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Agnieszka Jankowska, Paweł Kozakiewicz[1]

Evaluation of Wood Resistance to Artificial Weathering Factors Using Compressive Properties

Ocjena otpornosti drva na utjecaj umjetnih atmosferskih uvjeta mjerenjem tlačne čvrstoće

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ABSTRACT • *The purpose of the study was to determine the influence of artificial weathering on selected properties of wood. This paper presents the changes of incompressive strength of wood along fibers. The study involved wood of different density and anatomy - 17 species of tropical wood commercially available in Europe and Scots pine and European oak. The specimens were exposed to artificial weathering consisting of soaking wood in water, drying at 70 °C and exposure to UV radiation. Three-step aging cycle was repeated 140 times. In general, the tested wood species changed their compressive strength differently under the influence of artificial weathering. The process of artificial weathering caused a loss of strength of all tested wood species. The extent of changes depended on initial properties of wood (especially density) and anatomy. The changes were most pronounced at the beginning of the artificial weathering process.*

Key words: *tropical wood, Pinus, Quercus, artificial weathering, artificial aging*

SAŽETAK • *Cilj istraživanja bio je utvrditi utjecaj umjetnih atmosferskih uvjeta na promatrana svojstva drva. U radu je prikazana promjena tlačne čvrstoće drva uzduž vlakanaca. Istraživanje je provedeno na vrstama drva različite gustoće i anatomske građe – istraženo je 17 vrsta tropskog drva komercijalno dostupnoga u Europi te drvo običnog bora i europskog hrasta. Uzorci su bili izloženi umjetnim atmosferskim uvjetima: naizmjeničnom potapanju drva u vodi, sušenju na 70 °C i izlaganju UV zračenju. Ciklus koji se sastojao od ta tri postupka ponovljen je 140 puta. Općenito, promjena tlačne čvrstoća drva pod utjecajem umjetnih atmosferskih uvjeta za istraživane je vrste drva različita. Izlaganje umjetnim atmosferskim uvjetima prouzročilo je smanjenje tlačne čvrstoće svih istraživanih vrsta drva. Opseg promjena nakon izlaganja povezan je s početnim svojstvima drva (posebno s gustoćom) i anatomskom građom. Najveći intenzitet promjena zabilježen je na početku izlaganja umjetnim atmosferskim uvjetima.*

Ključne riječi: *tropsko drvo, Pinus, Quercus, umjetni atnosferski uvjeti, ubrzano starenje*

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1 INTRODUCTION
1. UVOD

The increasing demand for tropical wood products leads to expanded trade offers, and requires knowledge of the characteristics of exotic wood such as its physical, mechanical, technological properties and its resistance to external factors. Tropical wood species, having wide trunk diameters, attractive texture and high resistance to decay, are used in different industries e.g. furniture, timber, plywood, and outdoor applications such as garden furniture, fences, facades, terraces, etc. (Williams, 2005; Kilic and Niemz, 2012). The decisive element for the use of different wood species in the harsh outside environment is their durability. Natural durability of wood depends on work conditions (hazard classes and construction features), as well as on the type of wood. Variations of weather conditions and prolonged exposure to weathering elements cause the process called weathering.

Many researchers, involved in changes of wood properties caused by varying environmental conditions, describe the natural weathering of wood as a process of irreversible changes in the appearance and properties of a material as the effect of a long-term impact of weather: solar radiation, air and oxygen contained in it, changes in temperature and humidity, assuming no direct influence of biotic factors (Holz, 1981; Feist, 1990; Feistand Hon, 1984; Hon *et al*, 1986; Tolvaj and Faix, 1995; Colom *et al*, 2003; Williams, 1999, 2005). Wood weathering is a complex phenomenon (multifactorial) caused by solar radiation and by hydrolysis and leaching of wood components. Due to cyclical changes in humidity, swelling and shrinkage have a significant influence on changes in wood properties in the weathering process. Due to slowness and questionable repeatability of the process, it is difficult to examine wood weathering and its consequences. Substantial changes often appear in real terms after many years of using wood. For this reason, various methods of artificial weathering were developed in laboratories to simulate the natural effect of weather conditions and to determine changes occurring in wood in short time. These methods differ between themselves in order and intensity of effects of individual factors (eg. Temiz *et al.*, 2007; Evans *et al.*, 2008; Follrich *et al.*, 2011; Miklečić and Jirouš-Rajković, 2011). In addition, the fact should be taken into account that the size of samples used to determine the mechanical properties of artificially weathered wood is unrestricted, one published study - right for a type of test samples and artificial weathering – cannot be directly related to the results obtained in other trials.

Degradation phenomena have been reported in literature, e.g. Evans *et al.* (1996) studied the loss of mass and chemical changes occurring in wood *Pinus radiata* D. Don. during weathering. Evans *et al.* 2008, Bhat *et al.* (2010) tested wood and modified wood materials including its mechanical properties during weathering. Changes of physical properties were mainly tested (Oltean *et al*., 2009; Schnabel *et al*., 2009). Researches of tropical wood in this field are few. An example of the study of artificial weathering of tropical wood are tests made by Pastore *et al.*(2004) and Oltean *et al.* (2010) – change of appearance and color were tested.

In this paper, the effects of artificial weathering on compressive properties of several species of wood (assuming the absence of biotic interactions) were determined and compared to each other.The study includes seventeen species of wood from foreign forests (heartwood), commercially available in Europe. Parallel studies were performed on the control wood: pine *Pinus sylvestris* L. (individual sapwood and heartwood) and European oak *Quercus* sp. (heartwood). As the processs of weathering progressed, compression strength along fibers was determined.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Preparation of test specimens
2.1. Priprema uzoraka

Wood species selected for the research (Table 1) are a group of materials used for production of elements used in external conditions (such as elevation, terrace boards, garden furniture, etc.). This wood group represents different types of structures (coniferous, deciduous ring-pours and diffuse-pours) and differs in some details related to anatomy and density (Figure 1).

Samples of each wood species were collected from one board to obtain “identical sample”. Thanks to

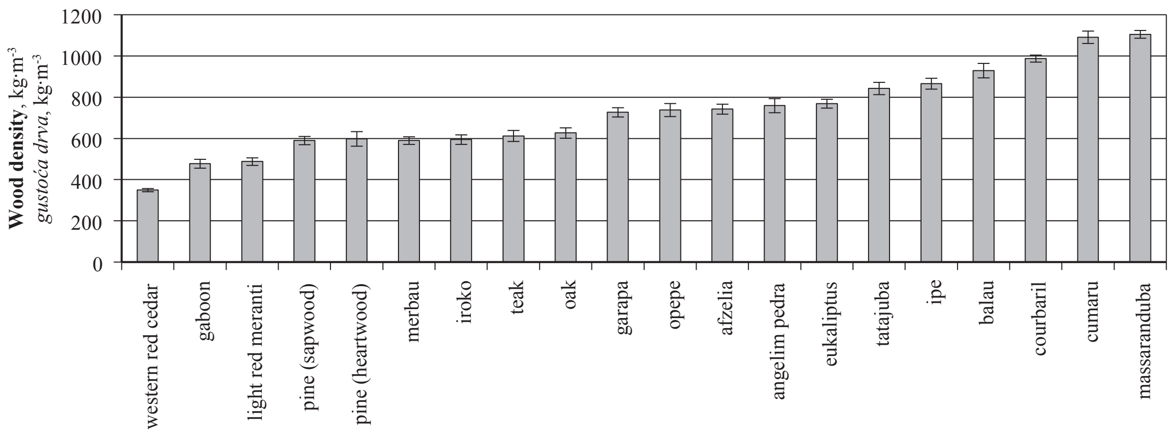

Figure 1 Comparison of average airdry wood density of species tested (for the whole batch of samples)
Slika 1. Usporedba prosječne gustoće uzoraka istraživanih vrsta drva (za cijelu seriju uzoraka)

Table 1 Research material
Tablica 1. Istraživani uzorci drva

Latin name / *Latinski naziv*	**Trade name and name according to PN-EN 13556 (2005)** / *Trgovački naziv i naziv prema PN-EN 13556 (2005)*	**Occurrence** *Stanište*	**Type of structure** *Vrsta anatomske građe*
Afzelia africana Smith ex Pers.	afzelia	Africa	deciduous diffuse-pours *listopadna difuzno-porozna*
Apuleia leiocarpa (Vog.) Macbride	garapa*	South America	
Aucoumea klaineana Pierre.	gaboon	Africa	
Bagassa guianensis Aubl.	tatajuba	South America	
Dipteryx odorata (Aubl.) Wild.	cumaru		
Eucalyptus sp.	eucalyptus	Asia	
Hymenea courbaril Linn.	courbaril	South America	
Hymenolobium sp.	angelim pedra		
Intsia bacori Prain. (*Intsia bijunga* Ktze.)	merbau	Asia	
Manilkara bidentata A. Chev.	massaranduba	South America	
Milicia excelsa (Welw.) C. C. Berg	iroko	Africa	
Nauclea diderrichii (Wild. & Th. Dur.) Merr.	opepe		
Pinus sylvestris L.	Scots pine	Europe	coniferous / *četinjača*
Quercus petraea Liebl., *Q. robur* L.	European oak		deciduous ring-pours *listopadna prstenasto-porozna*
Shorea sp., e.g. *S. acuminate* Dyer.	light red meranti	Asia	deciduous diffuse-pours *listopadna difuzno-porozna*
Shorea sp., e.g.. *S. laevis* Ridley	balau		
Tabebuia sp.	ipe	South America	
Tectona grandis L.	teak	Asia	deciduous ring-pours *listopadna prstenasto-porozna*
Thuja plicata D. Don	western red cedar	North America	Coniferous / *četinjača*

* *Apuleia leiocarpa* (Vog.) Macbride are not included in PN-EN 13556 (2005)

these samples, density was similar and the structure was kept in order to appearing changes in the weathering process, this being the main factor deciding on the examined properties. 30 groups of 6 samples were prepared from each wood species. Dimensions of samples were 15.0 x 15.0 x 22.5 mm (the last dimension along fibers). Each group was intended for the study of different stages of weathering. Before the determination of properties, each group was air conditioned at a temperature close to 20 °C (±2) and relative humidity (rH) around 60 % (±5).

2.2 Artificial weathering method
2.2. Izlaganje umjetnim atmosferskim uvjetima

The design of the artificial weathering cycle was based on literature (Matejak *et al*., 1983: Follrich, 2011). It took 30 hours to complete an artificial weathering cycle and it was divided into three steps (Figure 2). The first step was soaking speciemens in water at 20 °C (16 h). The conditions of the second step (8 h) were 70 °C and 5-10 % rH and the third step was performed at 30 °C and 20-25 rH (6 h) with irradiation with UV rays. Four fluorescent lamps100R's Lightech of 100 W each, and the spectrum 300 - 400 nm (90 % of the radiation spectrum is a wavelength of 340 -360 nm) were used for irradiating. 140 cycles of artificial weathering were conducted.

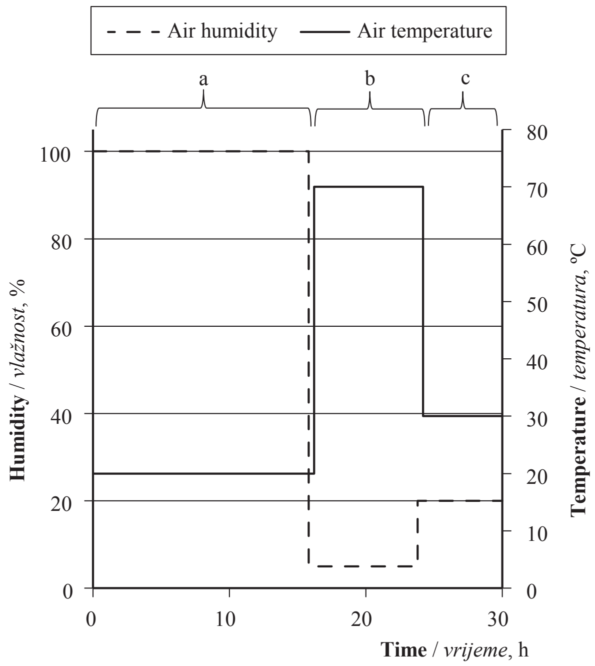

Figure 2 Changes in humidity and temperature during a full cycle of artificial weathering: a) soaking in water for 16 hours, b) drying at 70° C for 8 h, c) UV irradiation for 6 hours
Slika 2. Promjene vlažnosti i temperature tijekom jednog ciklusa umjetnih atmosferskih uvjeta

2.3 Mechanical testing
2.3. Određivanje tlačne čvrstoće

Examination of compressive strength of wood along fibers was performed before weathering, and then after 2, 4, 6, 8, 10, 12, 14, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60, 64, 68, 76, 84, 92, 100, 108, 116, 124, 132 and 140 cycles of artificial weathering. The compression test was performed according to PN-D 04102 (1979).

The use of slightly smaller dimensions of samples was a deviation from the mentioned norm. The deviation concerning the sample size occurred in view of the fact that no relation exists between the compressive strength along fibers and the size of samples when they are geometrically similar and when the section of the samples contained at least a couple of annual increments (Matejak *et al.*, 1983). The aim of this treatment was to cause great changes in wood during the aging process. Examination of compressive strength of wood along fibers (*RC*) was carried out on the 10-ton universal testing machine. Constant speed of loading samples of 2 mm/min was used during the compression tests. For individual groups of samples, average values as well as standard deviations were calculated.

In order to illustrate the effect of artificial weathering of wood, the approximate percentage of decrease of compressive strength along fibers per one cycle of artificial weathering was determined by the formula:

$$\Delta RC = (RC_0 - RC_n) \cdot (RC_0 \cdot n)^{-1} \cdot 100$$

where: ΔRC - percent decrease in compressive strength along fibers per one cycle of artificial weathering, RC_0 - compressive strength of wood along fibers before artificial weathering, RC_n - compressive strength of wood along fibers after n number of cycles of artificial weathering, n - number of artificial weathering cycles.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The study shows that the compressive strength of wood along fibers was reduced due to the artificial weathering process. The same direction of changes was observed for every tested wood species. By analyzing the average values of compressive strength along fibers, it has been observed that gaboon showed the greatest changes. 140 cycles of artificial aging process caused the loss of strength c. 35 % (from an initial value of 43 MPa to the final 28 MPa). Merbau also showed a large change - the change of c. 33 % occurred from 65 MPa to 43 MPa. Teak showed the greatest resistance to weathering stated by the smallest change in compressive strength along fibers. Strength of wood was falling from the initial value of 58 MPa to 48 MPa (reduction c. 18 %). Massaranduba showed a similar range of changes of compressive strength due to aging factors. 140 cycles of artificial weathering caused a loss of the compressive strength along fibers from the initial value of 92 MPa to 74 MPa (reduction c. 20 %). European oak, Scots pine (sapwood and heartwood) showed the rate of change of compressive strength along fibers similar to opepe and garapa (about 28 %). There was no difference in strength loss between Scots pine sapwood and heartwood. Both of them (heartwood and sapwood) were made from one board, which was the material of similar properties (similar density). It is important to emphasize European coniferous wood species, because sapwood is an important and often dominant part of trunk volume.

Based on the results, it can be assumed that, due to aging, the loss of compressive strength of wood along fibers is mainly caused by changes in wood structure. Cyclical changes in humidity and temperature caused strong stress (sorption and thermal) exceeding internal cohesion of wood. It resulted in cracks and significant loss of wood strength. There was also a mass loss due to leaching of a number of extractives from the cell walls and partial hydrolysis of hemicellulose and cellulose (relaxed frame of ligno-cellulosic, the disintegration of some long-chain tissue constituents of wood) in subsurface layers, which consequently led to the reduction of wood density. The main cause of deterioration of mechanical properties lies in cyclical changes of moisture conditions, whicih causes tissue destruction of wood (wood cracks). Wood cracks are the consequence of sorption stresses, which occur during rapid wetting and quick drying (Matejak *et al.*, 1983; Feist, 1983, 1990; Feist and Hon, 1984; Williams, 1999, 2005). High frequency of changes in humidity causes cracking of wood - the larger amplitude and changes of frequency, the larger the damage. The cumulative impact of wood weathering factors leads to the damage of a wood structure, which is reflected in changes of its initial mechanical properties.

It is hard to indicate one particular factor that affects the extent of loss of compressive strength along fibers of tested wood species. This is probably the interaction of many factors with many interactions between them - this is a submicroscopic construction of wood (cell walls), microscopic (size, layout and contribution of individual structural elements - rays, parenchyma, fibers, vessels), macroscopic (width and layout of annual growth, the share of earlywood and latewood) and its chemical composition (types of extractives - resins, tannins, oils, minerals and other).

Gaboon is a wood with tangled texture - wood shows variations of cross grain. Deviation of wood fibers from the direction parallel to the longitudinal axis of the trunk causes an additional loss of strength. The loss of strength rises with increasing slope and cracks. Similarly, merbau has an irregular arrangement of fibers. Any deviation from fiber direction parallel to the direction of the destructive force causes the loss of strength (slope of 15° lowers the compressive strength of wood by 20 % - Kollmann and Côte, 1968). Additionally, in the case of merbau, a relatively large content of extractives negatively affects the change of strength (Grabner *et al.*, 2005).

The change of the compressive strength along fibers of garapa and opepe, similar to European wood species of much lower density (Figure 1), can also be explained by a cross grain. Both opepe and garapa wood are characterized by variations of deflected fibers. In the case of teak, the smallest change in strength can be explained by limited changes in wood moisture due to artificial weathering. Acting hydrophobically, oily substances limited alternating swelling and shrinking, after soaking in water and drying, which led to weakening of wood structure through desorption cracks. The presence of oils in cumaru had no effect on changes in strength. Cumaru, merbau, gaboon and opepe show a cross grain. The consequence of irregular

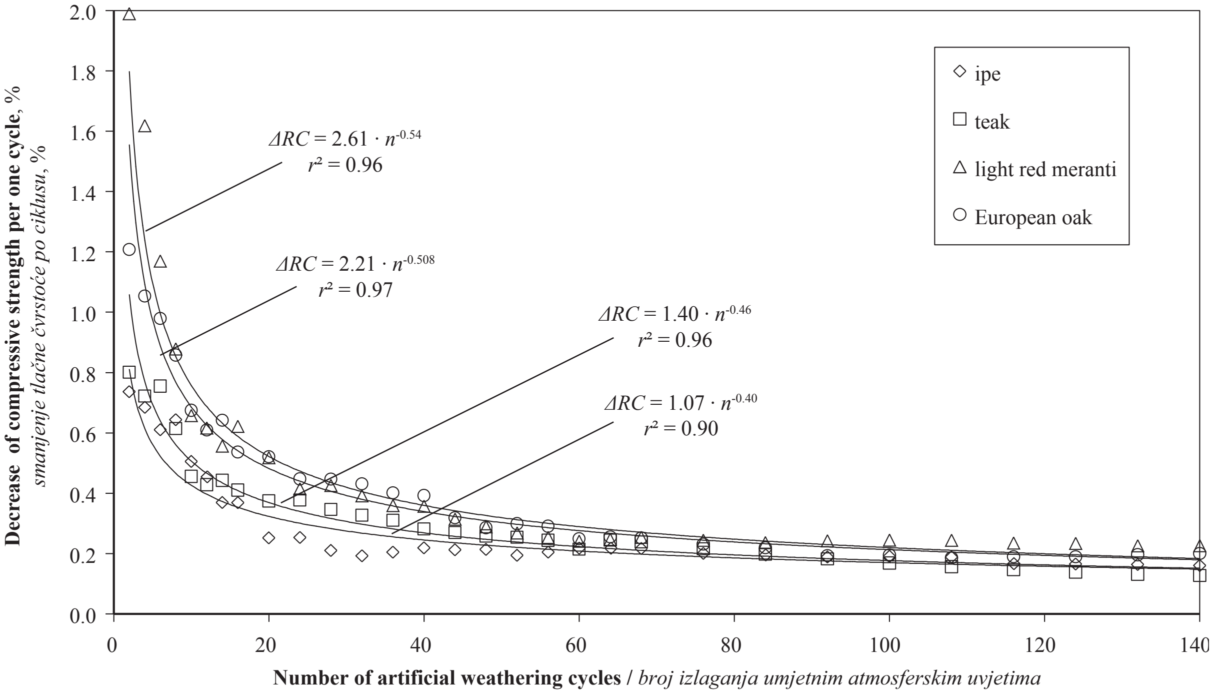

Figure 3 The dependence of decrease of compressive strength along fibers after one cycle of artificial weathering on the number cycles of artificial weathering for light red meranti, ipe, teak and European oak
Slika 3. Ovisnost smanjenja tlačne čvrstoće uzduž vlakanaca nakon jednog ciklusa izlaganja umjetnim atmosferskim uvjetima o broju ciklusa izlaganja drva svjetlocrvenog merantija, ipe, tika i europskog hrasta umjetnim atmosferskim uvjetima

structure is the reduction of the compression strength from 107 MPa to 78 MPa (approx. 27 %). The loss of compressive strength of other wood species ranged between 22 and 32 %, and without taking into account the extreme case of teak wood, the volume change decreases with the increase of wood density.

Irrespective of wood species, the results of testing compressive strength along fibers at different stages of artificial weathering process can be described by a straight line (a correlation coefficient above 0.91 in all cases) - Table 2. Regression analysis shows that the higher the density of wood is, the slope (gradient) value (*a*) decreases and the value of constatnt term (*b*) increases.

To illustrate the effect of artificial weathering of tested wood species, the approximate percent loss of the compressive strength along fibers per one cycle of aging (ΔRC) was determined. Irrespective of wood species, the character of changes was similar. Because of this, a few examples of the calculation of results are presented in Figure 3. The first cycles of artificial weathering process have the greatest influence on the loss of compressive strength. It could be due to the fact that the initial rapid changes in wood moisture caused the strongest stress sorption. As the number of conducted cycles of artificial aging rises, the loss of strength for one aging cycle is getting smaller and tends to a constant value (from about 45-50 cycles of the artificial aging process). Thus, the progressive aging changes in the strength of wood proceed more slowly.

Table 2 List of parameters of the equation ($RC_n = a \cdot RC_0 + b$) describing the change of compressive strength along fibers during artificial weathering
Tablica 2. Parametri jednadžbe ($RC_n = a \cdot RC_0 + b$) kojom se opisuju promjene tlačne čvrstoće uzduž vlakanaca tijekom izlaganja promatranih vrsta drva umjetnim atmosferskim uvjetima

Wood species *Vrsta drva*	RC_0	**Regression analysis** *Regresijska analiza*		
	MPa	*a**	*b**	*r**
western red cedar	35.50	-0.047	33.048	-0.93
gaboon	43.30	-0.042	40.388	-0.98
light red meranti	48.07	-0.091	45.677	-0.98
Scots pine (sapwood)	58.25	-0.102	55.889	-0.98
Scots pine (heartwood)	60.04	-0.103	57.920	-0.97
merbau	64.58	-0.120	60.070	-0.96
iroko	62.07	-0.096	60.220	-0.96
teak	58.10	-0.068	55.203	-0.91
European oak	46.12	-0.070	43.379	-0.95
garapa	67.77	-0.135	64.449	-0.98
opepe	74.17	-0.124	70.385	-0.96
afzelia	70.06	-0.127	65.347	-0.95
angelim pedra	71.06	-0.102	69.476	-0.98
eucalyptus	70.57	-0.125	67.657	-0.98
tatajuba	74.46	-0.110	69.373	-0.91
ipe	85.71	-0.132	83.472	-0.98
balau	97.15	-0.133	93.562	-0.97
courbaril	101.22	-0.143	97.349	-0.97
cumaru	107.72	-0.191	102.350	-0.95
massaranduba	92.43	-0.113	91.176	-0.98

* *a* – slope / *nagib*, *b* – constant term / *konstanta*, *r* – correlation coefficient / *koeficijent korelacije*

4 CONLUSION
4. ZAKLJUČAK

The presented results showed that the process of artificial weathering causes a reduction of the compressive strength along fibers of all tested wood species. The loss of the strength of wood was greater if wood was subjected to more artificial weathering cycles. Hydrophobic teak showed the greatest resistance to artificial weathering factors, expressed through the smallest decrease in the compressive strength along fibers. It is followed by massaranduba (the heaviest wood in the group). while gaboon and merbau showed the lowest resistance (loss of strength was partly the result of irregular arrangement of fibres). European wood species (oak and Scots pine) showed greater resistance to weathering factors as wood of similar density but of interlocked fibres.

At later stages of artificial weathering, the loss of compressive strength along fibers, after one cycle of artificial weathering. gets smaller and tends to a constant value - the highest intensity of change takes place at the beginning of the artificial weathering process. The rate (intensity) of changes depends on the initial density of wood.

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Influence of Feed Speed on the Content of Fine Dust during Cutting of Two-Side-Laminated Particleboards

Utjecaj posmične brzine na nastajanje fine prašine tijekom piljenja ploča iverica obostrano obloženih laminatom

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ABSTRACT • *This paper deals with the problems of wood dust production during the sawing of two-side-laminated particleboards. It points out the dangerous impact of wood dust particles on people´s health and other unfavourable influences in the working environment. The aim of the paper was to introduce the research of dustiness, to determine the content of fine particles in sawdust and analyse the influence of feed rate on the granularity of sawdust created in the process of sawing two-side-laminated particleboards using modern circular saw. Sawing parameters were chosen for the optimal cutting speed of the circular-saw blade Pilana TFZL, v_c = 84.3 m·s^{-1} and for three feed rates of a workpiece with the cut v_f = 10, 15, 20 m·min^{-1}. The collected sawdust particles were subjected to the particle-size analysis under exactly defined conditions by sieving and the basic granulometric analysis was made. Sieve analysis gives only a general particle-size distribution without any information considering the mass concentration of fine fraction of dust. Therefore, laser particle sizer Analysette 22 Microtec Plus was used to specify details concerning the size of dust particles smaller than 63 μm, which were collected in the bottom collector.*

Key words: *wood dust, particle-size distribution, circular saw blade, two-side-laminated particleboard*

SAŽETAK • *U radu se analiziraju problemi nastajanja drvne prašine tijekom piljenje ploča iverica obostrano obloženih laminatom. Upozorava se na štetan utjecaj čestica drvne prašine na zdravlje ljudi i na druge nepovoljne utjecaje u radnoj okolini.˝Cilj rada bio je predstaviti istraživanja o onečišćenju radnog prostora drvnom prašinom, odrediti sadržaj sitnih čestica u piljevini te analizirati utjecaj posmične brzine na granulometrijski sastav piljevine nastale tijekom piljenja ploča iverica obostrano obloženih laminatom na suvremenoj kružnoj pili. Parametri piljenja izabrani su za optimalnu brzinu rezanja lista kružne pile Pilana TFL, v_c = 84,3 m·s^{-1}, i za tri posmične brzine obratka v_f = 10, 15 i 20 m·min^{-1}. Analizirane su veličine čestica piljevine pri točno određenim uvjetima prosijavanja te je određen granulometrijski sastav piljevine. Analiza piljevine prosijavanjem daje samo opću raspodjelu veličina čestica, bez informacije o masenoj koncentraciji frakcija fine drvne prašine. Stoga je za detaljnije određivanje veličina čestica drvne prašine manjih od 63 μm koje su prikupljene u kolektoru na dnu sita primjenjen laserski uređaj Analysette 22 Microtec Plus.*

Ključne riječi: *drvna prašina, raspodjela veličine čestica, kružna pila, iverica obostrano obložena laminatom*

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1 INTRODUCTION
1. UVOD

Together with the main product, chip sawdust is also produced during wood machining. The shape, dimension and amount of sawdust particles depend on physical and mechanical properties of sawed wood as well as on the shape, dimensions, sharpness of the cutting blade and technical and technological conditions of the sawing process (Prokeš, 1978; Goglia, 1994; Lisičan, 1996; Dzurenda, 2007). The sawdust produced during wood machining also contains small dust particles, which, when dispersed in the air, can pose a serious health risk to woodworkers (Hubbard *et al*., 1996; Beljo-Lučić *et al*., 2011; Čavlović *et al*., 2013). In accordance with the current legislation, wood-working and furniture companies have the problem how to remove or at least reduce harmful factors in the working environment. Dusty environment and excessive noise are among the greatest factors adversely affecting the human health. From hygienic aspects, the term dust implies small particles of solid materials, which are dispersed in the atmosphere or deposited on various places in the workplace. Serious health problems are mainly met in cases when the source of dust occurs in badly ventilated spaces, where there is deposition and accumulation of wood dust. It results in a considerable concentration of wood dust in the atmosphere, which can cause serious health complications (Kopecký and Pernica, 2004). Wood dust is a known inducer of cancer in the nasal cavity and recent reviews have focused on this issue. A summary of investigations of wood dust and the risk of cancer can be found in Nylander and Dement (1993), where the authors state that operatives in the woodworking industry face a higher risk of developing nasal cancer, especially those working with machines that generate wood dust (Palmqvist and Gustafsson, 1999).

Wood dust is also associated with a variety of respiratory diseases including asthma, chronic bronchitis, nasal symptoms and eye symptoms, as well as chronic impairment in lung function (Carosso *et al*. 1987; Enarson and Chan-Yeung, 1990; Jacobsen *et al*., 2010).

There are only several reports about the dust generated during woodworking. Most of these reports are focused on dust of hardwood and softwood. There are even less papers dedicated to the creation of dust during the cutting of wood-based materials. For example, Chung *et al*. (2000) investigated the quantity, particle size distribution and morphology of dust created during the machining of MDF.

Particle boards are made by gluing wood particles together with some kind of resin. Therefore, machining, sanding or excessive heating of such composite material can cause decomposition releasing formaldehyde, carbon monoxide, hydrogen cyanide and phenol. The atmosphere pollution created by machining particle boards is an effect of dispersion of wood dust, which may act as a carrier of other chemicals contained in such boards, e.g. wood preservatives and wood adhesives that may themselves cause health effects if inhaled (Hursthouse *et al*., 2004). Therefore, special interest should be focused on fine dust created during cutting wood-based materials with the aim of preventing occupational diseases in woodworking industry.

The aim of this work was to determine the content of fine particles in sawdust created during sawing the particleboards by the modern circular saw at three levels of feed speed. The expected results may be the base of the preliminary evaluation of health risk related to dustiness.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Experimental sawing was carried out at the Department of Forest and Timber Technology, Mendel University in Brno, on a modern experimental stand (Figure 1) intended for research of cutting by circular sawblades. This experimental equipment makes it possible to measure parameters of a cutting process, vibrations of circular sawblades and their noise.

For the research into dustiness, it was necessary to equip the stand with a sucking device (URBAN Technik, Libchavy, Czech Republic) and with a GTE (Gravimetric Techniques Emissions, TESO Praha, Czech Republic) for isokinetic sampling of dust. In researching dustiness, information is primarily obtained on the machine dust emission, which is the source of knowledge of the particle size composition of sawdust. Cutting conditions should be selected so that the machine dust emission can be expressed by a functional relationship to the removed chip thickness. Sampling of sawdust and dust is carried out isokinetically, i.e. under conditions of the total correspondence of the sampled air and air flowing inside the sucking device air channel. The actual air sampling approaches the isokinetic sampling most when it is carried out by a probe with optimum dimensions and shape and if the air speed in the sampling probe nozzle is identical (as for size and direction) with the speed of air in the place of measurement.

Sampling was carried out by an isokinetic gravimetric set GTE. The sucking device has to guarantee controllable air flow through the sampling device in order to ensure that conditions for isokinetic sampling are kept in every point of sampling. The period of sampling was determined on the basis of the number of points of sampling and in the measurement cross-section and by the period of sampling in one point. The period of sampling in every point of sampling has to be the same, usually five to ten minutes, but at least three minutes. The method of sampling has to be in accordance with the ČSN ISO 9096 standard.

In cutting, a standard circular sawblade Pilana TFZL (Pilana Saw Bodies s.r.o, Hulín, Czech Republic) was used for trimming boards to size, diameter 350 mm, number of teeth 108 (geometry $\alpha = 18°$, $\beta = 66°$, $\gamma = 6°$). Before the experiment, the radius of edge blunting, which did not exceed the value of $r_0 = 9$ µm, was verified. Cutting parameters were set up for the optimum cutting speed ($v_c = 84.3$ m·s^{-1} and three feed rates of a workpiece with the cut $v_f = 10, 15, 20$ m·min^{-1}).

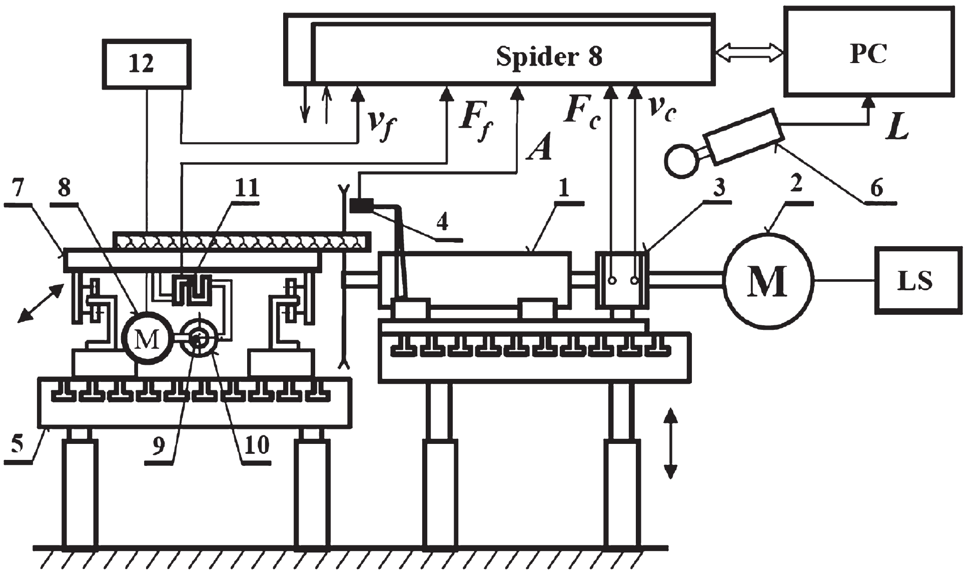

Figure 1 Schematic diagram of the experimental stand. 1 – spindle, 2 – electric motor with rpm control LS, 3 – sensor of cutting force F_c and speed v_c, 4 – contactless sensor of vibrations A, 5 – grid table, 6 – noise meter, 7 – feed car, 8 – electric motor of car feed, 9 – ball screw, 10 – nut, 11 – feed force sensor F_f, 12 – frequency converter for speed v_f
Slika 1. Shematski dijagram eksperimenta: 1 – vratilo, 2 – elektromotor s kontrolom broja okretaja LS, 3 – senzor sile rezanja F_c i brzine v_c, 4 – beskontaktni senzor vibracija A, 5 – rešetkasti stol, 6 – bukomjer, 7 – posmična naprava, 8 – elektromotor za pogon posmične naprave, 9 – kuglični vijak, 10 – matica, 11 – senzor posmične sile F_f, 12 – frekvencijski pretvarač za posmičnu brzinu v_f

Dustiness was evaluated for typical working conditions of circular saws. The measurement was made in trimming samples of two-side-laminated particleboards Duropal, which was produced by the company KRONOSPAN (Czech Republic). The density of rectangular prisms (800 × 350 × 39 mm) was $\rho = 700$ kg·m^{-3}.

2.1 Particle size analysis of sawdust
2.1. Analiza veličine čestica piljevine

Under exactly defined conditions, the basic granulometric analyses were carried out at the Department of Furniture Design, Poznan University Life of Sciences, by sieving, which means by screaning of sampled dust on a set of sieves with mesh size of 0.5 mm, 0.25 mm, 0.125 mm a 0.063 mm during the time T = 20 min on an automatic vibration sieving machine AS 200 (Retsch, Germany). The weights of fractions on sieves were subsequently weighed on the laboratory scales WPS 510/C/2 (Radwag, Poland) with a weighing accuracy of 0.001 g.

Sieve analysis gives only a general particle-size distribution without any information considering the fine fractions of dust (Dzurenda and Orłowski, 2011). Therefore, laser particle sizer Analysette 22 Microtec Plus (Fritsch, Germany) was used to determine the size distribution of dust particles collected in the bottom collector, which was below the sieve with the mesh size of 0.063 mm. This sizer automatically carries out a particle size measurement according to predetermined SOP (Standard Operating Procedure) and theoretical assumptions. The obtained results were processed by the MaScontrol (Fritsch, Germany) software in order to generate the particle-size distribution curves of the tested dust samples. It gives two types of quantities:

- the sum of the distribution Q_r
- the density of the distribution q_r

The curve of the distribution sum $Q_r(x)$ shows a standardized total quantity of all particles with equivalent diameters less than or equal to x. Each point along the curve of the distribution sum represents the sum of the quantity components of all particles. The curve of the density distribution $q_r(x)$ is the first derivative of $Q_r(x)$ by x. It frequently appears in the bell shape.

