientation of the veneers with thickness of 3.2 mm in plywood structure. The highest values of tensile strength perpendicular to the face grain of the panel are achieved in models that have more veneers with thickness of 3.2 mm running parallel to the direction of tensile loading (model I and III). Models II and IV have all three veneers with thickness of 3.2 mm running perpendicular to the tensile force. In fact, the higher values of tensile strength in cross-grain direction are achievd in models that have higher thickness ratio of the veeers that run parallel to the tensile force (model I and III which have 48.5 % and 44.3 % of panel thickness occupied by the veneers that run parallel to the direction of tensile force, compared to models II and IV which have 38.1 % and 35.1 % of panel thickness occupied by the veneers that run parallel to the direction of tensile force).

The lowest value of this property that is achieved in model IV, shows that positioning the veneers with thickness of 3.2 mm as surface layers of the panel, has a negative effect on the value of tensile strength in cross-grain direction of the panel.

The results for the tensile strength at the angle of 22.5º to the face grain of plywood are also shown in Table 2, where can be seen that all plywood models have similar values of this property. The analysis of variance of the obtained data (ANOVA: F (3, 16) = 1.727; p = 0.202) showed that there is no statistically significant differences in the mean values between all plywood models, which means that the orientation and position of the veneers with thickness of 3.2 mm has no significant impact on the tensile strength when the panels are stressed in tension at the angle of 22.5º to the face grain of plywood.

When plywood panels are exposed on tension at the angle of 45º to the face grain there are statistically significant differences in the mean values of tensile strength between plywood models (ANOVA: F (3, 16) = 3.305; p = 0.047). The post-hoc Tukey's test showed that there is a statistically significant difference in the mean values only between model II and model IV. The highest value of tensile strength in this direction of the panel is achieved in model IV, with notation that all plywood models have similar values of this property. The maen value of model IV is higher compared to the mean values of model I, II and III for 2.91 %, 8 % and 1.75 %, respectively.

In case when plywood panels are stressed in tension at the angle of 67.5º to the face grain of the panel, the highest value of tensile strength is achieved in model II, which value is higher for 26.46 % compared to model IV, which have the lowest obtained value of tensile strength in this direction of the panel. The analysis of variance of the obtained data (ANOVA: F (3, 16) = 16.405; p = 0.000) and the post-hoc Tukey's test showed that there are statistically significant differences in the mean values between model IV and all other plywood models. The differences between models I, II and III are very small and they are not statistically significant.

The national standard MKC D.C5.043 for load-bearing plywood for use in construction defines the minimal values of tensile strength of 24 N/mm^2 parallel to the face grain; 12 N/mm^2 perpendicular to the face grain and 6 N/mm^2 at the angles of 30 and 60º to the face grain of the plywood panel. According to this standard the values of tensile strength in other directions of plywood can be obtained by linear interpolation by the given values for tensile strength parallel, perpendicular and at the angle of 30º and 60º to the face grain of the plywood panel. The obtained minimal value by the linear interpolation for tensile strength at the angle of 22.5º to the face grain is 10.5 N/mm^2 and at the angle of 67.5º is 7.5 N/mm^2. All experimental plywood models exceed the minimal values defined bay the standard in all tested directions of the panel.

The obtained values of plywood tensile strength are within the limits of the values for this property listed in available literature. Nikolić (1988) for five-layer beech plywood gives the values of 71.1 N/mm^2 for tensile strength parallel to the face grain of the panel, 62.5 N/mm^2 for tensile strength perpendicular to the face grain and 22.2 N/mm^2 for tensile strength at the angle of 45º to the face grain of the plywood panel. Brezović *et al.* (2002) give the values of 49.12 and 28.63 N/mm^2 for tensile strength parallel and perpendicular to the face grain of poplar plywood. Arriga and Peraza (2004) for pine plywood with thickness of 15 and 18 mm give the values of 22.3 and 19.5 N/mm^2 for tensile strength parallel to the face grain and the values of 15.0 and 17.5 N/mm^2 for tensile strength perpendicular to the face grain of the panel. Kljak and Brezovic (2007a) give the values of 53.5 N/mm^2 and 59.2 N/mm^2 for tensile strength parallel and perpendicular to the face grain of seven-layer beech plywood with thickness of 10.52 mm.

On the basis of the polar diagrams of tensile strength showed on Figure 4 it can be noticed that models I and III, as well as models II and IV have similar tendency of increment or decrement of tensile strength in relation to the direction of tensile force regarding the orientation of the wood fibers of the surface veneers.

In models I and III, the highest value of tensile strength is achieved in direction perpendicular to the face grain of plywood, while in models II and IV the highest value of tensile strength is achieved in direction parallel to the face grain of the panel. The lowest value of tensile strength in all plywood models is achieved in direction at the angle of 45° to the face grain of plywood. At the angles of 22.5° and 67.5°, the values of tensile strength are higher compared to the value of tensile strength at the angle of 45°, but lower compared to the values of tensile strength parallel and perpendicular to the face grain of plywood. With the

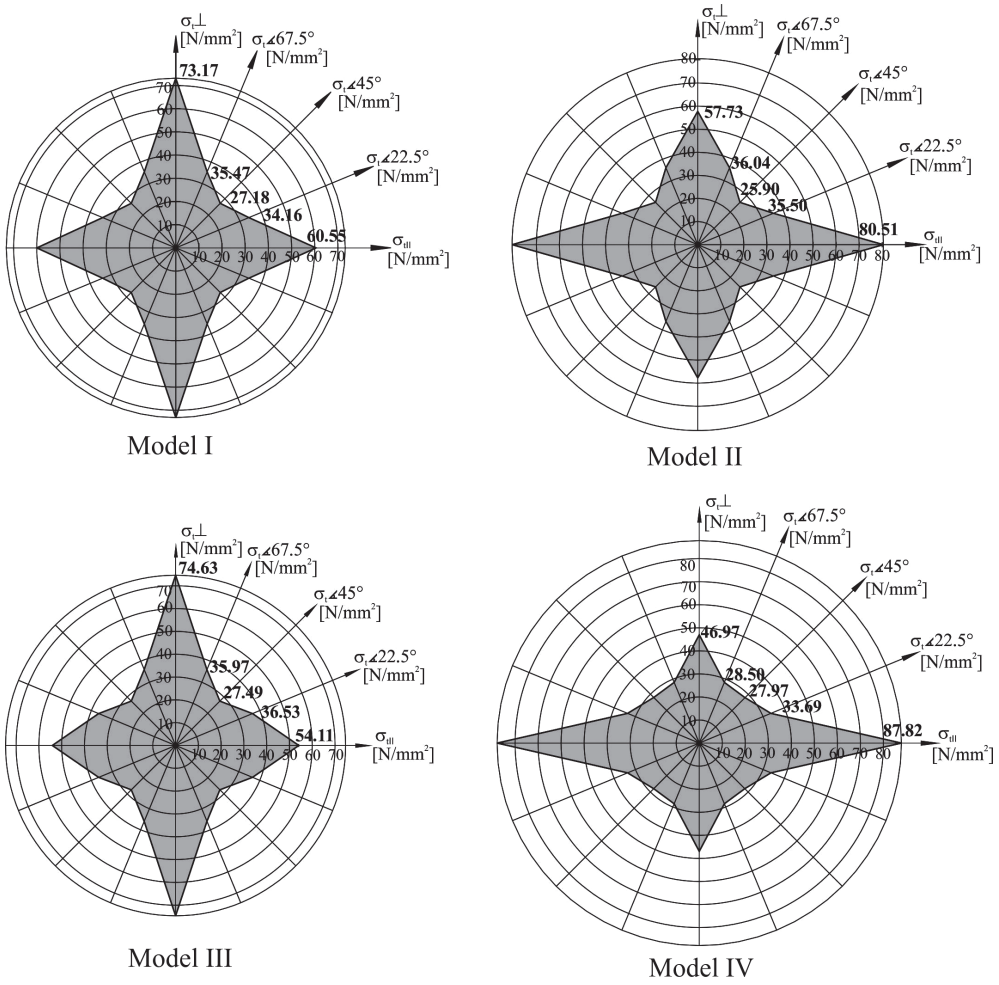


Figure 4 Polar diagrams of plywood tensile strength
Slika 4. Polarni dijagrami vlačne čvrstoće furnirskih ploča

exception of model IV, the values of tensile strength at the angels of 22.5º and 67.5º are similar to each other.

The differences in the values of tensile strength in different directions of plywood panel are a result of the orientation of wood fibers in plywood structure in relation to the direction of the action of tensile force. This means that the orientation of veneers in plywood structure has direct impact on plywood tensile strength.

The tensile strength of wood is higher in the direction of the wood fibers. By increasing the angle between the wood fibers and the direction of the tensile force, the tensile strength of wood is decreasing. At the angles between 60º and 90º, the tensile strength of wood is almost equal to the tensile strength perpendicular to the wood fibers (Lukić-Simonović, 1983).

The veneers with the thickness of 3.2 mm in experimental plywood account for the highest thickness percentage of the plywood panel, so the value of tensile strength depends on its orientation to the direction of the tensile force. The orientation of these veneer sheets in models II and IV is parallel to the face grain of the panel, which results in the highest value of the tensile strength in this direction of the plywood panel. In fact, the higher values of tensile strength parallel to the face grain are achievd in models that have higher thickness ratio of the veneers that run parallel to the tensile force. For the same reason, model I and III have higher values of tensile strength when the panels are stressed in tension perpendicular to the face grain of the panels. In this case, all three veneers with the thickness of 3.2 mm are oriented parallel to the direction of tensile force.

The values of the coefficients of equality of tensile strength (Table 3) calculated on the basis of the polar diagrams showed that differences in tensile strength in different directions of plywood panel are smaller in models I and III compared to models II and IV. The lowest coefficient is obtained in model IV, which means that the highest differences in tensile strength in different panel directions appear in this plywood model.

The coefficients of mass quality of plywood panels (Table 3) represent the tensile strength to weight ratio of plywood models. From the value of the coefficient of mass quality, the values of the material properties in relation to its density can be seen. The values of this coefficient show that the highest tensile strength to weigth ratio is determined in model II compared to other plywood models. The increment of the value of this coefficient speaks for a higher quality of plywood structure. For comparison, the coefficient of steel mass quality is 1026 (Nikolić, 1988).

The failure mode of the test specimens for the determination of the tensile strength is shown in Figure 5. The visual analysis of test specimens, during testing

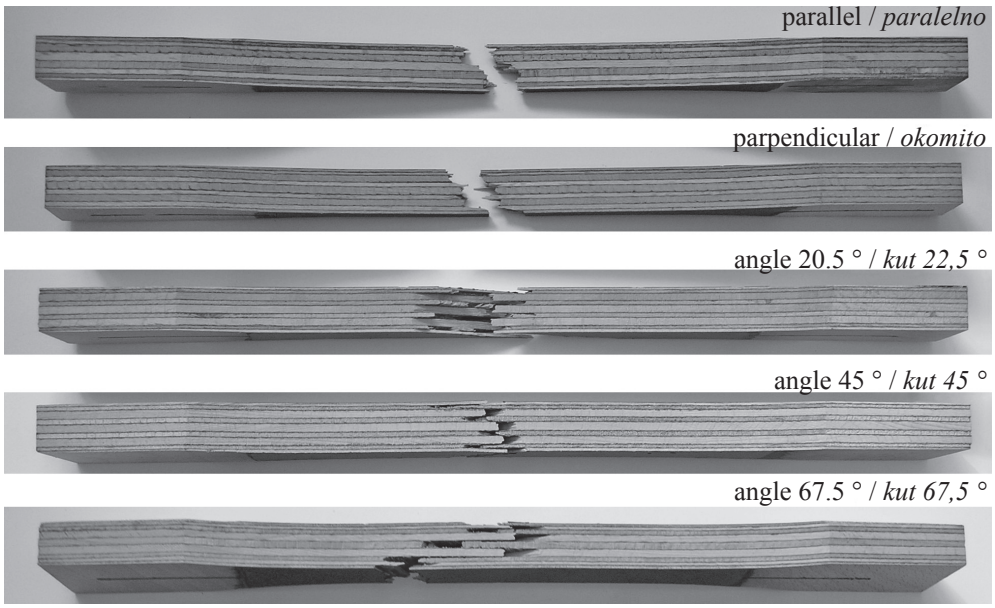


Figure 5 Faliure modes of test specimens for the determination of tensile strength
Sika 5. Načini loma ispitivanih uzoraka za određivanje vlačne čvrstoće

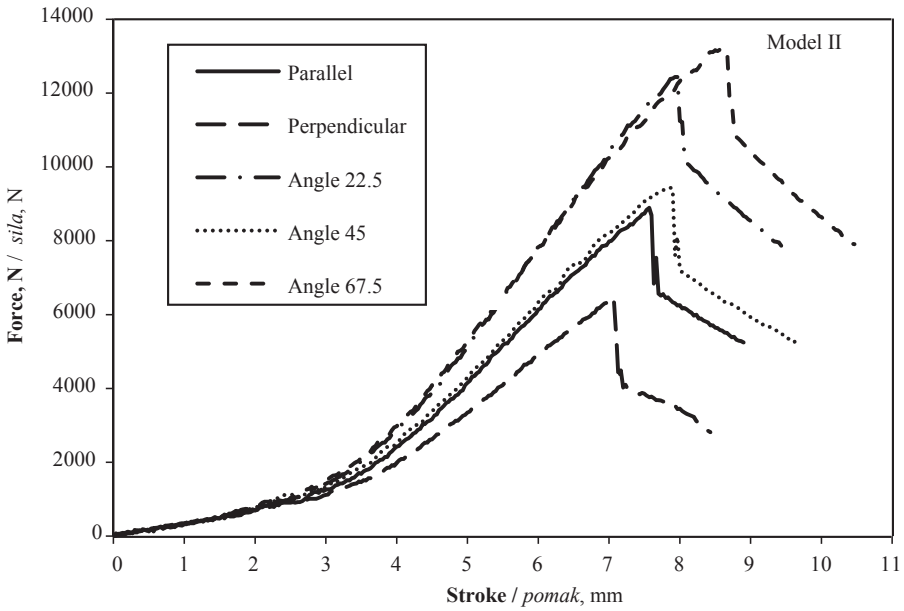


Figure 6 Force-stroke diagram during testing the tensile strength of representative plywood model
Slika 6. Dijagram sila – pomak pri ispitivanje vlačne čvrstoće reprezentativnog modela furnirske ploče

Table 3 Coefficients of equality of tensile strength (K_{et}) and coefficients of mass quality (K_{mq}) of plywood
Tablica 3. Koeficijenti jednakosti vlačne čvrstoće (K_{et}) i koeficijenti masene kvalitete (K_{mq}) furnirskih ploča

Model / *Model*	K_{et}	K_{mq}
I	0.30	1790
II	0.26	1855
III	0.29	1678
IV	0.19	1749

of tensile strength, showed that the failure of the test specimens occurred at once, whitout prior delamination of veneers.