In agreement with $dQ_r(x) = q_r(X)\ dx$, $q_r(x)$ is the component of a quantity $dQ_r(X)$, which is contained in the interval dx for particles from x and $x + dx$. The result is a random quantity r, where:

$$q_r(x) = \frac{x^r \cdot q_r(x)}{\sum_{1=1}^{n} x_i^r \cdot q_{Oi}(x_i)} = \frac{dQ_r(x)}{dx}$$

The fractions of dust in the range < 2.5 µm, 2.5 – 4 µm and further are obtained based on particle size distribution curves generated during the measurements. The mass of the dust particles collected in the bottom collector, under the sieve with the smallest mesh, had to be taken in subsequent calculations to determine the content of particles with these dimensions in the total mass of dust created during the machining due to the fact that these fractions referred to the samples separated by the sieve analysis. Therefore, the final result of the particle-size measurements of the smallest particles in the dust was the product of the fraction < 63 µm and the fractions calculated in applied ranges.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

According to the sieve analyses – granulometric composition of dry sawdust, histograms (Figure 2) of the distribution of particular particle fractions for the

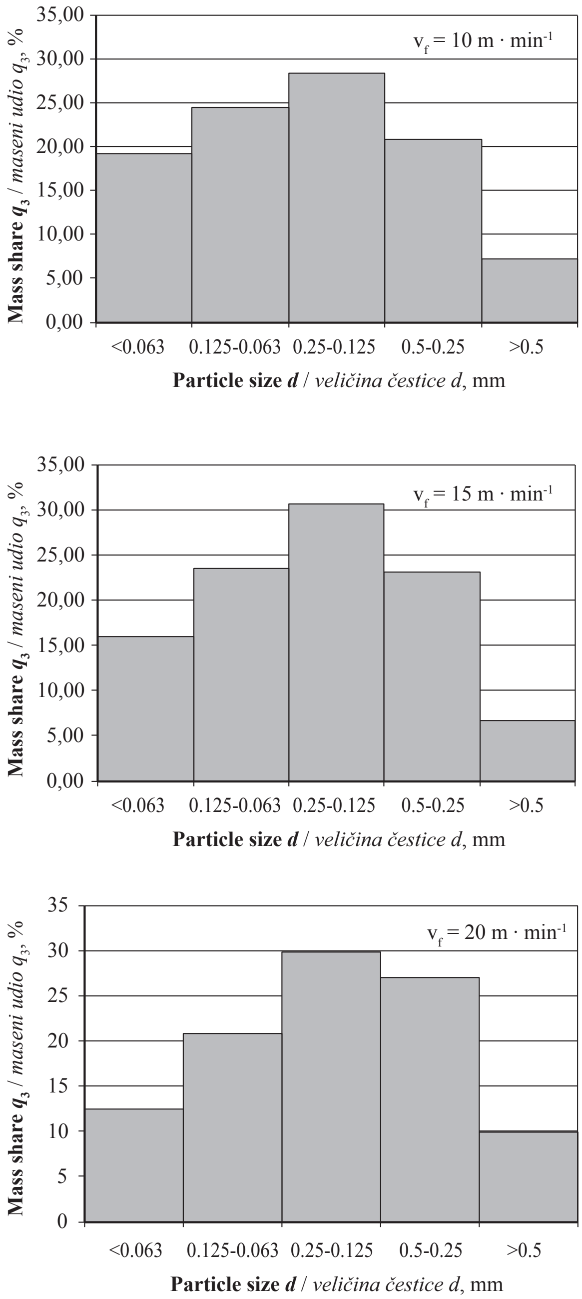

Figure 2 Histograms of sawdust particle-size distribution
Slika 2. Histogrami raspodjele veličina čestica piljevine

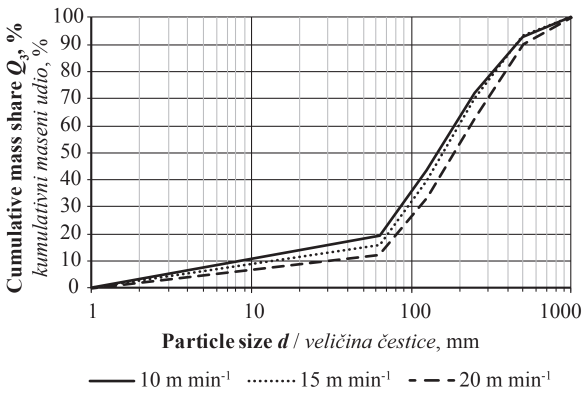

Figure 3 Cumulative particle-size distribution
Slika 3. Kumulativna raspodjela veličina čestica

feed speed v_f = 10 m·min^{-1}, 15 m·min^{-1} and 20 m·min^{-1} were generated. The highest gravimetric proportion occurs in the range from 0.125 to 0.250 mm. There is a relatively high percentage of particles smaller than 0.063 mm, which include potentially airborne particles and from the aspect of occupational health and safety, they can be the most dangerous for workers in the working environment. Substantial increase of the occurrence of these particles in the sawdust was noted with the decreasing feed speed.

Figure 3 shows the cumulative distribution of particle size of the analysed sawdust. It can be concluded that the dust created during cutting at feed speed of 10 m·min^{-1} is finer than during machining at feed speed of 15 or 20 m·min^{-1}. This result was expected due to a well-known fact that the amount of fine sawdust significantly increases with the decreasing feed speed – chip thickness (Barcík and Gašparík, 2014; Dzurenda *et al.*, 2010). Hemmilä *et al*. (2003) stated that decreasing feed speed causes decreasing of airborne dust emission but this is quite the opposite of the statement that increasing of chip thickness decreases airborne dust emission. Palmqvist and Gustasson (1999) came to the conclusion that the most important factor for the amount of wood dust created from machining of different materials is the average chip thickness.

The effect of cutting parameters on particle distribution of chipped wood during cutting along the grain when the working table is in upper position with higher contact angle of teeth and cutting material is not quite clear because of complex and varying morphology of the processed material, which ranges from softwood through light and dense hardwoods to particleboards, and differences in fragmentation of chips generated during sawing (Beljo Lučić *et al*., 2007).

Figure 4, 5 and 6 show the results of the analysis of dust sampled from the bottom collector of the sieving machine, which were generated by MaScontrol software in analysing the measuring data from the particle sizer. The graphs show the cumulative and discrete particle-size distribution of analysed dust. These results indicate that the content of fine particles in the tested dust created during cutting at the feed speed v_f = 10 m·min^{-1} is higher than when other speed values are used. Particle-size distribution obtained by the particle measurement method with laser diffraction gives a different range of the most numerous particles. It can be seen that the dust particles with the size below 63 μm account for less than 50 – 75 % of the total material analyzed. This demonstrates the inaccuracy of both methods, which is caused due to the specific shape of wood dust particles. Their length is usually larger than the other dimensions, therefore the wood dust particles pass through a sieve mesh of smaller size than their length.

Figure 7 demonstrates the total contents of particles with assumed critical size limits of 2.5, 4 and 10 μm in the tested sawdust, which were calculated on the basis of the particle-size distribution obtained by the laser diffraction method and taking into account the mass share of the fraction < 63 μm determined by the sieving method. It is easy to see that the largest share of fine dust is generated at feed speed v_f = 10 m · min^{-1} and

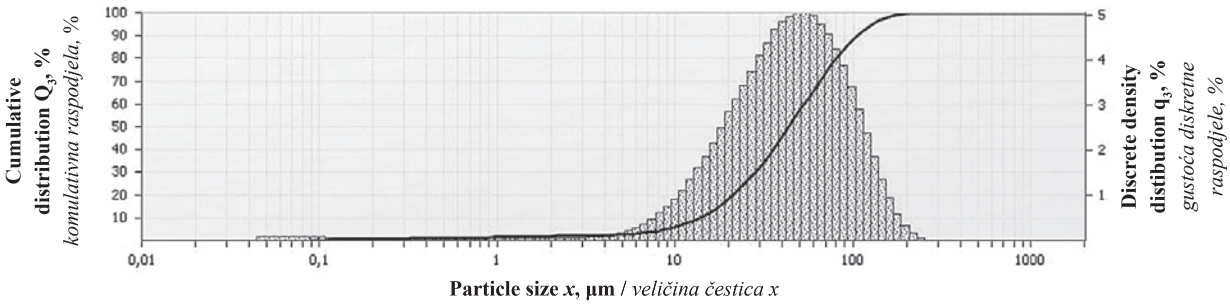

Figure 4 Particle size distribution of dust created during sawing at feed speed v_f = 10 m·min^{-1} obtained by laser particle measurement
Slika 4. Raspodjela veličina čestica drvne prašine nastale tijekom piljenja iverice pri posmičnoj brzini v_f = 10 m·min^{-1} dobivena laserskim mjerenjem čestica

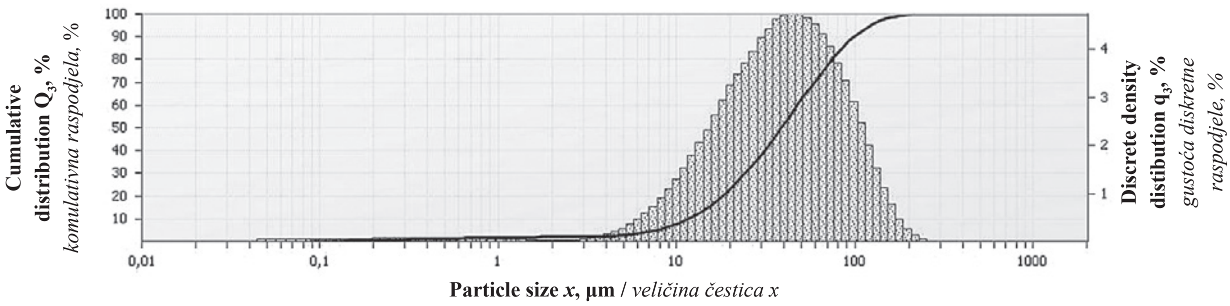

Figure 5 Particle size distribution of dust created during sawing at feed speed v_f = 15 m·min^{-1} obtained by laser particle measurement
Slika 5. Raspodjela veličina čestica drvne prašine nastale tijekom piljenja iverice pri posmičnoj brzini v_f = 15 m·min^{-1} dobivena laserskim mjerenjem čestica

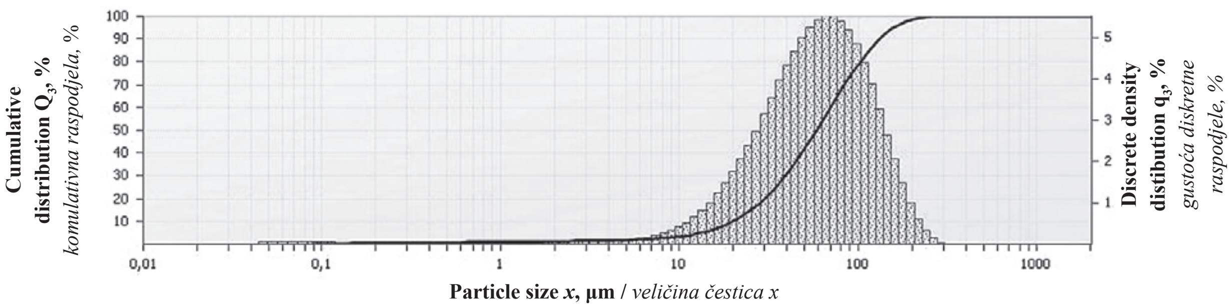

Figure 6 Particle size distribution of dust created during sawing at feed speed v_f = 20 m·min^{-1} obtained by laser particle measurement
Slika 6. Raspodjela veličina čestica drvne prašine nastale tijekom piljenja iverice pri posmičnoj brzini v_f = 20 m·min^{-1} dobivena laserskim mjerenjem čestica

that the amount of this dust increases with the decreasing feed speed.

The calculated rates of the smallest particles are shown in Table 1. The level of the occupational hazard on a given machining station caused by wood dust can be primitively estimated based on the comparison of the measured values.

It should be noted that the content of the particles with the size lower than 10 µm is only about 1 % in the total dust for the feed speed v_f = 10 and 15 m·min^{-1} and about 0.5 % for the feed speed v_f = 20 m·min^{-1}. This is generally negligible but during machining a large amount of dust can be created and it might pollute a huge volume of the air at the acceptable limit of dust concentration. These particles, when dispersed in surrounding air of the working place, are potentially re-

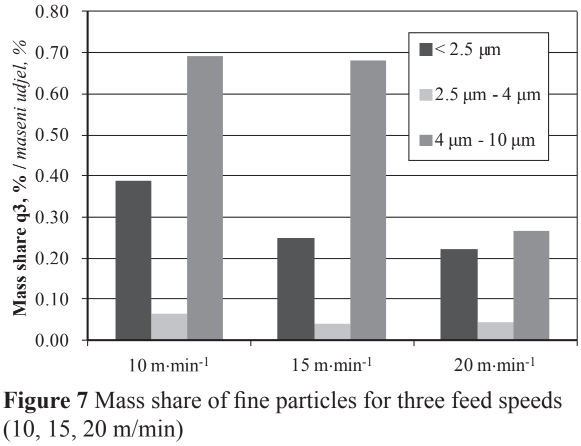

Figure 7 Mass share of fine particles for three feed speeds (10, 15, 20 m/min)
Slika 7. Maseni udjel finih drvnih čestica za tri posmične brzine (10, 15, 20 m/min)

Table 1 Mass rate of the smallest particles
Tablica 1. Maseni udjel najsitnijih čestica

Upper limit *Gornja granica* μm	**Mass rate in the smallest sieving fraction** *Maseni udjel u frakciji najsitnijih čestica* %			**Mass rate in the total dust** *Maseni udjel u ukupnoj drvnoj prašini* %		
	10 m·min^{-1}	15 m·min^{-1}	20 m·min^{-1}	10 m·min^{-1}	15 m·min^{-1}	20 m·min^{-1}
2.5	2.03	2.01	1.38	0.389	0.250	0.220
4	2.36	2.33	1.65	0.454	0.289	0.263
10	5.96	7.79	3.31	1.145	0.969	0.529
20	18.56	23.40	10.20	3.564	2.913	1.628
30	32.79	38.71	20.17	6.295	4.818	3.221
40	45.94	51.82	31.15	8.821	6.450	4.973
50	57.14	62.46	41.77	10.972	7.775	6.670
63	68.85	73.19	54.18	13.220	9.110	8.650

sponsible for the risk of occupational diseases. Its value is up to 5 mg·m^{-3} for agglomerated materials with phenol formaldehyde resin in the Czech Republic (ČSN ISO 481).

4 CONCLUSION
4. ZAKLJUČAK

There are many methods for the determination of particle-size distribution, but due to the fact that wood dust particles are irregularly shaped, the measurement of particle size done by different methods may give various results. Determination of the content of fine particles in the dust created during working of wood and wood composites often requires simultaneous application of measurement techniques with different measuring ranges due to the large dimensional range of analyzed particles.

On the basis of findings and results obtained, it can be concluded that the rate of fine dust created when trimming to size of laminated particleboards significantly increases with the decreasing feed speed. This is generally valid for other types of cutting operations of wood-based materials because a secondary partition of wood mater occurs. So this increase is particularly caused by the structure of agglomerated material but also by the used tool. Teeth of circular saw blades for trimming tend to have rather small cutting angle. Small angles may cause generating chips that are very bent and prone to disintegration (Očkajová and Beljaková, 2004), which increases the proportion of fine dust particles.

Although, based on tests, a seemingly insignificant amount of dust of 10 μm and smaller was found in the whole mass of the created sawdust, it can be assumed that in the process of sawing particleboards, there is a high risk of formation of dust particles harmful to the health of workers employed in woodworking stations. Even this relatively small amount of fine dust can cause the pollution of a huge volume of air in excess of the permitted level.

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The Effects of Poly(vinyl acetate) Filled with Nanoclay and Cellulose Nanofibrils on Adhesion Strength of Poplar and Scots Pine Wood

Utjecaj poli(vinil acetata) s punilom od nanočestica gline i celuloznih nanovlakana na čvrstoću lijepljenja drva topole i običnog bora

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ABSTRACT • *Cellulose nanofibrils (CNFs) and nano clay (NC) were selected to determine the effects of different fillers on the characterization of poly(vinyl acetate) (PVA). Characterizations of the PVA composites obtained were studied by thermogravimetric analysis (TGA/DTG), scanning electron microscopy (SEM) and the lap joint shear strength (LJSS). The morphological studies revealed that some clumpings were observed in SEM images for 1%, 2%, and 4% wt loadings for CNFs and NC fillers. Dispersed particle orientation morphology and the wave sheets appear to be uniformly distributed on the surface of the composites. Seen as the effects of fillers on the thermal stability, the results showed that NC has a greater effect than CNFs, depending on the loading rates of fillers. Lap joint shear strength generally increased after adding CNFs and NC to PVA matrix. Thus, it can be said that PVA has higher bonding performance and can be used in applications requiring higher bonding strength.*

Key words: *Poly(vinyl acetate), cellulose nanofibrils (CNFs), nano clay (NC), nanoparticles filled composites, adhesion*

SAŽETAK • *Za istraživanje utjecaja različitih punila na svojstva poli(vinil acetata) (PVA) odabrana su celulozna nanovlakna (CNFs) i nanočestice gline (NC). Svojstva PVA kompozita istražena su termoanalizom (TGA/DTG), skeniranjem elektronskim mikroskopom (SEM) i određivanjem smicajne čvrstoće spoja (LJSS). Morfološke su studije pokazale da su skupine čestica zabilježene na SEM slikama pri težinskom udjelu CNFs i NC punila od 1, 2 i 4 %. Raspršena morfologija orijentacije čestica i valovi ravnomjerno su raspoređeni na površini kompozita. Iz analize utjecaja punila na termičku stabilnost može se zaključiti da NC ima veći utjecaj od CNFs-a, ovisno o težinskom udjelu punila. Smicajna čvrstoća spoja općenito se povećava nakon dodavanja CNFs i NC punila na*

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PVA matricu. Prema tome, može se reći da PVA s CNFs i NC punilom ima veću učinkovitost lijepljenja i može se primijeniti u aplikacijama koje zahtijevaju veću čvrstoću lijepljenja.

Ključne riječi: *poli(vinilni acetat), celulozna nanovlakna (CNFs), nanočestice gline (NC), kompoziti s punilom od nanočestica, adhezija*

1 INTRODUCTION
1. UVOD

Nano particle filled composites, a class of nanostructured materials composed of various polymers and fillers, have superior physical, mechanical and other properties when compared with neat polymers (Rhim and Ng, 2007; Zhao *et al.*, 2008; Shchipunov, 2012). Various polymer matrixes are generally used in the production of polymer with nano fillers. Therefore, to obtain more environmentally friendly materials that decrease dependence on fossil-based resources, in recent years, different biodegradable polymers such as PVA have been developed. As the properties of such polymers are sometimes inferior to those of commercial non-biodegradable polymers, the composites filled with different fillers of such biodegradable polymers have been developed to obtain high performance in application area. For example the use of the composites for packaging and other applications has been strongly limited because of the poor barrier properties and weak mechanical properties. For this reason, biodegradable polymers have frequently been blended with other synthetic polymers and various fillers, or less frequently, chemically modified with the aim of extending their application (Guilbert *et al.*, 1997; Petersen *et al.*, 1999).

Polymers that are increasingly used in composite manufacturing to replace non-biodegradable polymers include starch, cellulose, polylactic acid, polyhydroxy alkanoates, pectin, chitosan, collagen among others (Mittal, 2011). To prepare biodegradable composites, many nano fillers, such as nanoclay, starch, cellulose, and carbon nanotubes, have been used. The composites have been prepared via several methods, such as in situ polymerization, solution exfoliation, and melt intercalation (Dennis *et al.*, 2001; Zeng *et al.*, 2005).

NC and CNFs are bio-fillers commonly used to produce biodegradable composites. NC has a unique structure and properties and a very high elastic modulus as compared to many biodegradable fillers. The higher elastic modulus enables NC to improve mechanical properties of polymers by carrying a significant portion of the applied stress (Zeng *et al.*, 2005; Fornes and Paul, 2003). CNFs, which was obtained from cellulose fibers, is a natural polymer with the chemical formula $(C_6H_{10}O_5)n$. It is a polysaccharide consisting of a linear chain of several hundred to more than 10,000 β (1→4) linked D-glucose units (Klemm *et al.*, 2005; Nishiyama, 2002). CNFs have a higher modulus and strength because of microfibrillar spiral angle (Ichhaporia, 2008). The linear chains have alcoholic hydroxyl groups. The hydroxyl groups form inter-molecular and intra-molecular hydrogen bonds with the macrostructure of cellulose. CNFs are used as a reinforcing agent in polymer composites because they offer many important advantages and strong mechanical properties (Mohanty *et al.*, 2005).

PVA is a widely used, cheap, biodegradable adhesive, but it has low adhesion strength (Kaboorani and Riedl, 2011). The aim of this study was to improve the adhesion properties of PVA with NFCs and NC. CNFs, with sustainability, industrial ecology, and green chemistry, and NC, with its unique structure and properties and very high elastic modulus, were selected to prepare the biodegradable composites in this study. PVA was used to prepare the biodegradable composites. The properties of the composites prepared with PVA and nano fillers at different loading rates (1 %, 2 %, and 4 %) were investigated by using thermogravimetric analysis (TGA/DTG), morphological characterization with scanning electron microscopy (SEM), and lap joint shear strength (LJSS).

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

2.1 Materials
2.1. Materijali

Cellulose nanofibrils (CNFs) were supplied by J. Rettenmaier & Sohne (JRS). NC was purchased from Nanocor, Canada. The NC, which was supplied as micro fine powders under the "I" series designation, was ready for use directly into the resin system. PVA, having a 1200 polymerization degree and a 90 % hydrolysis level, was purchased from Chemical Enterprise Caparol and used to prepare the composites. Poplar and Scots pine wood were used to determine the lap joint shear strength. They were cut to 20 x 150 x 5 mm according to BS EN 205 and, before bonding, the samples were put into the condition chamber at 20 ºC with relative humidity of 60 % for a week.

2.2 Method
2.2. Metode

CNFs and NC filled PVA composites were prepared with the solution method using various loading rates of nano particles as show in Table 1.

Particles were first dispersed in distilled water (1, 2, 4 g filler/10 ml DI) by mechanical stirring at 2000 rpm for 5 min. The suspensions obtained were mixed with PVA. The stirring was started with 1000 rpm for 1 min and was increased up to 2000 rpm and was continued for 20 min to achieve a viscous solution. The mixture was degassed for approximately 30 minutes in an oven without vacuum at 40 °C. It was cast on an aluminum plate and kept for one week until it was completely dried. All formulations were prepared with the same process.

The morphology of the surfaces of the composite films was observed with an environmental scanning electron microscopy (ESEM), the Phillips Electroscan

Table 1 Experimental design
Tablica 1. Dizajn eksperimenta

Samples / *Uzorci*	**Matrix** *Matrica*, %	**CNF**, %	**NC**, %
Pure PVA	100	-	-
PVA+1 % NC	99	-	1
PVA+2 % NC	98	-	2
PVA+4 % NC	96	-	4
PVA+1 % CNF	99	1	-
PVA+2 % CNF	98	2	-
PVA+4 % CNF	96	4	-

2020, with an accelerating voltage of 5 kV. The surface of all samples was sputter-coated with gold using a Denton sputter coater for enhanced conductivity. The thermal stability of the composites was investigated using a thermogravimetric/differential thermal analysis (TGA/DTG) (Perkin Elmer, TA Instruments, USA). The samples were heated from 25 ºC to 600 ºC with a heating rate of 10 ºC/min and a nitrogen flow of 100 mL/min. The shear tests were performed using a testing machine with load cell 1 of kN (Utest Inc., Turkey). The cross head speed was 5 mm/min. The dimension of wood samples was 10 mm in width and 150 mm in length. The bonding area of the samples was calculated before the test (220 g adhesive was used for 1 m^2 surface area) and the application was made by using a brush. Samples for tensile testing were prepared and tested according to TS EN 392:1999 and ISO 12579:2007. Utest machine was used to determine the lap shear strength, deformation and F_{max}. All data was automatically obtained with the utest machine software.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The composites prepared with CNFs and NC was found to be having different effects on morphological, mechanical and thermal properties. The SEM micrographs of composite surfaces with different loadings (1 %, 2 % and 4 % wt) of CNFs and NC are shown in Fig. 1 and Fig. 2. The images of composites show dispersed particle orientation morphology and the wave sheets appear to be uniformly distributed on the surface of composites. When the loading rates were increased from 1 % to 4 % for CNFs in Fig. 1, clumping for 1 %, 2 %, and 4 % wt loadings due to the strong hydrogen bonding affinity was observed. After increasing the loading rate of 4 % wt, the dispersion of CNFs deteriorated. For NC, partially agglomerated clay particles were also observed in the polymer matrix, as seen in Fig. 2.

As seen in Fig. 1, the aggregated nanofibrils appear as white dots in different parts of the composites. In Fig. 1, 2 % CNFs was homogenously dispersed in the PVA; nevertheless, a few aggregated fibrils were observed in the SEM picture. Clumping and aggregated parts in the 4 % CNFs were higher than composites with 1 % and 2 % CNFs. This status can be said to arise due to the hydrogen bonding among the cellulose nanofibrils and/or inadequate mixing or increasing of viscosity in the preparation of composites. As a result,

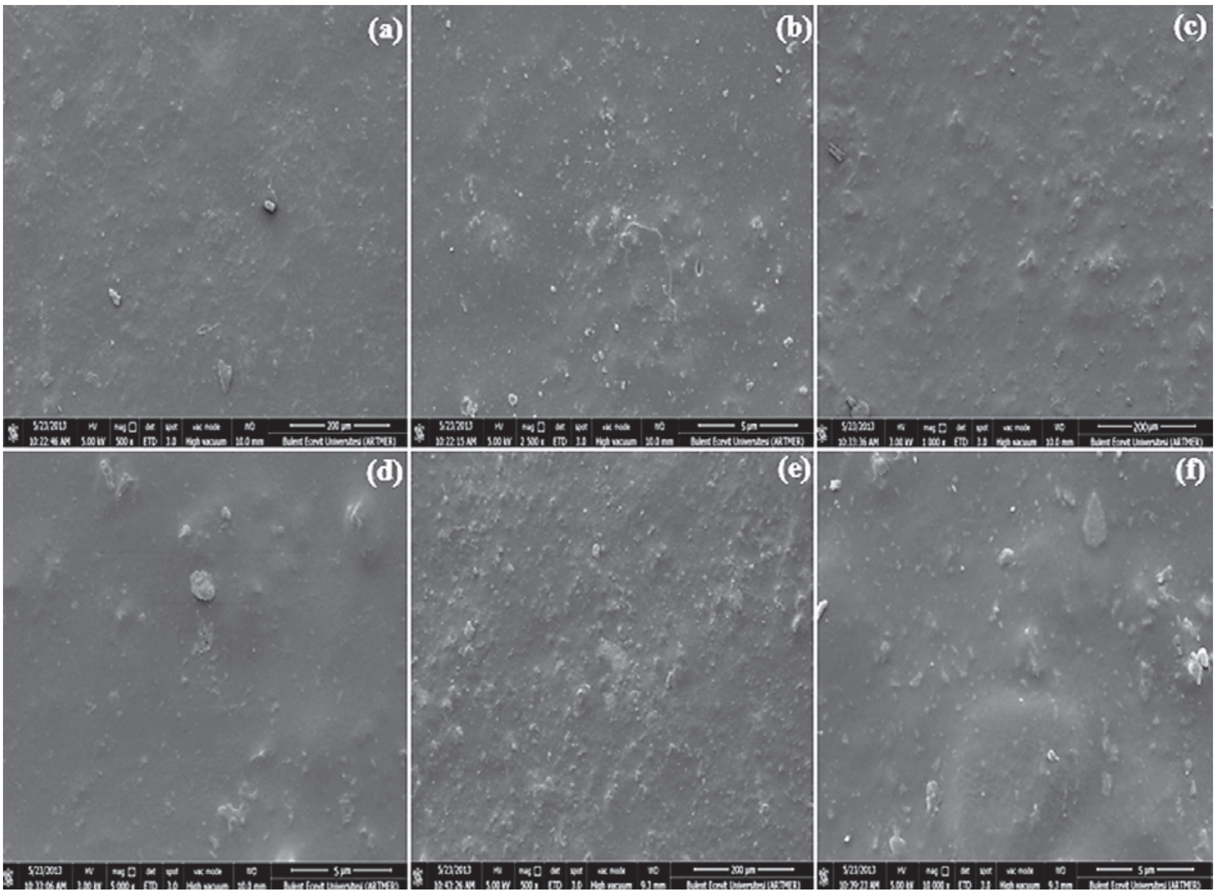

Figure 1 SEM images of PVA composites (a and b) 1 % CNFs, (c and d) 2 % CNFs, and (e and f) 4 % CNFs
Slika 1. SEM slike PVA kompozita (a i b) s 1 % CNFs-a, (c i d) 2 % CNFs-a i (e i f) 4 % CNFs-a

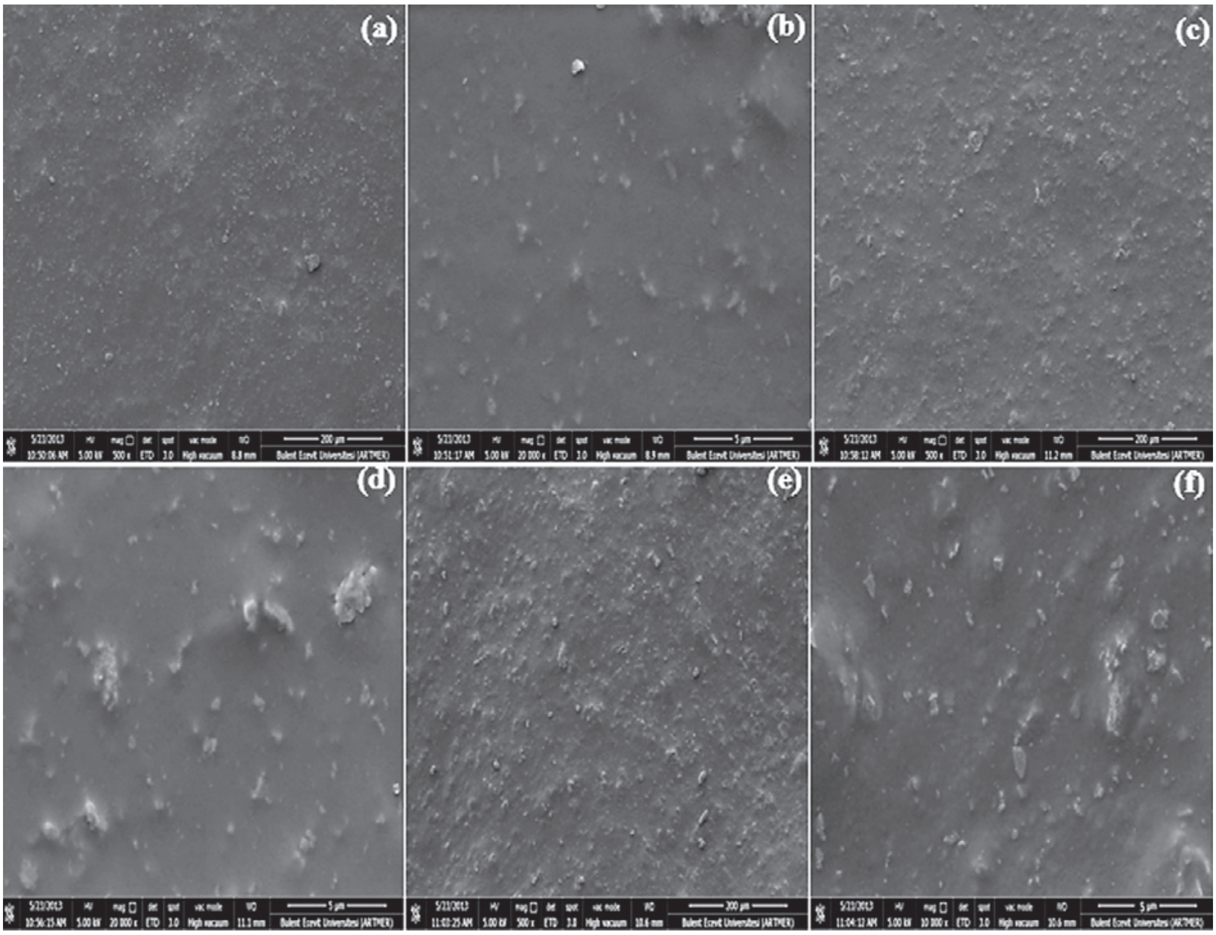

Figure 2 SEM images of PVA composites (a and b) 1% NC, (c and d) 2% NC, and (e and f) 4% NC
Slika 2. SEM slike PVA kompozita (a i b) s 1 % NC-a, (c i d) 2 % NC-a i (e i f) 4 % NC-a

clumping was observed in all the composites with CNFs. According to Fig. 2, the dispersion to all loading rates of NC in the composites was more homogenous than those of composites with CNFs. In SEM images, the clumping for 1 %, 2 %, and 4 % wt CNFs loadings was observed due to the strong hydrogen bonding affinity. For NC, partially agglomerated clay particles were also observed in the polymer matrix.

Qua *et al.* (2009) studied nanocomposites made of cellulose nanofibers with 110 nm length and PVA. SEM images showed that cellulose fibers appear as white dots on the fracture surface of PVA nanocomposites. There is some cellulose aggregation in PVA as a result of the high level of compatibility and interaction between the hydrophilic crystalline cellulose nanofibers and the PVA matrix. Lopez-Suevos *et al.* (2006) investigated the properties of PVA composites with cellulose nanofibrils. Their results revealed cellulose fibril aggregates in the matrix.

Mallakpour and Dinari (2013) worked on synthesis and properties of biodegradable poly (vinyl alcohol) / organo-NC bionanocomposites (BNCs). The SEM images of PVA/organo-clays BNCs show a flake-like structure and smooth morphology. The matrix is filamentous with interconnecting pores. However, increasing the NC content leads to a decrease in the number and size of the pores. This morphological change can be attributed to the re-ordered crystalline phase of the PVA matrix, causing a packed network. The thermal stability of composites was investigated using TGA/DTG separately under nitrogen. The data obtained are shown in Fig. 3 and Table 2. As seen in Fig. 3, there are three steps

Table 2 Summary data of thermal stability of biodegradable PVA nanocomposites
Tablica 2. Ukupni rezultati termičke stabilnosti biorazgradivih PVA kompozita

Samples / *Uzorci*	$T_{10\%}$	$T_{50\%}$	DTG_{max}	**Maximum decomposition** / *Maksimalna razgradnja*	
				Residue / *Ostatak*	Mass loss / *Gubitak mase*
	ºC	ºC	ºC	%/min.	%
Pure PVA	309.1	418.2	332.3	8.25	91.75
PVA+1 % CNF	307.6	418.5	334.5	9.12	90.88
PVA+2 % CNF	310.8	419.3	337.1	13.56	86.44
PVA+4 % CNF	311.2	419.8	336.5	24.32	75.68
PVA+1 % NC	309.3	415.1	333.6	30.51	69.49
PVA+2 % NC	309.6	425.1	335.4	32.32	67.68
PVA+4 % NC	310.54	427.2	336.2	34.53	65.47

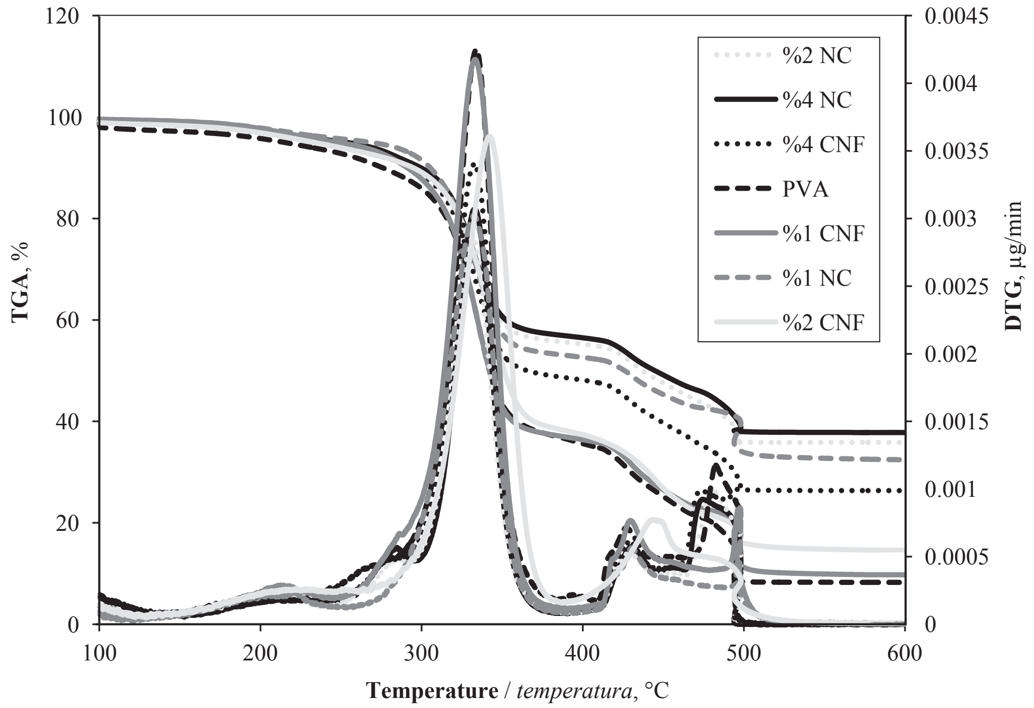

Figure 3 TGA curves of NC and CNFs reinforced PVA composites
Slika 3. TGA krivulje PVC kompozita pojačanih nanočesticama gline (NC) i celuloznim nanovlaknima (CNFs)

of thermal degradation of the composites in the temperature range of 100 ºC – 600 ºC.

The temperature range for the first step of thermal degradation (T_d) is 100 ºC – 200 °C. This corresponds to the loss of water from the composites. The temperature range for the second step of T_d is 250 ºC – 400 ºC. This corresponds to the decomposition of fillers (NC and CNFs) and weight loss of PVA from the composites. There is an additional third step of T_d in the temperature range of 400 ºC – 600 °C under nitrogen. This might be due to oxidation of partially decomposed fillers under nitrogen. According to the TGA analysis, adding of fillers improved the thermal stability and thermal stability of PVA matrix was found to increase with filler reinforcement. Similar results for different types of composite films have been reported (Wang *et al.*, 2006; Tunc *et al.*, 2007; Kumar *et al.*, 2010). The lap joint shear strength was used to evaluate the bonding properties of PVA composites. The test was conducted on both poplar and pine woods. The lap shear joint strength of the composite woods is shown in Fig. 4. A common and useful style of bonding testing is the lap shear joint strength test.

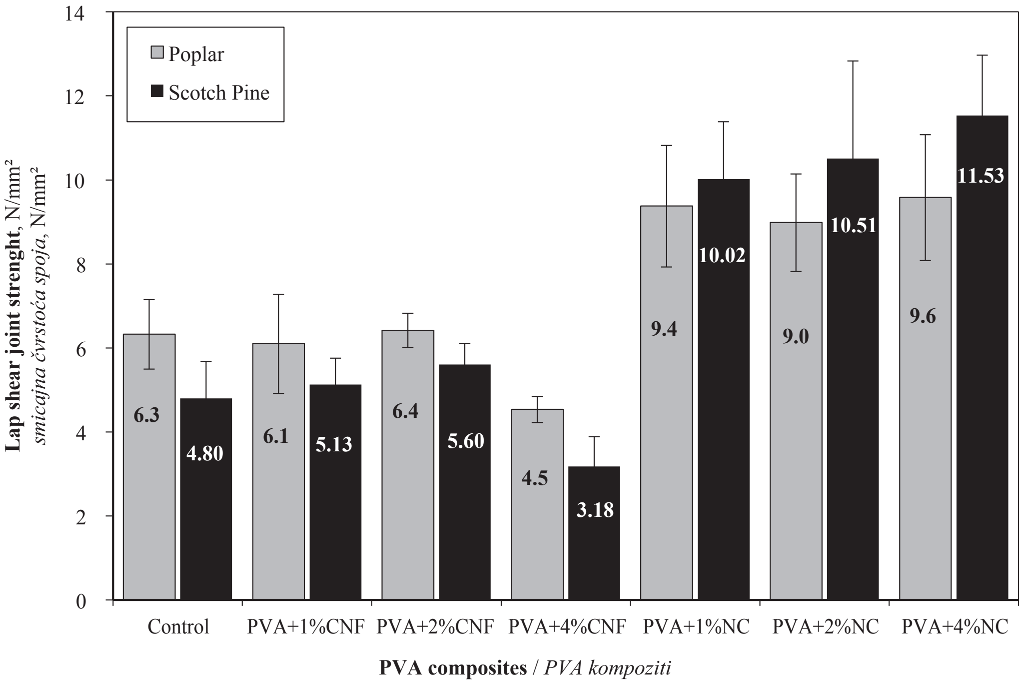

Figure 4 Lap shear joint strength of PVA composites
Slika 4. Smicajna čvrstoća spoja izvedenog PVA kompozitnim ljepilom

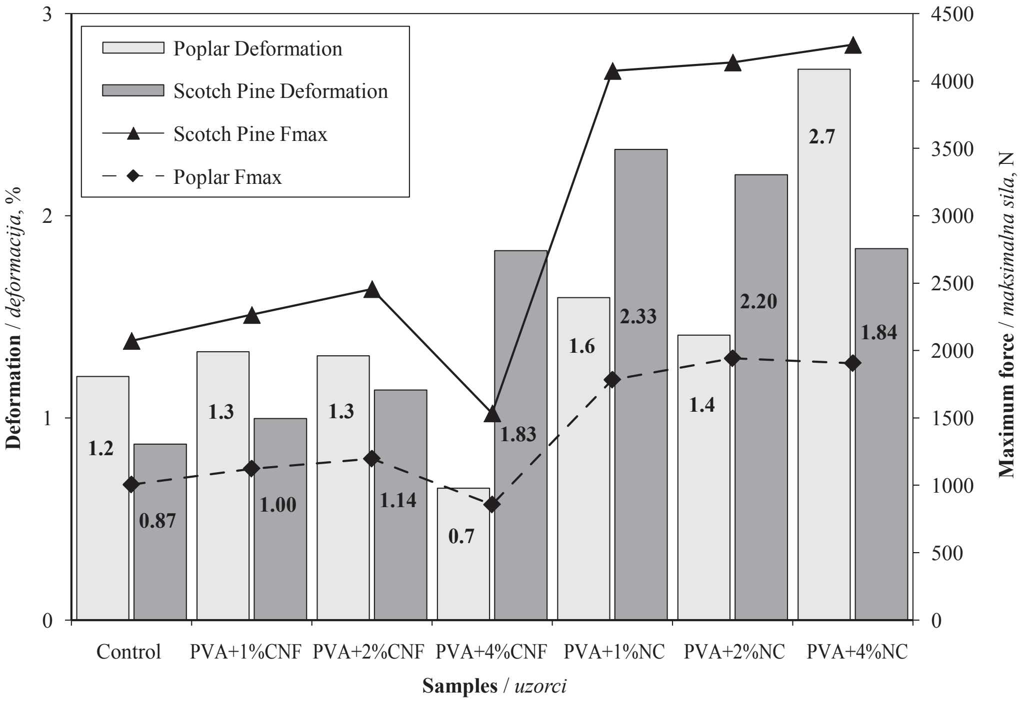

Figure 5 Deformation and F_{max} of PVA nanocomposites during tension test
Slika 5. Deformacija i F_{max} PVA nanokompozita tijekom tenzijskog testa

This test is both simple and economical in application. The test is important because of the conditions to which structural adhesives are often subjected in service. Adding NC to the polymer matrix had a higher improving effect on lap shear strength than adding CNFs. While the effect of CNFs was lower than NC on poplar and Scots pine wood.

Lap shear joint strength increased with adding 2 % CNFs on both woods, 1 % CNFs increased only with Scotch pine wood. However, 4 % loading rates of CNFs decreased the lap shear strength of both woods. The maximum increase of CNFs was 1.5% for poplar wood and 16.7 % for pine wood. Lap shear strength decreased at a different ratio for the 1 % and 4 % CNFs loadings. Adding of CNFs to the PVA matrix has a similar effect on both poplar wood and Scots pine wood. Seen as the reinforcing effect of NC, lap shear strength of both woods increased as loading rates rose from 1 % to 4 %. The maximum increase was 52.4 % in the 4 % for poplar wood and 140 % in the 4 % for Scots pine wood. The significant improvement in lap shear strength was achieved with adding of NC to both wood types. The different trends between woods can be attributed to anatomical structure. The significant improvement in the lap shear strength provided with NC is due to enlargement of the interaction area or enhanced adhesion strength per interaction area.

With an increase of CNFs and NC loadings added to PVA from 1 % to 4 %, F_{max} and deformation of both woods first increased and then decreased. Lap shear strength increased for the 1 % and 2 % CNFs loadings and decreased for 4 % loading. Seen as the reinforcing effect of NC, lap shear strength of both woods increased as loading rates rose from 1 % to 4 %. Adding NC to the polymer matrix had a higher effect than adding CNFs. This study demonstrated that adding of the NC

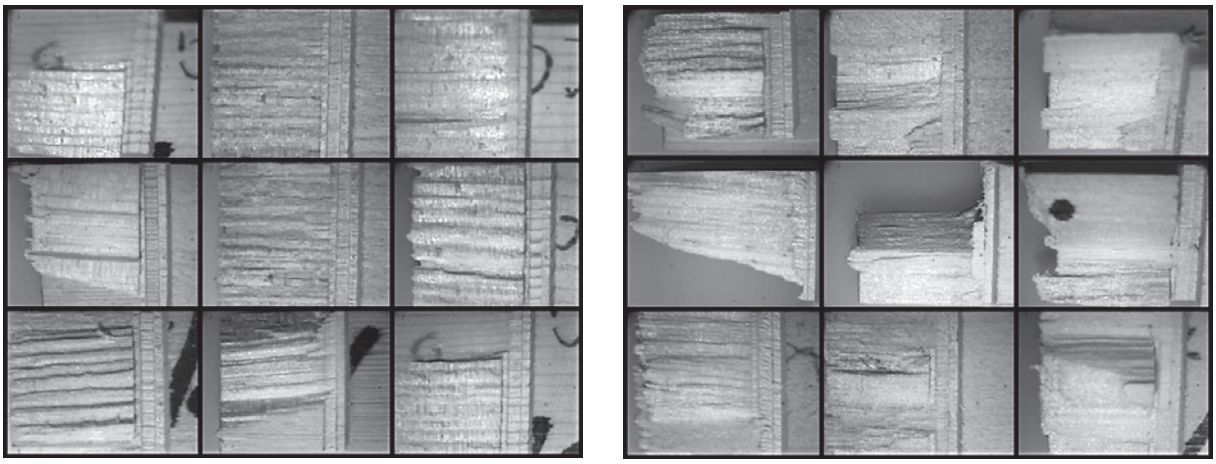

Figure 6 Failure types on wood samples during tension test
Slika 6. Vrste loma na uzorcima drva tijekom tenzijskog testa

to PVA matrix improved the adhesion performance. The improving effect of CNFs was less than NC.

Kaboorani and Riedl (2011) researched the effects of adding NC on the performance of PVA in the dry and wet state. The results showed that in the dry state, shear strength significantly improved and improvement rates rose from 7 % to 20 %. In the wet state, as loading NC was increased, marked improvements in shear strength were achieved, as high as 53 %. The F_{max} and deformation value are given for both wood types in Fig. 5. The fracture surfaces of the samples are shown in Fig. 6.

After inspecting the fracture surface of the lap shear samples, all the samples had ruptures in the wood.

4 CONCLUSION
4. ZAKLJUČAK

The PVA composites were successfully prepared with suspensions of CNF and NC by using the solution method. According to the results, adding of NC and CNFs to PVA affected all of the properties of polymer matrix. The effect of NC on the PVA composites was found to be higher than the effect of CNFs. Thermal stability of composites improved by adding of NC and CNFs and DTG_{max} increased depending on filler type. Morphological evaluations by SEM showed that the particle dispersion is a function of fillers and loading levels, and that there is a direct link between the quality of dispersion and the properties of composites. As a result, the PVA composites can be said to have higher performance than pure PVA polymer. Thus, high durable joints can be obtained in the application areas.

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Effect of Press Cycle Time on Application Behavior of Board Made from Chemically Modified Particles

Utjecaj trajanja ciklusa prešanja na ponašanje u primjeni ploče izrađene od kemijski modificiranih čestica

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ABSTRACT • *Although acetylation is effective in achieving high hydrophobicity, dimensional stability, and decay resistance of particleboards, springback and mechanical strength loss in modified boards should be improved to maintain high performance of this method. It is questioned if acetylation, due to the hydrophobic nature of modified flakes, could interfere with the polymerization reaction of the phenolic resin. In this research, the effect of different press durations on bioresistance, physical and mechanical behavior of acetylated particleboards at various weight percent gains (WPG) was investigated. Results showed that acetylated boards possessed very low moisture content, water absorption, thickness swelling and biological degradation values compared to control boards. Increasing press time intensified reduction in these boards, with the exception in untreated boards. Also acetylation resulted in high correlation between the springback and the strength losses of the boards due to weak bonding between the wood flakes. Prolongation of the press time in the acetylated boards caused significant reduction in springback and mechanical loss. Regarding the outdoor use with biological degradation for modified boards, an increase in the press time for improving these properties might be recommended.*

Key words: *press time, acetylation, particleboard, thickness swelling, mechanical strength, decay resistance*

SAŽETAK • *Iako je acetiliranje učinkovit postupak za postizanje visoke hidrofobnosti, stabilnosti dimenzija i otpornosti ploča iverica na propadanje, nužno je spriječiti njezine negativne posljedice kao što je smanjenje mehaničkih svojstava ploča, kako bi se održala visoka učinkovitost te metode. Postavlja se pitanje može li acetilacija zbog hidrofobne prirode modificiranog iverja utjecati na reakciju polimerizacije fenolne smole. U ovom se radu istražuje utjecaj različitog trajanja postupka prešanja na biološku otpornost iverice te fizikalno i mehaničko ponašanje acetiliranih ploča iverica pri različitim postocima porasta težine (WPG). Rezultati su pokazali da acetilirane ploče imaju vrlo nizak sadržaj vode, slabo upijaju vodu, manje debljinski bubre i bolja im je otpornost na biološku razgradnju u usporedbi s kontrolnim uzorcima ploče. Povećanje vremena prešanja poboljšava sva*

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navedena svojstva, osim u nemodificiranih ploča. Također, acetilacija je rezultirala visokom korelacijom između nereverzibilnog bubrenja i gubitka čvrstoće ploče zbog slabih veza među drvnim iverjem. Produljenje vremena prešanja acetiliranih ploča iverica uzrokovalo je znatno smanjenje bubrenja i gubitak mehaničkih svojstava ploča. S obzirom na vanjsku uporabu ploča iverica i potrebnu otpornost na biološku razgradnju modificiranih ploča, preporučuje se povećati vrijeme prešanja kako bi se poboljšalo svojstvo biološke otpornosti ploča iverica.

Ključne riječi: *vrijeme prešanja, acetiliranje, ploča iverica, debljinsko bubrenje, mehanička čvrstoća, otpornost na razgradnju*

1 INTRODUCTION
1. UVOD

The demand for composite wood products, such as particleboard, medium-density fiberboard and veneer board products, has recently increased substantially throughout the world (Sellers, 2000). Particleboards account for 57 % of the total consumption of wood-based panels and their consumption significantly increases each year (Pan *et al*., 2006). Increasing demand for wood-based panels, along with deforestation and forest degradation, has become an important raw material issue in the wood industry (Colak *et al.,* 2007). Efforts have been made primarily for enhancing the board strength properties, or improving the board dimensional stability and durability under environmental impact (Rowell, 2012). As a result of these concerns, alternative modification methods could play an important role in the manufacture of composite panels such as particleboards with longer service life (Menzies, 2013).

Acetylation as a common modification method to achieve an improvement in particleboard properties, like dimensional stability (Yang *et al*., 2014; Rowell *et al*., 2009) or durability (Papadopoulos, 2012; Alfredsen *et al*., 2013), involves the formation of a covalent bond between the hydroxyl groups of the cell wall polymers of wood and reagent molecules. In order to achieve this, an adequate modification intensity, meaning the relative amount of modification agent added as weight percent gain (WPG), is required (Thybring, 2013).

As known from previous studies, the side effect of acetylation is a decrease in the mechanical properties of particleboards (Wagner *et al*., 2007, Abdolzadeh *et al*., 2011), which are mainly caused by low bondability due to low wettability, the loss of a substantial amount of wood per unit mass and deterioration of fibers by acetylation (Korai, 2001). There is an adhesion problem between the hydrophilic water soluble melamine urea formaldehyde (MUF) resin and the hydrophobic acetylated flakes (Wagner *et al*., 2007). This problem was solved by several methods such as the application of non polar resin with better adhesion to hydrophobic acetylated flakes (Wagner *et al*., 2007), improvement of the wettability of acetylated flakes by addition of emulsifiers to the phenolic resin (Youngquist *et al*., 1988), and the increase of panel density (Hague *et al*., 1999).

It is questioned if acetylation could interfere with the polymerization reaction so that the phenolic resin would not be fully cured during the hot-pressing of the board. This interference may be due to the hydrophobic nature of modified flakes and the concomitant lowering of the heat transfer rate. In this research, the effect of different press cycle times on physical and mechanical behavior was investigated as well as the decay resistance of acetylated particleboards.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Acetylation
2.1. Acetilacija

Flakes were prepared by using a laboratory ring flaker (Pallmam pz8) from maple wood (*Acer insigne*). They were dried in the oven for 24h at 103±2 °C. After 12h soaking in the acetic anhydride, the flakes were heated at 120 °C for 40 and 180 minutes to achieve 9 and 16 % weight gains, respectively, (based on pre-test results). Modified flakes were washed with distilled water to remove acetic acid as the reaction by-product and unreacted acetic anhydride. Acetylated particles were dried in the oven at 103±2 °C for 24 h. Weight percent gain (WPG) was calculated using the equation (1).

$$WPG = \frac{W_{act} - W_{unt}}{W_{unt}} \cdot 100 \qquad (1)$$

Where *WPG* indicates the weight percent gain (%), W_{act} and W_{unt} are oven dry weights after and before the acetylation (g), respectively.

OH group's substitution was determined according to equation (2) mentioned in the paper of Li *et al*. (2011).

$$OH_{substd} = \frac{W_{act} - W_{unt}}{W_{unt} \cdot M_w} \cdot 1000 \qquad (2)$$

Where OH_{substd} indicates substitution of OH with acetyl groups (mmol/g), W_{act} and W_{unt} are oven dry weights after and before the acetylation (g), respectively. M_w is the molecular weight of the adduct acetyl (–C (O)-CH_3) group (g/mmol).

2.2 FTIR analysis
2.2. FTIR analiza

The Fourier transform infrared (FTIR) spectra were measured by using a Bio-rad spectrometer FTS-40 incorporating a Spectra Tech diffuse reflectance accessory unit. For FTIR analysis, dried acetylated flakes were milled and passed through a 40 mesh sieve. Spectra were obtained directly from wood powder on a detector prism.

2.3 Manufacture of boards
2.3. Proizvodnja ploča

Particles with size of 20-40 mesh were used for making the particleboards. After being blended with melamine urea formaldehyde (MUF) resin (10 % based on the oven dry weight), the single layer mats were pre-

Table 1 Duncan Multiple Range Classification of the effect of acetylation and press time on physical and mechanical properties
Tablica 1. Duncanova višestruka klasifikacija raspona utjecaja acetilacije i trajanja prešanja na fizikalna i mehanička svojstva ploča

WPG, %	Press time *Vrijeme prešanja,* min	WA (2)	WA (24)	TS (2)	TS (24)	SP	MC	MOR	IB	WL
0	4	B	B	B	B	CD	A	A	A	AB
	5	B	C	A	AB	CD	A	A	A	ABC
	6	A	A	A	A	BCD	A	B	B	A
9	4	C	D	C	C	BC	B	C	B	BC
	5	D	E	CD	C	D	C	B	B	BC
	6	D	EF	CD	D	CD	C	B	A	CD
16	4	E	G	DE	E	A	CD	D	C	D
	5	E	FG	DE	E	A	CD	D	C	D
	6	E	H	E	F	B	D	C	B	D

pared from the treated and untreated chips. Nominal dimension of boards was 400×400×15 mm^3 with 3 replications for each treatment. Mat was compressed under 3 N/mm^2 pressure for 4, 5 and 6 minutes at the temperature of 175 °C. Target density of the boards was 0.75 g/cm^3.

2.4 Particleboard properties evaluation
2.4. Određivanje svojstava ploča iverica

The boards were conditioned at 20±2 °C and 65 % relative humidity for 2 weeks until they reached equilibrium moisture content. After conditioning, they were cut into test specimens according to DIN 68763, EN 317 and EN113 Standards for mechanical, physical and decay tests, respectively. Five specimens were prepared from each sample board to determine the physical and mechanical properties. Water absorption and thickness swelling after 2 and 24-h immersion were determined. The decay test exposed to *Trametes versicolor* was carried out in 9 replications for each treatment.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The treatment with acetic anhydride resulted in WPG of 9 % and 16 %. Since unreacted chemicals from treated flakes were removed after the treatment, the WPG of modified samples after treatment indicated the evidence of chemical reactions. Statistical analysis of physical, mechanical and biological data were conducted using factorial design. Means of each treatment were compared according to Duncan multiple range test at $p \leq 0.05$.

3.1 Changes in chemical structures of wood after acetylation
3.1. Promjene kemijske građe drva nakon acetilacije

By increasing the reaction time, more intensity levels of modification (*WPG*) with acetic anhydride were obtained. Esterification of maple particles was established by the increase in weight (Table 2) and infrared spectroscopy (Fig. 1). It can be seen that at 9 % and 16 % weight gains, 2.09 and 3.70 mmol of OH groups per gram of wood are substituted, respectively, when reacted with acetic anhydride.

Infra-red spectra confirmed the occurrence of wood-acetic anhydride reaction. The strong intensity obtained in the region of 1738 cm^{-1} was due to the increased symmetric stretching of carbonyl group (C=C) of the acetyl group after treatment. This observation was confirmed by an increase in the intensities of absorption bands at 1245 cm^{-1} (C–O) and 1376 cm^{-1} (CH_3). As expected, such absorption was not present in unmodified wood (marked C, on Fig. 1). Also, the substitution of hydroxyl groups can be seen by FTIR spectroscopy. The accompanying decrease in the intensity of the broad band at 3413 cm^{-1} was also noticed, indicating that the hydroxyl group's content was decreased. The changes in the characteristic absorption bands in the infrared spectrum of treated wood verified that hydrophobic acetyl groups replace the hydrophilic hydroxyl groups of wood after acetylation.

Table 2 Reaction conditions and number of substituted hydroxyl groups in different acetylation levels
Tablica 2. Uvjeti reakcije i broj supstituiranih hidroksilnih skupina pri različitim stupnjevima acetilacije

Time *Vrijeme* min	Temperature *Temperatura* °C	Weight gain *Porast težine* %	OH groups substitution *Supstituirane OH skupine* mmol/g
0	0	0	0
40	120	9	2.09
180	120	16	3.70

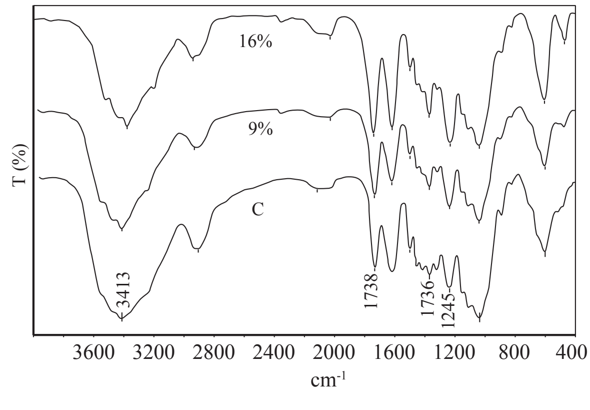

Figure 1 FTIR spectra of maple wood treated with acetic anhydride at different intensities
Slika 1. FTIR spektar javorova drva s anhidridom octene kiseline u različitom intenzitetu

3.2 Physical properties
3.2. Fizikalna svojstva

In the 2-h water-soaking test, acetylated boards had very low average water absorption (WA) and thickness swelling (TS) values compared to control boards (Fig.2&3). The WA and TS of the boards decreased with the increase of acetylation level. The average of WA and TS value in acetylated boards at 16 % WPG and 4min press were 66 % and 63 % less, respectively, than that obtained for unmodified boards. Increasing press time from 4 min to 6 min reduced WA and TS in most cases, with a few exceptions in untreated boards. Similarly, in a 24-h water soaking test, WA and TS values were decreased significantly by acetylation. After 24-h soaking in water, WA of modified boards at 9 % and 16 % WPG, and 6min compared to 4min press time, was reduced by 19.8 % and 29.8 %, respectively. Also, for the same soaking period, reduction trend of thickness swelling in modified boards with different press times was observed.

Due to reducing the number of hydroxyl groups and the occupation of intermolecular space in the wood cell wall, so called “bulking effect”, acetylation decreases the hygroscopicity of wood cell wall and consequently increases the dimensional stability of the

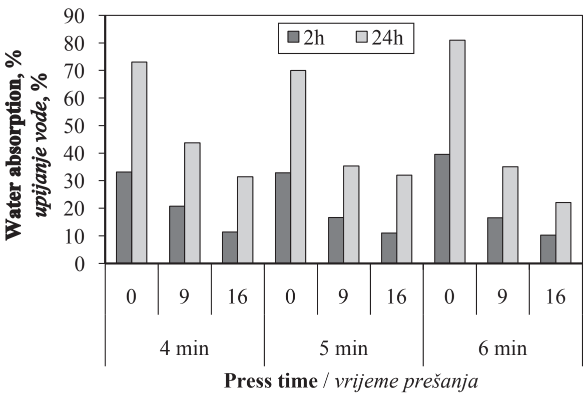

Figure 2 Effect of press time on water absorption of acetylated particleboards (WPG: 0 %, 9 % and 16 %)
Slika 2. Utjecaj trajanja prešanja na upijanje vode acetiliranih ploča iverica (WPG: 0 %, 9 % i 16 %)

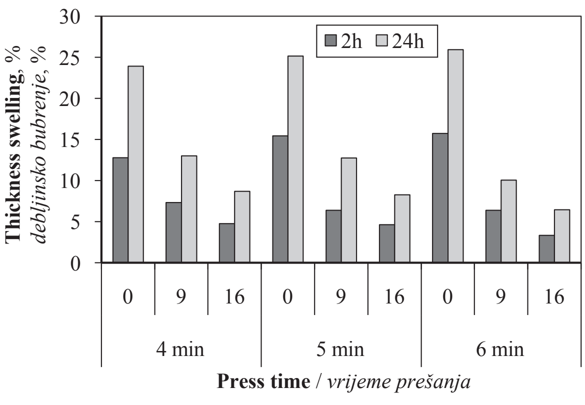

Figure 3 Effect of press time on thickness swelling of acetylated particle boards (WPG: 0 %, 9 % and 16 %)
Slika 3. Utjecaj trajanja prešanja na debljinsko bubrenje acetiliranih ploča iverica (WPG: 0 %, 9 % i 16 %)

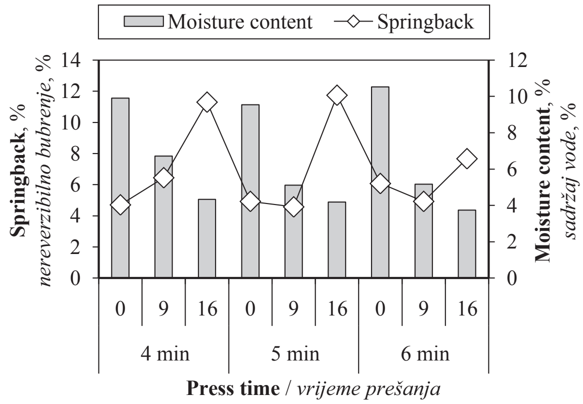

Figure 4 Effect of press time on springback and moisture content of acetylated particleboards (WPG: 0 %, 9 % and 16 %)
Slika 4. Utjecaj trajanja prešanja na nereverzibilno bubrenje i sadržaj vode acetiliranih ploča iverica (WPG: 0 %, 9 % i 16 %)

particleboards (Sander *et al*., 2003; Rowell, 2005; Hill, 2006). Results showed that acetylated boards had very low water absorption and thickness swelling values in water compared to control boards. Increasing press time intensified reduction in water absorption and thickness swelling in most cases, with a few exceptions in untreated boards. These findings also confirm the results presented by other authors (Yang *et al*., 2014; Rowell *et al*., 2009, Rowell, 2006).

A change in moisture content and springback of modified boards compared with untreated samples could be observed after conditioning (Fig. 4).The MC in the modified boards was reduced as the WPG increased. It was also revealed that the acetylation affected springback of the boards and caused significant increase as the WPG increased in the boards. Increase of the press time in the acetylated boards caused significant reduction in MC and springback.

Springback is an irreversible thickness swelling, which occurs after wetting of the composites or releasing of stresses accompanied by some loss of glue bonds (Mohebby*et al*., 2009). According to the results, the MC in the modified boards, inverse springback, was reduced as the WPG increased. Therefore, the springback of the boards was affected by the acetylation because of the interfering bonding between aqueous-based resin and the modified wood element due to low wettability, weaker bonding because of incomplete curing of resin in the core layer and lower compression in stiffer and denser mat (Vick and Rowell, 1990; Vick and Krzysik, 1991). It was reported that the majority of the failures in the acetylated wood composites was shown between resin and wood due to their hydrophobic nature; however, the failure in the control group of specimens occurred in the wood (Papadopoulos and Hill, 2002). Increase of the press time in the acetylated boards caused significant reduction in springback after conditioning.

3.3 Mechanical strength
3.3. Mehanička čvrstoća

The bending and bonding strength of chemically modified particleboards in different press times are

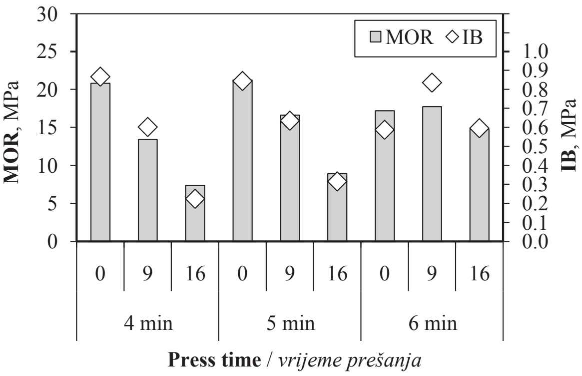

Figure 5 Effect of press time on mechanical strength of acetylated particleboards (WPG: 0%, 9% & 16%)
Slika 5. Utjecaj trajanja prešanja na mehaničku čvrstoću acetiliranih ploča iverica (WPG: 0 %, 9 % i 16 %)

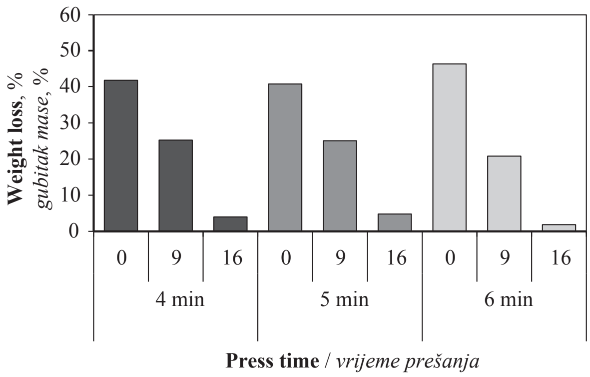

Figure 6 Effect of press time on weight loss of acetylated particleboards (WPG: 0 %, 9 % and 16 %)
Slika 6. Utjecaj trajanja prešanja na gubitak mase acetiliranih ploča iverica (WPG: 0 %, 9 % i 16 %)

summarized in Table 2. Unfortunately, at the 4 minutes press time, the mechanical stability of modified boards was lower than that of the control particleboard (Fig. 5). The bending and bonding strength decreased as the acetylation levels increased. Even a low degree of acetylation results in a high decrease of the mechanical strength of the board. By increasing press time to 6 minutes, IB raised 27.9 % and 62.4 % at 9 and 16 % WPG, respectively. In this condition, the MOR was improved by 24.3 % and 49.8 %.

The bending and bonding strength of the board decreased as the acetylation levels, which were somewhat compensated with prolongation of the press time, increased. Decrease in mechanical strength is caused by the substantial loss of wood due to the application of heat and generation of the acetic acid (Hill, 2006), decreased surface wetting, unsuitable dispersion of resin, and low bondability between the polar resins and the apolar acetylated wood flakes (Korai, 2001; Wagner *et al*., 2007; Abdolzadeh *et al*., 2011). Also, stiffer and denser acetylated particles need more moisture and pressure during hot pressing.

3.4 Decay resistance
3.4. Otpornost na propadanje

The biological behavior of acetylated particleboards with different press times against white rot fungi is presented in Fig. 6. It can be observed that the highest loss of weight was recorded on the untreated boards (46.29 %) at 6 minutes press time. The data from decay test indicates a positive relationship between the extent of modification and decay resistance (Fig. 6). Particleboards, modified with acetic anhydride at the highest modification level, showed the most significant improvement in decay resistance (1.90 % weight loss). Increasing press time reduced weight loss of acetylated samples by 17.5 and 53 % at 9 % and 16 % WPG, respectively.

Many researchers report that acetylation causes a good bioresistance of particleboards (Ghorbani*et al*., 2010). The mechanism of biological resistance of acetylated wood is not completely understood. However, the resistance is believed to be due to several established theories of mode of action in modified wood: inhibition of diffusion of fungal enzyme molecules because of the decreasing moisture amount in wood (Boonstra and Tjeerdsma, 2006) and micro pore blocking (Hill *et al*., 2005); and decay enzyme inefficiency due to unrecognizable substrate as a food source (Rowell, 2005).

Although acetylation is effective in achieving high hydrophobicity, dimensional stability, and decay resistance, springback and mechanical strength loss due to low bondability should be improved to maintain high performance of this method. According to the previous research (Bavaneghi and Ghorbani, 2015), acetylation decreases the heat transfer to the core layer. Therefore, delay in the heat transfer increased the springback and loss of mechanical properties because of incomplete resin curing. During the hot-pressing, the generated steam from both free and bound water in wood particles and the water in the resin are driven to the mat core (Vick and Rowell, 1990), and the thermosetting adhesives are polymerized throughout the panel.

Acetylation affects the conduction and convection, as the most important mechanisms for heat transfer in the hot press (Rowell, 2005), through the reduction in the hydrophilicity of the lignocellulosic material (Li *et al*., 2007), bound water in cell walls and free water in lower porosity. All of these reasons directly affect the temperature of the core layer. By increasing the press time, the resin in the core layer could be cured with the rising of the final temperature of the core layer. The increase of hot press time of the particleboard production improved resin curing and bonding and reduced springback. Stronger bonding between modified flakes caused more improvement in water resistance, thickness swelling and decay resistance due to decreased porosity.

Regarding the outdoor use with biological degradation, an increase in the press time for improving these properties might be recommended. For future research, focus should be placed on the effect of utilization of hydrophobic resin like isocyanate, more attention should be paid to the higher pressure in hot press and the mat moisture for producing particleboards with higher mechanical strength should be increased.

4 CONCLUSION
4. ZAKLJUČAK

Esterification of maple particles was established by the increase in weight and infra-red spectroscopy. According to the results, press time had significant effect on the physical, mechanical and biological properties of acetylated particleboards. The following can be concluded:

1. Water absorption and thickness swelling values were significantly reduced by acetylation. Prolongation of press time improved water resistance and thickness swelling due to stronger bonding between modified flakes and less porosity.

2. Treatment of acetylation on flakes resulted in a remarkable loss in MOR and IB values and an increasing springback. The higher press time of the particleboard manufacturing process improved mechanical properties and thickness stability because of achieving the required temperature for resin curing in core layer and reinforce bonding.

3. The decay test indicates a positive relationship between the extent of modification and decay resistance. Increasing press time reduced weight loss of acetylated boards by improving resin curing, and stronger bonding between modified flakes resulted in decreased porosity.

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Effect of Climatic Conditions on Tree-Ring Widths in Black Locust (*Robinia pseudoacacia* L.) in the city of Wrocław

Utjecaj klimatskih uvjeta na širinu godova bagrema (*Robinia pseudoacacia* L.) u gradu Wroclawu

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ABSTRACT • *The response of trees to weather conditions, expressed in the tree-ring widths, depends on the extent of urbanization in the area. Specific climatic conditions in an urban heat island can be expected to result in growth differences to trees growing in non-urban areas. Accordingly, the aim of this study was to characterize the effect of climatic conditions on tree-ring widths of black locust in the city of Wrocław. Materials consisted of wooden discs taken from felled trees at four sampling sites (4 streets of Wrocław) at a height of 1.3 m from the ground. Meteorological data were obtained for the period 1971-2013 from the Institute of Meteorology and Water Management (IMGW) in Wrocław. Analysis of the multiannual period showed a significant negative trend in annual ring widths of black locust in the city of Wrocław. A code WROB was assigned to the chronology. The annual ring widths averaged 3.4 mm, ranging from 1.6 to 5.6 mm. In the urban conditions of Wrocław, the air temperature and precipitation significantly influenced the annual ring widths of black locust. The results indicate the need for further research on a larger number of samples.*

Key words: *dendroclimatology, local chronology, regression analysis, south-western Poland, urban area*

SAŽETAK • *Odgovor stabala na vremenske uvjete, izražen širinom godova, ovisi o stupnju urbanizacije prostora u kojem drveće raste. Može se očekivati da će posebni klimatski uvjeti u urbanome toplom otoku rezultirati različitim rastom stabala u odnosu prema stablima u neurbaniziranim područjima. Prema tome, cilj ovog rada bio je istražiti utjecaj klimatskih uvjeta na širinu godova stabala bagrema u gradu Wroclawu. Istraživanje je provedeno na drvnim diskovima izrađenima od stabala posječenih na četiri mjesta uzorkovanja (u četiri ulice Wroclawa) na visini 1,3 m od tla. Meteorološki podaci za razdoblje 1971. - 2013. dobiveni su od Instituta za meteorologiju i vodno gospodarstvo (IMGW) u Wroclawu. Analiza višegodišnjeg razdoblja pokazala je značajan negativni trend godišnjih širina godova bagrema u gradu Wroclawu. Kronologiji je dodijeljena šifra WROB. Prosječna godišnja širina goda iznosi 3,4 mm, a širine godova kreću se od 1,6 do 5,6 mm. U urbanim uvjetima Wroclawa temperatura*

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zraka i količina oborina znatno su utjecale na godišnju širinu godova drva bagrema. Rezultati upućuju na potrebu nastavka istraživanja na većem broju uzoraka.

Ključne riječi: *dendroklimatologija, lokalna kronologija, regresijska analiza, jugozapadna Poljska, gradsko područje*

1 INTRODUCTION
1. UVOD

Black locust (*Robinia pseudoacacia* L.) was one of the first North American forest species introduced in Europe (Boring and Swank, 1984). Its natural range includes the eastern and central parts of the United States: the Appalachian Mountains, the Ozark Plateau and Ouachita Mountains (Feldhake, 2001; Call, 2002; Zajączkowski and Wojda, 2012). In the area of modern Poland, black locust was first planted in the 19th century. Since then, it has spread in Poland, not only through artificial plantings but also via self-seeding (Ślusarczyk, 2012). Currently, it can be found almost everywhere in the country, with the highest concentrations in the western part, in both deciduous and coniferous forests (Wojda *et al.*, 2014). Outside forest ecosystems, black locust can also be found in buffer strips, roadsides, shelter belts and city alleys (Łukaszewicz, 2010). It is especially appreciated in the reconstruction of historical parks and gardens (Majdecki, 1993). In the light of recent research, black locust can also be recommended as an energy crop in harsh habitat conditions, where it can be competitive with other energy crops (Rédei *et al.*, 2010; Böhmi *et al.*, 2011; Kraszkiewicz, 2013; Stolarski *et al.*, 2013).

The response of trees to weather, especially the air temperature and precipitation, expressed in tree-ring widths and the course of phenological phases, changes under the influence of human impact in the area (Walkovszky, 1998; Gillner *et al.*, 2014). Trees from urban heat islands are expected to show differences in this respect compared to trees growing in non-urban areas. However, the dendroclimatological analysis of trees from urban areas has been poorly researched so far (Cedro and Nowak, 2006; Meier and Scherer, 2012). Namely, most commonly studied are trees growing within their natural ranges in the open landscape, and far less often trees that can be found outside the natural range (Tsakov and Alexandrov, 2005; Feldhake, 2001; Zhang *et al.*, 2013; Čufar *et al.*, 2014).

Therefore, the aim of this study was to characterize the time course of the tree ring widths of black locust in the urban environment of the city of Wrocław and assess its relations with the air temperature and precipitation.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

Samples were made from 16 black locust trees located in four streets in Wrocław: Sucha (WS), Długa (WD), Witelona (WW) and Krucza (WK) (Figure 1). Individual sequences of ring widths are given in parentheses. Each tree was assigned a symbol and a number (1 to 16); for example WK15 and WK16 denoted trees felled in Witelota Street (Figure 2). Habitat conditions were similar in all sampling sites, with a predominance of surface covered by concrete and tarmac, etc., and low share of soils with open access to rainwater and sunlight. Discs were taken from trees at a height of 1.3 m above the ground. After drying and polishing the discs, the widths of tree-rings were measured in millimetres. The planned felling of the trees in 2014 provided the opportunity to obtain the disc samples, based on administrative decisions issued by the authorized body of the City of Wrocław. Direct sampling was performed by the arborysta.com company.

Meteorological data for the period 1971-2013, i.e. the average air temperature (Ta - analyzed year, PTa - previous year, °C) and total precipitation (Rf - analyzed year, PRf – previous year, mm) were obtained

Figure 1 Location of the research area (WS, WD, WW, WK) in Wroclaw (south-western Poland). WS – Sucha street, WD – Długa street, WW – Witelona street, WK – Krucza street
Slika 1. Lokacija područja istraživanja (WS, WD, WW, WK) u Wroclawu (sjeverozapadna Poljska); WS – ulica Sucha, WD – ulica Długa, WW – ulica Witelona, WK – ulica Krucza

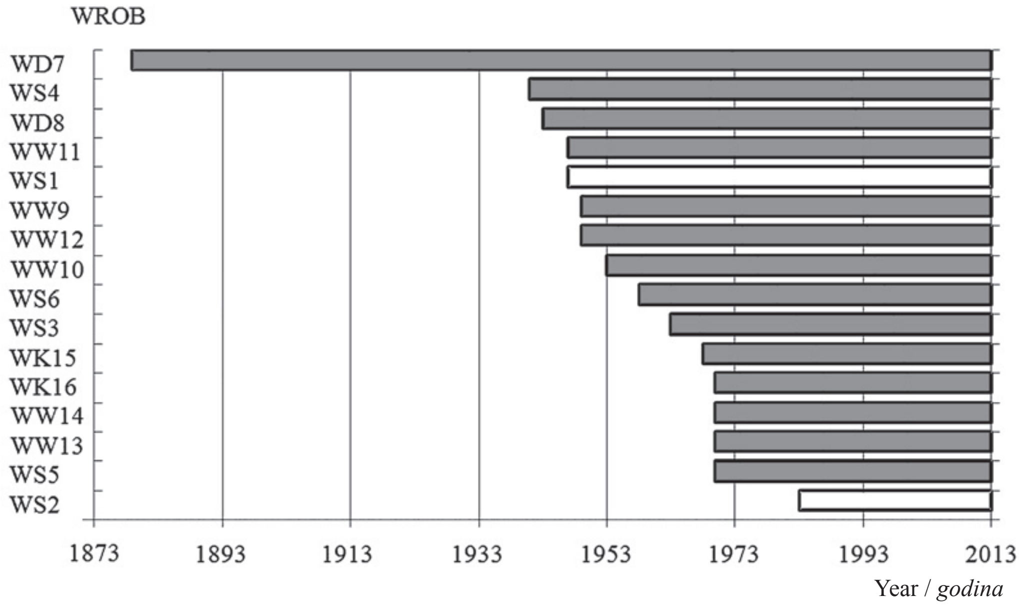

Figure 2 Dendrochronological dating of sequence included in the local chronology of black locust WROB. WS1, WS2 – sequences excluded from statistical analysis
Slika 2. Dendrokronološki slijed sekvenci uključenih u lokalnu kronologiju bagrema WROB; WS1, WS2 - sekvence isključene iz statističke analize

from the Institute of Meteorology and Water Management (IMGW) in Wrocław.