The force-stroke diagrams, during testing of tensile strength (Figure 6), showed that the failure of the material occurred at once without significant plastic deformation.

4 CONCLUSION
4. ZAKLJUČAK

On the basis of the research, it can be concluded that different veneer layouts in plywood structure have significant impact on plywood tensile strength. The difference in the values of tensile strength between different plywood models results from the orientation of the veneers in the plywood structure, particularly of the veneers with a thickness of 3.2 mm, as they account for the highest thickness percentage of the panel.

The highest values of tensile strength are achieved in plywood models in which the veneers with

the thickness of 3.2 mm are oriented parallel to the direction of tensile force. Therefore, the recommendation is to use the configuration of models II and IV in cases when the panels are loaded in tension parallel to the face grain of the panel.

When the panels are loaded in tension in cross grain direction, or when a greater equality of the values of tensile strength in different directions of the panel is required, then the configurations of models I and III are recommended.

The production of plywood with different veneer layouts in panel structure gives opportunities for production of panels that can meet different application requirements. Trough the change of the veneer position in plywood structure, without changing the number and thickness of veneers, plywood panels with different strength characteristics can be designed. Therefore, the choice of a certain plywood configuration will depends on the application area, i.e., the type of loads to which the panel is exposed during its use.

5 REFERENCES
5. LITERATURA

1. Arriga, F.; Pereza, F., 2004: Characteristic values of mechanical properties of radiata pine plywood, http://www.ewpa.com/Archive/2004/jun/Paper_314.pdf.
2. Brezović, M.; Jambreković, V.; Kljak, J., 2002: Utecaj karbonskih vlakana na neka relevantna svojstva furnirskih ploča. Drvna industrija, 53(1): 23-31.
3. Bal, B. C.; Bektaş, İ., 2014: Some mechanical properties of plywood produced from eucalyptus, beech and poplar veneers. Maderas Cienc. Tecnol, 16(1): 99-108. https://doi.org/10.4067/s0718-221x2014005000009.
4. Cai, Z.; Ross, R. J., 2010: Mechanical properties of wood-based composite materials, Chapter 12 in Wood handbook - Wood as engineering material. USDA, FPL, General Technical Report-190: 12-1 – 12-12.
5. Hrázský, J.; Král, P., 2005: Assessing the bending strength and modulus of elasticity in bending of exterior foiled plywoods in relation to their construction. J For Sci, 51(2): 77-94.
6. Hrázský, J.; Král, P., 2006: Effects of the Thickness of Rotary-Cut Veneers on Properties of Plywood Sheets. Part 2. Physical and Mechanical Properties of Plywood Materials. J For Sci, 52(3): 118-129.
7. Jakimovska Popovska, V., 2011: Comparative researches of the properties of laboratory plywood and some industrial manufactured wood-based panels. Master thesis, „SS.Cyril and Methodius“ University in Skopje (in Macedonian).
8. Jakimovska Popovska, V.; Iliev, B., 2013: Ifluence of plywood structure on compressive strength parallel to the plane of the panel, Proceedings of 1th International Scientific Conference „Wood Technology & Product Design”, 16-18 May 2013, Ohrid, pp. 194-200.
9. Kljak, J.; Brezović, M.; Jambreković, V., 2006: Plywood stress optimization using the finite element method. Wood Research, 51(1): 1-10.
10. Kljak, J.; Brezovic, M., 2007: Relationship between bending and tensile stress distribution in veneer plywood. Forest Products Journal, 57(12): 65.
11. Kljak, J.; Brezović, M., 2007a: Effect of shear components on stress values in plywood panel subjected to tensile load. Drvna industrija, 58(3): 135-139.
12. Krpan, J., 1970: Tehnologija furnira i ploča. Zagreb: Tehnička knjiga.
13. Lukić-Simonović, N., 1983: Poznavanje svojstava drveta (autorska skripta). Beograd.
14. Lovrić, A.; Zdravković, V.; Lovanović, L., 2015: Influence of composition and number of layers of poplar plywood (populous euramericana) on bending strength and modulus of elasticity. Proceedings of 2nd International Scientific Conference „Wood Technology & Product Design”, 2015, Ohrid, pp. 1-7.
15. Nikolić, M., 1988: Furnirne i slojevite ploče. Beograd: Građevinska knjiga.
16. Stark, N. M.; Cai, Z.; Carll, C., 2010: Wood handbook – Wood as engineering material, Chapter 11: Wood-based composite materials. USDA, Forest Product Laboratory, General Technical Report, 190: 11-28.
17. Youngquist, J. A., 1999: Wood-based composites and panel products. Chapter 10 in USDA, Forest Service, Wood as an engineering material. General Technical report FPL-GTR-113. Wood Handbook. USDA, Forest Service, Forest Products Laboratory.
18. ***MKC D.A8.066 – 1985: Ispituvanje na sloeviti proizvodi od drvo. Furnirski plochi. Opredeluvanje na jakost na zategnuvanje i modul na elastichnost. Makedonski standardi.
19. ***MKC D.C5.043 – 1982: Furnirski plochi za nosivi drveni inzhenerski konstrukcii vo gradezhnishtvoto. Makedonski standardi.
20. ***1957: Symposium on tension testing of non-metallic materials: presented at the fifty-ninth annual meeting, American Society for Testing Materials, Atlantic City, N. J., June 20, 1956. Philadelphia, Pa.: American Society for Testing and Materials. Special Technical Publication No. 194: 64.
21. ***2009: Structural plywood & LVL design manual, EWPAA-Engineered Wood Products Association of Australasia. http://www.ewp.asn.au (Accessed March 25, 2010).

Corresponding address:

Assist. Prof. VIOLETA JAKIMOVSKA POPOVSKA, Ph. D.

Department of Wood Composite Materials
Faculty of Design and Technologies of Furniture and Interior
University of SS. Cyril and Methodius in Skopje
P.O. Box 8
1130 Skopje, REPUBLIC OF MACEDONIA
e-mail: jakimovska@fdtme.ukim.edu.mk

Laszlo Bejo[1]

Operational vs. Embodied Energy: a Case for Wood Construction

Analiza operativne i ugrađene energije drvenih građevina

Review paper • Pregledni rad
Received – prispjelo: 21. 7. 2014.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*79;630*833.0*
doi:10.5552/drind.2017.1423

ABSTRACT • *The purpose of our article is to evaluate wood as a construction material in terms of the energy required for its construction and operation, compared to other types of construction materials. First, the role of construction and material manufacturing is evaluated within the full life cycle energy and CO_2 emissions of a building, concluding that the issue of embodied energy justifies the use of less energy intensive materials. Then the article reviews the literature dealing with the energy requirements of wood based construction, in order to establish whether the use of this natural, low density construction material is more energy efficient than using brick, reinforced concrete and steel structures. According to our analysis, the vast majority of the studies found that the embodied energy is significantly lower in wood based construction when compared to inorganic materials. According to several authors, wood construction could save much energy and significantly reduce the emissions related to the building sector on the national level. Carbon sequestration, and the related mitigation of the global climate change effect, can be significant if the share of durable wooden buildings can be increased in the market, using sustainably produced raw materials that are handled responsibly at the end of their lifetime. Some conflicting studies make important points concerning the heat storage, recycling and on-site labour demands related to these structures. These sources contribute to a deeper understanding of the issue, but do not alter the basic conclusions concerning the benefits of wood based construction. Some important aspects of wood extraction, manufacturing and construction that can help minimising the embodied energy of wood based structures are also discussed in the study.*

Key words: *climate change, embodied energy, emissions, carbon-dioxide, carbon sequestration, wood based construction*

SAŽETAK • *Cilj rada bio je ocijeniti drvo kao građevni materijal sa stajališta energije potrebne za proizvodnju građevnog materijala i operativne energije tijekom korištenja građevina, u usporedbi s ostalim vrstama građevnih materijala. Najprije je procijenjena uloga proizvodnje drvnoga građevnog materijala i izgradnje građevine u ukupnoj energiji i emisiji CO_2 u životnom ciklusu građevine, te je zaključeno da je, s obzirom na ugrađenu energiju, opravdana upotreba energetski manje intenzivnih materijala. Zatim je dan pregled literature koja se bavi energetskim zahtjevima gradnje na bazi drva, kako bi se utvrdilo je li upotreba toga prirodnoga građevnog materijala male gustoće energetski učinkovitija od upotrebe opeke, armiranog betona i čeličnih konstrukcija. Prema provedenoj analizi, velik broj studija pokazao je da je ugrađena energija znatno niža u konstrukciji utemeljenoj na drvu nego u onoj od anorganskih materijala. Nekoliko je autora ustvrdilo da se gradnjom na bazi drva može uštedjeti mnogo energije i znatno smanjiti emisije ugljikova dioksida u građevinskom sektoru na nacionalnoj razini. Vezanje uglji-*

[1] Author is associate professor at University of West Hungary, Simonyi Karoly Faculty of Engineering, Wood Sciences and Applied Arts, Sopron, Hungary.
[1] Autor je izvanredni profesor Sveučilišta zapadne Mađarske, Fakultet inženjerstva, znanosti o drvu i primijenjene umjetnosti, Sopron, Mađarska.

ka i s tim povezano ublažavanje globalnog učinka klimatskih promjena mogu biti veliki ako se poveća udio trajnih drvenih građevina na tržištu, izgrađenih primjenom sirovina proizvedenih održivim gospodarenjem šumama i ako se s građevinama na kraju njihova životnog vijeka odgovorno postupa. Neke studije čiji autori ne podržavaju gradnju drvom smatraju važnim naglasiti pitanja vezana za skladištenje topline i recikliranje te zahtjeve za radnom snagom na terenu pri gradnji objekata na bazi drva. Te studije pridonose boljem razumijevanju problema, ali ne mijenjaju osnovne zaključke o koristima gradnje na bazi drva. U istraživanju se također raspravlja o nekim važnim aspektima dobivanja drva te proizvodnje i ugradnje građevnog drva, koji mogu pridonijeti smanjenju energije ugrađene u drvene građevine.

Ključne riječi: *klimatske promjene, ugrađena energija, emisije, ugljikov dioksid, vezanje ugljika, gradnja na bazi drva*

1 INTRODUCTION
1. UVOD

In the EU and other parts of the world, the mitigation and prevention of anthropogenic environmental impact, and especially greenhouse gas emission, is becoming an increasingly critical question. Building-related emission was identified as one of the most important sources of pollution. Worldwide, much research has been devoted and measures were introduced to mitigate these problems through reducing the amount of non-renewable energy and CO_2 emission in residential and commercial structures. The EU resolution that all new buildings built after 2020 should be near-zero operation energy structures (EP&C 2010) is part of this effort.

The environmental performance and sustainability of buildings is a complex issue. In Europe the CEN/TC350 is responsible for the development of standardized methods for the assessment of the sustainability aspects of new and existing construction works. The committee developed several standards for the complex assessment of sustainability, including, but not limited to EN 15978:2011 and EN 15804, on the building and product levels, respectively. Furthermore, ISO 14025:2006 deals with the questions of environmental declarations. However, this article focuses primarily on the energy consumption related to residential construction in general, and wood-based construction in particular.

The regulations introduced in and outside of the EU put much emphasis on decreasing the energy used for the operation of the building (the so-called *operation energy*, related to heating and cooling, as well as to lighting and other processes). In the meantime, the energy used for producing and transporting the construction materials and for the construction process itself (the so-called *embodied energy*), as well as the related emission, receives much less attention.

The objectives of this article are to examine the importance of embodied energy within the total lifetime energy of residential buildings, and to evaluate wood as a construction material in terms of its lifetime energy balance, compared to traditional inorganic materials. The energy use and emissions of wood based construction is considered and compared to other building materials, and the carbon sequestration potential of wooden buildings is discussed. The counter-arguments of wood based construction are also analysed. Finally, we provide recommendations for maximising the environmental advantages of wood through minimising its embodied energy.

2 EMBODIED VS. OPERATIONAL ENERGY
2. UGRAĐENA ENERGIJA NASUPROT OPERATIVNOJ

The determination of embodied energy (i.e. the energy used for producing the building materials, their transportation and construction of a building, as well as the maintenance and demolition or deconstruction-related energy) is a very complicated process. There are several methods that may be employed. *Process analysis* (including the Life-Cycle Assessment methodology widely used and accepted in Europe) works well in known processes, but in many cases, in-depth information is missing about certain processes, and system boundaries are hard to determine. Using different databases may lead to a large variation in the results. *Input-output analysis* examines the energy requirements and emissions of an entire industry. This very practical, simple method does not differentiate between products and technologies within the given industry, which may differ significantly. Hybrid analysis may improve the precision of the assessment (Hammond and Jones, 2008; Stephan *et al.*, 2011; Crawford and Stephan, 2013). Depending on the applied method, the calculated embodied energy may vary significantly (Crawford and Stephan, 2013).