The individual sequences of tree-ring widths in black locust were used to assess similarities in the chronology of the analyzed trees (Figure 2). The most outlying sequences, WS1 and WS2, were excluded from further analysis due to a weak relationship with the pattern observed for the entire group of 16 trees. Local chronology was then established based on a correlation analysis and Student's *t* test performed on the remaining group of 14 trees. The sequences of ring widths were used to determine the local chronology. The individual sequences of 14 trees, as well as a local chronology of black locust WROB, are presented using the following statistical indicators: mean values ($\bar{x}$), standard deviation (Sd) and minimum (Min) and maximum (Max) values. Additionally, for annual ring widths, their prevalence was determined in one millimetre intervals, while for the local chronology the following parameters were determined: skewness, kurtosis, first-order autocorrelation (r_a), correlation coefficient (r) for linear trend, deviations from the long-term average in the period 1971-2013 (ΔWROB), and differences between successive years of WROB tree ring widths in the local chronology (ΔyWROB).

To evaluate the effect of the air temperature and precipitation on the annual ring width of black locust, master chronology was used, i.e. the arithmetic average of the 14 ring width sequences of the analyzed tree species. First, the chronology was transformed into an indexed chronology by removing the linear trend and long-term fluctuations, according to the formula proposed by Fritts (1976), and also after removing the first order autocorrelation in the residual chronology (Koprowski, 2006; Speer, 2010; Bijak *et al.*, 2012).

The evaluation of the accuracy of the relationship between annual ring widths and air temperature and precipitation in the period 1971-2013 was determined using a Pearson's correlation coefficient (Dobosz, 2001). Assessment of the combined influence of meteorological conditions was performed using the multiple stepwise regression equation. Multiple regression parameters were determined by the method of least squares. Fit of the regression to the empirical data was measured by the coefficient of determination R^2 (%) with the error of the regression equation *S*y (mm). A variable partial correlation analysis was used to determine the contribution of each of the selected factors to the prediction of the explanatory variable. The calculated partial correlation coefficients were squared and expressed in % (as r^2). In the correlation and regression analyses, the dependent variable was annual tree ring widths in the form of residual chronology, while the independent variable was meteorological elements from the months of the current year (from January to September) and the previous year (June to December). Similar periods were taken into account in dendroclimatic studies by Fritts (1976), Cedro and Nowak (2006) and Koprowski (2012). Statistical analyses were performed using STATISTICA 10. The scientific name of the analyzed tree species was taken from "Dendrology" by Seneta and Dolatowski (2009).

3 RESULTS
3. REZULTATI

The local chronology of black locust with the signature WROB for four sampling sites (WS, WD, WW, WK) located in the main streets in Wrocław was 134 years in length and represented the period 1880-2013 (Figure 2, Figure 3). The longest dendrogram (WD7) equalled the local chronology, while the shortest ones (WS5, WW13, WW14 and WK16) were 43 years in length (1971-2013).

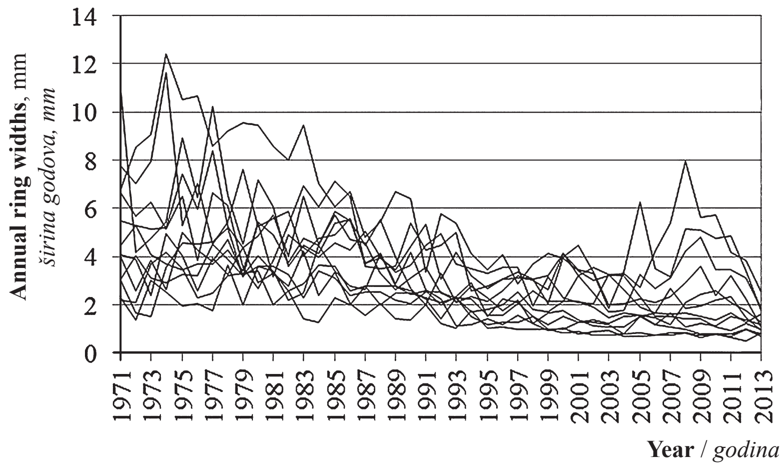

Figure 3 Dendrochronological curves included in the local chronology of black locust WROB. Years 1971-2013
Slika 3. Dendrokronološke krivulje uključene u lokalnu kronologiju bagrema WROB; razdoblje 1971. - 2013.

In the period 1971-2013, the tree-ring widths were widest in the tree WS3 (6.0 mm) followed by the trees WS5 and WK16 (4.4 and 4.2 mm, respectively) (Figure 4). The variability of annual ring widths, expressed as standard deviation, ranged from 0.7 mm (WS7) to 2.6 mm (WS3). Both the maximum and minimum annual ring widths in individual trees included in the local chronology varied significantly. Maximum annual ring widths ranged from 3.7 mm (WS6) to 12.4 mm (WS3), whereas minimum ring widths ranged from 0.5 mm (WD8) to 2.6 mm (WS3).

Diagrams showing the incidence of tree-rings in the adopted ranges revealed that over 77 % of all growth rings obtained in the years 1971 to 2013 ranged from 1 to 5 mm (Figure 5). Lower (<1 mm) and higher ranges (from 5 to 6 mm) showed a significantly lower incidence (about 5 % and 8 %, respectively). Growth rings wider than 6 mm occurred in 9 % of cases, while those >10 mm occurred in only 1 % of cases. The lower quartile for each dendrochronological curve ranged from 0.9 mm (WD8, WW9) to 3.9 mm (WS3), and the upper quartile from 2.5 mm (WD7) to 8.4 mm (WS3). The interquartile range varied from 1.0 (WS6) to 4.5 mm (WS3) and showed a moderate variability of annual growth rings among the individual sequences.

The average tree-ring width of black locust WROB for the period 1971-2013 was 3.4 mm, with a standard deviation of 1.2 mm (Table 1). The narrowest absolute

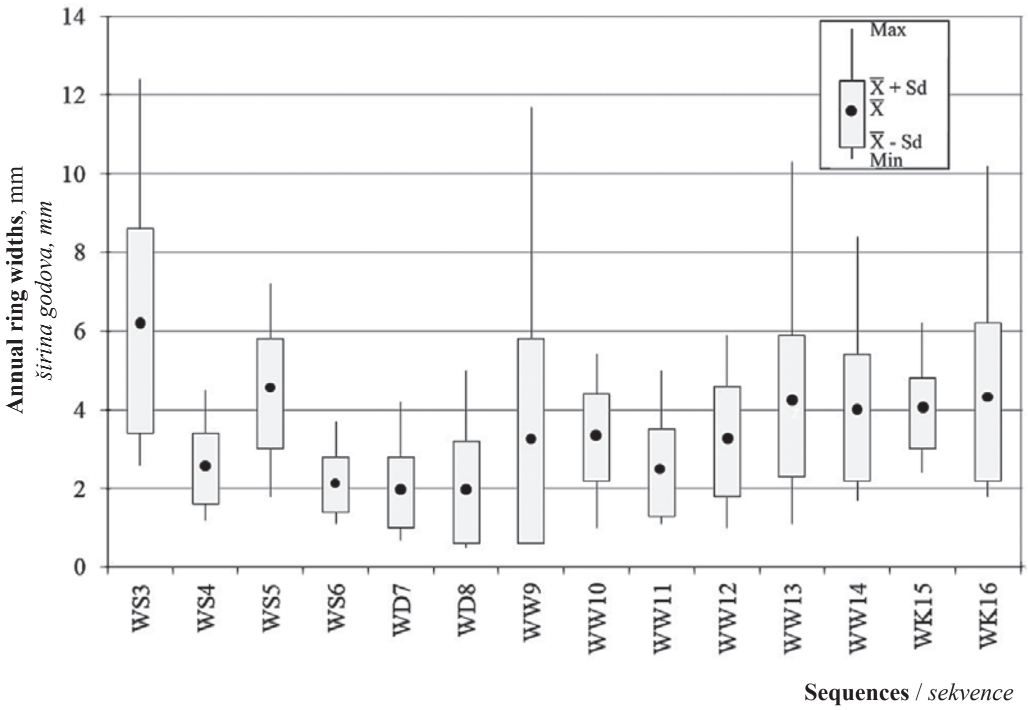

Figure 4 Statistical characteristics: $\bar{x}$, *Sd*, *Max*, *Min* of annual ring width sequences included in the local chronology of black locust WROB. Years 1971-2013
Slika 4. Statistička obilježja $\bar{x}$, *Sd*, *Max*, *Min* sekvenci godišnjih širina godova uključenih u lokalnu kronologiju bagrema WROB; razdoblje 1971. - 2013.

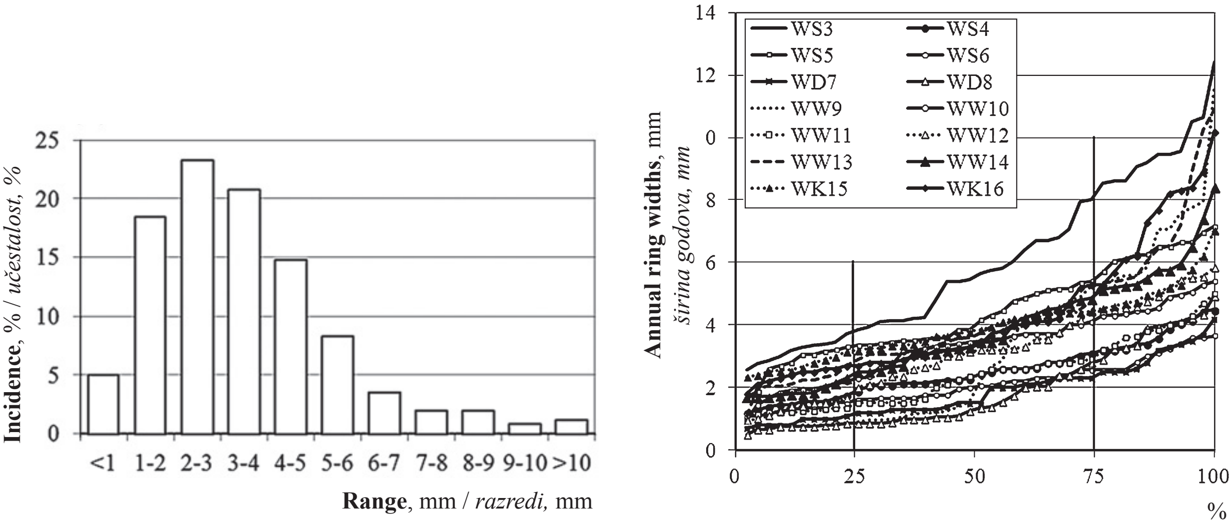

Figure 5 The incidence of tree ring width sequences included in the local chronology of black locust WROB. Years 1971-2013. Left side: distribution by ranges, right side: cumulative distribution
Slika 5. Učestalost sekvenci širine godova stabala uključenih u lokalnu kronologiju bagrema WROB; razdoblje 1971. - 2013.; lijeva strana – raspodjela prema razredu širine goda, desna strana – kumulativna distribucija

ring width (1.6 mm) was recorded in 2013. The widest absolute ring width (5.6 mm) was observed in 1974. In the analyzed period, the ring widths of black locust in Wrocław showed a significant, positive autocorrelation of the first order (r_a = 0.89, $P \geq 0.01$) and a significant negative linear trend (r = -0.93, $P \geq 0.01$). It was also found that the right side of the distribution of the local chronology WROB was more extended than the left side (Sk = 0.42), and that the distribution curve was flatter than in the normal distribution (K = -1.31).

In the first 18 analyzed years (i.e. period 1971-1988), the deviation from the average ring width in local chronology WROB was positive and ranged from 0.1 mm in 1987 to 2.2 mm in 1974 (Figure 6). A nega-

Table 1 Statistical characteristics designated for the local chronology of black locust WROB. Years 1971-2013
Tablica 1. Statistička obilježja određena za lokalnu kronologiju bagrema WROB; razdoblje 1971. - 2013.

WROB chronology *Kronologija WROB*	**Characteristics** / *Obilježja*						
	$\bar{x}$±*Sd* mm	Min/Year *Min/god.* mm	Max/Year *Maks./god.* mm	*Sk*	*K*	autocorrelation of the first order *autokorelacija prvog reda*	*r* for linear trend *r za linearni trend*
	3.4±1.204	1.6/2013	5.6/1974	0.42	-1.31	0.89***	-0.93***

*** significant at $P \geq 0.01$ / signifikantno pri $P \geq 0.01$, $\bar{x}$ – average / *srednja vrijednost* (mm), *Sd* – standard deviation / *standardna devijacija* (mm), *Min* – minimum value / *minimalna vrijednost* (mm), *Max* – maximum value / *maksimalna vrijednost* (mm), *Sk* – skewness / *asimetrija*, *K* – curtosis / *oštrina vrha krivulje frekvencijske distribucije*

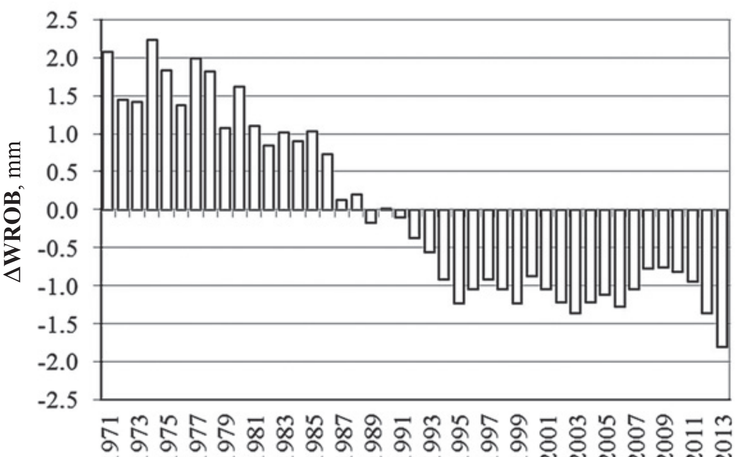

Figure 6 Deviations from the long-term average (1971-2013) of the annual ring widths (ΔWROB) in the local chronology of black locust WROB. Years 1971-2013
Slika 6. Odstupanja od dugoročnog prosjeka (1971. - 2013.) godišnjih širina godova (ΔWROB) u lokalnoj kronologiji bagrema WROB; razdoblje 1971. - 2013.

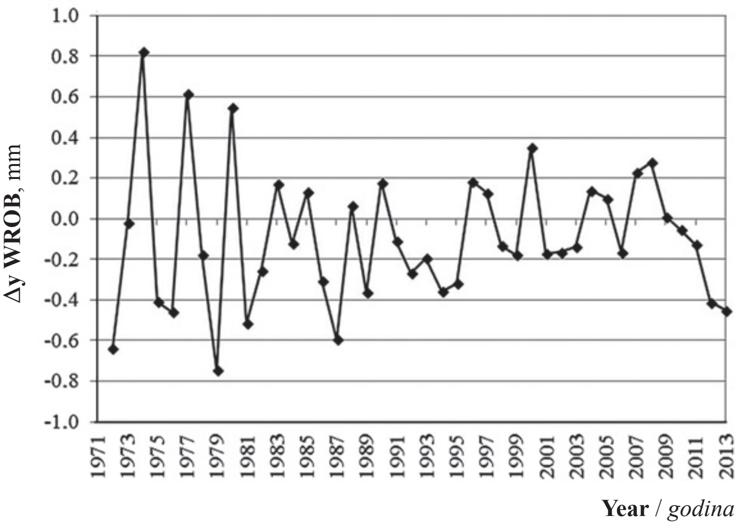

Figure 7 Differences between successive years in ring widths (Δ*y*) in the local chronology of black locust WROB. Years 1971-2013
Slika 7. Razlike u širini godova između uzastopnih godina (Δ*y*) u lokalnoj kronologiji bagrema WROB; razdoblje 1971. - 2013.

tive deviation was observed in the period 1989-2013 (with the exception of 1990, in which the deviation was 0 mm); the highest deviation was observed in 2013 (-1.8 mm). Differences were also found between adjacent years ranging from -0.7 mm between 1979 and 1978 to 0.8 mm between 1974 and 1973 (Figure 7). The differences, both positive and negative, were distinctly higher in the first half of the analyzed period. In 14 years, growth ring widths were wider than in the previous year, and in only two years they were identical to the previous years.

Annual ring widths of black locust in Wrocław WROB depended on the air temperature and precipitation (Figure 8). The annual ring widths in urban conditions correlated negatively with the air temperature in May-September of the analyzed year, and in December and August of the previous year, while they correlated positively with the air temperature in January-April of the analyzed year and in the period June-July and September-November of the previous year. Among the analyzed 16 months, only three months of the analyzed year demonstrated a significant effect of thermal conditions on tree-ring widths: positive in February (*Ta2*, $r = 0.29$, $P \geq 0.05$) and March (*Ta3*, $r = 0.28$, $P \geq 0.05$), negative in July (*Ta7*, $r = -0.34$, $P \geq 0.01$).

In the years 1971-2013, precipitation positively influenced ring widths in February-March and May-August of the analyzed year and in the period June and September-November of the previous year, while negatively in January, April and September of the analyzed year and in the period July-August and in December of the previous year. A significant relationship was found in September (*Rf9*, $r = -0.35$, $P \geq 0.01$) of the analyzed year

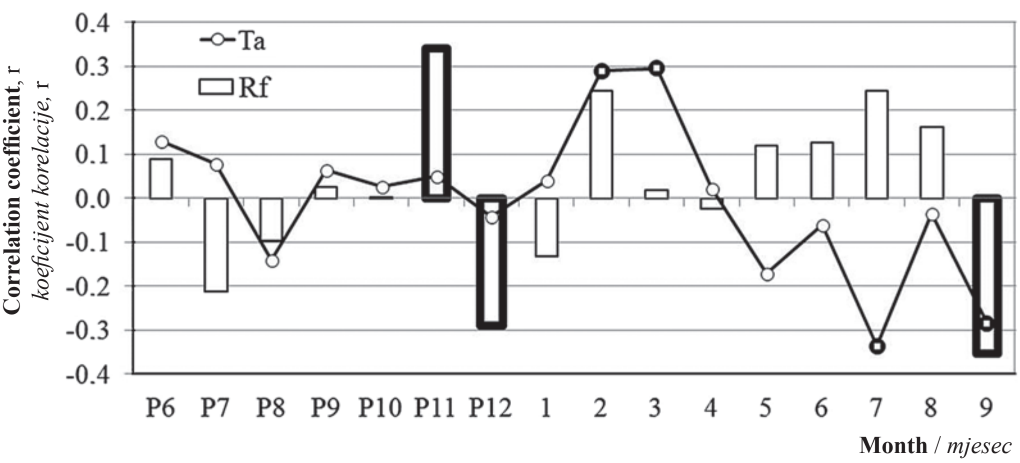

Figure 8 Relationship between residual ring widths in the local chronology of black locust WROB and the air temperature (*Ta*, °C) and total precipitation (*Rf*, mm). Years 1971-2013. Bold line indicates a significant correlation at least at $P \geq 0.05$; *P6*, *P7*… *P12* – month of the previous year, 1, 2… 9 – month of current year
Slika 8. Odnos između preostale širine godova u lokalnoj kronologiji bagrema WROB i temperature zraka (*Ta*, °C) te ukupnih oborina (*Rf*, mm); razdoblje 1971. - 2013.; zadebljane linije označavaju signifikantnu korelaciju barem na $P \geq 0,05$; *P6*, *P7* ... *P12* – mjesec prethodne godine; 1, 2 ... 9 – mjesec tekuće godine

Table 2 Evaluation of the combined effect of air temperature and precipitation on residual annual ring widths in the local chronology of black locust WROB based on multiple stepwise regression equation. Years 1971-2013
Tablica 2. Procjena kombiniranog utjecaja temperature zraka i oborina na preostale godišnje širine godova u lokalnoj kronologiji bagrema WROB na temelju stupnjevite regresijske jednadžbe; razdoblje 1971. - 2013.

Variable *Varijabla*	**Indicators describing independent variables of the equation** *Indikatori koji opisuju neovisne varijable jednadžbe*			**Indicators describing the equation** *Indikatori koji opisuju jednadžbu*			
	*r*² %	*t*	*P*	*F*	*R*² %	*Sd-Sy* mm	*Sy* mm
PRf11	11.6	2.2	0.05	5.4	29.9	0.012	0.082
PRf12	12.2	-2.3	0.05				
Rf9	14.9	-2.6	0.01				
Ta2			n.s.				
Ta3			n.s.				
Ta7			n.s.				

PRf11/PRf12 – precipitation in November/December of the previous year / *oborine u studenome/prosincu prethodne godine* (mm); *Rf9* – precipitation in September of the current year / *oborine u rujnu tekuće godine* (mm); *Ta2/Ta3/Ta7* –air temperature in February/March/July of the current year / *temperatura zraka u veljači/ožujku/srpnju tekuće godine* (°C); r^2 – square of partial correlation coefficient of x, y variables / *kvadrat djelomičnog koeficijenta korelacije x, y varijable* (%); t – Student's *t*-test / *Studentov t-test*; *P* – level of significance/ *razina značajnosti;* n.s. – non-significant at $P \geq 0.1$ / *nesignifikanto pri razini* $P \geq 0.1$; *F* – Snedocor's *F*-test / *Snedecorov F-test*; R^2 – determination coefficient / *koeficijent determinacije* (%); *Sd-Sy* – difference between a standard deviation of a dependent variable and a standard error of equation estimation / *razlika između standardne devijacije zavisne varijable i standardne pogreške procjene jednadžbe* (mm), *Sy* – standard error of equation estimation / *standardna pogreška procjene jednadžbe* (mm)

and in November (*PRf11*, $r = 0.34$, $P \geq 0.01$) and December (*PRf12*, $r = -0.29$, $P \geq 0.05$) of the previous year.

Multiple regression analysis, showing the combined effect of weather conditions (precipitation and air temperature) on ring widths, indicated that the biggest impact was exerted by precipitation in three months: *PRf11*, *PRf12* and *Rf9*, while thermal conditions proved to be insignificant (Table 2). Precipitation, significant at $p \geq 0.05$, determined the annual ring widths in black locust by about 30 %; the greatest impact was shown by *Rf9* ($r^2 = 14.9$ %, $P \geq 0.05$).

Precipitation in months that significantly contributed to a reduction in annual ring widths, averaged approximately 35 mm in *PRf12* and about 50 mm in *Rf9* (Table 3). The highest precipitation in *PRf12* and *Rf9* amounted to 100 mm in 1975 and 110 mm in 2013, with the lowest (4 mm) in 1973 and 7 mm in 1975. The precipitation in *PRf11* was characterized by a significantly lower variability (by about 10-20 %) than *PRf12* and *Rf9*, and a significant negative trend in the years 1971-2013 ($r = 0.35$, $P \geq 0.05$). The extreme levels of *PRf11* were the lowest among the three analyzed months (Max = 98 mm, Min = 2 mm).

4 DISCUSSION
4. RASPRAVA

There are few papers on the variability of annual ring widths of trees in the technosphere and its dependence on meteorological conditions. This is mainly due to the difficulty in obtaining permission from the local authorities for sampling with the use of a Pressler drill, and also due to the difficulty in collecting the appropriate sample size from a given type of sampling site (with similar conditions of growth and development for a given tree species). Trees in urban areas, including black locust, are exposed to many adverse environmental factors influencing the course of their vegetation, as reflected, for example, in tree-ring width. The most important include the deteriorated quality and quantity of soil, pollution of the ground with debris, calcium, chlorine and sodium ions, as well as altered meteorological parameters (Szczepanowska, 2001; Łukasiewicz, 2010; Rahmana *et al.*, 2014).

Most publications in the field of biology and dendroclimatology deal with trees in forests outside urbanized areas. Although research on black locust has been

Table 3 Statistical characteristics designated for precipitation (PRf, Rf, mm) significantly influencing (in the entire system of meteorological elements) the annual ring widths in the local chronology of black locust WROB. Years 1971-2013
Tablica 3. Statistička obilježja određena za oborine (PRF, RF, mm) koje znatno utječu (u cijelom sustavu meteoroloških elemenata) na širinu goda u lokalnoj kronologiji bagrema WROB; razdoblje 1971.-2013.

Variable *Varijabla*	**Characteristics** / *Obilježja*					
	x̄±Sd	Min/Year *min./god.*	Max/Year *maks./god.*	Range *raspon*	*V* %	*r* for linear trend *r za linearni trend*
	mm					
PRf11	38.8±18.4	2.0/2012	98.0/1971	96.0	47.5	-0.35**
PRf12	34.5±20.4	4.0/1973	100.0/1975	96.0	59.4	n.i.
Rf9	49.6±29.9	7.0/1982	110.0/2013	103.0	60.2	n.i.

V – coefficient of variability / *koeficijent varijabilnosti* (%), ** significant at $P \geq 0.05$ / *signifikantno pri* $P \geq 0,05$; for further explanations see Table 1/ *druga objašnjenja pogledati u tablici 1.*

carried out for example by Boring and Swank (1984), Farrar and Evert (1997), Feldhake (2001), Zhang *et al.* (2013), and Wang *et al.* (2013), a completely different climate and locations in those studies do not allow for comparison of their results with our paper. In the period 1971-2013, the average annual ring width of black locust in the sampling sites in Wrocław was 3.4 mm, ranging from 1.6 to 5.6 mm. Similar values, obtained in a forest in SE Poland (Forest District Krosno), were recorded by Feliksik *et al.* (2007), where the average annual ring width was 3.3 mm and ranged from 1.2 to 5.9 mm. It should be emphasized that comparisons concerning average tree-ring widths are especially prone to error. The average ring width at individual sampling sites does not take into account the differences arising from the age of the trees and the habitat conditions (Cailleret and Davi, 2011). The dendroclimatological analysis of the relationship between weather conditions and annual ring width in 1971-2013 indicates a significant influence of the air temperature and precipitation on the ring width of black locust. The air temperature, lower than the average in January-April (especially in February and March) and higher than the average in May-September (especially in July and September), adversely affected the tree-ring widths. A similar negative effect was induced by a wet September and December and a dry November. Similarly, Feliksik *et al.* (2007) found that cold winters and low air temperature in early spring, as well as low amount of precipitation during the summer (June-July), were the most important meteorological elements inhibiting the radial growth of black locust. The air temperature from late winter to early spring affects the physiological processes involved in the initiation of cambial cell production and in differentiation of xylem cells in the tree (Begum *et al.*, 2013). Importantly, premature initiation of cambial activity increases the risk of damage to biomass growth because of a sudden drop in air temperature below the physiological tolerances of the tree. The climate in the natural range of the black locust is distinctly different in terms of air temperature and (especially) precipitation in comparison with the climate of south-western Poland (Boring and Swank 1984, Dubicki *et al*., 2002; Feliksik *et al*., 2007; Kalbarczyk, 2010). For example, the average air temperature in January in the eastern and central parts of the United States ranges from about -4.0 °C to +7.0 °C, and in August from 18.0 to 27.0 °C (Boring and Swank, 1984). Wrocław averages from -9.0 °C to 4.2 °C and from 15.9 °C to 21.5 °C, respectively (Dubicki *et al.*, 2002). The U.S. precipitation ranges between 1020-1830 mm and is on average about 250 % higher than in Poland.

5 CONCLUSION
5. ZAKLJUČAK

In the years 1971-2013, a significant negative trend of annual ring width of black locust was observed in Wroclaw WROB. The annual growth averaged 3.4 mm and ranged from 1.6 to 5.6 mm, most frequently ranging from 2 to 3 mm. Differences between successive years ranged from -0.7 mm between 1979 and 1978 to 0.8 mm between 1974 and 1973.

In this study, a significant influence of air temperature and precipitation on the annual ring width of black locust was demonstrated. Multiple regression analysis showed that the annual ring widths of the analyzed tree species were mainly affected by precipitation in November and December of the previous year and September of the analyzed year, with different temporal distributions in individual years.

The results indicate that further research should be made on a larger number of samples.

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CEFTA Agreement and Opportunities for Wood Furniture Export of the Republic of Macedonia

CEFTA sporazum i mogućnosti izvoza namještaja Republike Makedonije

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ABSTRACT • *This paper is focused on business possibilities of CEFTA 2006 and its influence on export trend of wood furniture from the Republic of Macedonia. First, six categories of wood furniture export are analyzed such as: office furniture, kitchen furniture, bedroom furniture, living and dining room furniture, shop furniture and other furniture, presenting a positive trend in each category, except for living and dining room furniture. The total export of wood furniture shows a positive trend. The second part presents comparative research using mathematical and statistical methods for determining wood furniture export trends, analyzing the export to different countries and the use of the CEFTA 2006 agreement. The results show a positive trend of export of wood furniture from Macedonia towards CEFTA countries. The main purpose of this research is to provide an overview of the use of the CEFTA 2006 agreement in the field of wood furniture export from the Republic of Macedonia, providing policy and business recommendations for the use of the CEFTA 2006 agreement. Taking into consideration the CEFTA 2006 agreement benefits, CEFTA member countries would become more competitive and prepared towards the European and global market.*

Key words: *CEFTA, wood furniture, export, cooperation, forecasting trends*

SAŽETAK • *Cilj je ovog rada istražiti poslovne mogućnosti udruženja CEFTA 2006 i njegov utjecaj na izvozne trendove namještaja Republike Makedonije. U prvom dijelu rada analizirane su izvozne vrijednosti šest kategorija namještaja, i to uredskog namještaja, kuhinjskog namještaja, namještaja za spavaće sobe, namještaja za blagovaonice i dnevne sobe, namještaja za trgovine te ostalog namještaja za koji je utvrđen pozitivan trend uvoza. Jednako tako, utvrđen je pozitivan trend vrijednosti ukupnog izvoza namještaja. U drugom dijelu rada, primjenom statističkih i matematičkih metoda, prikazane su analize izvoza namještaja Republike Makedonije i analizirana uporaba CEFTA 2006 sporazuma. Nadalje, rezultati su pokazali zadovoljavajući pozitivan trend makedonskog izvoza namještaja prema zemljama članicama CEFTA-e. Cilj ovog istraživanja bio je dati pregled primjene CEFTA 2006 sporazuma na području izvoza namještaja od drva Republike Makedonije, s naglaskom na primjenu CEFTA 2006 sporazuma. Sporazum CEFTA 2006 donosi zemljama članicama prednosti u obliku postizanja veće konkurentnosti i pripremljenosti za svjetska i europska tržišta.*

Ključne riječi: *CEFTA, namještaj od drva, izvoz, suradnja, predviđanje trendova*

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1 INTRODUCTION
1. UVOD

The integration and implementation of the Central European Free Trade Agreement (CEFTA) has been the main activity of foreign trade policy of the Republic of Macedonia in the last decade. The reason for this activity is the expectation that the membership of the Republic of Macedonia in CEFTA will significantly contribute to the continuous efforts for strengthening the regional trade cooperation and increase export as an important step to Euro Atlantic Integration. New CEFTA 2006 provides a much more comprehensive framework for development of mutual economic relations among the countries, especially in wood furniture export. Timber companies must continually strive to improve or at least maintain their market share. Nowadays, consumers are very demanding and they require as much as possible information about the product to be sure about its quality (Oblak and Glavonjić, 2014). Analyzing the current wood furniture export from the Republic of Macedonia towards the CEFTA countries, presents a good base for future research of cooperation with other CEFTA countries and possibilities for further development.

1.1 The main benefits from CEFTA 2006
1.1. Glavne koristi od CEFTA-e 2006

The Republic of Macedonia was the last country to accede the original CEFTA. The agreement for extending and modernizing CEFTA was signed on 19 December 2006 and the "new" agreement was called CEFTA 2006 for the purpose of terminological differentiation. This modern and comprehensive free trade agreement entered into force on 26 July 2007 for five Parties - Albania, Macedonia, Moldova, Montenegro and UNMIK/Kosovo, while for Croatia it entered into force on 22 August 2007, for Serbia on 24 October 2007 and for Bosnia and Herzegovina on 22 November 2007. Thus, full implementation of CEFTA 2006 started at the end of 2007, according to the official report from the CEFTA web site (http://www.ceftatradeportal.com/, 2014).

CEFTA 2006 consolidates 32 bilateral free trade agreements previously concluded among its signatories, representing an international framework for increased liberalization of trade in goods. The application of CEFTA 2006 is expected to cause a significant increase of trade exchange in the region, which in turn will result in increased competitive advantages. Membership in CEFTA 2006 significantly contributes to the continuous efforts for strengthening the regional economic cooperation, further liberalization of foreign trade exchange, and continuation of activities for harmonization of trade rules with international standards (Mojsovska and Tosheva, 2011). CEFTA 2006 is a result of the efforts for as urgent as possible economic approximation and consolidation of the SEE countries. Such aspirations, on one hand, and the unequal progress of different countries regarding integration in the global economic trends, imposed a need to relax the preconditions for acceding to the agreement. Novelty in CEFTA 2006 is the broadening of the agreement with new trade issues that were not regulated by the original CEFTA. The purpose of introducing new issues was to increase the economic cooperation among the countries/territories in the region, as well as to increase the processes of harmonization of their measures with the international standards according to the CEFTA official web site (http://www.cefta.int/).

One of the main goals of CEFTA 2006 is to achieve substantial liberalization of trade among its members (Tosheva and Efremov, 2007). The Agreement provides full elimination of customs duties in the international trade of all signatories and for all industrial products not later than 31 December 2008. From 2009, the trade of furniture in CEFTA countries is without custom protection (Efremov, 2013), which is a unique opportunity for furniture companies in these countries. Another important goal of CEFTA 2006 is to encourage trade and investments by applying equitable, understandable and predictable rules, which would be a beneficial base for creating joint ventures and regional cooperation for joint entrance and export on global market. Therefore, this paper analysis the current use of CEFTA benefits of furniture companies from the Republic of Macedonia in the period 2005 to 2013.

1.2 Wood industry and production of furniture in the Republic of Macedonia
1.2. Prerada drva i proizvodnja namještaja u Republici Makedoniji

The Republic of Macedonia is a country with rich tradition in wood processing due to its forests, tradition and professional labor force. The lumber sawmills were among the first industries in our country, and the industry of furniture manufacturing, as continuation of sawmill production process, started to develop in the fifties of the last century. In that period, the major wood-processing plants were established, determined by the program for highly protected market of the former Yugoslavia. According to Glavonjic *et al.* (2009) and Kitek Kuzman *et al.* (2012), globalization and the regional cooperation and participation in the global marketplace are a major driver of reforms being implemented in post socialist Yugoslavia. Privatization of all the former plants has been completed, and the private initiative has established many new companies in this sector, in the process of which the companies have to adjust to the market conditions for doing business. Currently, in this industry, there are over five hundred furniture manufacturing companies and around sixty wood-processing companies. However, according to Shumanska (2014), in Macedonia the wood-processing companies are way behind the modern process of manufacturing due to the outdated technology, and this greatly affects the outcome of manufacturing and hence also the demand for these products.

The international trade of furniture from the Republic of Macedonia is limited, as the whole exchange is made with the neighboring countries. According to Meloska *et al.* (2011), the reasons for limited international trade mainly lies in small transportation costs, joint market of the former Yugoslavia and also the good knowledge of neighboring markets and already established relationships. Also, the import to the Republic of Macedonia, analyzed in the same paper of Meloska *et al.* (2011), shows that the same neighboring countries are the main importing countries for wood furniture, too.

Wood furniture manufacturers in Macedonia should undertake several actions towards expanding towards global market. Above all, a serious research of furniture market should be made. The market offer should not to be individual, but made through associations and groups, with strong promotional activities (Meloska *et al*., 2011). CEFTA 2006 supports the regional cooperation; therefore, it is necessary to analyze the current wood furniture export from the Republic of Macedonia towards the CEFTA countries. This is the starting analysis for a further and deeper analysis of export strategies of all CEFTA countries, aimed at establishing how they can benefit from the CEFTA 2006 agreement.

2 METHODS AND MATERIAL
2. METODE I MATERIJALI

The aim of this paper was to analyze the export trends of wood furniture from the Republic of Macedonia, with the focus on CEFTA countries (old CEFTA countries as Croatia, Slovenia, Bulgaria and Romania and CEFTA 2006 countries – Albania, Bosnia and Herzegovina, Kosovo, Macedonia, Montenegro, Moldova, and Serbia). The research methodology was quantitative and used the preliminary export data from the State Statistical Office of the Republic of Macedonia for the period 2005 to 2013 with custom tariff numbers converted into Standard International Trade Classification (SITC) and also data from Macedonian Chamber of Commerce. The analyses were done of the export presented in EUR, using mathematical and statistical methods, with graphics in Excel Microsoft Office. For analyzing the macroeconomic export trends of the Republic of Macedonia, dynamic economic analysis of time series data was performed, using one of the time series models presented in the research of Oblak *et al.* (2012).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Wood furniture export from Republic of Macedonia to CEFTA 2006 countries
3.1. Izvoz namještaja Republike Makedonije u zemlje CEFTA 2006

According to the preliminary export data from the State Statistical Office of the Republic of Macedonia for the period 2005 to 2013, in the period 2005 to 2008, the total export of wood furniture from the Republic of Macedonia shows a trend of continuous increase up to 2008, presented with a linear trend line in Graph 1. In 2009 and 2010, there is a decrease of about 15 and 21 percent, respectively, compared to the previous year. After 2011, there is an increasing trend until 2013 of about 4-6 percent per year compaed to the previous year. The linear trend line of the total wood furniture export is increasing, but however, the regression $R^2 = 0.260$ is not high enough to present clear dependence of the export amount during the years, and therefore it is not easy to predict and forecast.

In Table 1, it is important to stress the share of different types of wood in the total export of wood furniture. The shop, office and kitchen furniture covers just a small share of 2.97 percent, 4.02 percent and 6.84 percent from the total export of wood furniture, which presents an opportunity for increase in the future.

Table 1 Export of wood furniture by category from the Republic of Macedonia in the period 2005 to 2013
Tablica 1. Izvoz namještaja prema kategorijama proizvoda Republike Makedonije u razdoblju od 2005. do 2013.