Most studies focus on the resources invested before completing the construction (the so-called cradle-to-gate approach). However, total embodied energy should include maintenance and deconstruction processes, as well. There are several further sources of uncertainty in the determination of embodied energy, as pointed out by Dixit *et al*. (2010).

Based on the above, the objective determination of the average embodied energy related to a given construction material or a type of building is a very difficult task. This is one reason why, so far, more attention has been paid to operation energy than to embodied energy – especially in terms of government policies. However, difficulties and uncertainties in determining the embodied energy is not a good enough reason to disregard this potentially important environmental factor when considering the environmental impact of a building.

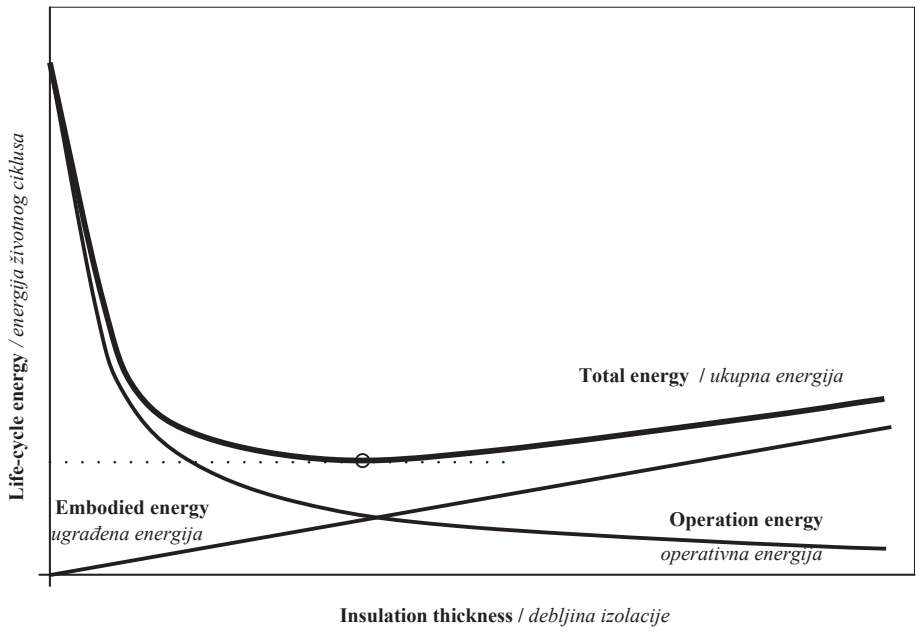


Figure 1 The relationship between embodied, operation and total life-cycle energy as a function of improved thermal insulation of buildings (based on Wind and Heschl 2008)
Slika 1. Odnos između ugrađene energije, operativne energije i energije ukupnoga životnog ciklusa u funkciji poboljšanja toplinske izolacije zgrada (prema Wind i Heschl, 2008.)

Determining operation energy, while not without its challenges, is much more straightforward than determining embodied energy. Operation energy measurement is done simply by measuring the amount of energy sources entering the building. Life cycle energy requirement is also simple to estimate with relatively good precision. Nevertheless, as some authors point out, there are certain uncertainties in determining operation energy as well, including:

- Fuel or electricity production sometimes also requires energy. The actual energy expenditure should include this extra energy as well, as reflected in the concept of primary energy;
- In addition to the quantity of energy, its 'quality' is also significant. Various types or forms of energy are not directly convertible into one another. Some authors suggest that the concept of 'exergy', which takes this into account, should be used instead (Hernandez and Kenny, 2011);
- Residents' lifestyle is also important. The way the residents use their dwelling, as well as some external factors (e.g. the amount of commuting required) also contribute to the energy use related to the given building (Dutil *et al*., 2011; Crawford and Stephan, 2013).

This shows that estimating or measuring the operation energy of buildings is not totally straightforward either. Nevertheless, the uncertainties are much smaller than in the case of embodied energy and CO_2 emissions.

When comparing life cycle embodied to operation energy, most studies place their relative proportion between 10:90 % and 20:80 %, (e.g. Cole and Kernan, 1996; Newton *et al.*, 2000; Scheuer *et al*., 2003; Sartori and Hestnes, 2007; Hernandez and Kenny, 2011; Ortiz *et al.*, 2009; Ramesh *et al.*, 2010; Szalay, 2012). These studies were conducted at different locations, using different building types and different assumptions, but, by and large, came to similar conclusions.

Others point out that these ratios are not necessarily valid today, and attribute an increasing significance to embodied energy (Dixit *et al.*, 2011). Some researchers argue that the role of operation energy is overestimated within the ecological impact of a building. Some studies even found the significance of embodied energy to be comparable to operation energy in many cases (e.g. Thormak, 2002; Gustavsson and Joelsson, 2010).

The role of embodied energy is especially amplified in low-energy, and in the so-called "zero-energy" buildings, that require thick walls and much (usually very energy-intensive) insulation material. This can mean that, after a point, improving the thermal properties (which leads to decreased operation energy, along with increased embodied energy) does not lead to more improvement in terms of total life-cycle energy and emission, and could in fact start increasing it (Figure 1).

Several studies showed that passive houses have much higher embodied energy content than traditional buildings (Dahlstrom, 2011; Thiers and Peuportier, 2012; Crawford and Stephan, 2013). Depending on the applied calculation method, their total life cycle energy and CO_2 emission may be even higher than in standard houses (Crawford and Stephan, 2013.) Other authors maintain that passive houses are definitely more energy efficient on the whole, but their total environmental impact may not be as favourable (Brunklaus *et al.*, 2010). Even using more conservative calculation methods, the significance of embodied energy may be high compared to the operation energy when the thermal insulation is improved. Further improvement in the energy efficiency is possible using environment friendly construction materials and technologies only (e.g. Dutil *et al.*, 2011; Szalay, 2012).

3 ENERGY BALANCE OF WOOD EXTRACTION AND BUILDING MATERIAL PRODUCTION COMPARED TO OTHER MATERIALS

3. ENERGETSKA BILANCA PRIDOBIVANJA DRVA I PROIZVODNJE GRAĐEVNOG MATERIJALA U USPOREDBI S DRUGIM MATERIJALIMA

Many studies available in the literature discuss the environmental impact of wood based construction. Unfortunately, these studies often use different methods and databases, and vary in terms of time, geography and technological capabilities of the analysed construction process. Accordingly, the calculated embodied energy and emission values can greatly diverge (e.g., according to a 2008 study by Hammond and Jones, literature values for the embodied energy of sawnwood range between 0.3 and 61.3 MJ/kg, and other materials show similar variations). Nevertheless, there is a very straightforward tendency when wood and wood based construction is compared to other materials.

In terms of the environmental impact of wood, most authors agree that wood is generally more environmentally friendly than other building materials. Almost all of the studies conclude that wood building elements and buildings require less embodied energy and cause lower CO_2 emissions than equivalent brick, concrete or steel structures (Richter and Sell, 1993; Peirquet *et al.*, 1998; Buchanan and Levine, 1999; Dias and Pooliyadda, 2004; Börjesson and Gustavsson, 2000; Lenzen and Treloar, 2002; Sharai-Rad and Welling, 2002; ASMI 2004; Lippke *et al.*, 2004; Perez-Garcia *et al.*, 2005, Puettmann and Wilson, 2005; Gustavsson and Sathre, 2006; Gustavsson *et al.*, 2006; Dutil *et al.*, 2011). One study (Sarri, 2001) found metal to have somewhat lower embodied energy, but in terms of non-renewable energy and CO_2 emissions, wood was still found to have a lower environmental impact.

The production of sawnwood is definitely less energy intensive than that of other materials. Due to its lower density, the extraction as well as the transportation, handling and processing of the raw material requires less energy. In addition, sawmilling by-products (like bark, sawdust, wood chips and trimming) can be used for heat or even electric energy production to partly cover the energy requirements of the mill. Also, used wood can be used at the end of its life cycle to produce more energy, which further improves the energy balance of wooden buildings.

Depending on the particular construction system, wood can be used as glued structural members, rather than solid wood. Because of the embodied energy of the adhesive, as well as the energy requirement of hot pressing, the embodied energy of glued structural members may be 1.5 to 2 times as high, and that of wood based composites may be 3 times of that of sawnwood, according to a North American study (Puettmann and Wilson, 2005). The database of Bath University in Great Britain shows similar differences (Hammond and Jones, 2008): glulam and MDF contain 1.5 times as much embodied energy, plywood and hardboard twice as much, and veneered chipboard 3 times as much as sawn timber. Other modification methods, including preservative and heat treatment, or the fire retardant included in cellulose fibre insulation, can significantly affect the embodied energy (Dutil *et al.*, 2011). According to Puettmann and Wilson (2005), however, the production of wood and wood based products still requires less energy than their inorganic counterparts. Naturally, these processes have other environmental implications, but these are beyond the scope of this review.

As evidenced above, there is a basic consensus regarding the relatively low embodied energy of wood products. In their case study of several buildings, Börjesson and Gustavsson (2000) concluded that the same building contains 60-80 % more embodied energy when built with a concrete structure, as compared to a wood based structure. CO_2 emission is at least 1.5 times higher, but may even be several times higher. Lenzen and Treloar (2002) later corrected this study, but they agreed with the conclusions concerning the relative impact of concrete and wood. Szalay (2003) calculated that the embodied energy of concrete and steel buildings is, respectively, 68 % and 136 % higher per square metre, than that of wooden buildings. North American case studies by Lippke *et al*. (2004), as well as Swedish and Finnish ones by Gustavsson *et al*. (2005) showed much lower differences of 16-32 %, but wood was still found more advantageous.

Petersen and Solberg (2005) point out that the results of various studies differ significantly depending on system boundaries, reuse or recycling at the end of the building service life, and other factors, but state that substituting wood for concrete or steel significantly decreased the production-related CO_2 emissions in all cases. Based on the ISO 14040 standard and the PAS 2050 ecological footprint determination methodology, Murphy (2009) regards wood as a green building material that has a positive effect on the climate change. He also points out that some information concerning the effect of wood needs to be refined. Gustavsson and Joelsson (2010) emphasise the importance of embodied energy and argue that the application of wood can significantly reduce the detrimental environmental effect of buildings.

Several studies examined the effect of the proliferation of wood construction on a larger region. Buchanan and Lavine (1999) estimated that, in New-Zealand, the CO_2 emission of the construction industry, and the total national emission could be decreased by 20 % and 1.5 %, respectively, by increasing the share of wood and wood based materials in the building industry by 17 %. Upton *et al.* (2008) calculated that the total life cycle energy of wooden residential buildings is 20-50 % lower, and, if all residential buildings were wood frame structures in the US, the embodied energy and the related CO_2 emissions could be decreased by 22 % and 27 %, respectively (and this in a country where most residential buildings are already built with a wooden structure).

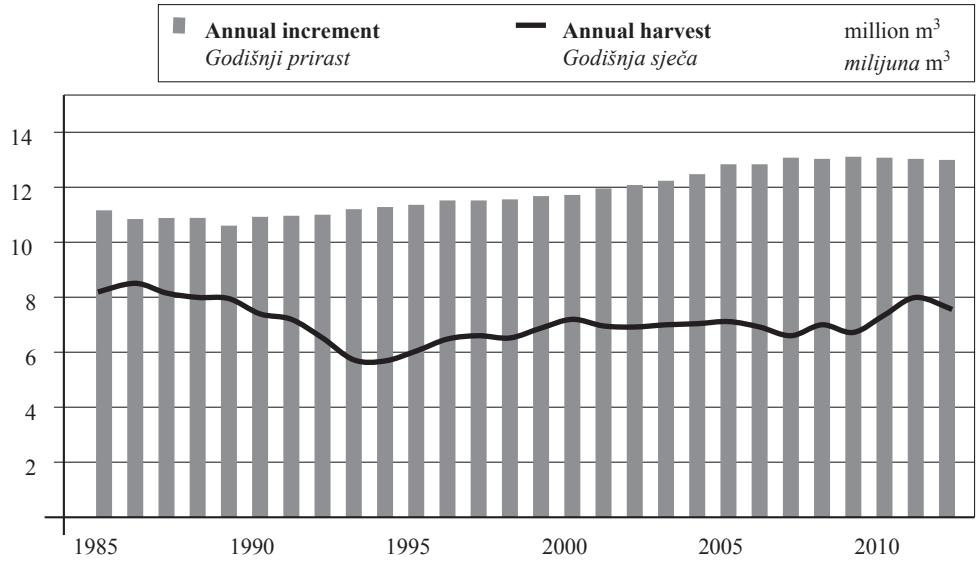


Figure 2 Annual increment and harvest in Hungarian forests (based on NEBIH 2013)
Slika 2. Godišnji prirast i sječa u mađarskim šumama (prema NEBIH, 2013.)

4 THE ROLE OF CARBON SEQUESTRATION IN WOODEN BUILDINGS
4. ULOGA VEZANJA UGLJIKA U DRVENIM GRAĐEVINAMA

Some of the studies consider the role of wood in carbon sequestration (Buchanon and Levine 1999, Börjesson and Gustavsson 2000, Lippke *et al.* 2004, Szalay 2004). However, this factor is often disregarded as one that is hard to compare with other indicators (Hammond and Jones 2008), or because the carbon stored in wood will eventually return to the atmosphere. Thus, the architectural use of wood is only advantageous compared to other wood products (Buchanan and Levine, 1999). Other studies state that the energy balance of "wood-intensive" buildings may be positive if wood comes from sustainable sources and is used for energy production at the end of its life cycle (Szalay, 2004; Salazar and Meil, 2009). According to Murphy (2009), carbon sequestration results in negative global warming potential, although he points out that this is very much a function of its reuse or recycling at the end of its life cycle (which is seldom actually studied; most models rely on assumptions).

Based on Hungarian studies by Schoberl *et al.* (2011) and Schoberl (2012), and also the above considerations, the following conclusions can be drawn, concerning carbon sequestration:

- The carbon sequestration effect of wood is useful only if the harvested material is continuously replenished, i.e., if it comes from sustainable forests. Fortunately, this is true in most of Europe. In Hungary, for example, the yearly increment shows a generally increasing

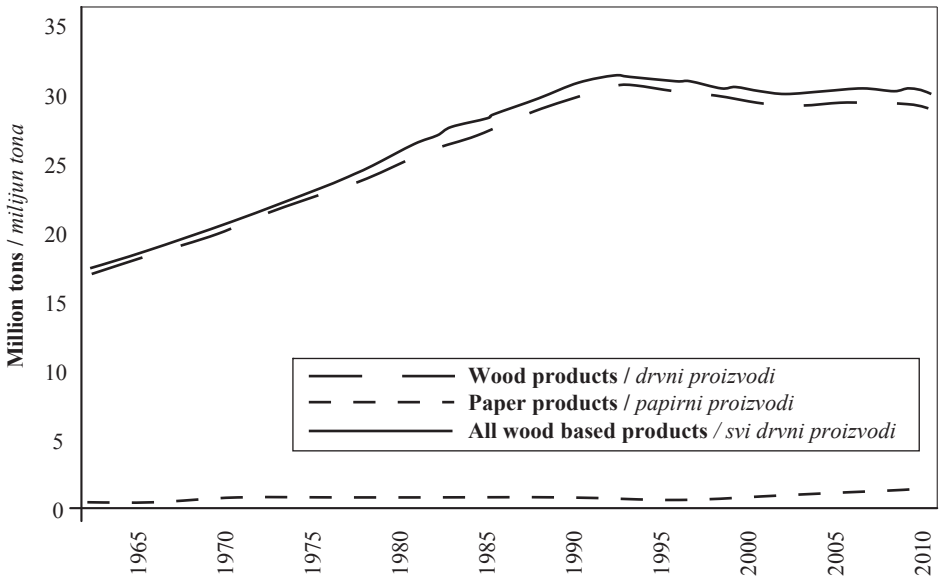


Figure 3 The amount of carbon stored in wood and paper products in Hungary
(based on Schoberl, 2011)
Slika 3. Količina ugljika pohranjena u drvnim proizvodima i proizvodima od papira u Mađarskoj (Schoberl, 2011.)

trend, while the harvest amounts to only about 50 % of the increment (Schiberna, 2011, Figure 1.).

- On the regional or national level, positive carbon sequestration requires the amount of wooden tools or products, and therefore the volume of carbon stored in them, to increase. According to the statistics, although it used to show a steady increase in Hungary until the mid-1990s, right now it is stagnating, or only slightly increasing (Figure 2). According to Schoberl *et al*. (2011), one way of increasing the stock of carbon stored in wood in Hungary would be to increase the share of wood within the construction industry.
- The service life of buildings, and the handling of building materials at the end of their life cycle is a key issue (Börjesson and Gustavsson, 2000). Wood fibres in construction wood constitute an important resource. The deconstructed material may be reused as construction wood or recycled into other materials (e.g. wood based panels, composites or paper). Thus, the carbon may not be released into the atmosphere as carbon-dioxide for a long time. Energy use also has a positive effect, but it results in a rapid release of the carbon into the atmosphere. Therefore, it should be encouraged, but only when wood is no longer serviceable in any other capacity. Depositing wood in landfills is the worst possible solution, since there the carbon will turn into CO_2 relatively quickly (depending on the durability of the wood species), and there is no energy gain. One should strive to reuse or recycle the deconstructed material at the highest possible level, and preferably several times.

An increased proportion of wooden buildings, built of material coming from sustainable forests, and handled responsibly at the end of their lifetime, can significantly contribute to the long term sequestration of atmospheric carbon, and, consequently, to the mitigation of global climate change.

5 POTENTIAL PITFALLS OF WOOD BASED CONSTRUCTION
5. MOGUĆI NEDOSTACI DRVA KAO GRAĐEVNOG MATERIJALA

Some authors bring forth arguments that may counteract the perceived benefits of wood construction, compared to inorganic materials.

The surface mass and the related daily and seasonal heat storage capacity of buildings are generally disregarded when comparing wood to traditional building materials. Hacker *et al.* (2008) calculate that, although the amount of CO_2 released during wood construction is much lower, considering the seasonal heat equalization coming from the higher thermal mass of concrete buildings, and the resulting savings in heating and cooling, the difference may be balanced in terms of life-cycle energy. Several other studies, financed by the American Portland Cement Association, also emphasise the energy saved due to the thermal mass of concrete buildings (Gajda, 2001; Marceau and Van Geem, 2002a, b, c). In Upton's (2008) evaluation, however, the embodied energy calculations are not detailed in these studies, and the thermal insulation of systems compared is not equivalent.

These studies are important in terms of pointing out the significance of thermal mass (which is especially important in areas with high seasonal temperature fluctuation, like most of Europe). Nevertheless, due to the above mentioned deficiencies, it is questionable whether the higher thermal mass provides enough of a benefit to make concrete a more energy efficient building material than wood. In addition, some wood construction systems may also possess a relatively high thermal mass. Several studies (Crespell and Gagnon 2010, TRADA 2010) mention the high thermal mass of CLT (Cross-Laminated Timber), for example. The examination of the Holz100 system by the Erwin Thoma GmbH, for example, revealed that the cool-off time of a building manufactured from their product may be three times as long as that of an equivalent brick building, based on a TRYNSYS simulation model (Kouba, 2001). Szalay (2004b) published a theoretical study, where she calculated that the daily heat equalization may be significantly better in solid wood buildings than in the case of insulated brick buildings, and even claimed that lightframe walls are not much worse than AAC (cellular concrete) walls in this respect.

Other publications (Anderson, 1998; SCI, 1998; de Spot, 1999; Adalbert *et al.*, 2001; SCSSC, 2002) emphasise the advantage of steel. These are mostly based on the recyclability of steel, downplaying the significance of embodied energy, lower needs for steel maintenance and land use issues concerning wood. Upton (2008) counters that, in studies comparing equivalent thermal insulation systems, the embodied energy of wood structures is almost always lower than that of steel framing. In addition, the proponents of steel usually disregard the fact that other materials (like wood) may also be reused or recycled to a certain extent.

Dutil *et al*. (2011) estimate that wood based construction often requires more on-site labour than steel. The related transportation of workers may diminish the positive ecological effect of wood. Thus the energy balance of steel construction may even be better than wood (although they do acknowledge that wood-related CO_2 emissions are still lower). Evaluating the energy balance of on-site construction, Cole (1998) shows that, for concrete buildings, embodied energy and CO_2 emissions related to worker transportation is much higher than that of either wood or steel. In his comparison, steel is somewhat better than wood, but it would be a gross exaggeration to say that this may cause steel structures to have lower embodied energy than wood. In addition, these comparisons are highly dependent on the particular technology employed (especially on the level of prefabrication, which may be very high in wood buildings).

In summary, these considerations aid a better understanding of the benefits of wood, but do not change the basic conclusion that wood based construction leads to much lower embodied energy and CO_2 emissions than in the case of inorganic building materials.

6 TAKING BEST ADVANTAGE OF THE ENERGY BENEFITS OF WOOD
6. ISKORIŠTAVANJE ENERGETSKIH PREDNOSTI DRVA NA NAJBOLJI NAČIN

Based on the review of the available literature, wood based construction uses less energy than other construction technologies. In the meantime, the details of this technology, like the acquisition, handling, transportation of the resources and workers, can be optimised to further improve the energy efficiency. Some of these are listed, as follows:

Certification

As mentioned earlier, some advantages of wood cannot be realised only if it comes from sustainable forests. European raw materials are typically like this, since most of Europe practices sustainable forestry. In the meantime, full certainty of sustainability is guaranteed only through buying certified materials. Soon, all of Europe will move toward accepting FSC or PEFC (Forestry Stewardship Council, Programme for the Endorsement of Forest Certification, respectively) certified materials only.

Transportation

Since wood is produced with relatively low CO_2 emission, the importance of processes that release CO_2 increases. This includes the shipping of material. Since, in Hungary, construction wood is typically bought from abroad, transportation may significantly increase CO_2 emissions, depending on the country of origin.

Assuming that an average diesel truck is used, 4.5×10^{-5} kg of CO_2 is released when hauling one kg of wood over a one kilometre distance[1]. According to the embodied carbon and energy inventory of the British Bath University, the embodied carbon of softwood lumber is 0.123 kg/kg, i.e. 0.45 kg of CO_2 is released when producing one kg of wood. Accordingly, the emissions related to transporting the material one kilometre is four orders of magnitude lower than that related to its production. This means that, even if wood travels 1000 km, there is only a slight emission increase. The calculations do not include other emissions arising from transportation (like producing and maintaining the vehicles and roads), and are not based on primary emissions, therefore the actual emissions are somewhat higher.

Nevertheless, wood should be acquired from as near as possible, preferably from domestic sources. Unfortunately, Hungarian climate and sites are not suitable for growing softwood of sufficient quality, but some poplar species may be suitable for substituting softwood. This may allow us to decrease the embodied energy and carbon.

Processing technology

Even though wood processing typically requires much less energy than other materials, it is still not negligible. Wood drying and hot pressing of wood based materials, in particular, are energy intensive processes. To take maximum advantage of the low embodied energy of wood, close attention should be paid to these processes, e.g. through natural drying (which also has a positive effect on wood quality), and using renewable energy sources (especially local energy production using wood processing by-products.)

Adhesives and additives; wood modification

As the literature shows, using adhesives significantly increases the embodied energy of wood. Impregnating cellulose fibre insulation with fire retardants has a similar disadvantage, and wood preservatives and modification methods (like high temperature treatment and other chemical agents) are also likely to increase the embodied energy. Increasing the dimensions and improving its properties through eliminating defects and re-gluing the material makes it much more suitable for structural applications, and creates higher value (e.g. defect-free, glued structural members allow smaller cross-sections and generate less waste, which has a positive effect on the energy balance and the emissions, too.) Therefore, careful consideration is needed to establish if the use of glued or modified wood is justified. In certain situations their drawbacks may be counterbalanced by the lower volume of required material, or improved durability. Also, developing more environment friendly adhesives and modifying agents is an important area of research.

Prefabrication

Most on-site processes are very labour-intensive. Related transportation of the workers may be an important factor. Therefore, prefabrication is preferred. Fortunately, most wood-based construction technologies allow high levels of prefabrication, and therefore on-site labour can be minimised.

Resource cascading

Taking advantage of the energy benefits and the carbon sequestration potential of wood requires reuse and recycling, as many times as possible. The repeated utilisation of the used material, at the highest possible value, is called cascading (Frühwald *et al.*, 2010). This requires a paradigm-shift, over which builders have little or no control. One way to foster cascading is using as much used material in the buildings, as possible. Using wood for energy production should be the last step of cascading. The energy gained at the end of the life cycle may be comparable, or even higher than the energy used for manufacturing the product. This energy may be taken into account in the LCA (Life Cycle Assessment) methodology, too.

7 CONCLUSIONS
7. ZAKLJUČAK

The aim of our study was to establish if wood based construction is environment friendly based on embodied energy and CO_2 emission. Based on an in-depth study of the literature, the following conclusions were drawn:

[1] According to Davis *et al.* (2013), transporting 1 kg material requires approx. 1.7×10^{-5} l/kg/km of diesel fuel. Based on the forumula $C_{12}H_{23} + 71\ O_2 \rightarrow 48\ CO_2 + 46\ H_2O$, 2.626 kg CO_2 is generated when burning one litre of diesel fuel, taking the density of fuel (0.832 kg/l) into account.

1. Embodied energy can account for upwards of 20 % of the total lifecycle energy of buildings. Minimising the embodied energy incorporated in the building is especially important in modern, energy efficient buildings where the relative importance of operation energy decreases, and embodied energy increases due to the larger volume of construction material required.
2. Based on most studies, manufacturing and using wood and wood based materials in buildings leads to much lower embodied energy and CO_2 emissions, compared to inorganic building materials. Most authors calculate that this leads to reduction in emissions and in the life-cycle energy of the buildings.
3. Increasing the share of wooden structures within the construction industry, built from sustainable and high-quality (durable) raw materials, and handled responsibly at the end of the building service life, may significantly contribute to the sequestration of atmospheric carbon dioxide on the long run. This may be an important strategy in mitigating the problem of global climate change.
4. There are certain considerations that can amend the positive conclusions concerning the benefits of wood in terms of energy use and emissions. However, these studies failed to prove that inorganic building materials may be better than wood in this respect.
5. Optimising certain aspects of the production of building materials and of the construction technology has a potential to further improve the energy efficiency of wood based construction. These strategies are outlined in detail in the article.

Based on the above, the final conclusion is that the use of wood in the construction industry carries significant environmental advantages in terms of energy efficiency and emission reduction.

Acknowledgements – Zahvala

This article was made in frame of the „EFOP-3.6.1-16-2016-00018 – Improving the role of research+development+innovation in the higher education through institutional developments assisting intelligent specialization in Sopron and Szombathely.