	Office furniture *Uredski namještaj*	**Kitchen furniture** *Kuhinjski namještaj*	**Bedroom furniture** *Namještaj za spavaće sobe*	**Living& Dining furniture** *Namještaj za dnevne sobe i blagovaonice*	**Shop furniture** *Namještaj za trgovine*	**Other furniture** *Ostali namještaj*	**Total export** *Ukupni izvoz*
	EUR	EUR	EUR	EUR	EUR	EUR	EUR
2005	47.828	136.277	778.006	1.820.132	20.816	218.516	3.021.574
2006	80.205	73.304	1.016.160	2.895.111	21.331	275.520	4.361.632
2007	132.224	156.145	879.077	3.782.205	554.468	793.703	6.297.821
2008	317.374	270.795	1.323.448	5.735.642	179.645	636.733	8.463.638
2009	290.192	504.624	1.819.974	3.920.803	21.640	659.863	7.217.096
2010	347.123	671.555	2.280.988	1.648.250	69.978	689.734	5.707.629
2011	179.864	540.787	2.419.134	1.373.211	136.661	1.371.588	6.021.245
2012	387.668	632.679	2.967.467	732.830	400.610	1.321.376	6.442.629
2013	399.476	723.188	3.441.278	548.342	206.277	1.383.095	6.701.657
Total EUR *Ukupno EUR*	2.181.954	3.709.354	16.925.533	22.456.525	1.611.426	7.350.128	54.234.920
%	4.02	6.84	31.21	41.41	2.97	13.55	100.00
Mean	242.439	412.150	1.880.615	2.495.169	179.047	816.681	6.026.102
Std Dev	134.565	253.527	958.347	1.720.364	186.800	448.294	1.579.669
Coef Var	56 %	62 %	51 %	69 %	104 %	55 %	26 %
AROC	30 %	23 %	20 %	-14 %	33 %	26 %	10 %
r (Corr.)	0.8324	0.9354	0.9785	-0.5433	0.2283	0.9168	0.5101

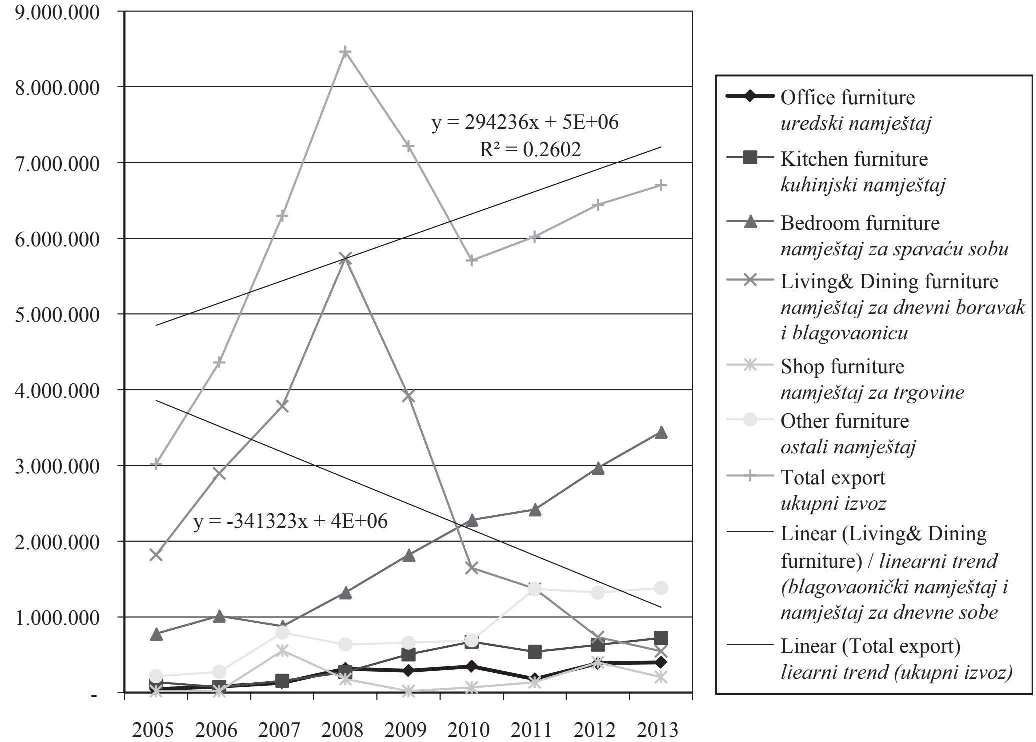

Figure 1 Export of wood furniture from the Republic of Macedonia in the period 2005 to 2013
Slika 1. Izvoz namještaja Republike Makedonije u razdoblju od 2005. do 2013.

When analyzing the export of different types of wood furniture presented in Table 1, comparing 2005 with 2013, increasing trends can be observed for all categories of wood furniture except for export of living and dining furniture, where there is a negative trend with negative AROC (average rate of change) (-14 %). This is the only category with lowering trend line presented in Graph 1. The other categories have a positive AROC: it is the highest for shop furniture (33 %), followed by office furniture (30 %), other furniture (26 %), kitchen furniture (23 %) and bedroom furniture (20 %). This results in a positive trend line of wood furniture export from Macedonia.

Further, the analysis is given of the export from the Republic of Macedonia for each category of wood furniture as follows: office furniture, kitchen furniture, bedroom furniture, living and dining furniture, shop furniture and other furniture.

3.2 Export of office wood furniture from Macedonia
3.2. Izvoz uredskog namještaja Republike Makedonije

Table 2 presents the export of office wood furniture in the period 2005 to 2013 to the ten main countries. Among the ten most important export markets, six are members of CEFTA or CEFTA 2006 (Croatia, Bosnia and Herzegovina, Kosovo, Serbia, Montenegro and Romania) and four are European countries (Holland, Germany, Greece and Switzerland). Holland holds the first place with the total export of EUR 544.745, but only in the last three years. The analysis of the export to CEFTA/CEFTA 2006 countries shows that there is a variable trend of export in different years, participating with 64 percent in the total export, meaning that these countries are important market for future increase of export of Macedonian office wood furniture (Graph 2).

Table 2 Export of office furniture from the Republic of Macedonia to main 10 export countries in the period 2005 – 2013
Tablica 2. Izvoz uredskog namještaja Republike Makedonije u deset najznačajnijih zemalja izvoznica u razdoblju od 2005. do 2013.

Countries *Države*	**Export in EUR** *Izvoz u EUR*
Netherlands / *Nizozemska*	544.745
Croatia/ *Hrvatska*	408.126
Bosnia&Herzegovina *Bosna i Hercegovina*	346.219
Kosovo/ *Kosovo*	275.834
Serbia+MN/ *Srbija + Crna Gora*[1]	235.204
Germany/ *Njemačka*	75.399
Greece/ *Grčka*	65.483
Montenegro/ *Crna Gora*	39.600
Switzerland/ *Švicarska*	36.610
Romania/ *Rumunjska*	35.075
Other countries/ *Ostale zemlje*	119.660
Total EUR/ *Ukupno EUR*	**2.181.954**

[1] In 2003, Serbia and Montenegro were reconstituted as a state union officially known as the State Union of Serbia and Montenegro, transitioning to two independent nations by 2006. In the period 2005-2006, the State Statistical Office of the Republic of Macedonia had collected joint preliminary data for Serbia and Montenegro, and from 2007 preliminary data was separated for Serbia and Montenegro as different states.

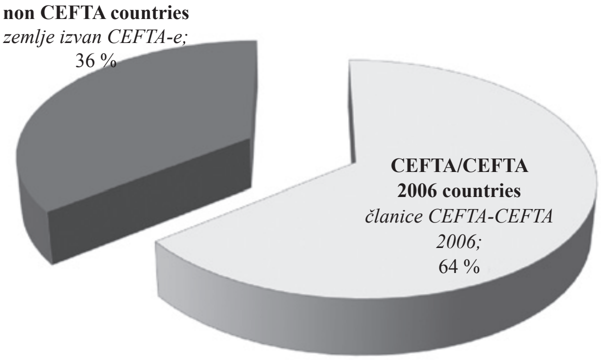

Figure 2 Macedonian export of office wood furniture to CEFTA and non CEFTA countries in the period 2005 – 2013
Slika 2. Makedonski izvoz uredskog namještaja u članice CEFTA-e i zemlje izvan CEFTA-e u razdoblju od 2005. do 2013.

3.3 Export of kitchen wood furniture from Macedonia
3.3. Izvoz kuhinjskog namještaja Republike Makedonije

Table 3 presents the export of kitchen wood furniture in the period 2005 to 2013 to the ten main countries. When comparing the ten most important export markets, again six are members of CEFTA or CEFTA 2006 and four are European countries (Switzerland, Greece, Germany and Sweden). CEFTA/CEFTA 2006 countries (Croatia, Slovenia and Serbia) hold the first three places with a total export of about EUR 2.527.000. The CEFTA/CEFTA 2006 countries show a variable trend of export in different years, but they participate with a 78 percent in the total export and they are important market for future increase of export of Macedonian kitchen wood furniture (Graph 3).

Table 3 Export of kitchen furniture from the Republic of Macedonia to main 10 countries
Tablica 3. Izvoz kuhinjskog namještaja Republike Makedonije u deset najznačajnijih zemalja

Country/ *Države*	**Export in EUR** *Izvoz u EUR*
Croatia/ *Hrvatska*	1.399.486
Slovenia/ *Slovenija*	791.706
Serbia+MN/ *Srbija + Crna Gora*	335.670
Switzerland/ *Švicarska*	327.890
Greece/ *Grčka*	201.352
Germany/ *Njemačka*	156.511
Montenegro/ *Crna Gora*	101.155
Kosovo/ *Kosovo*	91.179
Bosnia&Herzegovina *Bosna i Hercegovina*	89.554
Sweden/ *Švedska*	61.805
Other countries/ *Ostale zemlje*	153.046
Total EUR/ *Ukupno EUR*	**3.709.354**

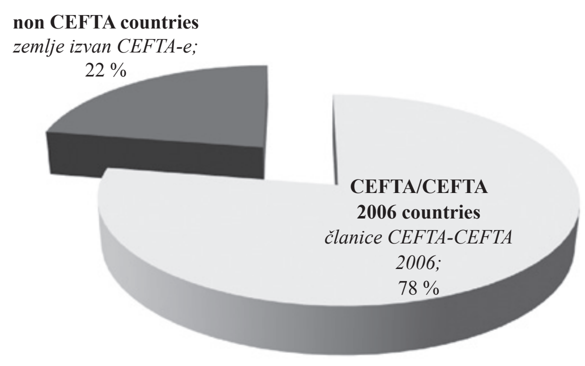

Figure 3 Export of kitchen furniture from the Republic of Macedonia to CEFTA and non-CEFTA countries in the period 2005 – 2013
Slika 3. Izvoz kuhinjskog namještaja Republike Makedonije u zemlje članice CEFTA-e i zemlje izvan CEFTA-e u razdoblju od 2005. do 2013.

3.4 Export of bedroom wood furniture from Macedonia
3.4. Izvoz namještaja za spavaće sobe iz Republike Makedonije

Table 4 presents the export of bedroom wood furniture in the period 2005 to 2013 to the ten most important countries. The analysis of the ten most important export markets shows that seven are members of CEFTA or CEFTA 2006 and three are European coun-

Table 4 Export of bedroom furniture from the Republic of Macedonia to the main 10 countries in the period 2005 – 2013
Tablica 4. Izvoz namještaja za spavaće sobe iz Republike Makedonije u deset zemalja u razdoblju od 2005. do 2013.

Countries/ *Države*	**Export in EUR** *Izvoz u EUR*
Serbia+MN/ *Srbija + Crna Gora*	5.296.161
Kosovo/ *Kosovo*	4.505.783
Croatia/ *Hrvatska*	2.961.108
Bosnia&Herzegovina *Bosna i Hercegovina*	1.110.687
Slovenia/ *Slovenija*	961.489
Greece/ *Grčka*	715.794
Norway/ *Norveška*	330.637
Bulgaria/ *Bugarska*	269.351
Germany/ *Njemačka*	205.094
Albania/ *Albanija*	165.771
Other countries/ *Ostale države*	403.657
Total EUR/ *Ukupno EUR*	16.925.533

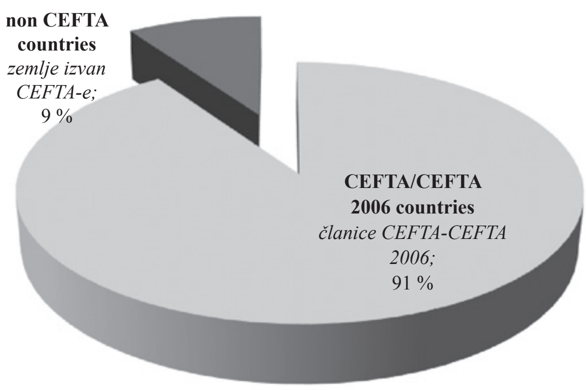

Figure 4 Export of bedroom furniture from the Republic of Macedonia to CEFTA and non CEFTA countries in the period 2005 – 2013
Slika 4. Izvoz namještaja za spavaće sobe iz Republike Makedonije u zemlje članice CEFTA-e i zemlje izvan CEFTA-e

tries (Greece, Norway and Germany). CEFTA/CEFTA 2006 countries (Serbia, Kosovo, Croatia, Bosnia and Herzegovina and Slovenia) hold the first five places with a total export of about EUR 14.835.000. The CEFTA/CEFTA 2006 countries show a variable export trend in different years, but they participate with a 91 percent in the total export and hence they are important market for future increase of export of Macedonian bedroom wood furniture (Graph 4).

3.5 Export of dining and living room wood furniture from the Republic of Macedonia
3.5. Izvoz blagovaoničkog namještaja i namještaja za dnevne sobe Republike Makedonije

Table 5 presents the export of dining and living room wood furniture in the period 2005 to 2013 to the ten most important countries. When comparing the ten most important export markets, seven are members of CEFTA or CEFTA 2006 and three are European countries (Greece, Holland and Germany). Croatia holds the first place with a total export of about EUR 7.730.446. The CEFTA/CEFTA 2006 countries show a variable export trend in different years, but they participate with a 70 percent in the total export and they are important market for future increase of export of Macedonian dining and living room wood furniture (Graph 5).

Table 5 Export of dining and living room furniture from the Republic of Macedonia to the 10 main countries in the period 2005 – 2013
Tablica 5. Izvoz blagovaoničkog namještaja i namještaja za dnevne sobe Republike Makedonije u deset najznačajnijih zemalja u razdoblju od 2005. do 2013.

Countries/ *Zemlje*	**Total EUR** *Ukupno EUR*
Croatia / *Hrvatska*	7.730.446
Greece / *Grčka*	5.329.133
Serbia+MN / *Srbija + Crna Gora*	2.929.847
Slovenia / *Slovenija*	2.830.155
Montenegro / *Crna Gora*	603.204
Bosnia&Herzegovina *Bosna i Hercegovina*	543.544
Kosovo / *Kosovo*	513.621
Bulgaria / *Bugarska*	444.125
Netherlands / *Nizozemska*	377.703
Germany / *Njemačka*	293.442
Other countries / *Ostale zemlje*	804.637
Total EUR / *Ukupno EUR*	**22.399.857**

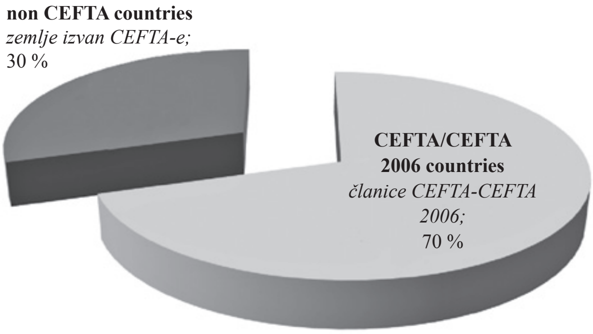

Figure 5 Export of dining and living room furniture from the Republic of Macedonia to CEFTA and non CEFTA countries in the period 2005 – 2013
Slika 5. Izvoz blagovaoničkog namještaja i namještaja za dnevne sobe Republike Makedonije u zemlje članice CEFTA-e i zemlje izvan CEFTA-e u razdoblju od 2005. do 2013.

Table 6 Export of shop furniture from the Republic of Macedonia to the 10 main countries in the period 2005 – 2013
Table 6. Izvoz namještaja za trgovine Republike Makedonije u deset najznačajnijih zemalja u razdoblju od 2005. do 2013.

Country/ *Država*	**Total EUR** *Ukupno EUR*
Serbia+MN / *Srbija + Crna Gora*	500.000
Germany / *Njemačka*	326.797
Italy / *Italija*	326.115
Kosovo / *Kosovo*	160.468
Greece / *Grčka*	64.378
UAE / *UAE*	60.514
Albania / *Albanija*	43.941
Montenegro / *Crna Gora*	26.085
Slovenia / *Slovenija*	22.563
Croatia / *Hrvatska*	14.082
Other countries / *Ostale zemlje*	66.485
Total EUR / *Ukupno EUR*	**1.611.426**

Figure 6 Export of shop furniture from the Republic of Macedonia to CEFTA and non CEFTA countries in the period 2005 – 2013
Slika 6. Izvoz namještaja za trgovine Republike Makedonije u zemlje članice CEFTA-e i zemlje izvan CEFTA-e

3.6 Export of shop wood furniture from the Republic of Macedonia
3.6. Izvoz namještaja za trgovine Republike Makedonije

Table 6 presents the export of shop wood furniture in the period 2005 to 2013 to the ten most important countries. When comparing the ten most important export markets, six are members of CEFTA or CEFTA 2006, three are European countries (Germany, Italy and Greece) and one is from the Middle East (UAE). Serbia holds the first place with a total export of about EUR 500.000. CEFTA/CEFTA 2006 countries show a variable export trend in different years, but they participate with a 49 percent in the total export and they are important market for future increase of export of Macedonian shop wood furniture (Graph 6).

3.7 Export of other furniture from the Republic of Macedonia
3.7. Izvoz ostalog namještaja Republike Makedonije

Table 7 presents the export of other wood furniture in the period 2005 to 2013 to the ten main coun-

Table 7 Other furniture export from Republic of Macedonia to main 10 export countries in the period 2005 – 2013
Tablica 7. Izvoz ostalog namještaja Republike Makedonije u deset najznačajnijih zemalja izvoznica u razdoblju od 2005. do 2013.

Country/ ***Zemlja***	**Total EUR** *Ukupno EUR*
Kosovo/ *Kosovo*	1.038.426
Serbia+MN/ *Srbija +Crna Gora*	961.319
Slovenia/ *Slovenija*	857.182
Germany/ *Njemačka*	734.953
Croatia/ *Hrvatska*	618.749
Greece/ *Grčka*	587.678
Norway/ *Norveška*	471.623
Montenegro/ *Crna Gora*	469.482
Netherlands/ *Nizozemska*	392.258
Bosnia&Herzegovina *Bosna i Hercegovina*	215.667
Other countries/ *Ostale zemlje*	1.002.792
Total EUR/ *Ukupno EUR*	**7.350.128**

Figure 7 Export of other furniture from the Republic of Macedonia to CEFTA and non CEFTA countries in the period 2005 – 2013
Slika 7. Izvoz ostalog namještaja Republike Makedonije u zemlje članice CEFTA-e i zemlje izvan CEFTA-e

tries. When comparing the ten most important export markets, six are members of CEFTA or CEFTA 2006 and four are European countries (Germany, Greece, Norway and Holland). CEFTA/CEFTA 2006 countries (Kosovo, Serbia and Slovenia) hold the first three places with a total export of about EUR 2.857.000. The CEFTA/CEFTA 2006 countries show a variable export trend in different years, but they participate with a 59 percent in the total export and they are important market for future increase of export of Macedonian other wood furniture (Graph 7).

The above analysis shows clearly which product categories are the most exported to CEFTA countries and which category of wood furniture is the most exported to CEFTA countries.

3.8 Export of wood furniture to CEFTA and other countries
3.8. Izvoz namještaja u zemlje članice CEFTA-e i ostale zemlje

Descriptive statistics (means and standard deviations, coefficients of variations and average rate of change in percentage) were determined for annual export of wood furniture from the Republic of Macedonia for the period 2005 – 2013. The results are given in Table 8.

According to the data shown in Table 8 for the analyzed period 2005 to 2013, the CEFTA countries are the strategic markets for the export of wood furniture with the total export of about EUR 39.098.000 and a share of 75 percent in the total export. Of the first four countries, three are CEFTA countries that cover the export of Macedonian furniture (Table 8). Croatia holds the first place with the highest export of about 24 percent of the total export, followed by Ser-

Table 8 Descriptive statistics for the total export to main countries from the Republic of Macedonia in the period 2005 – 2013
Tablica 8. Deskriptivna statistika ukupnog izvoza Repubike Makedonije u najznačajnije zemlje u razdoblju od 2005. do 2013.

Year *Godina*	**Croatia** *Hrvatska*	**Serbia** *Srbija*	**Greece** *Grčka*	**Kosovo** *Kosovo*	**Slovenia** *Slovenija*	**Bosnia & Herzego-vina** *Bosna i Hercego-vina*	**Germany** *Njemačka*	**Nether-lands** *Nizozem-ska*	**Monte-negro** *Crna Gora*	**Norway** *Nor-veška*
2005	684.660	1.251.087	739.790	-	211.627	24.237	5.165	-	-	-
2006	1.273.001	1.220.575	865.863	-	569.786	33.029	98.200	-	-	106.331
2007	1.754.899	1.648.005	1.145.094	-	623.380	150.502	236.563	1.753	136.225	194.860
2008	2.571.370	1.943.611	1.484.073	-	793.266	398.310	127.099	1.282	182.061	245.792
2009	2.036.208	1.068.783	1.084.594	777.846	902.274	255.788	38.021	39.185	296.039	197.830
2010	1.110.764	683.513	673.697	1.293.433	467.050	401.424	65.245	312.169	165.598	23.278
2011	1.109.243	717.848	636.615	1.383.704	463.558	396.575	504.836	188.487	153.522	139.483
2012	1.209.687	927.161	228.138	1.493.620	719.450	381.917	305.729	359.594	273.539	-
2013	1.382.164	797.617	105.953	1.636.708	734.543	277.835	411.337	435.649	111.531	2.466
Total EUR	13.131.996	10.258.201	6.963.818	6.585.311	5.484.933	2.319.617	1.792.195	1.338.119	1.318.514	910.041
%	24 %	19 %	13 %	12 %	10 %	4 %	3 %	2 %	2 %	2 %
Mean	1.459.111	1.139.800	773.758	731.701	609.437	257.735	199.133	148.680	146.502	101.116
Std Dev	570.520	429.663	436.059	731.769	208.829	154.930	176.115	178.418	102.733	97.987
Coef Var	39 %	38 %	56 %	100 %	34 %	60 %	88 %	120 %	70 %	97 %
AROC	9 %	-5 %	-22 %	20 %	17 %	36 %	73 %	151 %	-3 %	-42 %
r (Corr.)	-0.0121	-0.6177	-0.6569	0.9411	0.4141	0.7531	0.7055	0.8969	0.5709	-0.2992

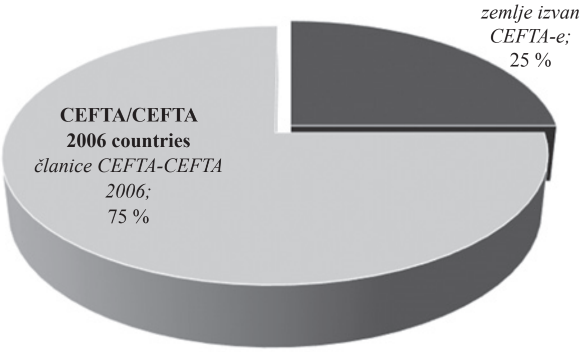

Figure 8 Total export of furniture from Macedonia to CEFTA and non CEFTA countries for the period 2005-2013
Slika 8. Ukupni izvoz namještaja Republike Makedonije u zemlje članice CEFTA-e i zemlje izvan CEFTA-e zarazdoblje od 2005. do 2013.

bia with a share of about 19 percent of the total export, and then Greece with about 13 percent and Kosovo with about 12 percent.

When the rates of change in successive time periods are approximately equal, and assuming that the average rate of change will not change, it would be possible to predict variable values in future periods. Based on the average rate of change for export (10 %) of furniture from Macedonia in the observed period, prediction model for future values of export were developed. Correlation analysis was used to determine the correlation level between the values of export as dependent variable and time as independent variable. Pearon's linear correlation coeficient r – which describes the direction and strength of correlation relationships, was positive $r = 0.5101$, but not very high and close to 1, which shows that the predicted trend line presented in Graph 1 of this research is not reliable.

Furthermore, export of wood furniture from the Republic of Macedonia is different for different categories and influences the total export. It can be concluded that Macedonian wood furniture manufacturers use CEFTA 2006, but not enough. The reason is a great number of small manufactures, investment in serial production and newer and modern machinery and low buying power of customers on the market, which all result in lower export. This situation has to be changed if wood furniture companies intend to be more competitive and ready for the global market.

4 CONCLUSION
4. ZAKLJUČAK

It is a generally accepted fact that socioeconomic development greatly depends on investment, and therefore long-term development can only be achieved through investment, because well targeted investment activity is the primary assumption for all aspects of competitiveness (Ojurović *et al.*, 2013). In recent decades, the furniture industry has gone through major changes. The life cycles of products are becoming increasingly shorter, leading to an increasing need for intensified development of new products or updating the existing ones. At the same time it is necessary to continually update the technology and equipment as well as to include developmental and research activities, education and the search for financial resources for the development and business operation of companies (Berginc *et al.*, 2011).

CEFTA 2006 is an exceptionally important step in the trade cooperation and integration of the region. Based on trade liberalization, from 2009 furniture trade in CEFTA countries is free of custom duties. This preferential treatment is a very important facilitator for higher export from the Republic of Macedonia to the CEFTA market.

Regarding the export of six categories of wood furniture from the Republic of Macedonia in the period 2005-2013 to CEFTA/CEFTA 2006 countries: the export of office wood furniture accounts for 64 percent, export of kitchen wood furniture accounts for 78 percent, export of bedroom wood furniture accounts for 91 percent, export of dining and living wood furniture accounts for 70 percent, export of shop wood furniture accounts for 49 percent and export of other wood furniture accounts for 59 percent of the total export.

According to preliminary statistical data for the period 2005-2013, Macedonian wood furniture industry achieved an export of EUR 39,098,000 to CEFTA/CEFTA 2006 countries and a share of 75 percent in the total export. It can be concluded that the countries in the region, especially CEFTA/CEFTA 2006 countries, will be the strategic markets for Macedonian export of wooden furniture in the future. Preferential conditions specified in the CEFTA agreement and knowledge of the market based on experience gained in the former Yugoslavia is a solid basis for Macedonian furniture manufacturing companies to build their own competitiveness first on the CEFTA market and then also on the European and global market.

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Analysis of Drying Kiln Aerodynamics Based on a Full Three-Dimensional Turbulent Numerical Computation

Analiza aerodinamike sušionica na temelju trodimenzionalnoga turbulentnog numeričkog računanja

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ABSTRACT • *This paper introduces a numerical methodology based on a 3D turbulent flow computation developed to assess the aerodynamic performances of lumber drying kilns. The numerical results are validated against experimental data obtained by applying five different fan speeds and reversible airflow. The distributions of the energy loss coefficient and of the non-uniformity flow coefficient were plotted along the flow path in both normal and reverse directions and the regions with larger air loss values were identified. The numerical computation revealed that three quarters of the airflow delivered by the fans bypasses the wood stacks through different gaps, consequently leading to a low aerodynamic efficiency (of 24-25 %) of the kiln.*

Key words: *drying kiln, airflow, Computational Fluid Dynamics, validation, aerodynamic efficiency*

SAŽETAK • *U radu je prezentirana numerička metodologija utemeljena na proračunima 3D turbulentnog protoka zraka, koja je razvijena kako bi se ocijenila aerodinamička izvedba sušionica za drvnu građu. Numerički su rezultati provjereni usporedbom s eksperimentalnim podacima dobivenim primjenom pet različitih brzina ventilatora i reverzibilnog protoka zraka. Raspodjele koeficijenta gubitka energije i koeficijenta neujednačenosti protoka prikazane su duž puta protoka u normalnome i obrnutom smjeru te su utvrđene regije u kojima su identificirane veće vrijednosti gubitka zraka. Numerički je proračun pokazao da tri četvrtine protoka ventilatorskog zraka zaobilaze složaje drva kroz različite praznine, što posljedično dovodi do niske aerodinamične učinkovitosti sušionica (od 24-25 %).*

Ključne riječi: *sušionice, protok zraka, računalna dinamika fluida, provjera valjanosti, aerodinamična učinkovitost*

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1 INTRODUCTION
1. UVOD

Despite having been in use for over a century, conventional heat-and-vent drying kilns (Figure 1) are still in need of innovative solutions in order to improve their aerodynamic performances, which lead to better product quality and energy savings.

Most drying kilns allow for reversible airflow, in order to reduce moisture variation along flow path. Furthermore, the air inside the kiln is regulated to flow for a set time in one direction (further called, *normal* direction) and then for the same time in the opposite direction (further called, *reverse* direction). The normal direction (marked in Figure 1b by continuous arrows) flows through the fan's outlet boundary → fan house → plenum chamber → stacks → plenum chamber → heating coils → fan house → fan's inlet boundary. The reverse direction (marked in Figure 1b by dotted arrows) flows through the fan's outlet boundary → fan house → heating coils → plenum chamber → stacks → plenum → fan house → fan's inlet boundary.

The lumber boards are sticker-stacked to enhance kiln-drying by generating air channels between the boards. These channels are called sticker spaces or fillet spaces. When the stacks are placed inside the kiln, there are two large lateral spaces (plenum chambers) between the front door and the stacks and between the back wall and the stacks. Their function is to distribute the airflow evenly through the sticker spaces. Additionally, several further gaps (CPS, CPL, CPV and CPO) are generated around the stacks (Figure 1a).

Since these gaps have a lower aerodynamic resistance than the stacks, a part of the volumetric flow rate generated by the fans will bypass the lumber stacks. A bypass of 10-25 % normally occurs when a good kiln loading strategy is chosen (Langrish and Keey, 1996).

The airflow in lumber drying kilns has been studied since the 1930s by means of classical devices such as vane anemometers, hot-wire anemometers or pressure probes, but also by means of modern techniques like the Laser-Doppler anemometer (Ledig *et al.,* 2007). In addition, numerical methods such as CFD (Computational Fluid Dynamics) are used to better understand and design drying equipment at lower costs than needed for experimental tests (Jamaleddine and Ray, 2010).

CFD has been used by several researchers to study the aerodynamics of lumber drying kilns or parts of it (Arnaud *et al.*, 1991; Langrish and Keey, 1996; Salin and Ohman, 1998; Riepen and Paarhuis, 1999; Bian 2001; Hua *et al.*, 2001; Sun, 2001; Bedelean and Sova, 2010). As a result, various solutions or recommendations have been formulated. Extensive reviews on different solutions and methodologies to improve the aerodynamic performances of lumber dryers have been published by Keey *et al.* (2000) and by Ledig *et al.* (2007).

Most of previous studies, that have analyzed the aerodynamics of drying kilns, have focused on the airflow either in front or inside the stacks, but not along the entire loop (i.e. fan's outlet boundary → fan house → plenum chamber → stacks → plenum chamber → heating coils → fan house → fan's inlet boundary). One possible reason is that the simultaneous interaction of all loop components upon the airflow behavior is very complex (Arnaud *et al.*, 1991). In addition, there is a lack of numerical models in literature that are able to take into account all sources of airflow perturbations within the kiln (Ledig *et al.*, 2001) such as: position of the fans, end-wall effects, separation zones, influence of the gaps around the stacks on the airflow bypass, etc.

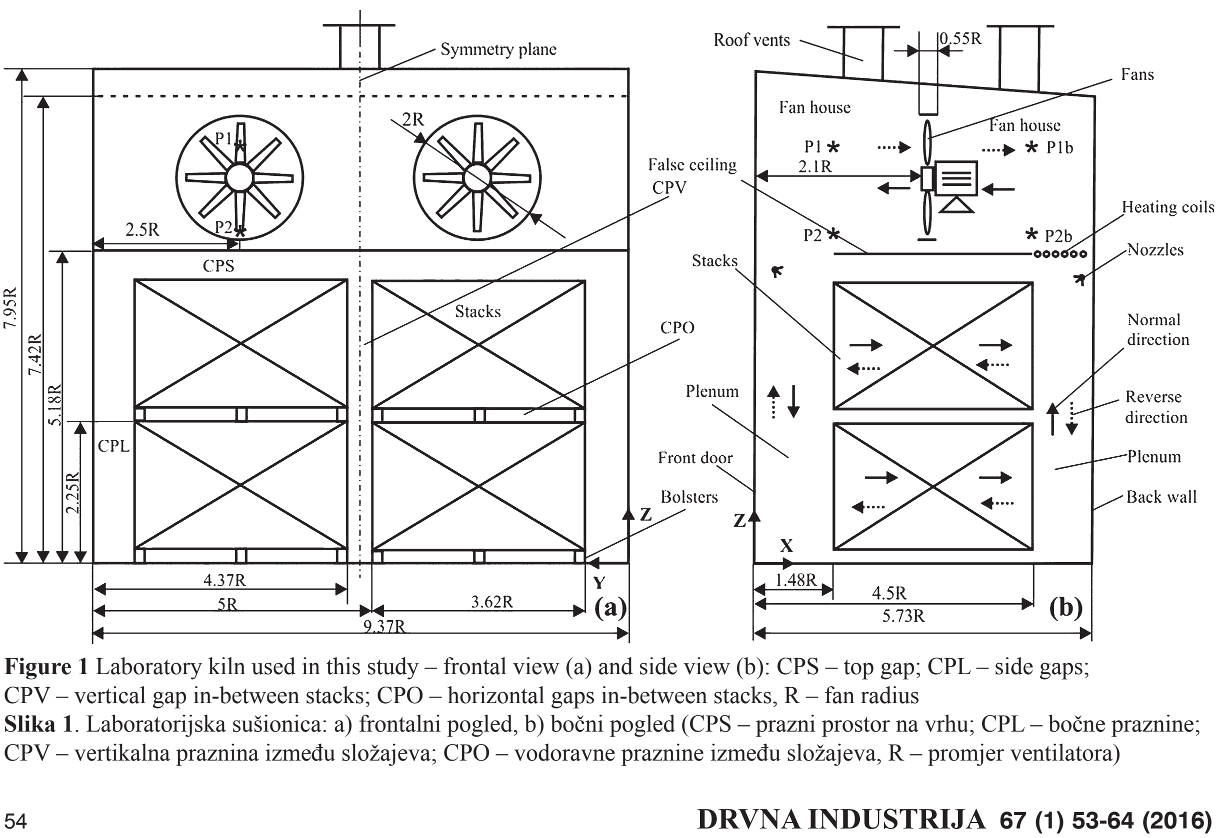


Figure 1 Laboratory kiln used in this study – frontal view (a) and side view (b): CPS – top gap; CPL – side gaps; CPV – vertical gap in-between stacks; CPO – horizontal gaps in-between stacks, R – fan radius
Slika 1. Laboratorijska sušionica: a) frontalni pogled, b) bočni pogled (CPS – prazni prostor na vrhu; CPL – bočne praznine; CPV – vertikalna praznina između složajeva; CPO – vodoravne praznine između složajeva, R – promjer ventilatora)

This work introduces a novel methodology based on the fluid flow computation in 3D geometries, i.e. a lumber drying kiln. *To demonstrate the applicability of the proposed methodology, the aerodynamics* of a heat-and-vent drying kiln (semi-scale model) was investigated in both normal and reverse airflow directions. In addition, the trapezoidal shape of the fan house (see Figure 1b) was taken into account. The methodology proposed in this paper paves the way towards a better analysis of the aerodynamics phenomena in order to improve the perfomances of lumber drying kilns.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1. Description of the drying kiln
2.1. Opis sušionice

The experiments were performed in a 4 m^3 heat-and-vent laboratory kiln, schematically presented in Figure 1. The kiln is equipped with two reversible overhead fans, a heating coil, two vents and two spray pipes, one on each side of the kiln. The fan speed can be adjusted from 0 to 1450 min^{-1} using an inverter and the power absorbed by each fan can be modified within the range of 0…3000 W. Consequently, the volumetric flow rate can be modified within the range of 0…8.33 $m^3 \cdot s^{-1}$. The fan hub radius is r = 0.109 m. The outer fan radius is R = 0.405 m. This radius (R) is further considered as the reference size; all other linear dimensions are related to it in order to obtain dimensionless sizes. Similarly, the annular section delimited by the two radii π (R^2-r^2) will be considered as a reference for the transformation of areas into dimensionless sizes.

2.2 Material and kiln setup
2.2. Materijal i postavke sušionice

Four stacks were placed inside the kiln as a 2 x 2 matrix (Figure 1). Each stack contained eighty-eight sticker-stacked spruce (*Picea abies*) boards. Three stickers were placed in a row, at the ends and at half the length of the boards. Based on these input data, twenty 1200 x 676 x 24 mm sticker spaces arranged as a 2 x 10 matrix were generated in each stack. Three bolsters were placed below each stack (Figure 1a).

2.3 Numerical setup
2.3. Numeričke postavke

The 3D computational domain (Figure 2b) was created by dividing the small-scale experimental kiln by a symmetry plane at mid length (Figure 2a). The governing equations (momentum and continuity) for the incompressible, steady and viscous flows are written as follows:

$$\rho v_i \frac{\partial v_i}{\partial x_i} = \rho g_i - \frac{\partial p}{\partial x_i} + \mu \frac{\partial^2 v_i}{\partial x_i^2} \text{ and } \frac{\partial v_i}{\partial x_i} = 0 \qquad (1)$$

Where, v is the velocity ($m \cdot s^{-1}$), p is the pressure (Pa), ρ is the air density ($kg \cdot m^{-3}$), μ is the dynamic air viscosity (Pa·s), and g is the gravitational acceleration ($m \cdot s^{-2}$).

The inlet boundary of the 3D computational domain is the annular section between the outer fan diameter and the fan hub diameter. A uniform normal velocity corresponding to each volumetric flow rate value is imposed as the inflow condition, together with the turbulent quantities. A constant pressure on the annular outlet surface is imposed as the outflow boundary condition. The symmetry condition is imposed on the symmetry plane and the non-slip condition is imposed on all wall boundaries.

The Reynolds number corresponding to the airflow in the drying kiln ranges between 1.2×10^5 and 8.7×10^5. The Reynolds number is computed using the bulk velocity on the annular surface of the fan, the outer fan diameter and the kinematic air viscosity at 20 °C.

Turbulent flows with a high Reynolds number are difficult to model. Turbulence flows are greatly influenced by wall boundaries (Hinze, 1975), especially

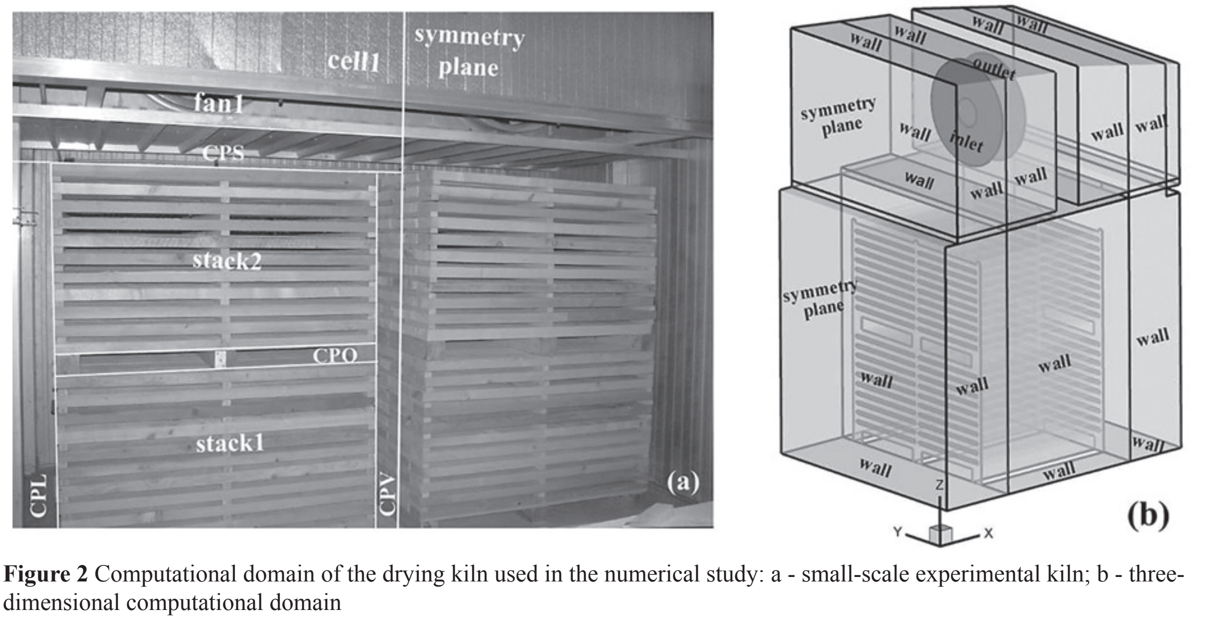


Figure 2 Computational domain of the drying kiln used in the numerical study: a - small-scale experimental kiln; b - three-dimensional computational domain

Slika 2. Računalna domena sušionice koja je korištena u numeričkoj studiji: a) mala eksperimentalna sušionica; b) trodimenzionalna računalna domena when dealing with flows through relatively narrow channels. The viscosity affects the near-wall region, where the variables of the numerical solution change most rapidly. The non-equilibrium wall function approach is used to model this region. The wall function approach substantially saves computational resources for high Reynolds number flows, since it is economical, robust and reasonably accurate for the near-wall treatments (Craft *et al.,* 2004). The near-wall treatment employs the non-equilibrium wall function for the turbulence model, with the potential benefit of better accounting for the adverse pressure gradients (Kim and Choudhury, 1995) in comparison to the standard wall functions.

Reynolds stress model (RSM) accounts for the effects of the streamline curvature, rotation, and rapid changes of the strain rate in a more rigorous manner than one-equation and two-equation models, and it is strongly recommended for highly anisotropic flows (Perot and Natu, 2004). In other words, the RSM accurately predicts complex flows. However, the fidelity of the RSM predictions is still limited by the closure assumptions employed to model various terms in the exact transport equations for the Reynolds stresses. The modeling of the pressure-strain and dissipation-rate terms is particularly challenging, and is often considered responsible for compromising the accuracy of RSM predictions. The effects of strong turbulence anisotropy can only be rigorously modeled by applying the second-moment closure adopted in the RSM. The RSM closes the Reynolds-averaged Navier-Stokes equations by solving transport equations for the Reynolds stresses, together with an equation for the dissipation rate. The RSM involves the calculation of individual Reynolds stresses using differential transport equations. The individual Reynolds stresses are then used to obtain closure of the Reynolds-averaged momentum equation. Therefore, the RSM yields results that are clearly superior to the simpler models. This means that seven additional transport equations are solved in 3D flows. However, additional computational resources are required.

On the inlet section, one must specify the individual Reynolds stresses $\overline{v_i^{'}v_j^{'}}$ and the turbulence dissipation rate ε. The turbulent kinetic energy $k = \overline{v_i^{'}v_j^{'}}/2$ is ascertained by taking the trace of the Reynolds stress tensor. However, the turbulence intensity T_u (%) expresses the "strength" of the turbulence motion being defined as the ratio of the root-mean-square of the velocity fluctuations v' (m·s^{-1}), to the mean flow velocity V (m·s^{-1}), according to Eq. (2):

$$T_u = \frac{1}{V}\sqrt{\tfrac{1}{3}\overline{v_i^{'}v_i^{'}}}. \qquad (2)$$

Turbulence intensities of 7 % and approximately 3 % were measured by Fernandez Oro *et al.* (2008) in the rotor wakes of the axial fan and in the main stream, respectively. Therefore, an average value of 5 % was selected on the annular inlet section of the drying kiln.

The second turbulent quantity corresponds to the characteristic length of the turbulence that has to be imposed on this section. This turbulent quantity characterizes the spatial dimension of the largest eddy of the turbulent structure. In our case, this length value was considered as l = 0.81 m; equal to the outer diameter of the axial fan.

Three grids with hexahedral cells were generated using Gambit (Fluent Inc., 2006a) in order to assess the numerical solution with respect to the mesh refinement. As a result, the following structured meshes were considered in our procedure: a coarse grid (of approximately 1.2 M cells), a medium grid (of approximately 2.1 M cells) and a fine one (of approximately 2.6 M cells).

The 3D turbulent steady computation was carried out using Fluent (Fluent Inc., 2006b) running in parallel. The incompressible flow equations were discretized using a finite volume method (FVM). The semi-implicit pressure linked equations (SIMPLE) algorithm for pressure-velocity coupling was selected for the numerical investigation. The convection terms are discretized using a 2nd order upwind scheme in both momentum and turbulence equations and a PRESTO scheme for pressure. The parallelization was obtained by a domain decomposition procedure. The communication time was minimized by employing the METIS graph partitioning procedure (Karypis and Kumar, 1998).

2.4 Experimental method
2.4. Eksperimentalna metoda

It was necessary to disassemble the heating coils in order to capture the flow features, particularly since this study focused on the aerodynamics of a drying kiln. The same strategy was applied by several researchers (Arnaud *et al.*,1991; Bian, 2001; Hua *et al.*, 2001) in order to numerically investigate the airflow inside a lumber drying kiln. In particular, the pressure drop on the heating coils and other kiln elements (bends, baffles) is less than that of the lumber stacks (Perre and Keey, 2006).

The static pressure and air velocity were measured at two different positions (P1 and P2, see Figure 1b), in both air stream directions (normal and reverse). The measurements were done for five fan speeds, namely 1450, 1250, 1000, 750 and 500 min^{-1}. The fan speed was strictly controlled by a frequency inverter. The measurements were performed both in descending (1450…500 min^{-1}) and ascending order (500...1450 min^{-1}) to determine the experimental error. The kiln doors and vents were closed during the measurements.

At each point of interest, the static pressure and air velocity were recorded for 10 minutes, for each investigated fan speed; as a result, around 400 data were recorded for both static pressure and air velocity during this time. The static pressure was measured using a differential pressure sensor FD A602 – S1K with an accuracy of ±0.5 %, provided by Ahlborn. The static pressure probes with a diameter of 0.006 m were connected to the pressure sensor by means of two silicone hoses. The air velocity was measured using a rotating vane air velocity sensor FVA915S220, which was also delivered by Ahlborn, with an 11 mm measuring head diameter and an accuracy of ±3 %. Both sensors were connected to a data-logger Almemo 2590 – 4S. The

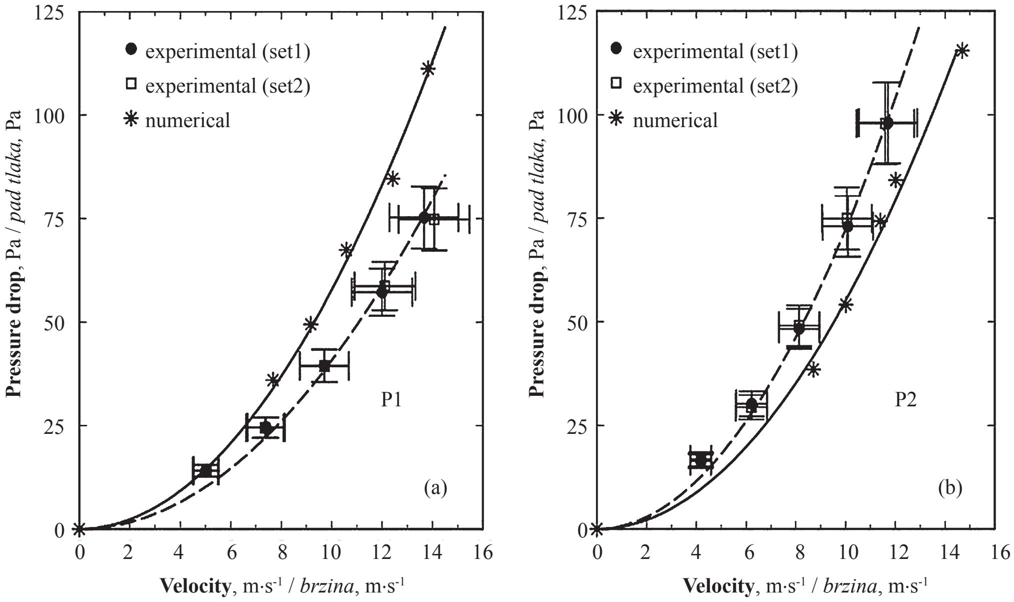


Figure 3 Validation of numerical results against experimental data measured in normal air flow direction at measuring points P1 (a) and P2 (b)

Slika 3. Provjera valjanosti numeričkih rezultata na temelju eksperimentalno dobivenih podataka pri normalnom smjeru protoka zraka na mjernim mjestima P1 (a) i P2 (b)

data were simultaneously recorded through different input channels. The AMR Control Software V.5.15 was used to acquire and transfer the data from the data-logger to a laptop computer.

2.5 Model validation
2.5. Provjera valjanosti modela

The numerical results are validated against the experimental data obtained in both directions of airflow. First, the measuring positions P1 and P2 located in the fan house are considered, see Figure 1. Figures 3 and 4 plot the pressure drop against the air velocity in both flow directions at these two points. A reasonable agreement between the numerical results (marked with stars) and the experimental data in the normal direction of the airflow was obtained (Figure 3). However, better agreement can be observed in the reverse direction of airflow (Figure 4). When comparing the results obtained in these two measuring locations (P1 and P2), a better validation of the numerical results against the experimental data is revealed at location P2, positioned near the false ceiling.

2.6 Numerical methodology for aerodynamic analysis of the drying kiln
2.6. Numerička metodologija za aerodinamičku analizu sušionice

When experimentally investigating the flow in a drying kiln, usually the average pressure is measured at the fan inlet and outlet. In addition, the loss coefficient

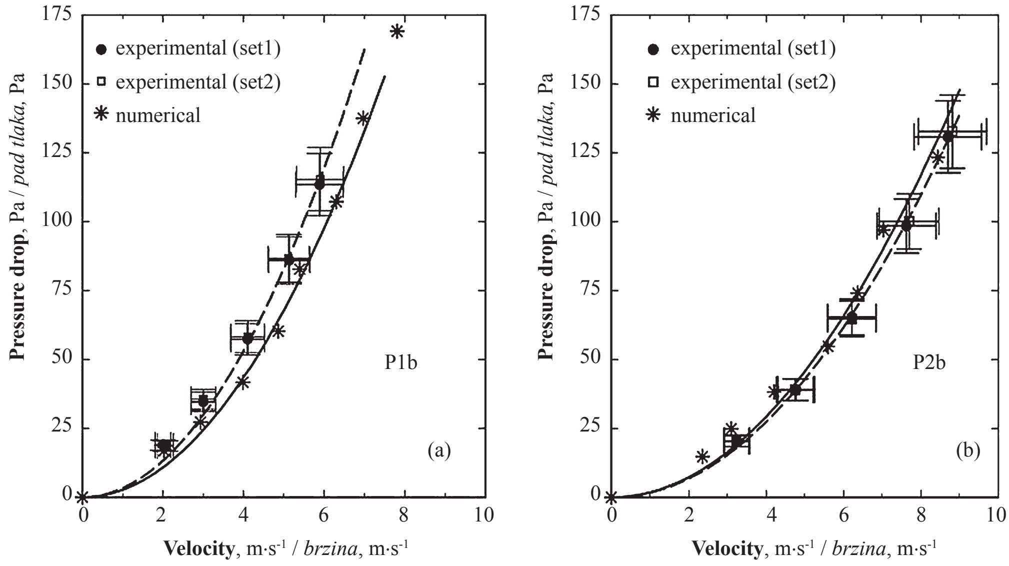


Figure 4 Validation of numerical results against experimental data measured in reverse air flow direction at measuring points P1 (a) and P2 (b)

Slika 4. Provjera valjanosti numeričkih rezultata na temelju eksperimentalno dobivenih podataka pri obrnutom smjeru protoka zraka na mjernim mjestima P1 (a) i P2 (b) is defined using the average air velocity, computed as the volumetric flow rate divided by the corresponding cross-section area. However, this rather simple approach, inspired from basic aerodynamics, does not provide meaningful results, especially when the flow is highly non-uniform, with large recirculation regions.

On the other hand, when a full 3D flow computation is performed on the drying kiln, both velocity and pressure fields are assessable in several sections, and a more rigorous approach can be employed to assess the flow within the control volume bounded by the closed surface consisting of the inlet section, outlet section and kiln walls, as shown in Figure 2b. When computing incompressible flows, the static pressure is defined up to an arbitrary constant. As a result, only pressure difference representations make sense. On the other hand, the dynamic pressure is relevant as an absolute value, since the lack of dynamic pressure clearly corresponds to flow stagnation.

Therefore, integral quantities are defined in order to compute the relevant parameters associated to the drying kiln aerodynamics. In order to analyze the energy transformation process, as well as its efficiency, the following integral quantities on a generic cross section *S* were introduced (Susan-Resiga *et al.*, 2010):

$$\Pi(S) \equiv \int_S p_p \cdot v_n \, dS \tag{3}$$

$$K(S) \equiv \int_S \frac{\rho \cdot v^2}{2} v_n \, dS \tag{4}$$

$$W(S) \equiv \Pi(S) + K(S) \tag{5}$$

Where, Π is the flux of the potential energy (W), K is the flux of the kinetic energy (W) and W is the flux of the mechanical energy (W) and v_n is the normal component of the velocity on the surface S.

In numerical computations, the static pressure is actually the piezometric pressure $p_p = p + \rho g z$. For a control volume of the drying kiln, bounded by the closed surface previously described, the net flux of the specific mechanical energy is

$$W = W_{IN} - W_{OUT} \tag{6}$$

For viscous flows, the viscous friction converts part of the mechanical energy into heat yield ($W > 0$). This energy flux imbalance is associated with the aerodynamic losses. As a result, $W(S)$ decreases monotonically from the inlet to the outlet of the drying kiln. In the present analysis, the authors considered only steady flows. Therefore, it is correct to consider the specific energy flux as defined by Eq. (6).

The total aerodynamic power, that has dissipated up to section S, is $W(S) - W_{out} > 0$, where $W_{out} = \Pi_{out} + K_{out}$ with $W_{out} = W(S_{out})$, $\Pi_{out} = \Pi(S_{out})$ and $K_{out} = K(S_{out})$, corresponding to the integral quantities on the annular outlet section.

The *energy loss coefficient* is usually defined as

$$\zeta(S) \equiv \frac{W(S) - W_{out}}{K_{out}} = \frac{\Pi(S) - \Pi_{out}}{K_{out}} - \left(1 - \frac{K(S)}{K_{out}}\right) \tag{7}$$

The first term in Eq. (7) corresponds to what is called the *potential energy coefficient*

$$c_\Pi(S) \equiv \frac{\Pi(S) - \Pi_{out}}{K_{out}} \tag{8}$$

while the second term in Eq. (7) corresponds to the so-called *kinetic energy coefficient*

$$c_K(S) \equiv 1 - \frac{K(S)}{K_{out}} \tag{9}$$

The variance in kinetic energy within the drying kiln should also be considered. The flux of specific kinetic energy is computed according to Eq. (4). On the other hand, for an ideal flow with constant average volumetric flow rate (normal) velocity on each cross-section, the flux of specific kinetic energy would be $K^{ideal}(S)$, defined by the following equation:

$$K^{ideal}(S) = Q \cdot \frac{\rho}{2} \cdot \left(\frac{Q}{S}\right)^2 \tag{10}$$

This is the reference baseline, and $K(S)$ will always have higher values. Consequently, the airflow non-uniformity can be quantified through the coefficient

$$\xi(S) \equiv \frac{K(S)}{K^{ideal}(S)} \tag{11}$$

Besides the non-uniformity coefficient $\xi(S)$, the kinetic energy excess is also relevant for the analysis of the drying kiln aerodynamics.

In practice, the pressure drop is usually examined instead of the aerodynamic power loss. The corresponding pressure loss for the kiln control volume is defined by the equation:

$$W = \Delta p \cdot Q \tag{12}$$

Where, Δp is the total pressure drop in the kiln (Pa) and Q is the volumetric flow rate ($m^3 \cdot s^{-1}$) computed according to the following equation:

$$Q(S) \equiv \int_S v_n \, dS \tag{13}$$

Where, v_n ($m \cdot s^{-1}$) is the normal component of the velocity on the surface S.

The following flow-related quantities associated with kiln drying are written in dimensionless form:

$$w = \frac{W}{\frac{1}{2} \cdot \rho \cdot v_{ref}^2 A_{ref}} \tag{14}$$

$$k = \frac{\Delta p}{\frac{1}{2} \cdot \rho \cdot v_{ref}^2} \tag{15}$$

$$q = \frac{Q}{v_{ref} \cdot A_{ref}} \tag{16}$$

Where, w is the dimensionless aerodynamic power loss, k is the dimensionless pressure loss, q is the dimensionless volumetric flow rate, A_{ref} is the reference area (m^2) associated to the annular inlet section and v_{ref} is the reference velocity ($m \cdot s^{-1}$) corresponding to the bulk velocity through the reference section.

Since the tested kiln had gaps around the stacks, the volumetric flow rate generated by the fan (Q) can be conveniently divided into two parts: one part goes through the stacks (Q_1) and the other goes around the stacks (Q_2) via the gaps. The bypass coefficient (b) in Eq. (21) is defined, according to Nijdam and Keey (1996), as a ratio between the two flow rates:

$$b = \frac{Q_2}{Q_1} \quad (17)$$

The aerodynamic efficiency of the kiln can be defined either as a ratio between the volumetric flow rate through the stacks (Q_1) and the total volumetric flow rate delivered by the fan (Q) or by means of the bypass coefficient, according to Eq. (18):

$$\eta = \frac{Q_1}{Q} = \frac{1}{(1+b)} \quad (18)$$

3 RESULTS AND DISCUSION
3. REZULTATI I RASPRAVA

3.1 Aerodynamic analysis of drying kiln
3.1. Aerodinamična analiza sušionice

The numerical simulations for turbulent flow in the drying kiln were performed in both airflow directions, for five fan speeds, as detailed in the experimental approach.

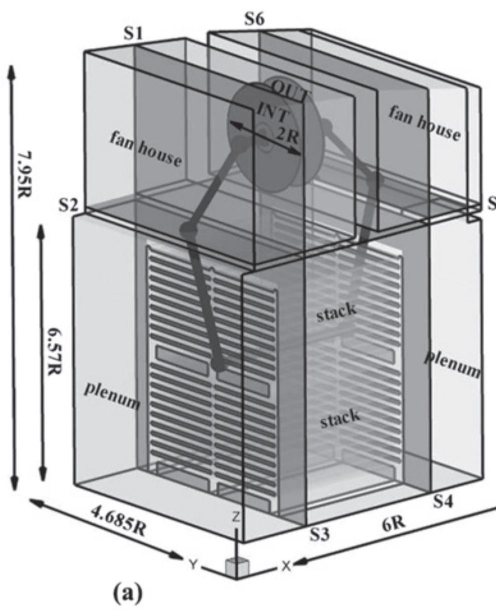
The cross-sections S of the kiln geometry, defined for the numerical analysis, are marked with grey shadows in Figure 5a. The thick black line represents the mid-line, which connects the successive centers (bold black bullets) of these cross-sections.

From the geometrical point of view, the airflow in the drying kiln is suddenly modified when the flow direction and/or the shape of the cross section changes along the kiln's mid-line, as shown in Figure 5b.

The cross-section area is expressed as a dimensionless size by relating it to the annular fan section, while the mid-line length is expressed as a dimensionless size by relating it to the outer fan radius. In our case, it can be observed that the mid-line length of the drying kiln is about fourteen times longer than the reference radius. It is important to mention that the lumber stacks are located approximately at mid length of the kiln's mid-line. Figure 5b shows a region with constant area distribution associated to the stacks and several sudden expansions/contractions of the cross-section area along the aerodynamic passage.

However, only one distribution is associated to each airflow direction using the dimensionless sizes. As a result, the distribution of the potential energy coefficient c_Π defined according to Eq. (8) is plotted against the dimensionless length of the kiln's mid-line, as illustrated in Figure 6a. The overall potential energy drop is the same in both airflow directions (normal and reverse). The potential energy drop from the annular inlet section to the stack is smaller than the value determined from the stack up to the outlet section in both airflow directions. The most significant variation of the potential energy coefficient is observed in the fan house located in front of the outlet section.

The kinetic energy coefficient c_K, expressed according to Eq. (9), is plotted versus the dimensionless length of the kiln's mid-line in Figure 6b. The overall kinetic energy difference, defined between the inlet and outlet sections of the drying kiln, is the same in both airflow directions (normal and reverse). In spite of this, the c_K distribution along the kiln's mid-line significantly differs between the normal and reverse direction of the airflow. A greater decrease is obtained up to the cross-section defined at the stack inlet in the normal flow direction compared to the reverse direction. This discrepancy includes the cross-section area variation from the annular fan inlet section to the stack inlet sec-



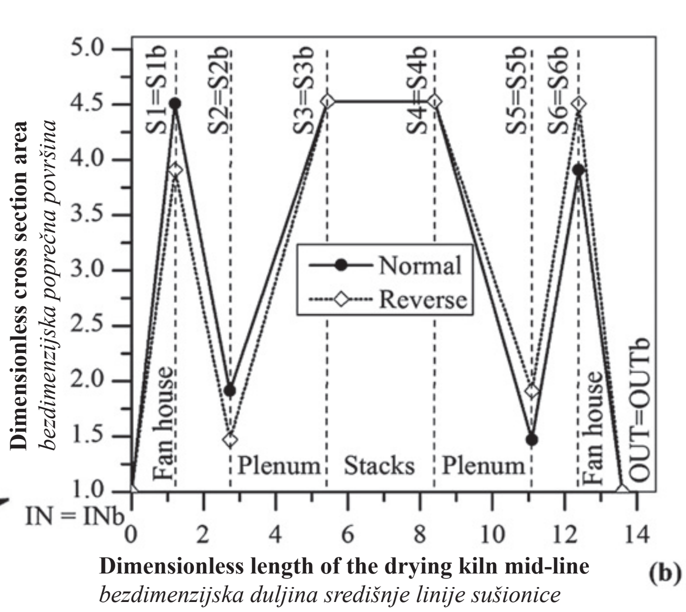


Figure 5 Kiln cross-sections (S1…S6) defined for the numerical analysis (a) and dimensionless cross-section area distribution vs. dimensionless length of the kiln mid-line (b) in ● normal and ◊ reverse air flow direction
Slika 5. a) Poprečni presjeci sušionice (S1…S6) određeni za numeričku analizu; b) raspodjela bezdimenzijske površine poprečnog presjeka sušionice u odnosu prema bezdimenzijskoj duljini središnje linije sušionice pri normalnome (●) i obrnutom (◊) smjeru protoka zraka

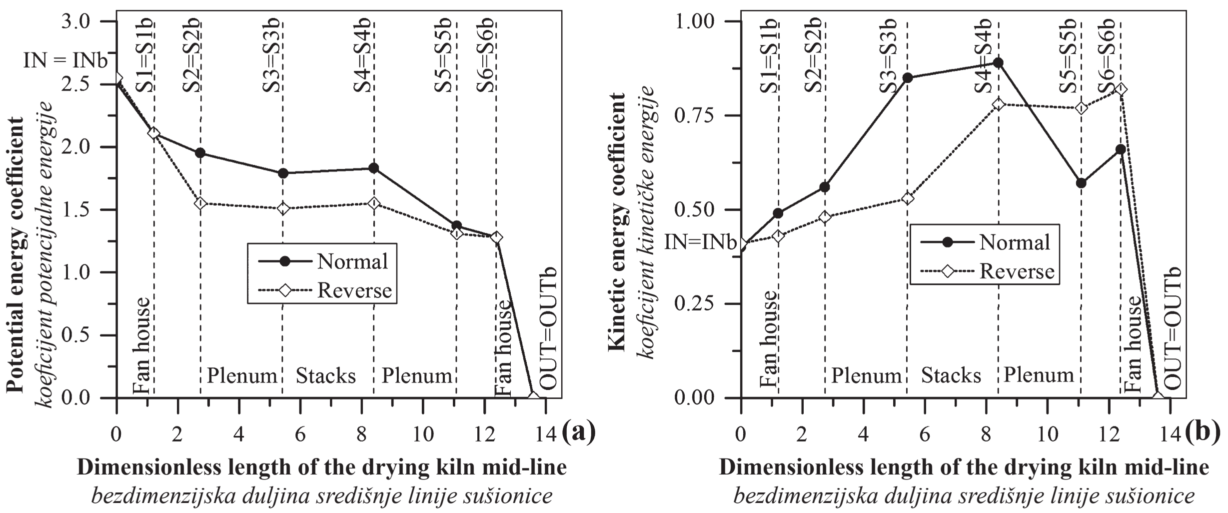


Figure 6 Distribution of potential (a) and kinetic energy (b) coefficient versus the dimensionless length of the kiln mid-line, in ● normal and ◊ reverse air flow direction

Slika 6. Raspodjela koeficijenta potencijalne (a) i kinetičke energije (b) u odnosu prema bezdimenzijskoj duljini središnje linije sušionice pri normalnome (●) i obrnutom (◊) smjeru protoka zraka

tion in both directions. A significant difference in the variation and values of the c_K in both directions is also revealed in the stacks. This difference is clearly generated by the aerodynamic conditions, because the cross-sectional area of the stack is considered constant from the point of the air inlet until the air outlet. In the last fan house, the kinetic energy increases again, due to the significant decrease of the cross-sectional area.

The energy loss coefficient ζ determined along the kiln's mid-line, as defined according to Eq. (7), is represented in Figure 7a. The overall energy loss coefficient between the inlet and outlet sections of the drying kiln is about 2.0 in both airflow directions. However, the energy loss coefficient distribution along the kiln's mid-line is different to that in the opposite airflow direction. The value of the energy loss coefficient is practically the same for the stack inlet cross-section (*S3* in the normal air direction and *S3b* in the reverse direction). This value is roughly half of the overall energy loss.

A monotonic decrease of the energy loss coefficient from the inlet to the outlet is revealed in both airflow directions. In the normal direction, the energy loss coefficient decreases up to the stack inlet cross-section, then it becomes negligible along the stacks and it decreases again, but considerably less, in the plenum and in the fan house. A significant difference observed in the reverse direction is contributable to the stacks region, where the energy loss coefficient is no longer constant, but instead decreases by approximately 10 % and is due to the distribution of the kinetic energy component, as depicted in Figure 6b.

The non-uniformity coefficient ξ defined according to Eq. (11) is illustrated along the kiln's mid-line in

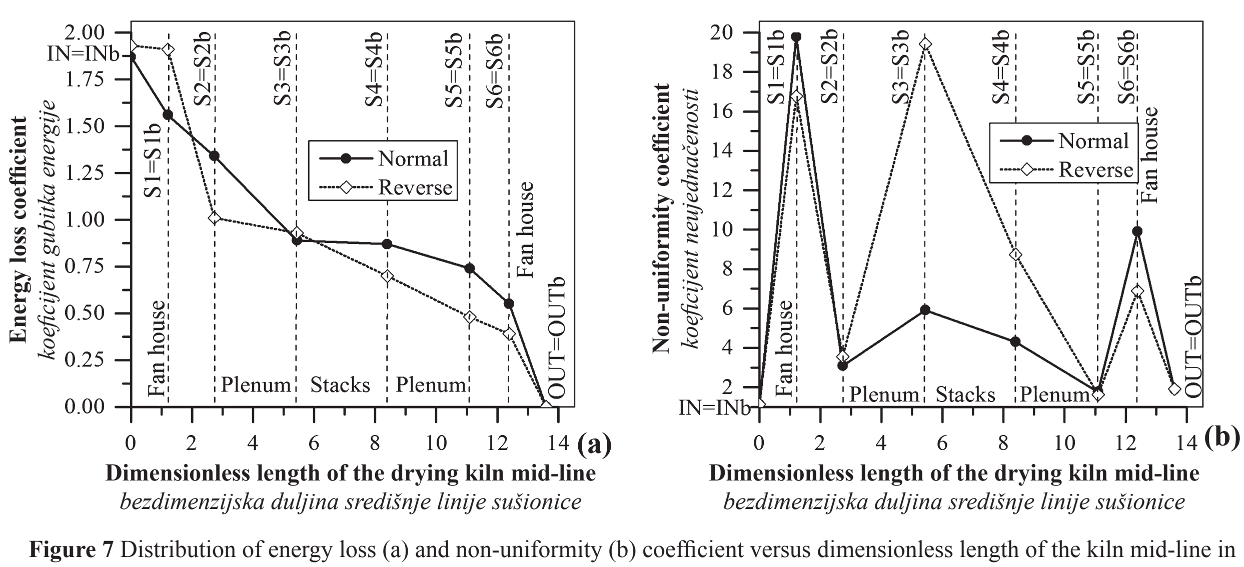


Figure 7 Distribution of energy loss (a) and non-uniformity (b) coefficient versus dimensionless length of the kiln mid-line in ● normal and ◊ reverse air flow direction

Slika 7. Raspodjela gubitka energije (a) i koeficijenta neujednačenosti (b) u odnosu prema bezdimenzijskoj duljini središnje linije sušionice pri normalnome (●) i obrnutom (◊) smjeru protoka zraka

Table 1 Overall dimensionless quantities associated to the given kiln configuration in both (normal and reverse) air flow directions
Tablica 1. Ukupne bezdimenzijske vrijednosti povezane s konfiguracijom sušionice u oba smjera protoka zraka (normalnome i obrnutome)

Dimensionless volumetric flow rate (q) *Bezdimenzijski volumni protok*		**Dimensionless aerodynamic power loss (w)** *Bezdimenzijski aerodinamički gubitak snage*		**Dimensionless pressure loss (k)** *Bezdimenzijski gubitak tlaka*	
Normal *Normalni smjer*	Reverse *Obrnuti smjer*	Normal *Normalni smjer*	Reverse *Obrnuti smjer*	Normal *Normalni smjer*	Reverse *Obrnuti smjer*
1.21		5.14 ±0.08	5.4 ±0.11	2.83 ±0.05	2.91 ±0.09

Figure 7b. This parameter is computed relative to the ideal value on each cross section, in order to avoid the influence of a variable flow area.

The unit value of this coefficient indicates a uniform distribution of the flow over the cross section. In contrast, larger values suggest a non-uniform flow compared to the ideal case. The non-uniformity coefficient distributions in both airflow directions reveal larger values. Thus, a greater degree of non-uniformity is observed in the fan house located in front of the inlet section. Naturally, the air jet delivered by the fan in the house leads to greater non-uniformity of the flow, which is in agreement with the numerical results. Moreover, the value in the normal flow direction is larger than the value in the reverse direction, due to the differences in the fan house geometry. Figure 1 shows that the fan house geometry is divergent in the normal flow direction, inducing thus large recirculation regions. However, the recirculation regions are smaller in the reverse flow direction due to the convergent fan house geometry.

The values of the non-uniformity coefficient ξ on the stack inlet and outlet cross-sections are 2 to 4 times larger in the reverse airflow direction than in the normal direction.

The overall dimensionless quantities associated with this configuration of the drying kiln, analyzed in both normal and reverse airflow directions, are given in Table 1. These overall values concerning aerodynamic parameters are useful in the design of axial fans for lumber drying kilns.

3.2 Bypass analysis
3.2. Analiza zaobilaženja

Considering the volumetric flow rate generated by the fan (Q), only 24 % in the normal direction and 25 % in the reverse direction pass through the sticker spaces (Q_1). The other part (Q_2) bypasses the stacks. This small percentage of volumetric flow rate that goes through the sticker spaces is due to the fact that the area of gaps around the stacks is about 1.15 times larger than that of the sticker spaces and, also, due to the fact that their aerodynamic resistance is smaller than that opposed by the stacks.

The bypass coefficient computed using Eq. (17) reveals that the volumetric flow rate that bypasses the stacks (Q_2), also called "air leakage", is about three times larger than the air quantity that goes through the sticker spaces (Q_1) in both air directions: the bypass coefficient is 3.15 for the normal airflow direction and 3.04 in the reverse direction. Therefore, the aerodynamic efficiency values of the tested kiln are, according to Eq. (18), 0.24 and 0.25, respectively, in the normal and reverse directions. These are very low values and they apply when the kiln is loaded at full capacity. When the kiln is partially loaded, the aerodynamic efficiency value is further reduced. This happens due to the increasing ratio between the aerodynamic resistance associated to the stack region and the aerodynamic resistance of the gaps around the stacks. Therefore, the drying kiln has to be equipped with baffles in order to overcome both negative effects of the air bypass upon the drying time and the drying uniformity (Riley, 2006; Bedelean and Sova, 2012).

The influence of the airflow direction upon the air losses recorded in each gap around the stacks at the inlet section (*S3* / *S3b*) is illustrated in Figure 8. The graph shows that the air leakage through the top gap (CPS) is 15 % higher in the reverse direction than in the normal direction. As a result, the reverse flow direction favors the drying of the first row of boards located in the upper stack. On the other hand, the air loss in the side gap (CPL) is approximately 13 % higher in the normal direction. The air loss in the vertical gap (CPV), however, is not as strongly influenced by the airflow direction, being only slightly (by 2 %) higher in the normal direction (Figure 8).

The air leakage balance between the inlet and outlet section is analyzed in Figure 9 in each airflow

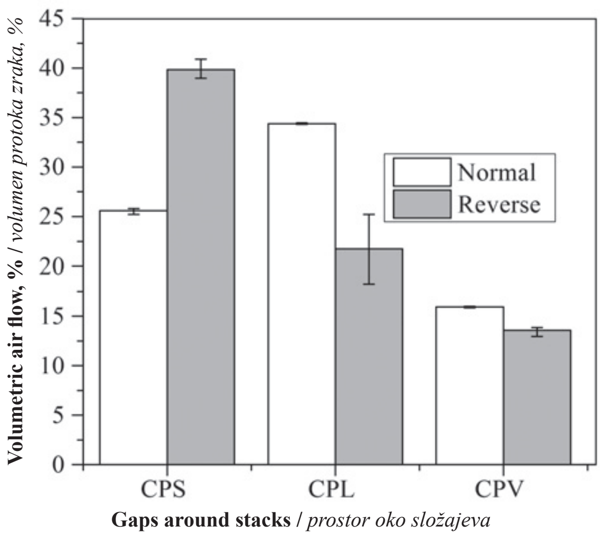


Figure 8 Distribution of air leakage (Q_2) on the stack inlet section in both flow directions
Slika 8. Raspodjela količine zraka koja pri oba smjera protoka zaobilazi složaj (Q_2) na njegovu ulaznom dijelu

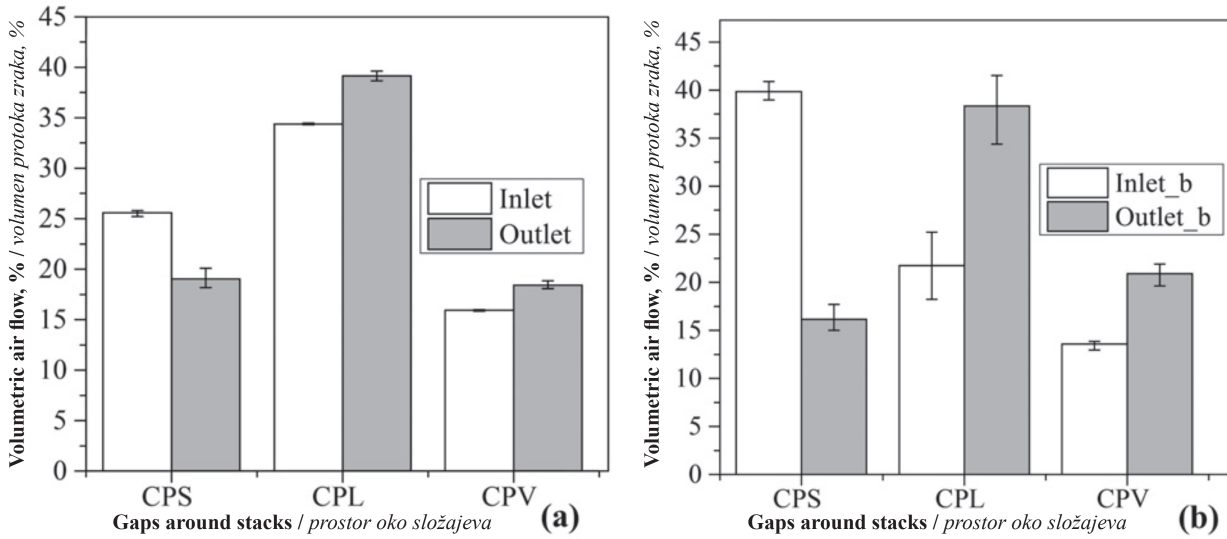


Figure 9 Distribution of air leakage on both the inlet (S3 and S3b) and outlet section (S4 and S4b) of the stacks in normal and reverse flow direction
Slika 9. Raspodjela količine zraka koja pri oba smjera protoka zaobilazi složaj na njegovu ulaznom (S3 i S3b) i izlaznom dijelu (S4 i S4b)

direction, in order to better understand the aerodynamics of the drying kiln.

A moderate air leakage balance (within a 7 % limit) is obtained in the normal flow direction between the inlet (*S3*) and outlet section (*S4*). In this case, air leakage through the top gap (CPS) of the outlet surface is redistributed towards the side gap (CPL) by 5 % and the vertical gap (CPV) by 2 %.

In the reverse direction, a significant redistribution of the air leakage between the inlet (*S3b*) and outlet sections (*S4b*) takes place. The air leakage through the top gap (CPS) ranges between 40 % (at the inlet) and 16 % (at the outlet), which means a difference of 24 % (Figure 9b). This value is 3.5 times greater than the air leakage in the normal flow direction. Correspondingly, 14 % and 10 % of the air leakage through the top gap (CPS) on the outlet surface is redistributed towards the side gap (CPL) and the vertical gap (CPV), respectively. The redistribution of the air losses along the flow path from the inlet towards the outlet section of the stacks is due to the pressure distribution in the outlet plenum of the drying kiln.