8 REFERENCES
8. LITERATURA

1. Adalberth, K.; Almgren, A.; Holleris Petersen, E., 2001: Life cycle assessment of four multi-family buildings. International Journal of Low Energy and Sustainable Buildings, 2.
2. Anderson, J., 1998: Development of an environmental research strategy in Sweden. Journal of Construction Steel Research, 46(1/3): 13-14. https://doi.org/10.1016/S0143-974X(98)00053-4
3. Börjesson, P.; Gustavsson, L., 2000: Greenhouse gas balanced in building construction: wood versus concrete from life-cycle and forest land-use perspectives. Energy Policy, 28: 575-588. https://doi.org/10.1016/S0301-4215(00)00049-5.
4. Brunklaus, B.; Thormark, C.; Baumann, H., 2010: Illustrating limitations of energy studies of buildings with LCA and actor analysis. Building Research & Information, 38(3): 265-279. https://doi.org/10.1080/09613211003654871.
5. Buchanan, A. H.; Levine, S. B., 1999: Wood-based building materials and atmospheric carbon emissions. Environmental Science & Policy, 2(6): 427-437. https://doi.org/10.1016/S1462-9011(99)00038-6.
6. Cole, R. J.; Kernan, P. C., 1996: Life-Cycle Energy Use in Office Buildings. Building and Environment, 31(4): 307-317. https://doi.org/10.1016/0360-1323(96)00017-0.
7. Cole, R. J., 1998: Energy and greenhouse gas emissions associated with the construction of alternative structural systems. Building and Environment, 34: 335-348. https://doi.org/10.1016/S0360-1323(98)00020-1.
8. Crawford, R. H.; Stephan, A., 2013: The significance of embodied energy in certified passive houses. In: Proc. ICCBM 2013: Int. Conf. on Construction and Building Materials, Copenhagen, pp. 473-479.
9. Crespell, P.; Gagnon, S., 2010: Cross-Laminated Timber: a Primer. FPI Special Publication, issue 52.
10. Dahlstrom, O., 2011: Life Cycle Assessment of a Single-Family Residence built to Passive House Standard. Master thesis, Norwegian University of Science and Technology, Trondheim, Norway.
11. Davis, S. C.; Diegel, S. W.; Boundy, R. G.; Moore, S., 2013: Vehicle Technologies Market Report. Report for the US Dept. of Energy. ORNL/TM-2014/58, Oak Ridge National Laboratory, Oak Ridge, TN. https://doi.org/10.2172/1068745.
12. Dias, W. P. S.; Pooliyadda, S. P., 2004: Quality based energy contents and carbon coefficients for building materials: A systems approach. Energy, 29(4): 561-580. https://doi.org/10.1016/j.energy.2003.10.001.
13. Dixit, M. K.; Fernández-Solís, J. L.; Lavy, S.; Culp, C. H., 2010: Identification of parameters for embodied energy measurement: A literature review. Energy and Buildings, 42: 1238-1247. https://doi.org/10.1016/j.enbuild.2010.02.016.
14. Dutil, Y.; Rousse, D.; Quesada, G., 2011: Sustainable Buildings: An Ever Evolving Target. Sustainability, 3: 443-464. https://doi.org/10.3390/su3020443.
15. Frühwald, A.; Diederichs, S.; Morgan, R., 2010: Verwendungspotentiale heben durch Kaskadennutzung am Beispiel Holz. Erneuerbare Energie, 4: 37-49.
16. Gajda, J., 2001: Energy use of single-family houses with various exterior walls. PCA CD026. Skokie, IL: Portland Cement Association.
17. Gustavsson, L.; Joelsson, A., 2010: Life cycle primary energy analysis of residential buildings. Energy and Buildings, 42: 210-220. https://doi.org/10.1016/j.enbuild.2009.08.017.
18. Gustavsson, L.; Sathre, R.; Pingoud, K., 2006: Greenhouse Gas Benefits of Wood Substitution: Comparing Concrete- and Wood-Framed Buildings in Finland and Sweden. IEA Bioenergy: T38 (2005): 05.
19. Gustavsson, L.; Sathre, R., 2006: Variability in energy and carbon dioxide balances of wood and concrete building materials. Building and Environment, 41: 940-951. https://doi.org/10.1016/j.buildenv.2005.04.008.
20. Gustavsson, L.; Pingoud, K.; Sathre, R., 2006: Carbon dioxide balance of wood substitution: comparing concrete- and wood-framed buildings. Mitigation and Adaptation strategies for global change, 11(3). Netherlands: Springer. https://doi.org/10.1007/s11027-006-7207-1.
21. Hacker, J. N.; De Saulles, T. P.; Minson, A. J.; Holmes, M. J., 2008: Embodied and operational carbon dioxide

emissions from housing: A case study on the effects of thermal mass and climate change. Energy and Buildings, 40: 375-384. https://doi.org/10.1016/j.enbuild.2007.03.005.
22. Hammond, G. P.; Jones, C. I., 2008: Embodied energy and carbon in construction materials. Proceedings of the Inst. of Civil Engineers, 161(2): 87-98. https://doi.org/10.1680/ener.2008.161.2.87.
23. Hernandez, P.; Kenny, P., 2011: From net energy to zero energy buildings: Defining life cycle zero energy buildings. Energy and Buildings, 42: 815-821. https://doi.org/10.1016/j.enbuild.2009.12.001.
24. Kouba, R., 2001: Thermische Simulation zum Holz100 Bausystem. Research report, Institut für Wärmetechnik, TU Graz, Austria.
25. Lenzen, M.; Treloar, G., 2002: Rejoinder to: Greenhouse gas balanced in building construction: wood versus concrete from lifecycle and forest land-use perspectives. Energy Policy, 30: 249-255. https://doi.org/10.1016/S0301-4215(01)00142-2.
26. Lippke, B.; Wilson, J.; Perez-Garcia, J.; Bowyer, J.; Meil, J., 2004: CORRIM: life-cycle environmental performance of renewable building materials. Forest Prod. J. 54(6): 8-19.
27. Marceau, M.; Van Geem, M., 2002: Life cycle assessment of an insulating concrete form house compared to a wood frame house. SN2571. Skokie, IL: Portland Cement Association.
28. Marceau, M.; Van Geem, M., 2002: Life cycle assessment of a concrete masonry house compared to a wood frame house. SN2465. Skokie, IL: Portland Cement Association.
29. Marceau, M.; Van Geem, M., 2002: Life cycle assessment of a lightweight concrete masonry house compared to a wood frame house. SN2573. Skokie, IL: Portland Cement Association.
30. Murphy, R., 2009: Incorporating Life Cycle Assessment (LCA) of wood materials in green building design. UNECE/FAO Workshop on Responding to Climate Change: Wood's place in a global approach to green building, 12 October 2009, Geneva.
31. Newton, P.; Tucker, S.; Ambrose, M.; 2000: Housing Form, Energy Use and Greenhouse Gas Emissions. In: M. Jenks, K. Williams, E. Burton (ed.). Achieving Sustainable Urban Form. Taylor & Francis, London, pp. 74-83.
32. Ortiz, O.; Castells, F.; Sonnemann, G., 2009: Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23: 28-39. https://doi.org/10.1016/j.conbuildmat.2007.11.012.
33. Peirquet, P.; Bowyer, J.; Huelman, P., 1998: Thermal performance and embodied energy of cold climate wall systems. Forest Prod. J., 48(6): 53-60.
34. Perez-Garcia, J.; Lippke, B.; Briggs, D.; Wilson, J.; Bowyer, J.; Meil, J., 2005: The environmental performance of renewable building materials in the context of residential construction. Wood Fiber Sci. CORRIM Special Issue, 37: 3-17.
35. Petersen, A. K.; Solberg, B., 2005: Environmental and economic impacts of substitution between wood products and alternative materials: a review of micro-level analyses from Norway and Sweden. Forest Policy and Economics, 7: 249-259. https://doi.org/10.1016/S1389-9341(03)00063-7.
36. Puettmann, M.; Wilson, J., 2005: Life-cycle analysis of wood products; cradle-to-gate LCI of residential wood building materials. Wood Fiber Sci. CORRIM Special Issue, 37: 18-29.
37. Ramesh, T.; Prakash, R.; Shukla, K. K., 2010: Life cycle energy analysis of buildings: An overview. Energy and Buildings, 42: 1592-1600. https://doi.org/10.1016/j.enbuild.2010.05.007
38. Richter, K.; Sell, J., 1993: Life-cycle analysis: a useful approach to promote wood as a construction material. Wood Design Focus, 4(2): 14-17.
39. Salazar, J.; Meil, J., 2009: Prospects for carbon-neutral housing: the influence of greater wood use on the carbon footprint of a single-family residence. Journal of Cleaner Production, 17: 1563-1571. https://doi.org/10.1016/j.jclepro.2009.06.006.
40. Sarri, A., 2001: Environmental specifications of building parts and buildings [in Finnish]. TKK Rakentamistalous. Sponsored by Rakennustieto Oy. Helsinki: Rakennustietosaatio RTS. (CORRIM Special Issue).
41. Sartori, I.; Hestnes, A. G., 2007: Energy Use in the Life Cycle of Conventional and Low-Energy Buildings: A Review Article. Energy and Buildings, 39: 249-257. https://doi.org/10.1016/j.enbuild.2010.05.007.
42. Scharai-Rad, M., Welling, J., 2002: Environmental and energy balances of wood products and substitutes. Food and Agriculture Organization of the United Nations (FAO).
43. Scheuer, C.; Keoleian, G. A.; Reppe, P., 2003: Life Cycle Energy and Environmental Performance of a New University Building: Modeling Challenges and Design Implications. Energy and Buildings, 35(10): 1049-1064. https://doi.org/10.1016/S0378-7788(03)00066-5.
44. Schiberna, E., 2011: Fenntartható (tartamos) erdőgazdálkodás (*Sustainable forest management*) (in Hugarian). In: S. Molnar (ed.). Örök társunk a fa. NymE Publishers, Sopron, Hungary, pp. 11-15.
45. Schoberl, M., 2012: Fatermékekben tárolt szén hazai civilizációs anyagárama és a klíma- védelem. (*Material flow of the carbon stored in wood products in Hungary, and the climate protection*) (in Hugarian). Faipar, 60(4):10-13.
46. Schoberl, M.; Borcsok, Z.; Fuhrer, E., 2011: Erdő és a faanyag szerepe a klímavédelemben. (*The role of forests and wood in climate protection*) (in Hugarian). In: S. Molnar (ed.). Örök társunk a fa. NymE Publishers, Sopron, Hungary, pp. 21-26.
47. Stephan, A.; Crawford, R. H.; Myttenaereb, K., 2011: Towards a more holistic approach to reducing the energy demand of dwellings. Procedia Engineering, 21: 1033-1041. https://doi.org/10.1016/j.proeng.2011.11.2109.
48. De Spot, M., 1999: The application of structural steel to single-family residential construction. Ottawa, Ont.: Node Engineering.
49. Thiers, S.; Peuportier, B., 2012: Energy and environmental assessment of two high energy performance residential buildings. Building and Environment, 51: 276-284. https://doi.org/10.1016/j.buildenv.2011.11.018.
50. Thormak, C., 2002: A low energy building in a life cycle – Its embodied energy, energy need for operation and recycling potential. Building and Environment, 37(4): 429-435. https://doi.org/10.1016/S0360-1323(01)00033-6.
51. Szalay, Z., 2003: Embodied Energy in Timber Buildings. In: L. Végh, J. Novák, J. Valentin (eds.). Environmentally Compatible Structures and Structural Materials (ECS). Proc. 4th Int. Seminar on ECS. 19-20 June, 2003. Prague, Czech Republic.
52. Szalay, Z., 2004a: The Role of Timber Buildings in Carbon Storage. In: proc. XXXII IAHS World Congress on Housing Sustainability of the Housing Projects. September 21-25, 2004, Trento, Italy.

53. Szalay, Z., 2004b: A faszerkezetű épületek hőtárolóképessége. (*The heat storage capacity of timber buildings*) (in Hugarian). In: proc. EPKO 2004. International Construction Science Conference. June 3-6, 2004. Sumuleu Ciuc, Romania.
54. Szalay, Z., 2012: Megéri-e közel nulla energiaigényű épületeket építeni? (*Is it worth building near-zero energy buildings?*) (in Hugarian). Magyar Épületgépészet, 61(11): 3-6.
55. Upton, B.; Miner, R.; Spinney, M.; Heath, L. S., 2008: The greenhouse gas and energy impacts of using wood instead of alternatives in residential construction in the United States. Biomass and Bioenergy, 32: 1-10. https://doi.org/10.1016/j.biombioe.2007.07.001.
56. Wind, G.; Heschl, C., 2008: Graue Energie – ein wesentlicher Faktor zur Energieoptimierung von Gebäuden. Studienzentrum Pinkafeld. http://www.ibwind.at/download/GraueEnergie081121.pdf (Accessed: February 9, 2017).
57. ***Athena Sustainable Materials Institute, 2004: Comparative environmental impact assessment. In: Energy and the environment in residential construction. Sustainable Building Series, no. 1, Canadian Wood Council, pp. 5-11.
58. ***EN 15804:2012 Core product category rules for environmental product assessment. European Committee for Standardisation, Brussels, Belgium, 64 pp.
59. ***EN 15978:2011 Methodology for environmental assessment of buildings. European Committee for Standardisation, Brussels, Belgium, 64 pp.
60. ***ISO 14025:2006 Environmental labels and declarations – Type III environmental declarations – Principles and procedures. International Organization for Standardization, Geneva, Switzerland, 25 pp.
61. ***NÉBIH 2013: Erdővagyon, erdőgazdálkodás Magyarországon. (Forest assets and forest management in Hungary.) National Food Chain Safety Office, Forest Management Directoriate, Budapest, Hungary. <https://www.nebih.gov.hu/data/cms/160/852/2013_leporello_magyar_vx3_jav_masodik_kiad_300dpi.pdf> (in Hugarian).
62. ***Steel Construction Institute, 1998: A comparative environmental life cycle assessment of modern office buildings. Silwood Park, Ascot, Berkshire, UK: The Steel Construction Institute.
63. ***Steel Construction Sector Sustainability Committee, 2002: Sustainable steel construction: building for a better future – a sustainability strategy for the UK steel construction sector. Ascot, Berkshire, UK: The Steel Construction Institute.
64. ***TRADA 2011. Cross-laminated timber: introduction for specifiers. Wood Information Sheet 2.3/61.

Corresponding address:

Assoc. prof. LASZLO BEJO, Ph. D.

University of Sopron
Simonyi Karoly Faculty of Engineering
Wood Sciences and Applied Arts
Bajcsy-Zs. U. 4
H-9400 Sopron, HUNGARY
e-mail: laszlo.bejo@skk.nyme.hu

Mohamed Z. M. Salem[1,2], Martin Böhm[1], Ramadan A. Nasser[2]

Measuring the Formaldehyde Content from Different Types of Oriented Strand Board Manufactured with Different Thicknesses and Glued with Different Resins

Mjerenje sadržaja formaldehida u pločama s orijentiranim iverjem različite debljine i proizvedenih upotrebom različitih ljepila

Professional paper • Stručni rad
Received – prispjelo: 12. 9. 2016.
Accepted – prihvaćeno: 11. 5. 2017.
*UDK: 630*824.328; 630*863.215*
doi:10.5552/drind.2017.1640

ABSTRACT • *This study measures the formaldehyde content (FC) of different types of oriented strand board (OSB) panels. Panels with different thicknesses were produced on the OSB production line of a prominent manufacturer of board composite materials in the Czech Republic. The resins used were polyurethane (PU1, PU2) and melamine-urea-formaldehyde (MUF). The corrected FC from 3-layer OSB/3 panels (MUF/surface, PU2/core) ranged from 5.95 ± 0.42 to 7.24 ± 0.67 mg formaldehyde/100 g of dry board. The corrected FC of the 3-layer OSB panels bonded with PU2 resin ranged between 0.48±0.04 and 0.57±0.11 mg formaldehyde/100 g dry board. Additionally, the corrected FC of 3-layer OSB/3 panels bonded with PU1 resin ranged from 0.09±0.22 to 0.46±0.40 mg formaldehyde/100 g dry board. Furthermore, the corrected FC of 3-layer OSB/4 panels bonded with PU1 resin ranged from 0.178±0.309 to 0.473±0.027 mg formaldehyde/100 g dry board. These results showed that the FC was limited to the natural content of formaldehyde in solid wood, where the values are extremely low, and which resulted in the production of green product. Additionally, the FC of OSB panels bonded with PU1 was lower than that of panels glued with PU2.*

Keywords: *construction panels, formaldehyde content, green products, OSB*

SAŽETAK • *U istraživanju je provedeno mjerenje sadržaja formaldehida u različitim tipovima ploča s orijentiranim iverjem (OSB). Ploče različitih debljina izrađene su na proizvodnoj liniji poznatog proizvođača pločastih*

[1] Authors are visitor researcher and assistant professor at Department of Wood Processing, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Prague, Czech Republic. [2]Authors are associate professor and professor at Forestry and Wood Technology Department, Faculty of Agriculture (EL–Shatby), Alexandria University, Egypt.
[1] Autori su gostujući istraživač i docent Odjela za preradu drva, Fakultet šumarstva i drvne tehnologije, Češko sveučilište prirodnih znanosti, Prag, Republika Češka. [2]Autori su izvanredni profesor i profesor Odjela šumarstva i drvne tehnologije, Agronomski fakultet (EL-Shatby), Sveučilište u Aleksandriji, Egipat.

kompozitnih materijala u Republici Češkoj. Pritom su upotrijebljene smole poliuretan (PU1, PU2) i melamin-urea-formaldehid (MUF). Korigirani sadržaj formaldehida u troslojnim pločama OSB/3 (MUF/površinski slojevi, PU2/srednji sloj) iznosio je od 5,95 ± 0,42 do 7,24 ± 0,67 mg formaldehida u 100 g suhe ploče. Korigirani sadržaj formaldehida u troslojnim OSB pločama s PU2 smolom kretao se u rasponu između 0,48 ± 0,04 i 0,57 ± 0,11 mg formaldehida u 100 g suhe ploče. Dodatno, korigirani sadržaj formaldehida u troslojnim pločama OSB/3 lijepljenim PU1 smolom iznosio je između 0,09 ± 0,22 i 0,46 ± 0,40 mg formaldehida u 100 g suhe ploče. Nadalje, korigirani sadržaj formaldehida u troslojnim pločama OSB/4 lijepljenima PU1 smolom kretao se u rasponu između 0,178 ± 0,309 i 0,473 ± 0,027 mg formaldehida u 100 g suhe ploče. Ti rezultati pokazuju da je sadržaj formaldehida ograničen na prirodni sadržaj formaldehida u masivnom drvu, pri čemu su vrijednosti iznimno niske, što je rezultiralo proizvodnjom zelenog proizvoda. Sadržaj formaldehida u OSB pločama lijepljenima PU1 smolom bio je manji nego u pločama lijepljenima PU2 smolom.

Ključne riječi: *građevinske ploče, sadržaj formaldehida, zeleni proizvodi, OSB ploča*

1 INTRODUCTION
1. UVOD

Oriented strand board (OSB) is an engineered wood-based panel consisting of strands of wood that are bonded together with a synthetic resin; the strands are oriented, partially randomly overlapped, and pressed together in layers (Hodoušek *et al.,* 2015). In the outer layers, strands are generally oriented longitudinally in line with the panel length, whereas in the middle layers, strands generally lie perpendicular to the outer layers. Recent methods for manufacturing OSB require very thin, long chips with the following optimum dimensions: 0.4 to 0.6 mm in thickness, 5 to 20 mm in width, and 60 to 120 mm in length)Peña *et al.,* 2006; Ohlmeyer *et al.,* 2008; Böhm *et al.,* 2011).

OSB-like plywood is widely used as a structural material in the manufacture of housing, framing, and other industrial products (Böhm *et al.,* 2012; Salem *et al.,* 2013). Longer and thinner chips that are accurately oriented increase the strength, rigidity, and other physical properties of OSB panels (Han *et al.,* 2006 and 2007).

Additionally, for good production of OSB, the density of the surface layers should be higher than the density of the intermediate layer, with a "U"-shaped density profile along the panel thickness (Xu and Winistorfer, 1995; Painter *et al.,* 2006; Böhm *et al.,* 2011). OSB consists of three layers, and it achieves a high level of dimensional stability with excellent mechanical performance. OSB is manufactured primarily from spruce strands, good quality softwood (Böhm *et al.,* 2011; Hodoušek *et al.,* 2015).

Polyurethane or polyisocyanate resins are widely used in OSB worldwide, MDF mills in Europe, and a few MDF mills in North America (Papadopoulos *et al.,* 2002). It is important to understand how these resins react with wood furnish, as this knowledge will determine whether the urethane linkage will strengthen the board and provide durability in different environmental conditions. Theoretically, isocyanate groups can react with hydroxyl groups in wood furnish and form irreversible urethane linkages (Pizzi and Mittal, 2003; Smith, 2012). Isocyanate-bonded composite panels have benefits including water-resistant chemical bonds, strong mechanical bonds and toughness, high strength, low resin dosage, extreme moisture resistance, and low swelling (Papadopoulos, 1999). Polyurethane can be used in the core layer alone or in all layers of OSB depending on the quality and/or formaldehyde emission restrictions (Vangronsveld *et al.,* 2010).

Formaldehyde emissions (FE) from wood, wood products, and flooring materials are affected by wood type or species, board thickness, resin type, resin additives, panel manufacturing techniques, moisture content, the drying and hot-pressing techniques, and surface finishing materials (Yu and Crump, 1999; Kim *et al.,* 2007; An *et al.,* 2010; Salem *et al.,* 2011; He *et al.,* 2012; Hematabadi *et al.,* 2012; Salem *et al.,* 2012; Kim and Tanabe, 2014). Primarily, the formaldehyde emitted from a new wood-based product comes from free formaldehyde present in the material, and the emission exponentially declines until a steady-state level is reached (Yu and Crump, 1999). Boards bonded with melamine-urea-formaldehyde (MUF) resin exhibit the lowest formaldehyde content (FC) and FE because of the addition of melamine to UF resin (Aydin *et al.,* 2006).

Previously, differences in the bending stress of the upper and lower faces of OSB/3boards and the air permeation rate of OSB/3 and OSB/4 boards have been studied (Ohlmeyer *et al.,* 2008; Hodoušek *et al.,* 2015). In the present study, OSB/3 and 4 boards, which are extensively produced in Europe for their use as heavy-duty load-bearing boards in humid conditions, were evaluated to determine their formaldehyde content with the perforator or extraction method (EN 120, 1993).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Production of OSB/3 and OSB/4 panels
2.1. Proizvodnja ploča OSB/3 i OSB/4

Industrially manufactured OSB/3 and OSB/4 panels with various thicknesses were investigated to determine their formaldehyde content during the period of August 2014. All panels were manufactured using 80 % Norway spruce (*Picea abies* L.) and 20 % Scots pine (*Pinus sylvestris* L.). According to EN 300 (2006), OSB/3 boards were manufactured as load-bearing boards for use in humid conditions, and OSB/4 boards were manufactured as heavy-duty load-bearing boards for use in humid conditions.

Briefly, mixed wood strands of 80 % Norway spruce and 20 % Scots pine of a predetermined shape with a width of 50 mm, length of 130 mm, and a thick-

Table 1 Resin properties of OSB/3 panels
Tablica 1. Obilježja OSB/3 ploča

Conditions *Uvjeti*	**OSB/3 Surface layers** *OSB/3 površinski slojevi*	**OSB/3 Middle layer** *OSB/3 srednji sloj*
Raw material / *sirovina*	Spruce 80 %, Pine 20 % / *smrekovina 80 %, borovina 20 %*	
Pressing pressure, N/mm^2 / *tlak prešanja,* N/mm^2	< 3	
Pressing temperature, °C / *temperatura prešanja,* °C	180 to 225	180 to 225
Resin[a] / *Smola*[a]	MUF: 35 kg/m^3, (8.5 %)*	PU2: 12 kg/m^3, (3.5 %)*
Paraffin, kg/m^3 board / *parafin,* kg/m^3 *ploče*	2.7	
H_2O, L/m^3 board / *H_2O,* L/m^3 *ploče*	30	
H_2O, % [b]	10.5	5.5
Hardener, % [c] / *očvršćivač, %* [c]	2.4	
Wood material, kg/1-m^3 of the board, ATRO, coniferous) *drvni materijal,* kg/1-m^3 *ploče, ATRO, četinjače)*	535	

a: Percentage content of component at 0 % moisture / *postotni udjel komponente pri sadržaju vode 0 %*
b: refers to water addition / *odnosi se na dodanu vodu*
c: refers to catalyst addition (hardener addition) / *odnosi se na dodani katalizator (dodani očvršćivač)*

ness of less than 2 mm, were used to manufacture OSB panels. The wood strands were dried, mixed, and bonded with 4 % polyurethane type 1 (PU1) and 2 (PU2). The mat was randomly formed and hot-pressed with 5 to 8 s/1 mm panel thickness at temperatures from 240 to 190 °C (from entry to output of the press).

Other OSB/3 boards were manufactured using melamine-fortified urea formaldehyde resin (MUF) for the surface layers and PU resin for the core layer with the following categories; OSB/3-A: Surface (MUF) and Core (PU2), OSB/3-B: Surface (PU2) and Core (PU2), and OSB/3-C: Surface (PU1) and Core (PU1). The mat was randomly formed and hot-pressed with 10 s/1 mm panel thickness at approximately 220 °C. The ″ratio of core to surface layers was 60/40. Properties of the resins used are presented in Table 1. Other properties of the resin used for OSB/4 and PU1 have been described previously (Hodoušek *et al.,* 2015).

2.2 Measuring formaldehyde content by the perforator method (EN 120)
2.2. Mjerenje sadržaja formaldehida perforatorskom metodom (EN 120)

In Europe and China, the EN 120 perforator method (1993) is the most frequently used procedure for measuring formaldehyde content (FC) as well as for production control in the wood-based panel industry, and it has good correlation with referenced chamber methods (Risholm-Sundman and Wallin, 1999; Salem *et al.,* 2011 and 2012; Liu and Zhu, 2014).

The collected panels were conditioned for 4 weeks at 20 °C and 65 % RH before measuring the FC with the perforator method (EN 120) (Böhm et al., 2012). At least three replicates from each type of OSB were used. Each replicate of approximately 110 g with dimensions of 25×25 mm were taken from OSB panels with various thicknesses. The samples were extracted in 600 mL of boiling toluene for 2 h in a perforator apparatus. The formaldehyde content was expressed as mg HCHO/100 g of dry board (mg/100 g o.d.). The E1 emission limit is ≤ 8 mg/100 g o.d. The measured FC in boards with different moisture content (MC) was normalized to the FC of boards conditioned to 6.5 % MC according to EN 312 (2003). With MC ranging from 3 % to 10 %, the EN 120 test value was multiplied by a factor *F*, which was calculated from the equation:

$$F = -0.133 \cdot H + 1.86 \quad (1)$$

As formaldehyde content is very sensitive to sample humidity, the moisture content was measured by the following formula (EN 322 1993):

$$H = \frac{m_1 - m_0}{m_0} \cdot 100 \quad (2)$$

where H is the moisture content, m_1 is the mass of the test pieces before drying (g), and m_0 is the mass of the test pieces after drying (g).

2.3 Determination of formaldehyde by the acetylacetone method
2.3. Određivanje formaldehida acetilacetonskom metodom

The amount of formaldehyde released from panels and absorbed by water was determined photometrically by the acetylacetone spectrophotometric analysis method. This method is based on the Hantzsch reaction, in which aqueous formaldehyde reacts with ammonium ions and acetylacetone to yield diacetyldihydrolutidine (DDL); DDL has an absorption maximum at 412 nm (Nash, 1953). This technique is widely applied as a standard procedure for the specific analysis of formaldehyde.

2.4. Statistical analysis
2.4. Statistička analiza

Measured formaldehyde content was analyzed using SAS version 8.2 (2001). The data were analyzed using analysis of variance in CRD to show the significant differences between the formaldehyde content values with Duncan's multiple-range test at 0.05 level of probability. The values are presented as mean ± SD.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Formaldehyde content in different OSB panels
3.1. Sadržaj formaldehida u različitim OSB pločama

The formaldehyde content of OSB panels was extremely dependent on the moisture content of the samples (Tables 2, 3, and 4). It was important that the

products be near or in equilibrium with the humidity in the test atmosphere (Meyer 1979).