The convergent study is performed in order to assess the numerical solution accuracy. The bypass coefficient (*b*) and the aerodynamic efficiency (η) are computed on different grids. As a result, the relative error (*e*) is computed using Eq. (19) for both quantities (*b* and η) with respect to the corresponding value obtained on the finest grid (2.6M cells). The symbol ⊗ corresponds to the value obtained on the medium grid (2.1M cells) or coarse grid (1.2M cells), respectively.

$$e_{\otimes} = \frac{\otimes - \otimes_{2.6\,M}}{\otimes_{2.6\,M}} \mathbf{x} 100\ [\%] \quad (19)$$

The relative error (*e*) values for both quantities (*b* and η) and both grids (medium and coarse) are included in Table 2. The relative error values associated to the aerodynamic efficiency computed on both grids (coarse and medium) are less than 5 %. Therefore, the numerical results selected for validation against experimental data belong to the medium grid.

Table 2 Numerical results determined by convergence study
Tablica 2. Numerički rezultati dobiveni konvergentnom analizom

Quantity / *Veličina*	**Grid type** / *Vrsta mreže*		
	Coarse *Gruba*	Medium *Prosječna*	Fine *Fina*
b	3.06	3.15	3.26
e_b, %	-6.14	-3.37	---
η	24.63	24.10	23.47
e_η, %	4.94	2.68	---

4 CONCLUSION
4. ZAKLJUČAK

The paper introduces a methodology developed to assess the aerodynamic performances of lumber drying kilns. The 3D computational domain corresponds to half of the drying kiln (by dividing the kiln along a symmetry plane at mid length) including a fan, two wood stacks and the airflow loop. The 3D turbulent computations are performed for five fan speeds considering air flow in both normal and reverse directions. A finite volume method (FVM) was used to solve the incompressible flow equations. The Reynolds stress model (RSM) was selected in order to capture the features of the turbulent flow associated with a drying kiln.

The experiment was carried out in a 4 m^3 heat-and-vent kiln loaded at maximum capacity, and five different fan speeds under reversible airflow conditions were tested. The numerical results obtained were validated against the experimental data that were measured in the drying kiln. A reasonable agreement was obtained between the numerical results and the experimental data in both airflow directions.

Further, the methodology core was embedded in the integral quantities defined in the paper. This approach was taken in order to assess the aerodynamic performances of the drying kiln, by expressing the energy loss coefficient and the non-uniformity coefficient. The energy loss coefficient was determined based on the computed potential and kinetic energy coefficients. The value of the overall energy loss coefficient between the inlet and outlet section of the drying kiln in both airflow directions was determined to be about 2. However, the energy loss coefficient distribution along the drying kiln differed from one airflow direction to the other. A significant difference was observed in the reverse direction, which contains the stacks region; here the energy loss coefficient was no longer constant, but it decreased by approximately 10 % due to the distribution of the kinetic energy component.

The non-uniformity coefficient is considered a good indicator for quantifying the flow distribution with respect to the ideal one. Larger values suggest greater flow non-uniformity. The non-uniformity coefficient distributions in both airflow directions reveal larger values in the fan house located in front of the inlet section. This is in good agreement with the numerical results.

Finally, the bypass coefficient and the aerodynamic efficiency were computed, in order to assess the aerodynamic performances of the drying kiln. The bypass coefficient revealed that the quantity of air that goes around the stacks is three times greater than the quantity of air that passes through the sticker spaces for the given configuration. As a result, very low aerodynamic efficiency values were yielded: 24 % in the normal flow direction and 25 % in the reverse direction, even with a full-loaded kiln. A detailed analysis of air leakage through each gap around the stacks revealed changes in the percentage of air loss through the top gap (from inlet to outlet section), namely, 7 % and 24 % in the normal and reverse airflow directions, respectively. In order to overcome the negative effects of the air bypass upon the drying time, energy consumption and drying uniformity, the drying kiln has to be equipped with baffles.

The methodology developed and validated in this paper can be further applied to assess the aerodynamic performance of lumber drying kilns with different configurations. Also, various solutions (*e.g.* baffles) to improve the airflow in lumber drying kilns could be simulated based on the quantities defined in this paper (*e.g.* energy loss coefficient, non-uniformity coefficient and bypass coefficient).

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Influence of Thermal Modification on Surface Properties and Chemical Composition of Beech Wood (*Fagus sylvatica* L.)

Utjecaj toplinske modifikacije na površinska svojstva i kemijski sastav bukovine (*Fagus sylvatica* L.)

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ABSTRACT • *Thermal modification leads to the degradation of the compounds in wood, thereby changing the chemical composition of wood, which can affect the further wood finishing. In order to determine the effect of thermal modification on wood finishing, it is important to know the properties of its surface. In this research, the influence of thermal modification on pH, surface free energy, contact angle of coating and chemical composition of beech wood was studied. The results of this study show that acidity and water contact angle on beech wood was higher and polar component of surface free energy was lower after thermal modification. Furthermore, contact angle of waterborne coating on beech wood was increased by increasing the modification temperature and the content of extractives soluble in hot water and in organic solvent was increased after thermal modification of beech wood.*

Key words: *thermal modification, contact angle, surface free energy, wood chemical composition*

SAŽETAK • *Toplinska modifikacija uzrokuje razgradnju spojeva u drvu, čime se mijenja kemijski sastav drva što može utjecati na njegovu površinsku obradu. Kako bi se utvrdio učinak toplinske modifikacije na površinsku obradu drva, važno je znati svojstva njegove površine. U ovom je radu istraživan utjecaj toplinske modifikacije na pH drva, njegovu slobodnu površinsku energiju, kvašenje premaza i na kemijski sastav bukovine. Rezultati istraživanja pokazuju da je toplinska modifikacija povećala kiselost drva i kut kvašenja vode na bukovini i smanjila polarne komponente slobodne površinske energije. Nadalje, kut kvašenja vodenog premaza na bukovini povećao se s povećanjem temperature modifikacije, a sadržaj ekstraktiva topljivih u vrućoj vodi i organskom otapalu povećao se nakon toplinske modifikacije bukovine.*

Ključne riječi: *toplinska modifikacija, kut kvašenja, slobodna površinska energija, kemijski sastav drva*

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1 INTRODUCTION
1. UVOD

Thermally modified wood, also known as the heat treated wood, has large application outdoors due to reduced hygroscopicity, improved dimensional stability, improved biological durability and attractive appearance, especially for facades, decking and garden furniture. Despite some improved properties compared to unmodified wood, thermally modified wood is still susceptible to surface degradation by weathering when exposed to outdoor conditions. Therefore, it is necessary to protect the surface of the thermally modified wood to prevent discolouration and formation of surface cracks (Militz, 2002; Miklečić *et al.*, 2010). In order to determine the effect of thermal modification on wood finishing, it is important to know the properties of surface of thermally modified wood such as pH (Ljuljka *et al.*, 1996), wettability (Pétrissans *et al.*, 2003) and surface free energy (De Meijer *et al.*, 2000). In previous research, Bonstra *et al.* (2007) reported that high temperatures lead to the increase of wood acidity. Moreover, according to research of Gérardin *et al.* (2007) and Petrič *et al.* (2012), thermal modification reduces the surface free energy of wood. However, there is no information in literature on the influence of thermal modification on contact angle of waterborne coatings. Furthermore, the change of chemical composition of wood after thermal modification can disrupt the interaction between coating and wood surface. This applies particularly to extractives, which have influence on coating adhesion strength and wettability (Ghofrani *et al.*, 2015).

The aim of this study was to analyse the influence of thermal modification on the surface pH, free energy and contact angle of waterborne coating of beech wood. These characteristics of wood surface could affect the interaction between wood and coating. Furthermore, we wanted to analyse the influence of thermal modification on the change of chemical composition of wood.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Radial-textured samples of unmodified and thermally modified beech wood (*Fagus sylvatica* L.) with no visible defects were used in this study. Beech wood is the most widely distributed three species in Croatia and it is often modified to open up new fields of application. The samples had 4-5 annual rings per centimetre, and the width of annual ring was 2-2.5 mm with 30-48 % share of latewood. All wood samples were conditioned to 8.4 % moisture content at (23 ± 2) °C and (50 ± 5) % relative humidity (RH).

Eight wood samples with dimensions of 1020 mm x 150 mm x 28 mm (*L* x *R* x *T*) have been modified using high temperature and vapour in commercial heat treatment chamber in the industrial process of modification without the use of chemicals. Two temperatures were used for the modification: 190 °C - lighter samples

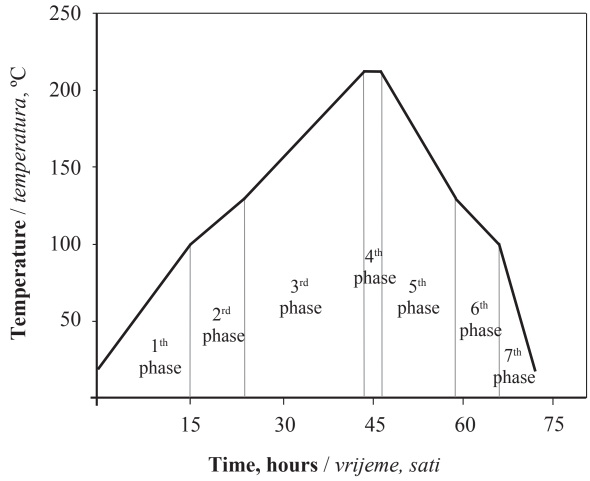

Figure 1 Phases of industrial thermal modification of wood samples
Slika 1. Faze toplinske modifikacije uzoraka drva u industrijskom procesu

(S) and 212 °C - darker samples (T), as used in ThermooWood process (Finish Thermowood Association). The process of thermal modification lasted 74 hours (Figure 1) and was conducted in seven phases.

2.1 Determination of wood pH
2.1. Određivanje pH drva

For the determination of wood pH, a water extract from the wood was prepared according to the methods of Pedieu *et al.* (2008). For each type of tested wood, a sample of 25 g was milled and dried at (103 ± 2) °C to the constant weight, and then conditioned in a desiccator to (23 ± 2) °C. Following conditioning, the sample was added into 250 mL of boiling deionised water and boiled for 20 min in the Erlenmeyer flask with a reflux condenser. The solution was then filtered and cooled to 23 °C. The pH of the filtered sample was measured with pH meter *Mettler Toledo - SG7*. Three measurements were made for each type of wood sample.

2.2 Determination of wood surface free energy
2.2. Određivanje površinske energije drva

The surface free energy of unmodified and thermally modified wood samples was calculated from the average contact angles using the Owens Wendt Rabel and Kaelble (OWRK) method (Wu, 1971) and using the Lifshitz-van der Waals - Acide Base (LW-AB) method (Good, 1992). The contact angle used for calculating the surface free energy was measured by the Wilhelmy method. According to that method, a wood sample is immersed in a liquid of known surface tension to a certain depth and the force acting on a vertically immersed plate is measured (Hakkou *et al.*, 2005). In this study, deionised water and formamide as polar liquids and diiodomethane as nonpolar liquid were used (Table 1).

For the determination of surface free energy, four unmodified (N) and thermally modified wood samples were prepared at 190 (S) and 212 °C (T) with dimensions of 100 mm x 30 mm x 2 mm. Each sample was then sawn up into three samples with dimensions of 20

Table 1 The values of surface tension and surface tension components of water, formamide and diiodomethane presented in mJ/m²
Tablica 1. Vrijednosti površinske napetosti i komponenti površinske napetosti vode, formamida i dijodometana prikazane u mJ/m²

Liquid *Tekućina*	γ_L	**LW-AB method**				**OWRK method**	
		γ_i^{LW}	γ_i^+	γ_i^-	γ_i^{AB}	γ_L^d	γ_L^P
Deionised water / *deionizirana voda*	72.8	21.8	25.5	25.5	51.0	22.0	50.2
Formamide / *formamid*	58.0	39.0	2.3	39.6	19.0	32.3	26.0
Diiodometane / *dijodometan*	50.8	50.8	0.00	0.00	0.00	50.8	0.00

Table 2 Composition of waterborne polyacrylate coating
Tablica 2. Sastav vodenoga poliakrilatnog premaza

Name of component *Naziv sastavnice*	**Type of component** *Vrsta sastavnice*	**Content, %** *Sadržaj, %*
Binder / *vezivo*	Esters of acrylic and metacrylic acid and styrene *esteri akrilne i metakrilne kiseline i stiren*	70.00
Solvent / *otapalo*	Deionised water / *deionizirana voda*	19.00
Coalescent / *koalescent*	Isopropyl alcohol, butyl glycol / *izopropilni alkohol, glikol butil*	0.80
Rheological additive /*reološki aditiv*	Nonionic / *neionski*	0.40
Defoaming agent /*sredstvo protiv pjenjenja*	Silicone type / *tip silikona*	0.30
Wetting agent /*Sredstvo za vlaženje*	Silicone type / *tip silikona*	0.15
Wax / *vosak*	Paraffin and high-density polyethylene *parafin i polietilen velike gustoće*	8.20
Other components / *ostale sastavnice*	No dana / *nema podataka*	0.85

mm x 30 mm x 2 mm (L x R x T) and sanded with 80, 120 and 180 grid paper. The cross section of the prepared samples was immersed in nitrocellulose lacquer (2 mm) to exclude the absorption of test liquids, and then the samples were conditioned for 24 hours at (23 ± 2) °C and (50 ± 5) % RH. The first sample was used to determine the advancing contact angle of deionised water, the second of formamide (99+ %, J. T. Baker, USA) and the third of diiodomethan (99+ % Across Organics Belgium). The measurements were carried out at (23 ± 2) °C and (50 ± 5) % RH with the tensiometer (Krüss K100) by immersing the wood samples in a radial direction with the following parameters: speed before touching the liquid 6 mm/min, touch sensitivity 0.01 g, immersion velocity 12 m/min, immersion depth before measuring 2 mm, maximum immersion depth 7 mm.

2.3 Determination of contact angle of waterborne coating
2.3. Određivanje kuta kvašenja vodenog premaza

The contact angle was measured by the sessile drop method using a *Krüss Drop Shape Analysis System - DSA100*. Two unmodified (N) and thermally modified wood samples were prepared at 190 (S) and 212 °C (T) with dimensions of 30 mm x 20 mm x 5 mm (*L* x *R* x *T*). The samples were sanded with 80, 120 and 180 grid paper and conditioned for 72 hours at (23 ± 2) °C and (50 ± 5) % RH followed by measurement. For each sample, three drops of 5 µL of waterborne polyacrylate coating (Table 2) were deposited on the wood sample at different locations.

The value of contact angle was taken after 2 seconds of contact of the coating drop and the wood sample, because the preliminary results showed that this period of time is necessary in order to obtain drop stabilisation. The obtained contact angle was the mean value of the left and right contact angle of the drop.

2.4 Determination of wood chemical composition
2.4. Određivanje kemijskog sastava drva

The unmodified and thermally modified samples were milled and sieved to obtain a fraction between 1.19-1.25 mm. The extractives content in the wood samples soluble in organic solvent was determined according to ASTM D1107 with a mixture of ethanol-benzene (1:1, v/v %), and the extractives content soluble in hot water was determined according to ASTM D1110. The obtained extract was dried in an oven at (103 ± 2) °C to constant weight and the extractives content was determined after isolation and drying to constant mass using the gravimetric method. The lignin content in the wood was determined by Klason method according to TAPPI T222om-11 on the extracted samples with a mixture of ethanol-benzene in which the water content was measured. Similarly as the lignin content, cellulose content was determined on the extracted samples with a mixture of ethanol-benzene in which the water content was measured according to the method of Miranda *et al.* 2012 (as cited in Kürscher and Hoffer, 1929). The lignin and cellulose content was determined gravimetrically in relation to absolutely dry extracted sample. In determining of extractive, lignin and cellulose content, two measurements were made for each type of wood sample.

3 RESULTS AND DISCUSION
3. REZULTATI I DISKUSIJA

The pH results presented in Table 3 show that thermal modification caused an increase in acidity of beech wood. As a reason for the increasing of wood acidity, Bonstra *et al.* (2007) indicated the formation of formic and acetic acid in the wood when it is subjected to high temperatures. They obtained a slightly higher acidity of thermally modified wood (pH = 3.5-4), but this may be due to the use of different wood species and different parameters during the process of thermal modification. From the obtained results, it can be concluded that there was no significant difference between the lower and higher temperature of modification, suggesting that already at 190 °C major changes in the pH of beech wood occurred. An increase in the acidity of thermally modified wood can have a negative effect on curing of coatings and on the interaction of thermally modified wood with metal objects.

The contact angle values of water, formamide and diiodomethane on unmodified and thermally modified wood are presented in Table 4. The results show that the water contact angle on thermally modified beech wood was higher compared to formamide and diiodomethane. Similar results were obtained for spruce wood (*Picea abies* Karst.) thermally modified in initial vacuum (Petrič *et al.*, 2012). Furthermore, the increasing of the modification temperature caused increasing of the water contact angle. Hakkou *et al.* (2005) reported that after heat treatment in the temperature range between 100 and 160 °C, the wood wettability changed suddenly.

Table 3 pH values of unmodified beech wood (N), thermally modified beech wood at 190 °C (S) and thermally modified beech wood at 212 °C (T)
Tablica 3. pH vrijednost nemodificirane bukovine (N), bukovine toplinski modificirane na 190 °C (S) i na 212 °C (T)

Type of wood *Vrsta drva*	pH
N	4.9 (0.00)*
S	4.3 (0.01)
T	4.4 (0.01)

* The values in parentheses are standard deviations. / *Vrijednosti u zagradama standardne su devijacije.*

One of the reasons of higher contact angle of water on the modified wood can be partial degradation of hemicellulose associated with the reorganisation of lignocellulosic compounds in the wood, which is the main cause of hydrophobicity of thermally modified wood (Pétrissans *et al.*, 2003; Hakkou *et al.*, 2005; Gérardin *et al.*, 2007). Furthermore, increasing of the contact angle of water can also cause extractives for which Ayrilmis *et al.* (2009) found that during the thermal modification migrate towards the wood surface and inactivate it. Extractives on the wood surface can also contaminate the test liquid, which can affect the measurement of the water contact angle with Wilhelmy method (Walinder and Johansson, 2001).

Smaller contact angle of formamide on thermally modified wood compared to unmodified wood was unexpected. It was expected that the ratio of the contact angle of formamide on thermally modified wood as compared to unmodified wood would be similar to the contact angle of water as reported by Gérardin *et al.* (2007) on beech wood (*Fagus sylvatica* L.) and pine wood (*Pinus sylvestris* L.) and Pavlić (2009) on pine wood (*Pinus sylvestrys* L.), because formamide is a polar liquid like water. One of the reasons for a lower contact angle may be less polarity of formamide compared to water. Petrič *et al.* (2012) reported that the contact angle of formamide can be affected by increased porosity of thermally modified wood and specific chemical reactions in the wood caused by thermal modification. Swelling of the polysacharide cell wall caused by dimethyl formamide as determined by Inari *et al.* (2007) may be the cause of low contact angle of formamide compared to the contact angle of water. They also noticed that the chemical modification of wood with phenolic isocyanate in dimethyl formamide had a stronger impact on lignin in thermally modified wood than on lignin in unmodified wood. Table 4 also shows that the contact angle of diiodomethane increased with thermal modification of beech wood and was higher on thermally modified wood at 190 ° C than at 212 ° C. In the literature there are various data for the contact angle of diiodomethane on wood, from values of more than 70° on spruce wood (*Picea abies* L.) and meranti wood (*Shorea* spp.) (De Meijer *et al.*, 2000) to values not significantly higher than 0 ° on viscoelastic thermal compressed wood (Petrič *et al.*, 2009). From the three test liquids, the smallest dissipation of the contact angle measurements was recorded for the water. A marked increase in the contact angle of water on thermally modified wood will result in poor wetting of aqueous coatings, which may affect the adhesion and properties of coated thermally modified wood during use.

Table 4 Average values of the contact angle (Θ_a) on unmodified (N) and thermally modified beech wood at 190 °C (S) and 212 °C (T)
Tablica 4. Srednje vrijednosti kontaktnog kuta (Θ_a) na nemodificiranoj bukovini (N) i na bukovini toplinski modificiranoj na 190 °C (S) i 212 °C (T)

Type of substrate *Tip podloge*	**Contact angle** / *kontaktni kut*, Θ_a (°)		
	Water *Voda*	Formamide *Formamid*	Diiodomethane *Dijodometan*
N	55.9 (3.41)*	38.3 (6.66)	34.2 (9.97)
S	73.0 (1.15)	31.1 (6.12)	45.7 (4.60)
T	81.1 (2.40)	32.4 (5.96)	35.6 (5.99)

* The values in parentheses are standard deviations. / *Vrijednosti u zagradama standardne su devijacije.*

Results of the surface free energy, dispersing and polar component of the surface free energy of unmodified and thermally modified wood (Table 5) were calculated according to Owens Wendt Rable Kaebi method and to the Lifshitz-van der Waals - Acid Base method. The contact angle results on the wood surface, from which the surface free energy is calculated, depend on a number of variables such as measurement methods, the preparation of the wood surface, measuring time, moisture content, course-grained, early and late wood, surface roughness, surface contamination. With such a large number of influencing variables, comparison of the results of the surface free energy from the literature can only provide limited information. According to OWRK method, a reduction of the surface free energy of thermally modified beech wood compared to unmodified wood was obtained with a slight increase of disperse and a high decrease of the polar component with an increase of modification temperature (Table 5). Gérardin *et al.* (2007) obtained similar results for thermally modified beech (*Fagus sylvatica* L.) and pine wood (*Pinus sylvestris* L.) and Petrič *et al.* (2012) for thermally modified spruce wood (*Picea abies* Karst.). Results according to LW-AB method also show a reduction of the surface free energy of thermally modified wood compared to unmodified wood. However, only on the samples modified at a higher temperature (212 °C), a strong reduction of the polar component was obtained (Table 5). These results indicate that there is a difference between these two methods of calculating the surface free energy of wood, which should be taken into consideration when they are compared. The resulting reduction of the surface free energy of thermally modified wood is too small to have a greater influence on wetting and adhesion of coatings. However, a marked decrease of the polar component indicates that the polar liquids, such as waterborne coatings, will poorly wet the surface of thermally modified wood, which may result in poorer adhesion.

Figure 2 shows that the wetting of the waterborne coating was better on the surface of the unmodified wood than on the surface of thermally modified wood i.e. it had a higher contact angle on thermally modified wood. The increase of the contact angle of waterborne coating on thermally modified wood was expected because of increasing of the contact angle of water on thermally modified wood (Table 4). Furthermore, the increasing of the coating contact angle on thermally modified wood can be caused by reducing the polar component of the surface free energy (Table 5). It can also be noted that the contact angle of the coating was increased with the increase of the modification temperature, which can be the result of increasing the crystallinity of cellulose (Pétrissans *et al.*, 2003) and increasing the extractive content in thermally modified wood (Figure 3).

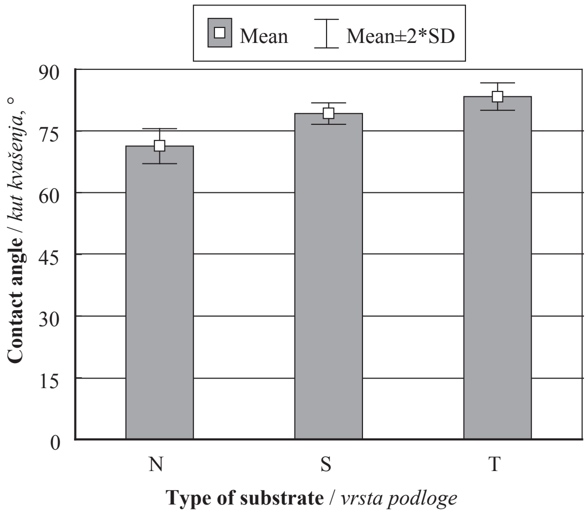

Figure 2 Contact angle of waterborne polyacrylate coating on unmodified (N) and thermally modified beech wood at 190 °C (S) and 212 °C (T)
Slika 2. Kut kvašenja vodenoga poliakrilatnog premaza na nemodificiranoj bukovini (N) i na bukovini toplinski modificiranoj na 190 °C (S) i 212 °C (T)

Figure 3 presents the content of extractives (soluble in hot water and organic solvent), cellulose and lignin before and after thermal modification of beech wood. It can be seen that the content of extractives soluble in hot water was increased after modification regardless of the modification temperature, while the content of extractives soluble in organic solvent and lignin was increased with the increase of the modification temperature. Similar results were obtained for thermally modified Norway spruce (*Picea abies* L.), Scots pine (*Pinus sylvestris* L.) and Radiata pine (*Pinus radiate* D.) (Boonstra and Tjeerdsma, 2006) and for Turkey oak (*Quercus cerris* L.) (Todaro *et al.*, 2013). According to the research of Esteves and Pareira (2009), most extractives disappear or decompose during thermal modification; however, new compounds are formed, which are isolated as a result of degradation of the compounds in the cell walls of the wood. Boonstra and Tjeerdsma (2006) noted that increasing of the extractives content also attributed to the degradation of the cell walls of the

Table 5 Surface free energy of unmodified (N) and thermally modified beech wood at 190 °C (S) and 212 °C (T) obtained by OWRK method
Tablica 5. Slobodna površinska energija nemodificirane bukovine (N) i bukovine toplinski modificirane na 190 °C (S) i 212 °C (T) dobivene OWRK metodom

Type of substrate *Tip podloge*	**Surface free energy** / *Slobodna površinska energija*, mJ/m²							
	OWRK method			LW-AB method				
	s_{spolar}	$s_{sdispers}$	s_{stotal}	γ_{SV}^{LW}	γ_{SV}^{+}	γ_{SV}^{-}	γ_{SV}^{AB}	γ_{tot}
N	13.9	38.7	52.6	42.4	20.9	0.4	6.1	48.5
S	6.8	39.9	46.7	36.7	2.4	4.7	6.8	43.4
T	2.6	46.3	48.9	41.8	0.1	4.0	1.4	43.2

s_{spolar} – polar component / *polarna komponenta*
$s_{sdispers}$ – dispersion component / *disperzijska komponenta*
s_{stotal} – total surface free energy / *ukupna slobodna površinska energija*
γ_{SV}^{LW} – Lifshitz–van der Waals component / *Lifshitz-van der Waalsova komponenta*
γ_{SV}^{+} – Lewis acid parameter / *Lewisov kiselinski parametar*
γ_{SV}^{-} – Lewis base parameter / *Lewisov bazni parametar*
γ_{SV}^{AB} – Lewis acid–base component / *Lewisova kiselinsko-bazna komponenta*
γ_{tot} – total surface free energy / *ukupna slobodna površinska energija*

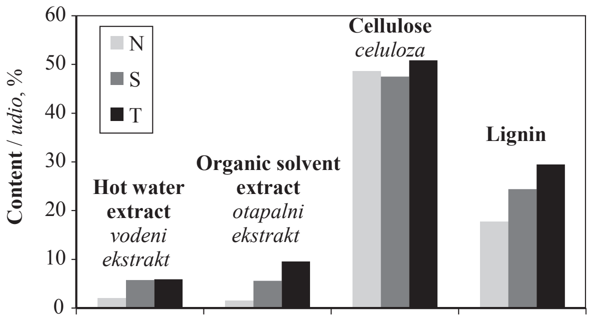

Figure 3 Percent content of extractives, cellulose and lignin in unmodified (N) and thermally modified beech wood at 190 °C (S) and 212 °C (T)
Slika 3. Postotni udio ekstraktivnih tvari, celuloze i lignina u nemodificiranoj bukovini (N) i u bukovini toplinski modificiranoj na 190 °C (S) i 212 °C (T)

wood. Therefore, it can be assumed that increasing of extractives content after thermal modification of beech wood indicates a greater degradation of the wood. Kamdem *et al.* (2002) suggested that higher lignin content does not mean the creation of new lignin during thermal modification than a reduction of other compounds in the wood. Furthermore, higher lignin content after thermal modification can be explained by the formation of some compounds by the thermal decomposition of carbohydrate, which can be contained in the isolated lignin (Yildiz *et al.*, 2006). The content of cellulose was slightly changed after thermal modification of beech wood, indicating that the cellulose is stable at high temperatures up to 212 °C.

4 CONCLUSION
4. ZAKLJUČAK

In this research, it was found that thermal modification caused higher acidity of beech wood, while there were no significant differences in wood pH between modification temperature at 190 °C and 212 °C.

Furthermore, thermal modification caused higher contact angle of water and lower polar component of wood surface free energy, which led to poor wetting of the thermally modified beech wood with waterborne coating.

The results showed that there is a difference between OWRK and LW-AB methods of calculation of wood surface free energy.

The contact angle of waterborne coating was increased on thermally modified beech wood with the increase of the modification temperature.

The content of extractives soluble in hot water and in organic solvent was higher after thermal modification. However, the content of extractives soluble in organic solvent increased with the increase of the modification temperature, which can be an indicator of wood degradation at high temperatures.

Klason method of lignin isolation proved not suitable for lignin isolation from thermally modified wood because with this method wood compounds formed by the thermal decomposition can be isolated.

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Mechanical Properties of Finger-Jointed Wood from Composite Utility Poles Made of Small Diameter Timber

Mehanička svojstva zupčasto spojenog drva od kompozitnih stupova proizvedenih od tanke oblovine

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ABSTRACT • *Engineering small diameter timber into structural members may provide an efficient way to utilize low-value material obtained after forest thinning operations. This study evaluates the strength and stiffness properties of finger-jointed and solid wood small clear samples cut from composite poles made of small diameter timber. The strength and stiffness of finger-jointed small clear samples were compared with the strength and stiffness of solid wood small clear samples and the strength and stiffness of composite poles. Finger-jointed samples tested in a perpendicular orientation, yielded the lowest bending strength but were not significantly lower than samples tested in a parallel orientation. Therefore, finger joint orientation was not a significant factor regarding the strength of the poles. The bending strength of composite poles was usually lower than the strength of the solid wood samples but higher than the strength of finger-jointed samples cut from the poles. However, the bending stiffness of the composite poles was substantially higher than the bending stiffness of both solid wood and finger-jointed samples cut from the poles.*

Key words: *bamboo, finger-joints, poles, small diameter timber*

SAŽETAK • *Prerada tanke oblovine u konstrukcijske elemente može biti učinkovit način iskorištavanja oblovine niske vrijednosti dobivene nakon operacije prorjeđivanja šuma. U ovoj studiji procjenjuju se čvrstoća i krutost uzoraka drva sa zupčastim spojem i uzoraka cjelovitog drva od kompozitnih stupova proizvedenih od tanke oblovine. Čvrstoća i krutost malih uzoraka drva sa zupčastim spojem uspoređena je s čvrstoćom i krutošću malih uzoraka od cjelovitog drva te s čvrstoćom i krutošću kompozitnih stupova. Uzorci sa zupčastim spojem opterećeni okomito na spoj imali su najmanju čvrstoću na savijanje, no čvrstoća im nije bila znatno manja od čvrstoće uzoraka sa zupčastim spojem opterećenih paralelno sa spojem. Dakle, orijentacija zupčastog spoja nije bio važan činitelj čvrstoće stupova. Čvrstoća savijanja kompozitnih stupova uglavnom je bila manja od čvrstoće uzoraka od cjelovitog drva ali je bila veća od čvrstoće uzoraka drva sa zupčastim spojem izrađenih od kompozitnih stupova. Međutim, krutost kompozitnih stupova bila je znatno veća od krutosti uzoraka od cjelovitog drva, kao i uzoraka sa zupčastim spojem izrađenih od kompozitnih stupova.*

Ključne riječi: *drvo bambusa, zupčasti spoj, stupovi, tanka oblovina*

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1 INTRODUCTION
1. UVOD

Wildfires and forest diseases and insects are major threats to a forest. Studies have shown that silvicultural techniques such as thinning offer the most promising and long-lasting means of preventing insect attacks (Nebeker *et al*., 1985). Catastrophic wildfires have also created an incentive to manage forest fuel loading and restore healthy forests via the removal of bio-fuels by thinning operations. The restoration to a healthy forest and the minimization of forest wildfires both require thinning of overstocked forests. As a result, an ample supply of small-diameter timber (SDT) will continue for the foreseeable future.

The current processing options for using SDT for value-added products, however, are limited. Most SDT produced in the southeastern U.S. is used as feedstock for the production of oriented strand board or pulp and paper (Hodges *et al*., 2005). According to Wolfe (2000), the value of roundwood from SDT can be twice that in the square form, and nine times that of wood chips. Round timber has less strength variability and more mature wood in the surface rings. Therefore, engineering SDT into structural members may greatly improve the value of SDT and its utilization efficiency.

In a previous report, we have evaluated a novel technique for making laminated utility poles using SDT (Piao *et al*., 2015). Eight laminated utility poles, each consisting of four tapered round logs, were fabricated. Each round log was finger-jointed together by round segments made from southern pine (*Pinus* spp.) SDT. The eight laminated utility poles along with three commercial solid wood poles were mechanically tested in a cantilever mode. In this report, finger joint samples and solid wood samples were cut from seven of the eight laminated utility poles. The mechanical properties of roundwood finger joints were not found in the literature. The objective of this study was to determine the strength and stiffness of finger joints along each pole and compare these values with the strength and stiffness of solid wood next to the finger joints in the poles.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

The fabrication details of laminated utility poles is described in Piao *et al*., (2014) and is briefly described below. A total of three hundred and fifty-six small-diameter, southern pine (*Pinus* spp.) logs were collected for an on-going series of studies. Logs were collected during thinning operations conducted in typical southern pine plantation forests. The butt diameters of the logs ranged from 3.6 to 12.8 cm. All logs were approximately 12.2 m in length. After harvest, the logs were air dried in sheds for six months to an approximate equilibrium moisture content of 19 %. After air drying, each log was manually debarked. Each debarked log was visually marked off and cut into several (straight) segments. Each log segment was shaved into a tapered, round segment using a 2.4-m, heavy-duty wood lathe.

A heavy-duty, finger-joint shaper was used to cut finger joints into the shaved log segments at one or both ends of each segment. The cutter of the shaper contained 15, two-wing, cutter blades. Each cutter blade had a tip angle of 10.7 degrees. The length, tip thickness, and pitch length of the blades measured 28, 1.588, and 7.938 mm, respectively. All finger joints at one end of each log segment were cut in one pass through the cutter.

Tapered, finger-jointed logs were fabricated using shaved segments of decreasing circumferences (from bottom to top). Segments were consolidated into a tapered, finger-jointed log in a 12.2-m long finger-joint press using a resorcinol phenol formaldehyde resin at 506 g/m^2. Each finger-jointed, tapered, roundwood log had a butt-end diameter of 15.5 cm and a length of either 9.1 or 9.6 m at test. The taper of all finger-jointed logs was 2.3 degrees, which equals the standard pole log taper required by the American National Standard Institute (ANSI) (ANSI, 2008).

Thirty six tapered, finger-jointed segmented logs were made. Nine laminated utility poles, each consisting of four of the finger-jointed logs, were fabricated and tested. Six of the nine were reinforced with bamboo strips, while three were not. Locations of the finger joints in the segmented logs were different for the four logs comprising a laminated utility pole, so that at most one finger joint would appear in any cross section of a laminated utility pole (Figure 1). Data categorized by finger joint location is not presented in this paper because an insufficient number of test samples could be obtained from upper locations in the pole due to taper.

Of the four finger-jointed logs comprising a laminated utility pole, three of the logs consisted of five finger-jointed segments, while one log consisted of four finger-jointed segments. The minimum distance between finger joints on two logs comprising a side surface of a laminated utility pole was 0.6 m.

To construct all laminated utility poles, two adjacent flat surfaces were cut into each finger-jointed, tapered log using a portable bandmill. After the first flat

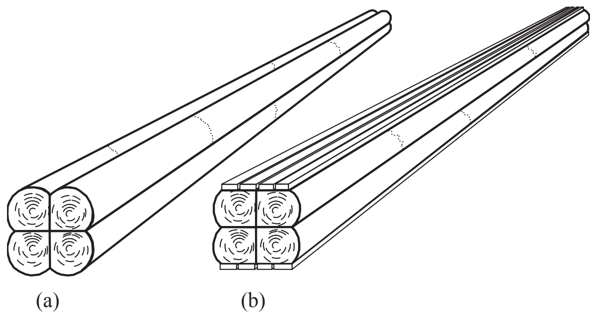

Figure 1 Schematic diagrams of laminated utility poles made from small-diameter timber: (a) depicts an unreinforced utility pole and (b) portrays a pole reinforced by bamboo strips on the top and bottom surfaces
Slika 1. Shematski prikaz lameliranih stupova proizvedenih od tanke oblovine: (a) nacrtan je nearmirani kompozitni stup i (b) prikazan je stup ojačan bambusovim trakama na gornjoj i donjoj površini

Table 1 Number of solid wood (A and C) and finger joint (B) bending samples obtained from laminated composite poles made of small diameter timber
Table 1. Broj uzoraka cjelovitog drva (A i C) i uzoraka sa zupčastim spojem (B) izrađenih od lameliranih kompozitnih stupova proizvedenih od tanke oblovine

Pole# / *Stup*	A and/or C	B
1	62	57
2	67	66
3	62	58
4	14	15
5	26	23
6	49	31
7	17	15

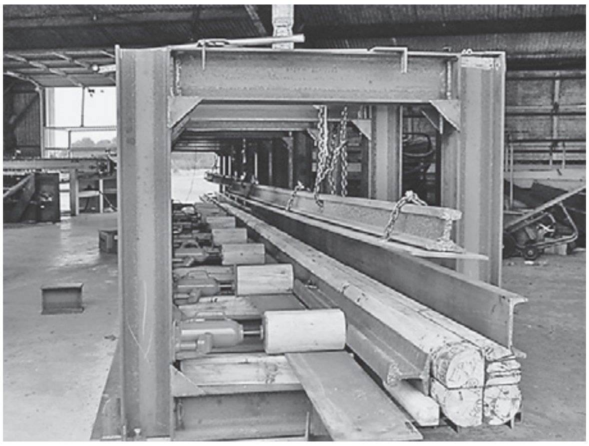

Figure 2 Cold press used to assemble laminated poles
Slika 2. Hladna preša za sastavljanje lameliranih stupova

surface was cut, each log was turned 90 degrees, and the second flat surface was cut. One additional flat surface was cut into each of the four finger-jointed logs that were to form a bamboo reinforced laminated utility pole. Before gluing, the flat surfaces of each log were sanded using a hand-held sander equipped with 100-grit sandpaper. This removed the saw-blade marks and smoothed the surfaces.

Using a roller spreader, the same type resorcinol formaldehyde resin that was used to glue the finger joints together was applied evenly to the two flat surfaces of each of the four logs that were to be pressed into an unreinforced laminated utility pole. These four glued pole logs were assembled and consolidated into a single unreinforced pole in a cold press (Figure 2).