Table 2 shows the measured and corrected FC of 3-layer OSB/3-A panels (MUF/surface, PU2/core). The corrected values ranged between 5.95±0.42 and 7.24±0.67 mg formaldehyde/100 g o.d., and these values are in the range of E1 emission class (E1 ≤ 8 mg formaldehyde/100 g o.d.). The formaldehyde values depended on the oven-dry weight of the board, so that moisture content affected the FC measured by EN 120 (Salem *et al.,* 2012).

Table 3 shows the measured and corrected FC of 3-layer OSB-B bonded with PU2 resin. The lowest value (0.48±0.04 mg formaldehyde/100 g o.d.) was found in panels with a thickness of 15 mm, and the highest value (0.57±0.11 mg formaldehyde/100 g o.d.) occurred in panels of 12-mm thickness. The FC of all panels was much lower than required by the E1 emission classification. The variation in minimum and maximum values could be related to the sample taken from the edge of the board or near the center of the board.

Table 4 shows the measured and corrected FC of 3-layer OSB/3-Cpanels bonded with PU1 resin. The corrected FC values ranged from 0.09±0.22 mg formaldehyde/100 g o.d. (18-mm panels) to 0.46±0.40 mg formaldehyde/100 g o.d. (20-mm panels). Table 5 pre-

Table 2 Measured and corrected formaldehyde content of 3-layer OSB/3-A panels (MUF/surface, PU2/core)
Tablica 2. Izmjereni i korigirani sadržaj formaldehida u troslojnim pločama OSB/3-A (MUF/površinski slojevi, PU2/srednji sloj)

Thickness *Debljina*	**Measured FC, mg/100 g o.d.** *Izmjereni sadržaj formaldehida,* mg/*100* g *o.d.*			**Corrected FC, mg/100 g o.d.** *Korigirani sadržaj formaldehida,* mg/*100* g *o.d.*		
	Value* *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*	Value *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*
8 mm	5.66 ± 0.85	3.95	6.11	7.22 ± 0.78a	5.66	7.77
10 mm	5.50 ± 1.10	3.13	6.48	7.08 ± 1.11ab	4.63	7.89
12 mm	5.97 ± 0.70	4.49	7.19	7.24 ± 0.67a	5.65	7.96
15 mm	5.16 ± 0.72	3.68	6.38	6.48 ± 0.72abc	4.91	7.32
18 mm	5.28 ± 0.49	4.41	6.51	6.33 ± 0.57bc	5.66	7.96
22 mm	4.92 ± 0.51	4.50	5.71	5.95 ± 0.42c	5.43	6.44
25 mm	5.35 ± 0.43	4.87	5.70	6.14 ± 0.11c	6.02	6.24

*Mean ± SD / *srednja vrijednost ± SD*; Means with the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple-range test. / *Prema Duncanovu višestrukom usporednom testu, prosječne vrijednosti označene istim slovom statistički se značajno ne razlikuju ($P < 0,05$).*

Table 3 Measured and corrected formaldehyde content of 3-layer OSB-B
Tablica 3. Izmjereni i korigirani sadržaj formaldehida u troslojnim pločama OSB-B

Thickness *Debljina*	**Measured FC, mg/100 g o.d.** *Izmjereni sadržaj formaldehida,* mg/*100* g *o.d.*			**Corrected FC, mg/100 g o.d.** *Korigirani sadržaj formaldehida,* mg/*100* g *o.d.*		
	Value* *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*	Value *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*
12 mm	0.44 ± 0.09	0.35	0.53	0.57 ± 0.11a	0.45	0.70
15 mm	0.37 ± 0.04	0.31	0.40	0.48 ± 0.04a	0.42	0.53
18 mm	0.39 ± 0.06	0.30	0.52	0.50 ± 0.08a	0.35	0.66
22 mm	0.42 ± 0.06	0.36	0.54	0.52 ± 0.07a	0.47	0.69
25 mm	0.37 ± 0.08	0.32	0.47	0.48 ± 0.09a	0.43	0.58

*Mean ± SD / *srednja vrijednost ± SD*; Means with the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple-range test. / *Prema Duncanovu višestrukom usporednom testu, prosječne vrijednosti označene istim slovom statistički se značajno ne razlikuju ($P < 0,05$).*

Table 4 Measured and corrected formaldehyde content of 3-layer OSB/3-C panels bonded with PU1 resin
Tablica 4. Izmjereni i korigirani sadržaj formaldehida u troslojnim pločama OSB/3-C lijepljenim smolom PU1

Thickness *Debljina*	**Measured FC, mg/100 g o.d.** *Izmjereni sadržaj formaldehida,* mg/*100* g *o.d.*			**Corrected FC, mg/100 g o.d.** *Korigirani sadržaj formaldehida,* mg/*100* g *o.d.*		
	Value* *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*	Value *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*
12 mm	0.24 ± 0.26	0.000	0.600	0.31 ± 0.34ab	0.000	0.785
15 mm	0.22 ± 0.23	0.000	0.500	0.29 ± 0.31ab	0.000	0.678
18 mm	0.07 ± 0.18	0.000	0.600	0.09 ± 0.22b	0.000	0.713
20 mm	0.37 ± 0.32	0.000	0.600	0.46 ± 0.40a	0.000	0.726
22 mm	0.17 ± 0.24	0.000	0.600	0.22 ± 0.30ab	0.000	0.794
25 mm	0.11 ± 0.20	0.000	0.500	0.14 ± 0.25b	0.000	0.624

*Mean ± SD / *srednja vrijednost ± SD*; Means with the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple-range test. / *Prema Duncanovu višestrukom usporednom testu, prosječne vrijednosti označene istim slovom statistički se značajno ne razlikuju ($P < 0,05$).*

Table 5 Measured and corrected formaldehyde content of 3-layer OSB/4 panels bonded with PU1 resin
Tablica 5. Izmjereni i korigirani sadržaj formaldehida u troslojnim pločama OSB/4 lijepljenim smolom PU1

Thickness *Debljina*	**Measured FC, mg/100 g o.d.** *Izmjereni sadržaj formaldehida,* mg/*100* g *o.d.*			**Corrected FC, mg/100 g o.d.** *Korigirani sadržaj formaldehida,* mg/*100* g *o.d.*		
	Value* *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*	Value *Srednja vrijednost*	Min. *Minimalna vrijednost*	Max. *Maksimalna vrijednost*
15 mm	0.240 ± 0.23	0.000	0.500	0.295 ± 0.289a	0.000	0.650
18 mm	0.167 ± 0.289	0.000	0.500	0.178 ± 0.309a	0.000	0.535
22 mm	0.220 ± 0.205	0.000	0.400	0.260 ± 0.239a	0.000	0.460
25 mm	0.400 ± 0.000	0.400	0.400	0.473 ± 0.027a	0.434	0.497

*Mean ± SD / *srednja vrijednost ± SD*; Means with the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple-range test. / *Prema Duncanovu višestrukom usporednom testu, prosječne vrijednosti označene istim slovom statistički se značajno ne razlikuju ($P < 0,05$).*

sents the measured and corrected FC of 3-layer OSB/4 panels bonded with PU1 resin. The average values ranged from 0.178±0.309 mg formaldehyde/100 g o.d. (18-mm panels) to 0.473±0.027 mg formaldehyde/100 g o.d. (25-mm panels).

These results showed that FC was limited to the natural content of formaldehyde in solid wood, where the values are extremely low and result in the production of green products. Additionally, the FC values of panels bonded with PU1 were lower than those of panels bonded with PU2. In contrast, the perforator method measures the total extractable formaldehyde in the board, which shows that not all formaldehyde is emitted at room temperature (Xiong and Zhang, 2010).

4. CONCLUSIONS
4. ZAKLJUČAK

1. The measured formaldehyde content of all OSB panels produced was lower than the E1 emission class.
2. All OSB panels produced with different glues and thicknesses were recognized as green boards.
3. Additional parameters will be studied to measure the physical and mechanical properties of different OSB panels and to provide a better evaluation of the product.

Acknowledgments – Zahvala

We gratefully acknowledge financial support from the Internal Grant Agency of the Czech University of Life Sciences Prague, Project No. 20174305.

5 REFERENCES
5. LITERATURA

1. An, J.-.Y.; Kim, S.; Kim, H.-J., 2011: Formaldehyde and TVOC emission behavior of laminate flooring by structure of laminate flooring and heating condition. J. Hazard. Mater., 187(1-3): 44-51. http://dx.doi.org/10.1016/j.jhazmat.2010.08.086.
2. Aydin, I.; Çolakoğlu, G.; Colak, S.; Demirkir, C., 2006: Effects of moisture content on formaldehyde emission and mechanical properties of plywood. Build. Environ., 41(10): 1311-1316. http://dx.doi.org/10.1016/j.buildenv.2005.05.011.
3. Böhm, M.; Salem, M. Z. M.; Srba, J., 2012: Formaldehyde emission monitoring from a variety of solid wood, plywood, blockboard, and flooring products manufactured for building and furnishing materials. J. Hazard. Mater., 221-222(6): 68-79. http://dx.doi.org/10.1016/j.jhazmat.2012.04.013.
4. Böhm, M.; Šedivka, P.; Bomba, J.; Reisner, J., 2011: Strength characteristics of OSB in bending – difference between upper and lower panel faces. Drvna industrija, 62(2): 123-127. http://dx.doi.org/10.5552/drind.2011.1036.
5. Han, G.; Wu, Q.; Lu, J. Z., 2006: Selected properties of wood strand and oriented strandboard from small-diameter southern pine. Wood Fiber Sci., 38(4): 621-632.
6. Han, G.; Wu, Q.; Lu, J. Z., 2007: The influence of fines content and panel density on properties of mixed hardwood oriented strandboard. Wood Fiber Sci., 39(1): 2-15.
7. He, Z.; Zhang, Y. P.; Wei, W. J., 2012: Formaldehyde and VOC emissions at different manufacturing stages of wood-based panels. Build. Environ., 47(1): 197-204. http://dx.doi.org/10.1016/j.buildenv.2011.07.023.
8. Hematabadi, H.; Behrooz, R.; Shakibi, A.; Arabi, M., 2012: The reduction of indoor air formaldehyde from wood based composites using urea treatment for building materials. Constr. Build. Mater., 28(1): 743-746. http://dx.doi.org/10.1016/j.conbuildmat.2011.09.018.
9. Hodoušek, M.; Böhm, M.; Lemaster, R. L.; Bureš, M.; Beránková, J.; Cvach, J., 2015: Air permeation rate of oriented strand boards (OSB/3 and OSB/4). BioResources, 10(1): 1137-1148. http://dx.doi.org/10.15376/biores.10.1.1137-1148.
10. Kim, H.; Tanabe, S.-I., 2014: Influence of sorption area ratio and test method on formaldehyde reduction performance for sorptive building materials. Constr. Build. Mater., 70(15): 175-182. http://dx.doi.org/10.1016/j.conbuildmat.2014.07.110.
11. Kim, S.; Kim, J.-A.; An, H.-Y.; Kim, H.-J.; Kim, S. D.; Park, J.-C., 2007: TVOC and formaldehyde emission behaviors from flooring materials bonded with environmental friendly MF/PVAc hybrid resins. Indoor Air, 17(5): 404-415. http://dx.doi.org/10.1111/j.1600-0668.2007.00488.x.
12. Liu, Y.; Zhu, X., 2014: Measurement of formaldehyde and VOCs emissions from wood-based panels with nanomaterial-added melamine-impregnated paper. Constr. Build. Mater., 66(15): 132-137. http://dx.doi.org/10.1016/j.conbuildmat.2014.05.088.
13. Meyer, B., 1979: Urea Formaldehyde Resins, Addison-Wesley Publishing, Boston, MA.
14. Nash, T., 1953: The colorimetric estimation of formaldehyde by means of the Hantzsch reaction. Biochem. J., 55(3): 416-421. https://doi.org/10.1042/bj0550416.
15. Ohlmeyer, M.; Makowski, M.; Fried, H.; Hasch, J.; Schöler, M., 2008: Influence of panel thickness on the

release of volatile organic compounds from OSB made of *Pinus sylvestris* L. Forest Prod. J., 58(1/2): 65-70.
16. Painter, G.; Husman, H.; Pritzker, M., 2006: Prediction of oriented strand board properties from mat formation and compression operating conditions. Part 1. Horizontal density distribution and vertical density profile. Wood Sci. Technol., 40(2): 139-158. http://dx.doi.org/10.1007/s00226-005-0044-7.
17. Papadopoulos, N. A., 1999: The Effect of Selected Process Variables on the Mechanical Properties and Dimensional Stability of Particleboards, M. S. thesis, University of Wales, Cardiff, UK.
18. Papadopoulos, A. N.; Hill, C. A. S.; Traboulay, E.; Hague, J. R. B., 2002: Isocyanate resins for particleboard: PMDI vs EMDI. Holz Roh Werkst., 60(2): 81-83. http://dx.doi.org/10.1007/s00107-001-0275-8.
19. Peña, S. V.; Rojas, I. M., 2006: Tecnología de la Madera (3rd ed.), Artes Gráficas Cuesta, S.L., Madrid, Spain.
20. Pizzi, A.; Mittal, K. L., 2003: Handbook of Adhesive Technology, Taylor & Francis Group, New York.
21. Risholm-Sundman, M.; Wallin, N., 1999: Comparison of different laboratory methods for determining the formaldehyde emission from three-layer parquet floors. Holz Roh Werkst., 57(5): 319-324. http://dx.doi.org/10.1007/s001070050351.
22. Salem, M. Z. M.; Böhm, M.; Beránková, J.; Srba, J., 2011: Effect of some manufacturing variables on formaldehyde release from particleboard: Relationship between different test methods. Build. Environ., 46(10): 1946-1953. http://dx.doi.org/10.1016/j.buildenv.2011.04.004.
23. Salem, M. Z. M.; Böhm, M.; Srba, J.; Beránková, J., 2012: Evaluation of formaldehyde emission from different types of wood-based panels and flooring materials using different standard test methods. Build. Environ., 49(3): 86-96. http://dx.doi.org/10.1016/j.buildenv.2011.09.011.
24. Salem, M. Z. M.; Böhm, M.; Srba, J., 2013: Evaluation of mechanical properties and formaldehyde emission of plywood manufactured for construction applications. Drvna industrija, 64(2): 87-93. http://dx.doi.org/10.5552/drind.2013.1245.
25. SAS, 2001: User Guide: Statistics (Release 8.02), SAS Institute, Cary, NC.
26. Smith, G., 2012: Lectures and course notes for WOOD 487, Department of Wood Science, University of British Columbia, Vancouver, BC, Canada.
27. Xiong, J. Y.; Zhang, Y. P., 2010: Impact of temperature on the initial emittable concentration of formaldehyde in building materials: experimental observation. Indoor Air, 20(6): 523-529. http://dx.doi.org/10.1111/j.1600-0668.2010.00675.x.
28. Xu, W.; Winistorfer, P. M., 1995: A procedure to determine thickness swell distribution in wood composite panels. Wood Fiber Sci., 27(2): 119-125.
29. Vangronsveld, E.; Berckmans, S.; Verbinnen, K.; Van Leeuw, C.; Bormans, C., 2010: Isocyanate and total inhalable particulate air measurements in the European wood panel industry. Int. J. Hyg. Envir. Heal., 213(6): 475-488. http://dx.doi.org/10.1016/j.ijheh.2010.08.011.
30. Yu, C. W. F.; Crump, D. R., 1999: Testing for formaldehyde emission from wood-based products - A review. Indoor Built Environ., 8(5): 280-286. http://dx.doi.org/10.1177/1420326x9900800502.
31. *** EN 120, 1993: Wood-based panels -Determination of formaldehyde content -Extraction method called perforator method, European Committee for Standardization, Brussels, Belgium.
32. *** EN 300, 2006: Oriented Strand Boards (OSB) – Definitions, classification, and specifications, European Committee for Standardization, Brussels, Belgium.
33. *** EN 312. (2003). "Particleboard-Specifications," European Committee for Standardization, Brussels, Belgium.
34. *** EN 322, 1993: Wood-based panels - determination of moisture content, European Committee for Standardization, Brussels, Belgium.

Corresponding address:

Assoc. Prof. MOHAMED Z. M. SALEM, Ph.D.

Forestry and Wood Technology Department
Faculty of Agriculture (EL-Shatby)
Alexandria University
Alexandria , EGYPT
e-mail: zidan_forest@yahoo.com

HURA

NAZIVI I NALAZIŠTE

Drvo vrste *Hura crepitans* L. iz botaničke porodice *Euphorbiaceae* potječe iz Srednje i Južne Amerike. Areal mu se proteže od Velikih Antila preko Venezuele, Kolumbije i Brazila do Bolivije. Pretežito raste u tropskim listopadnim kišnim šumama duž riječnih tokova.

Ostali su nazivi drva abillo, jubillo (Venezuela), açacu (Brazil), acuapa, ceiba blanca (Španjolska), assacú (Francuska, Španjolska, Italija), hura, rakuda, sandbox, possum wood (Velika Britanija, SAD), sablier (Francuska, Italija, Gvajana).

STABLO

Hura crepitans je listača srednje visine, naraste između 20 i 60 m. Promjer debla kreće se od 1 do 2 m, a visina do prve grane iznosi od 10 do 30 m. Deblo je cilindričnog oblika. Kora mu je glatka, siva i debela te sadržava gorak, otrovan mliječni sok.

DRVO

Makroskopska obilježja

Drvo je rastresito porozno. Srž i bjeljika podjednake su boje – žutobijele, svjetlosmeđe do svijetle sivomaslinaste. Drvni su traci uočljivi povećalom. Žica drva je ravna, srednje finoće.

Mikroskopska obilježja

Pore su pretežito pojedinačne i pojavljuju se u kratkim radijalnim nizovima do šest zajedno. Malobrojne su, promjera od 45...150...230 mikrometara. Često su ispunjene tilama. Gustoća pora kreće se od 2 do 5 po mm^2 poprečnog presjeka. Udio pora u drvu iznosi oko 8 %.

Drvni su traci homocelularni do slabo izraženo heterocelularni. Široki su jednu stanicu i difuznog su rasporeda. Njihova je širina od 24 do 26 mikrometara, a visina od 70 do 450 mikrometara, odnosno od 4 do 15 stanica. Gustoća drvnih trakova je 5 do 9 po milimetru na poprečnom presjeku. Udio trakova u drvu iznosi oko 10 %.

Drvna su vlakanca libriformska i vlaknaste traheide. Dugačka su od 1000...1300...1800 mikrometara. Dvostruka debljina staničnih stijenki vlakanaca iznosi 3,0...4,0…6,0 mikrometara, a promjer lumena je 8,0...19,0...40,0 mikrometara. Volumni udio vlakanaca u drvu kreće se oko 80 %. Aksijalni parenhim i parenhim drvnih trakova često su ispunjeni kristalićima u obliku romba.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	340...380...450 kg/m^3
Gustoća prosušenog drva, $\rho_{12\text{-}15}$	360...420...490 kg/m^3
Gustoća sirovog drva, ρ_s	600...750 kg/m^3
Poroznost	oko 75 %
Totalno radijalno utezanje, β_r	2,7...3,5 %
Totalno tangentno utezanje, β_t	4,5...6,5 %
Totalno volumno utezanje, β_v	7,6...10,4 %

Mehanička svojstva

Čvrstoća na vlak, paralelno s vlakancima	23,7...57...100 MPa
Čvrstoća na vlak, okomito na vlakanca	oko 2,5 MPa
Čvrstoća na tlak	30...38...45 MPa
Čvrstoća na savijanje	57...67...83 MPa
Modul elastičnosti	6,1...7,2...9,7 GPa
Tvrdoća prema Brinellu, paralelno s vlakancima	22...25...28 MPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro i lako ručno i strojno obrađuje. Dobro se lijepi, ljušti, površinski obrađuje i politira.

Sušenje

Drvo se dobro i brzo suši.

Trajnost i zaštita

Srž drva slabo je otporna na gljive truležnice (razred otpornosti 5) i srednje otporna na termite (razred otpornosti S). Otpornost srži na tercijarne kukce klasificirana je kao srednje trajna (razred otpornosti 3). Srž je permeabilna (razred 1).

Uporaba

Od drva hure izrađuju se furniri, osobito ljušteni, kao i konstrukcijsko drvo za izradu laganih konstrukci-

ja, za proizvodnju oplata drvenih klupa, sanduka, bačava, drvene ambalaže i srednjica stolarskih ploča. Na području svoga prirodnog areala drvo se često upotrebljava i za izradu drvenih splavi.

Sirovina

Drvo se na tržištu prodaje u obliku trupaca ili kao piljena građa. Dužina trupaca obično je 4 – 8 m, a srednji promjer drva je 0,5 – 1 m.

Napomena

Drvu vrste *Hura crepitans* L. za sada ne prijeti nestanak (nije na popisu CITES – Convention on International Trade in Endangered Species, niti na popisu IUCN – Red list of Threatened Species). Može se upotrebljavati kao zamjena za drvo *obeche* (*Triplochiton scleroxylon*). Drvo sličnih svojstava imaju i vrste *Hura polyandra* Baill., *Alstonia congensis* Engl., *Dyera constulata* Hook, *Ricinodendron heudolotii* Pierre.

Literatura

1. Richter, H. G.; Dallwitz, M. J., 2000: Commercial timbers: descriptions, illustrations, identification, and information retrieval. In English, French, German, and Spanish. Version: 4th May 2000.
2. Wagenführ, R.; Scheiber, C., 1974: HOLZATLAS, VEB Fachbuchverlag, Leipzig, 324-325.
3. ***https://tropix.cirad.fr/FichiersComplementaires/EN/America/ACACU.pdf (preuzeto 2. svibnja 2017.).
4. ***1964: Wood dictionary, Elsevier publishing company, Amsterdam.
5. HANDBOOK OF HARDWOODS, 1972: 2nd Edition, Department of the Environment, Building Research Establishment, Princes Laboratory.

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

Upute autorima

Opće odredbe

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

Predaja rukopisa podrazumijeva uvjet da rad nije već predan negdje drugdje radi objavljivanja ili da nije već objavljen (osim sažetka, dijelova objavljenih predavanja ili magistarskih radova odnosno disertacija, što mora biti navedeno u napomeni) te da su objavljivanje odobrili svi suautori (ako rad ima više autora) i ovlaštene osobe ustanove u kojoj je istraživanje provedeno. Cjelokupni sadržaj Drvne industrije dostupan je za skidanje s interneta, tiskanje, daljnju distribuciju, čitanje i ponovno korištenje bez ograničenja sve dok se naznače autor(i) i originalni izvor prema Creative Commons Attribution 4.0 International License (CC BY). Autor(i) zadržavaju izdavačka prava bez ograničenja.

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

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

Upute

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

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

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

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

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

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

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

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

Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.

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

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

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

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

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

Primjeri navođenja literature

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

Primjer

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

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

Primjeri

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

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

Ostale publikacije (brošure, studije itd.)

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

Web stranice

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

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

Dodatne informacije o načinu pisanja znanstvenih radova mogu se naći na web adresi:
www.ease.org.uk/publications/author-guidelines

Instructions for authors

General terms

The "Drvna industrija" ("Wood Industry") journal publishes scientific papers (original scientific papers, review papers, previous notes), professional papers, conference papers, professional information, bibliographical and survey articles and other contributions related to biology, chemistry, physics and technology of wood, pulp and paper and wood products, including production, management and marketing issues in the wood industry.

Submission of a paper implies that the work has not been submitted for publication elsewhere or published before (except in the form of an abstract or as part of a published lecture, review or thesis, in which case it must be stated in a footnote); that the publication is approved by all co-authors (if any) and by the authorities of the institution where the research has been carried out. The complete content of the journal *Drvna industrija* (Wood Industry) is available on the Internet permitting any users to download, print, further distribute, read and reuse it with no limits provided that the author(s) and the original source are identified in accordance with the Creative Commons Attribution 4.0 International License (CC BY). The authors retain their copyrights.

The scientific and professional papers shall be published either in Croatian, with an extended summary in English, or in English with an extended summary in Croatian. The titles, headings and all the relevant results shall be presented bilingually. Other articles are generally published in Croatian. The Editor's Office shall provide the translation into Croatian for foreign authors. The scientific and professional papers will be subject to a thorough review by at least two selected referees. The Editorial Board shall make the choice of reviewers, as well as the decision about the classification of the paper and its acceptance (based on reviewers' recommendations).

All contributions are subject to proofreading. The editors will require authors to modify the text in the light of the recommendations made by reviewers and language advisers, and they reserve the right to suggest abbreviations and text improvements. Authors are fully responsible for the contents of their contributions. It shall be assumed that the author has obtained the permission for the reproduction of portions of text published elsewhere, and that the publication of the paper in question does not infringe upon any individual or corporate rights. Papers shall report on true scientific or technical achievement. Authors are responsible for the terminological and metrological consistency of their contributions. The contributions are to be submitted by e-mail to the following address: E-mail: drind@sumfak.hr

Details

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

The first page of the paper submitted should contain full title, name(s) of author(s) with professional affiliation (institution, city and state), abstract with keywords (approx. 1/2 sheet DIN A4).

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

Scientific and professional papers shall be precise and concise. The main chapters should be characterized by appropriate headings. Footnotes shall be placed at the bottom of the same page and consecutively numbered. Those relating to the title should be marked by an asterix, others by superscript Arabic numerals. Footnotes relating to the tables shall be printed under the table and marked by small letters in alphabetical order.

Latin names shall be printed in italics and underlined.

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

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

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

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

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

All graphs and tables shall be black and white (unless requested otherwise with additional payment). Tables and graphs should be inserted into the text in their original format in order to insert them subsequently into the Croatian version. If this is not possible, original document should be sent in the format in which it was made (excel or statistica format).

The captions to figures and drawings shall not be written in block letters. Line drawings and graphs should conform to the style of the journal (font size and appearance). Letters and numbers shall be sufficiently large to be readily legible after reduction of the width of a figure or table. Photomicrographs should have a mark indicating magnification, preferably in micrometers. Magnification can be additionally indicated at the end of the figure title, e.g. "Mag. 7500:1".

Discussion and conclusion may, if desired by authors, be combined into one chapter. This text should interpret the results relating to the problem outlined in the introduction and to related observations by the author(s) or other researchers. Repeating the data already presented in the "Results" chapter should be avoided. Implications for further studies or application may be discussed. A conclusion shall be expressed separately if results and discussion are combined in the same chapter. Acknowledgements are presented at the end of the paper. Relevant literature shall be cited in the text according to the Harvard system ("name – year"), e.g. (Bađun, 1965). In addition, the bibliography shall be listed at the end of the text in alphabetical order of the author's names, together with the title and full quotation of the bibliographical reference. The list of references shall be selective, and each reference shall have its DOI number (http://www.doi.org) (check at http://www.crossref.org).:

Example of references

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

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

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

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

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

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

The paper will be sent to the author in pdf format before printing. The paper should be carefully corrected and sent back to the Editor's Office with the list of corrections made and the form for the transfer of copyrights from the author to the publisher. Corrections should be limited to printing errors; amendments to or changes in the text will be charged. Each contributor will receive 1 copy of the journal.

Further information on the way of writing scientific papers can be found on the following website:

www.ease.org.uk/publications/author-guidelines