Of the seven composite poles elected for finger joint test in this study, Poles 1 to 3 were made of wood only (without bamboo strip reinforcement), while Poles 4 to 7 were reinforced with bamboo strips. As shown in Table 1, Poles 1 to 3 produced more bending samples (finger-jointed and solid wood) than Poles 4 to 7. Since some materials were removed from the logs cut from bamboo strip-reinforced Poles 4 to 7, they usually produced less finger joint and solid wood samples than the composite poles without bamboo strip reinforcement. In addition to bamboo reinforcement, the number of bending samples obtained from each pole is also dependent on the diameter of the finger joint logs in the poles, and the failure locations and taper of the poles in the bending tests. Therefore, there is substantial variation in the number of bending samples obtained from the seven composite poles.

A finger joint in a log usually consisted of two log sections obtained from different trees. As a result, the strengths of the two pieces of wood consisting of a finger joint sample are usually different. To correct for the difference, solid wood samples were removed from the segments on both sides of a finger-jointed segment and were used as a control in the strength analysis of the finger joint.

After testing the poles in a cantilever fashion in accordance with ASTM D 1036-1999 (ASTM, 1999), Poles 1 to 7 were used to measure the finger joint strength of the poles. Each selected laminated pole was split along the glue lines of the pole into four finger-jointed pieces (Figure 3). Solid wood and finger joint bending samples from these logs were obtained as follows. A 1.3m segment was marked off at each finger-joint location along the entire length of each finger-jointed log with the finger joint being located at the midpoint of the segment. The segment location in a finger-jointed log (1 to 5 from the bottom to the top) was labeled. After removal, each 1.3m segment was cut into three 42 cm sections, which were labeled as Segments A, B, and C, respectively, in Figure 4. Segment B, which contained a finger joint in the middle, was used to measure the strength and stiffness of the finger joint, while Segments A and C were used to measure the strength and stiffness of solid wood (without joints). The failure modes of all samples were recorded and will be reported in a separate manuscript.

Bending samples 46 cm long by 2.5 cm wide by 2.5 cm thick were then cut from Segments A, B, and C. Each segment was first cut into 2.5 cm thick boards. Each board was trimmed to remove any curved surfaces (obtain true shaped boards for the bending samples). Two to five contiguous bending samples were removed from the board, depending on the width of the board. Samples having defects in the wood, such as splits and knots in the middle of the samples, were discarded. The total number of usable bending samples obtained from each composite pole is summarized in Table 1. All test variables and their levels are shown in Table 2.

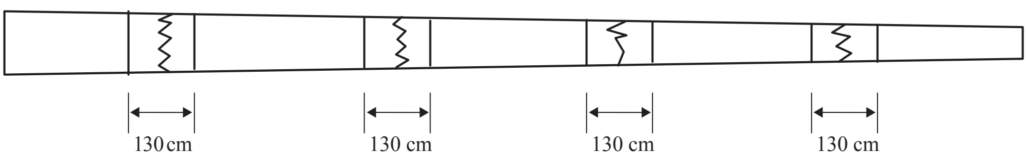

Figure 3 Diagram of an individual finger-jointed log (one of four) removed from the pole
Slika 3. Skica zupčasto spojene drvene grede (jedne od četiri) izdvojene iz stupa

Table 2 Test variables and their levels
Tablica 2. Varijable testa i njihove razine

Variables *Varijable*	**Number of laminated poles fabricated**[1] *Broj proizvedenih lameliranih stupova*	**Sample sections in each pole**[1] *Sekcije uzoraka u svakom stupu*	**Loading directions**[2] *Smjer opterećenja*
Levels / *Razine*	7	4	2

[1] Sections from 1 (bottom section) to 4 (top section) / *Sekcije od 1. (donja sekcija) do 4. (gornja sekcija)*. [2] Perpendicular and parallel / *Okomito i paralelno*.

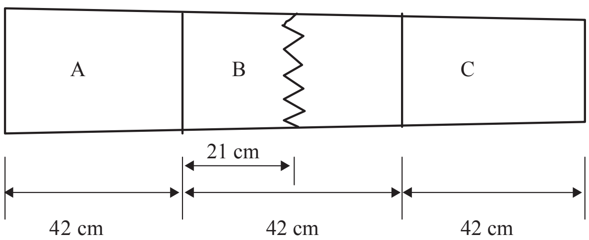

Figure 4 Cutting plan for samples A and C (solid wood) and B (with finger joint)
Slika 4. Plan izrade uzoraka A i C (cjelovito drvo) te uzorka B (sa zupčastim spojem)

Prior to bending testing, samples were conditioned in an air-conditioned room maintained at 21 °C for 5 weeks. The annual growth rings were counted on both ends of each finger joint sample. Of the two ring counts obtained from both ends of a finger joint or a solid wood sample, the mean value was used as the number of annual growth rings of the sample. Of all the finger joint samples obtained in a pole, half of the samples were loaded with the cross head parallel to the joint fingers (hereafter referred to as parallel orientation) and the other half were loaded with the cross head perpendicular to the joint fingers (hereafter referred to as perpendicular orientation). All samples were tested in static bending and loaded to failure on an Instron testing machine according to ASTM D143-94 (ASTM, 1994). All samples were loaded continuously throughout the test at a movable crosshead rate of 1.3 mm/min on a 360 mm loading span.

After testing, a 2.5 cm section was immediately cut from each sample near the point of failure and was used for moisture content (MC) measurement. The section was weighed and then put in an oven at 103±2 °C for 24 h. Each section was weighed again after drying, and the MC of each sample tested was calculated. The density at the time of testing was determined.

In the data analysis, the strength and stiffness of the small clear samples cut from segments A and C (Figure 4) were pooled and their strength average was used as the solid wood control to the strength of finger joint samples obtained from Segment B. Analysis of variance (ANOVA) was adopted to analyze the bending strength and stiffness data using Model 1 given below,

$$\text{Model 1: } y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ijk} + \varepsilon \quad (1)$$

where y_{ijk} denotes MOR/MOE, μ is the overall mean, α_i is an effect due to poles, β_j is an effect due to sections where the samples were cut, γ_k is an effect due to loading directions, $\alpha\beta\gamma_{ijk}$ is an effect due to the interaction between blade profile and joint orientation, and ε_{ijk} is the random residual error. Analyses were carried out using the GLM procedure of the SAS software computing system (SAS 2010). A significance level of 0.05 was used for each statistical analysis.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Numeric values for density, growth ring counts, MC at test, and moduli of rupture (MOR) of the finger joint and solid wood samples tested in this study are given in Table 3, while the moduli of elasticity (MOE) of the samples are given in Table 4. Also enclosed in Tables 3 and 4 are the MOR and MOE averages, respectively, for the composite poles from which the finger joint and solid wood samples were cut. The MOR and MOE values of laminated composites poles in Tables 3 and 4 were obtained from a previous study (Piao *et al*., 2013). Except for Composite Poles 2 and 5, the

Table 3 Physical properties and bending strength (MOR) of finger joints and solid wood cut from small-diameter timber laminated utility poles
Tablica 3. Fizikalna svojstva i čvrstoća savijanja (MOR) uzoraka sa zupčastim spojem i uzoraka cjelovitog drva izrađenih od lameliranih stupova od tanke oblovine

Pole# *Stup*	**Density** *Gustoća*	**Ring count average** *Prosječan broj godova*	**MC** *Sadržaj vode*	**MOR of small clear samples** *MOR malih uzoraka*			**MOR of composite poles** *MOR kompozitnih stupova*
				Test direction / *Smjer opterećenja*		Solid wood *Cjelovito drvo*	
				Parallel *Paralelno*	Perpen-dicular *Okomito*		
	g/cm³	rings/cm	%	MPa	MPa	MPa	MPa
1	0.40	2.57	9.6	32.7	31.9	40.9	31.8
2	0.48	3.00	10.3	42.7	40.0	51.1	53.1
3	0.45	2.45	10.2	39.0	38.2	50.9	45.9
4	0.45	3.83	10.1	30.5	30.9	39.1	38.0
5	0.46	3.63	10.4	26.9	30.3	31.7	39.3
6	0.48	3.18	11.3	39.3	30.7	40.0	38.7
7	0.46	3.66	11.1	38.7	26.1	39.5	38.6

Table 4 Physical properties and bending stiffness (MOE) of finger joints and solid wood cut from small-diameter timber laminated utility poles
Tablica 4. Fizikalna svojstva i modul elastičnosti (MOE) uzoraka sa zupčastim spojem i uzoraka cjelovitog drva izrađenih od lameliranih stupova od tanke oblovine

Pole# *Stup*	**MOE of small clear samples** / *MOE malih uzoraka*			**MOE of composite poles** *MOE kompozitnih stupova*
	Test direction / *Smjer opterećenja*		Solid wood *Cjelovito drvo*	
	Parallel / *Paralelno*	Perpendicular / *Okomito*		
	GPa	GPa	GPa	GPa
1	5.76	5.93	4.88	8.87
2	6.94	6.50	5.61	17.27
3	6.86	6.95	5.67	11.96
4	7.49	6.12	6.15	9.32
5	6.38	5.68	6.14	12.01
6	7.38	6.74	6.29	11.17
7	7.11	6.20	6.58	11.11

bending strength averages of composite poles were lower than the bending strength averages of small clear solid wood samples cut from these poles. However, except for Composite Pole 1, the bending strength averages of composite poles were higher than the bending strength averages of finger joints in the poles, regardless of finger joint orientations (parallel or perpendicular) in the test. These results indicate favorable strength of a composite pole that is made of finger-jointed small diameter timber.

As expected, of all the seven composite poles tested in this study, the solid wood samples gave significantly higher (p =< 0.0001) bending strength than finger-jointed samples, regardless of finger joint orientations in the test (Table 3). The bending strength averages of finger joints tested in the parallel orientation, finger joints tested in the perpendicular orientation, and solid wood samples were 36.1, 32.8, and 42.3 MPa, respectively. Finger-jointed samples tested in the perpendicular orientation (32.6 MPa) yielded the lowest bending strength but were not significantly lower (p = 0.0939) than samples tested in the parallel orientation (36.1 MPa). The strength of the finger joints ranged from 26.9 MPa to 42.7 MPa when tested in the parallel orientation and 26.1 MPa to 40.0 MPa when tested in the perpendicular orientation (Table 3). Standard deviations were used instead of range of values. The ANOVA showed that both the pole effect and test orientation significantly affected (p =< 0.0001) MOR. The effect of section locations of finger joints along the poles was not significant (p = 0.1726). There was no significant difference for MOR among the finger joint locations.

It is important to know the strength of finger joints as compared to the strength of solid wood. Table 5 shows the strength percentages of finger joints to solid wood in both orientations. Of the seven poles tested in this study, the strength of finger joints in the parallel orientation was 76.6 to 97.8 percent of the strength of solid wood, while the percentages were 66.1 to 95.5 for finger joints in the perpendicular orientation. The strength averages for parallel and perpendicular orientations were 85.6 and 78.4 percent of the strength of solid wood samples, respectively. The overall strength percentage of finger joints (both orientations) to solid wood was 82.0.

The MOE results of the poles are presented in Table 4. The ANOVA found that pole and test direction main effects were marginally significant (p = 0.0390 and 0.0206, respectively). The MOE for solid wood was lower than parallel jointed MOE (p = 0.0057). Table 4 also shows that the MOE of composite poles was substantially higher than the MOE of small clear samples, regardless of finger jointing or not. This is partly attributable to the resorcinol phenol formaldehyde (RPF) resin used in this study. In the jointing of both composite poles and finger joints, RPF was used as resin to bond wood members together. The cured RPF resin usually has a higher stiffness that the wood used in the study (Piao *et al*., 2005). The MOE did not significantly vary based on pole locations in the finger-

Table 5 Percentages of finger joint MOR as compared to the MOR of solid wood. Both finger joint and solid wood samples were cut from small-diameter timber laminated utility poles
Tablica 5. Postotak vrijednosti čvrstoće savijanja (MOR) uzoraka drva sa zupčastim spojem u odnosu prema čvrstoći savijanja uzoraka od cjelovitog drva; obje vrste uzoraka izrezane su od lameliranih stupova izrađenih od tanke oblovine

Pole# *Stup*	**Parallel** / *Paralelno* %	**Perpendicular** / *Okomito* %	**Pole main effects** / *Utjecaj na čvrstoću stupa* %
1	79.9	77.9	78.9
2	83.5	78.2	80.9
3	76.6	75.1	75.8
4	78.1	79.1	78.6
5	84.7	95.5	90.1
6	98.4	76.7	87.6
7	97.8	66.1	82.0
Joint main effects *Zajednički učinak*	85.6	78.4	82.0

jointed logs ($p = 0.2054$). In addition, these differences can be partly attributable to the addition of the bamboo strips on the composite poles, which enhanced strength properties over poles without bamboo strips. Finally, due to the well known pattern of increased density from pith to bark in southern pine trees, the poles contained the highest density on the surface, which is critical because the surface properties are essential for determining the overall strength and stiffness of any member under static loading.

4 CONCLUSION
4. ZAKLJUČAK

Finger-jointed and solid wood small clear samples cut from seven composite utility poles were evaluated for their strength and stiffness properties. The strength and stiffness of the finger-jointed small clear samples were compared with those of small clear solid wood samples and those of composite poles made of small diameter timber. The bending strength of composite poles was less than the strength of the solid wood samples but greater than the strength of finger-jointed samples cut from the poles. However, the bending stiffness of the composite poles was substantially higher than the bending stiffness of both solid wood and finger-jointed samples cut from the poles primarily due to a number of factors including the RPF resin that was used to bond finger joints and finger-jointed logs in the poles, inclusion of bamboo strip reinforcement of the poles, and a likely higher percentage of mature wood in the poles as in the small test samples. Finger-jointed samples tested in a perpendicular orientation yielded the lowest bending strength but were not significantly lower than samples tested in a parallel orientation, indicating that joint orientation was not an important issue regarding the strength of the poles. The strength averages for parallel and perpendicular orientations were 85.6 and 78.4 percent of the strength of solid wood samples, respectively. The overall strength percentage of finger joints (both orientations) to solid wood was 82.0. This study has demonstrated that small diameter timber can potentially be used to make finger-joint logs for the production of laminated utility poles.

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Measurement of Wood Cutting Forces during Bandsawing Using Piezoelectric Dynamometer

Mjerenje sila rezanja piezoelektričnim dinamometrom tijekom piljenja drva tračnom pilom

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ABSTRACT • *Optimization of wood cutting conditions can decrease the cutting forces, which directly relates to the energy consumption. The aim of this study was to measure cutting force components in bandsaw processing of green oak and beech wood at 90°-90° cutting direction (mode A). For this purpose, a piezoelectric dynamometer (KISTLER type 9257A) mounted on the log carriage of vertical bandsaw machine (ESTERER model EB 1400) was used to measure the parallel, normal and lateral cutting forces for different cutting speeds (20, 30 and 40 m s^{-1}) and feed rates (20, 30 and 40 m min^{-1}). Results showed that all cutting force components change by increasing the cutting speed and feed rate over the analysed range. However, little changes were observed for lateral force. Overall, oak wood required greater cutting forces compared to beech wood. Conclusively, in the studied range, with increasing cutting speed ratio to feed rate, main cutting force and normal force were decreased.*

Key words: *bandsawing, cutting forces, cutting speed, feed rate, piezoelectric dynamometer*

SAŽETAK • *Optimizacijom uvjeta rezanja drva mogu se smanjiti sile rezanja čija veličina izravno utječe na potrošnju energije tijekom piljenja. Cilj istraživanja bio je odrediti sastavnice sile rezanja tijekom piljenja svježe hrastovine i bukovine tračnom pilom, uz smjer rezanja 90° - 90° (mod A). U tu svrhu piezoelektrični je dinamometar (Kistler tip 9257A) montiran na posmična kolica za trupce vertikalne tračne pile (ESTERER model EB 1400) i upotrijebljen za mjerenje paralelne, okomite i bočne sile rezanja pri različitim brzinama rezanja (20, 30 i 40 $m \cdot s^{-1}$) i posmičnim brzinama (20, 30 i 40 $m \cdot min^{-1}$). Rezultati su pokazali da se sve sastavnice sile rezanja mijenjaju s povećanjem brzine rezanja i posmične brzine u istraživanom rasponu. Male promjene zabilježene su za bočnu silu. Rezultati su pokazali da su za piljenje hrastovine potrebne veće sile rezanja nego pri piljenju bukovine. Zaključno, u promatranom se rasponu brzina s povećanjem omjera brzine rezanja i posmične brzine smanjuju glavna i okomita sastavnica sile rezanja.*

Ključne riječi: *piljenje tračnom pilom, sile rezanja, brzina rezanja, posmična brzina, piezoelektrični dinamometar*

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1 INTRODUCTION
1. UVOD

Optimization of wood cutting conditions can decrease the cutting forces, which directly relates to the energy consumption. The cutting speed and feed rate are the main machining parameters affecting the cutting forces. The effect of cutting speed was well reviewed by Lubkin (1957). There are some contradictory reports regarding the cutting speed and cutting force relations. Some studies indicated that the cutting speed had practically no effect on cutting forces (Franz, 1958; McKenzie, 1961; Eyma *et al*., 2005), while others showed a cutting force curve with a minimum at some speeds, or a linear change of cutting force by increasing the speed (Pahlitzsch and Dziobek, 1959; Porankiewicz *et al*., 2007). Davim (2011) mentioned that the parallel force increases with increasing cutting speed from 30 m s^{-1} to 60 m s^{-1} for five different coated carbide tools in wood cement board machining. Porankiewicz *et al.* (2007) reported that during milling of laurel blanco wood (*Cordia alliodora*), the parallel force increases by increasing of cutting speed over the analysed range (10 m·s^{-1} < v_c < 40 m·s^{-1}). Eyma *et al*. (2005) measured the cutting speed in beech (*Fagus sylvatica*) and Ipe (*Tabebuia* sp.) wood in the cutting speed range of 0.1 to 8 m·s^{-1}. Their results showed that the cutting speed had no effect on cutting forces. Similar to the cutting speed, the feed rate can impact the cutting forces. Lucic *et al*. (2004) showed that the cutting force during circular rip-sawing of oak wood (*Quercus robur* L.) in transversal cutting direction (90º-90º) increases by increasing the feed rate. Heisel *et al*. (2007) indicated that parallel and normal force increases with increasing of feed rate from 20 m·min^{-1} to 55 m·min^{-1}.

According to the literature, the contradictory results reported about the cutting speed impact on cutting forces can be attributed to the use of different cutting speed range, wood species and machining process. However, the method of cutting force measurement cannot be neglected. The measuring of cutting forces can be carried out using various methods such as pendulum (Eyma *et al.*, 2005), strain gauge (Porankiewicz *et al.*, 2008) and piezoelectric dynamometer. The pendulum dynamometer is a good tool to measure the cutting energy, but it cannot measure the cutting force components. The strain gauge dynamometer is not suitable for high dynamic loads and high cutting speeds and its applicability is extremely limited and the results are difficult to apply to the real situation. Piezoelectric dynamometer is characterized by high sensitivity and a good response to large stresses and thus the accurate date acquisition. Up to now, the piezoelectric dynamometer has been applied to measure the cutting forces in different wood machining processes, such as routing (McKenzie, 2001; Eyma *et al.*, 2004; Goli and *et al.*, 2010), horizontal bandsawing using a single bandsaw tooth (Loehnertz and Cooz, 1998; Ko and Kim, 1999; Cooz and Mayer, 2006) and shaping (Aguilera and Martin, 2001). However, there is no information about using the piezoelectric dynamometer for measuring the cutting force components in an industrial vertical bandsaw. Hence, the aim of this study was to measure the cutting force components during bandsawing of oak and beech wood at different cutting speeds and feed rates using piezoelectric dynamometer.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

2.1 Specimen preparation
2.1. Priprema uzoraka

Beech (*Fagus sylvatica* L.), a diffuse porous species and oak (*Quercus robur* L.), a ring porous species, with mean specific gravity of 0.53 and 0.59, respectively, were selected for the study. For each species, 3 trees with the age range of 75 to 85 years old were randomly cut from the southern forests near Rosenheim in Germany. Then, straight grain lumbers with dimensions of 5000×150×150 mm were prepared. Finally, defect free samples with dimensions of 150×150×150 mm were cut from the straight grain lumbers using circular saw (OptiCut S50). After drying of wood samples inside the kiln (LAUBER TROCKNUNGSTECHNIK) to the target moisture content of about 30 %, a conditioning box was used to homogenize the wood moisture content through the specimen thickness. Three different feed rates (20, 30 and 40 m·min^{-1}) and cutting speeds (20, 30 and 40 m·s^{-1}) were considered for the experiments. A total of 108 specimens were prepared with 6 replications for each treatment.

2.2 Measuring cutting forces
2.2. Mjerenje sila rezanja

Cutting operation for each wood species was carried out in the sawmill laboratory of the University of Applied Sciences in Rosenheim, Germany using a vertical band saw machine (ESTERER model EB 1400) with log carriage (ESTERER model EW 1000) at 90°-90° cutting direction (Figure 1).

A new blade (ALBER SÄGEBLÄTTER) was used for cutting tests. Technical characteristics and geometry of the used bandsaw are shown in Table1.

A Piezoelectric dynamometer (KISTLER type 9257A) attached to the steel plate was firmly mounted

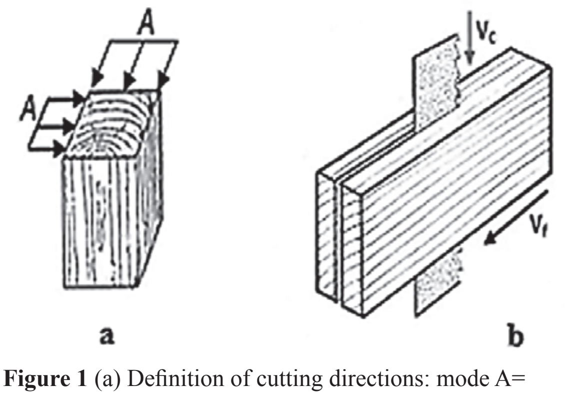

Figure 1 (a) Definition of cutting directions: mode A= cutting direction 90°-90°(Kivimma, 1950); (b) Angle of inclination between cutting direction and grain orientation during band sawing

Slika 1. a) Definicija smjera rezanja: mod A – smjer rezanja 90°-90°(Kivimma, 1950.); b) kut između smjera rezanja i smjera drvnih vlakanaca tijekom piljenja tračnom pilom

Table 1 Technical characteristics of the used saw blade
Tablica 1. Tehnička obilježja upotrijebljene tračne pile

Properties / *Obilježje*	**Value** *Vrijednost*	**Properties** / *Obilježje*	**Value** *Vrijednost*
Blade length, mm /*duljina lista pile,* mm	10035	Sharpness angle, ° /*kut oštrenja*, °	33
Blade width, mm / *širina lista pile,* mm	175	Rake angle, ° / *prsni kut*, °	36
Blade thickness, mm / *debljina lista pile,* mm	1.5	Clearance angle, ° / *leđni kut,* °	21
Kerf, mm / *širina propiljka,* mm	3.1	Tangential clearance angle, ° *tangencijalni kut,* °	4
Tooth pitch, mm / *korak zuba,* mm	45	Radial clearance angle, ° / *radijalni kut,* °	2
Number of teeth / *broj zubi*	223	Gullet depth, mm / *visina pazuha,* mm	15
Tooth form / *oblik zuba*	Swage set / *stlačeni*	Wheel diameter, mm / *promjer kotača pile,* mm	1400
Tooth alloy / *legura zuba*	Stellite / *stelit*	Saw power, kW / *snaga motora,* kW	55-90

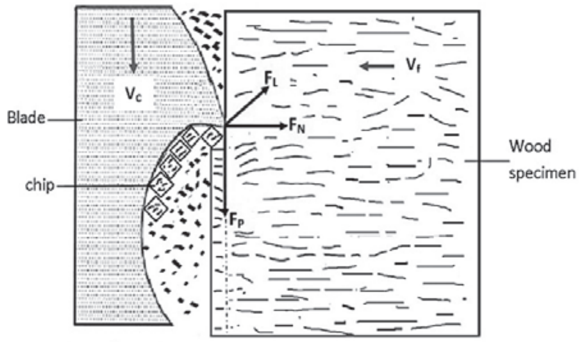

Figure 2 Cutting force components for the applied bandsawing
Slika 2. Sastavnice sile rezanja pri piljenju tračnom pilom

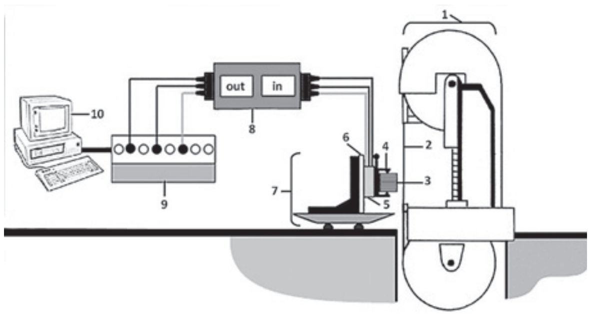

Figure 3 Experimental set-up;1 – band saw; 2 – saw blade; 3 – wood specimen; 4 – clamp; 5 – piezoelectric gauge; 6 – steel plate; 7 – feed table; 8 – amplifier; 9 – A/D converter; 10 – computer
Slika 3. Shema eksperimenta: 1 – tračna pila; 2 – list pile; 3 – uzorak drva; 4 – držači; 5 –piezoelektrični mjerač; 6 – čelična ploča; 7 – posmični stol; 8 – pojačalo; 9 – A/D konverter; 10 – računalo

on the carriage of the saw machine to measure the cutting forces in the three principal axis, including the parallel, normal and lateral forces. The position of the analysed cutting force components in the parallel (F_P), normal (F_N), and lateral (F_L) directions in the bandsawing are defined in Figure 2.

The wood samples were fixed on the dynamometer by a fixture and then calibrated. The signal from the dynamometer was amplified through the charge amplifier (KISTLER type 5007). The amplified signals were collected by means of A/D converter. Finally, the acquired data were presented on the monitor screen. For better data analysis, 10 percent of the obtained data at the beginning and end of cutting were eliminated, due to high saw balde vibration in these situations. General scheme of experimantal set up is shown in Figure 3.

The teeth number involved during bandsawing (Z_e) is given by:

$$Z_e = \frac{h}{p} \tag{1}$$

Where h is specimen thickness (mm) and p is tooth pitch (mm). Then, cutting force components (F) for one tooth and one millimeter of tooth thickness were determined using the following equation:

$$F = \frac{F_{ave}}{Z_e \cdot w} (\frac{\mathrm{N}}{\mathrm{mm}}) \tag{2}$$

Where F_{ave} are the mean cutting forces (N) obtained in three directions and w is tooth thickness (mm). Figure 4 shows the cycles of the cutting forces signal obtained during bandsawing by piezoelectric dynamometer.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Based on statistical analysis, the effect of cutting speed and feed rate on the orthogonal cutting forces at the 90°-90° cutting direction was significant. In contrast to the lateral force, it was established that the parallel and normal forces depended on wood species. Table 2 shows the Pearson correlation coefficients for cutting speed, feed rate and cutting forces. According to Table 2, it can be noted that 60 % (r^2 = 0.77) of the variation in the parallel and normal forces is explained by the cutting speed and 51 % (r^2 = 0.71) by the feed rate. The cutting speed and feed rate had little effect on the lateral force and there was no correlation between the cutting speed and feed rate.

3.1 Effects of cutting speed on cutting forces
3.1. Utjecaj brzine rezanja na sile rezanja

Results showed that the parallel and normal forces decreased when the cutting speed increased (Figures 5-7). Overall, the parallel force for the cutting speed of 20 m·s^{-1} was about 50 % greater than that for the cutting speeds of 30 and 40 m·s^{-1}(Figure 5). These results can probably be explained by the decreased friction between the tool and work-piece due to the increase of the cutting speed. Another positive effect of the cutting speed on the parallel force reduction can be attributed

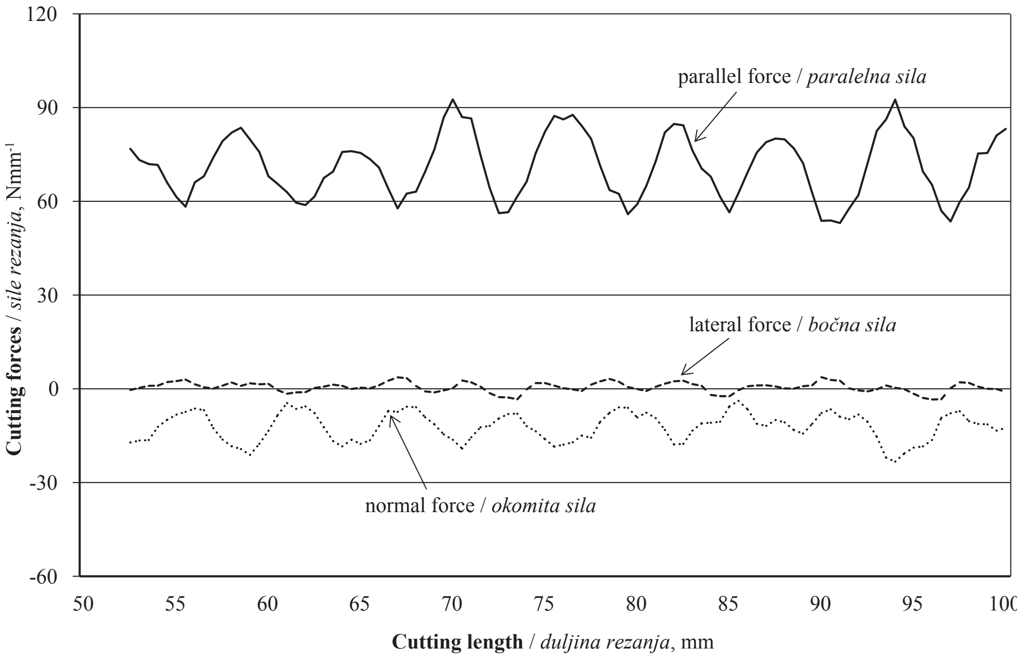

Figure 4 The cycles of cutting forces signal obtained during bandsawing by piezoelectric dynamometer
Slika 4. Ciklusi signala sila rezanja dobivenih piezoelektričnim dinamometrom tijekom piljenja tračnom pilom

Table 2 The Pearson correlation coefficients between cutting speed, feed rate and cutting forces
Tablica 2. Pearsonov koeficijent korelacije između brzine rezanja, posmične brzine i sila rezanja

Variable Varijabla	**Cutting speed** *Brzina rezanja*	**Feed rate** *Posmična brzina*	**Parallel force** *Paralelna sila*	**Normal force** *Okomita sila*	**Lateral force** *Bočna sila*
Cutting speed / *brzina rezanja*	1	0.0	-0.77**	0.78**	-0.42*
Feed rate / *posmična brzina*		1	0.71**	-0.71**	0.40*
Parallel force / *paralelna sila*			1	-0.90**	0.55**
Normal force / *okomita sila*				1	-0.63**
Lateral force / *bočna sila*					1

** Correlation is significant at the 0.01 level / *korelacija je signifikantna pri 0.01*; * Correlation is significant at the 0.05 level / *korelacija je signifikantna pri 0,05*

to the temperature increase in the cutting zone up to 700 °C and wood strength reduction due to softening of wood lignin (Blackwell and Walker, 2006; Iskra *et al.*, 2005). According to the results, with increasing ratio of the cutting speed to feed rate, parallel force decreases gradually (Figure 6). The value of normal force at different cutting speeds for both wood species was negative (Figure 7). Negative normal force occurs at larger rake angles (Koch, 1964). Negative normal force can also be attributed to wood machining defect, such as raised grains that could increase friction force and the ratio of tool cutting edge radius to chip thickness, pushing the tool out (Palmqvist, 2003). Our finding is in agreement with some previous researches (Pahlitzsch and Dziobek, 1959) and in contrast to other researches (Porankiewicz *et al.*, 2007; Eyma *et al.*, 2005).

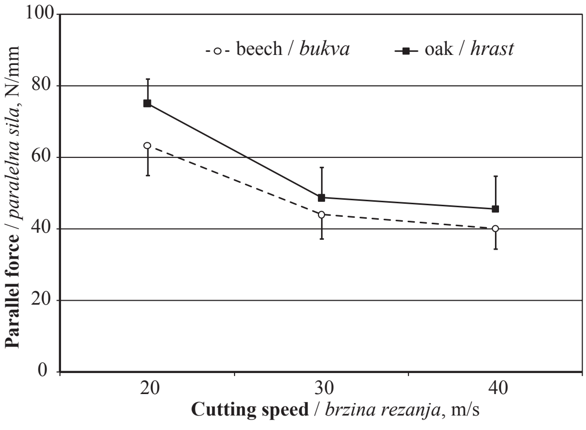

Figure 5 Relationship between parallel force and cutting speed
Slika 5. Odnos između paralelne sile rezanja i brzine rezanja

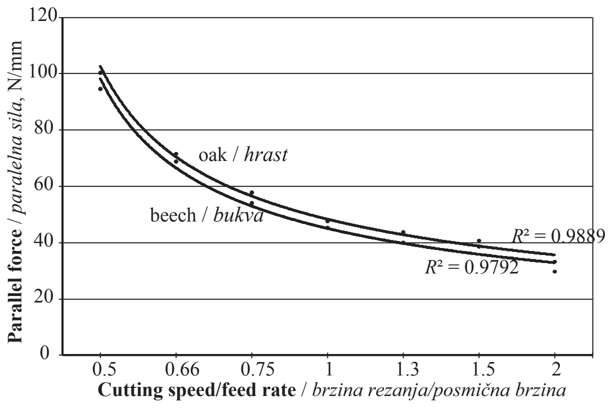

Figure 6 Relationship between ratios of cutting speed /feed rate on parallel force
Slika 6. Odnos između paralelne sile rezanja i omjera brzine rezanja i posmične brzine

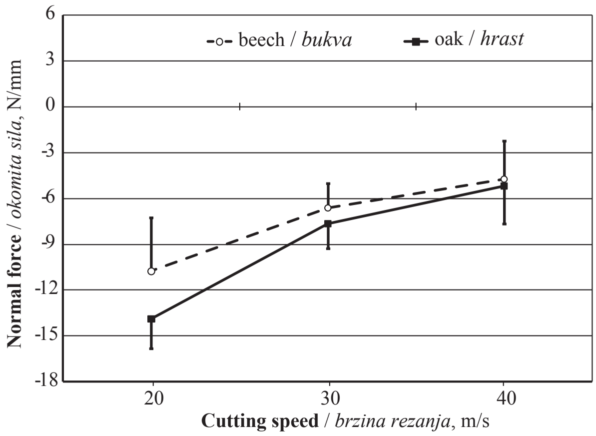

Figure 7 Relationship between normal force and cutting speed
Slika 7. Odnos između okomite sile i brzine rezanja

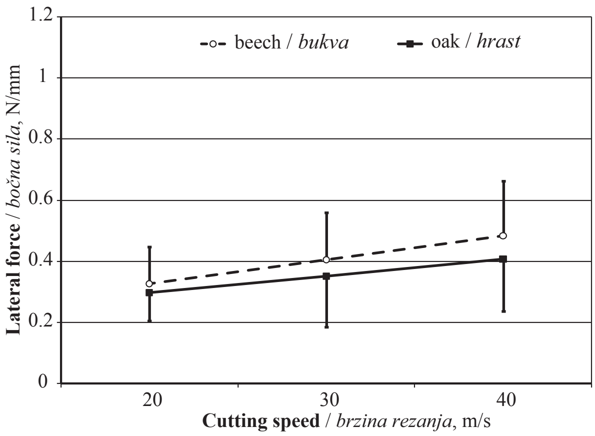

Figure 8 Relationship between lateral force and cutting speed
Slika 8. Odnos između bočne sile i brzine rezanja

Result also revealed that oak wood required more cutting force than beech wood, which can be due to the higher specific gravity of oak wood (SG ≈ 0.53 for beech wood and SG ≈ 0.59 for oak wood). The greatest and lowest parallel and normal forces were observed for oak wood with the cutting speed of 20 m·s^{-1} and for beech wood with the cutting speed of 40 m·s^{-1}, respectively.

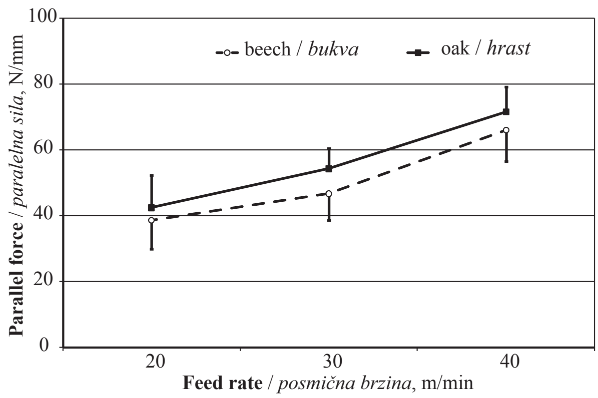

Figure 9 Behaviour of parallel force during bandsawing at different feed rates
Slika 9. Promjene paralelne sile tijekom piljenja tračnom pilom pri razičitim posmičnim brzinama

Results indicated that the lateral force for beech wood was a little higher than that of oak wood (Figure 8). Due to the symmetric shape of the teeth, the lateral force was expected to be zero. This means that readings deviating from zero can be attributed to irregular disturbances as a result of inhomogeneity, increasing of friction between saw tooth and chips, poor ground teeth or blade vibrations as indicated by Loehnertz and Cooz (1998). The greatest lateral force value was observed for beech wood at the cutting speed of 40 m·s^{-1}, and the lowest one was observed for oak wood at the cutting speed of 20 m·s^{-1}

3.2 Effects of feed rate on cutting forces
3.2. Utjecaj posmične brzine na sile rezanja

Results showed that parallel force increased by more than 65 % as a result of feed rate increasing from 20 to 40 m·min^{-1} (Figure 9). A greater cutting force is required for pulling thicker chips. Normal forces were negative with an increasing trend in the studied conditions (Figure 10). The effect of feed rate on lateral force was insignificant (Figure 11). Our results are in agreement with some previous findings (Pahlitzsch and Dziobek, 1959; Lucic *et al.*, 2004). The greatest and lowest cutting forces were observed for oak wood with the feed rate of 40 m·min^{-1} and for beech wood with the feed rate of 40 m·min^{-1}, respectively.

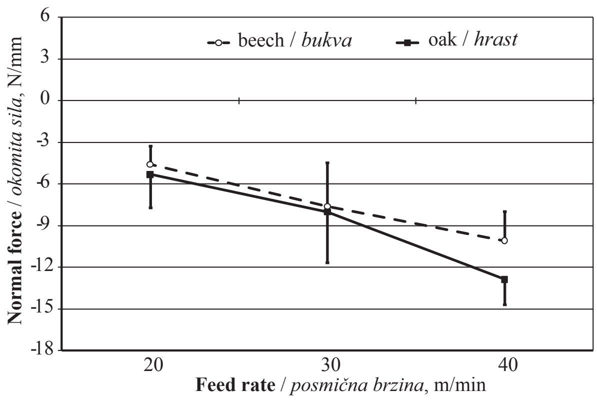

Figure 10 Behaviour of normal force during bandsawing at different feed rates
Slika 10. Promjene okomite sile tijekom piljenja tračnom pilom pri razičitim posmičnim brzinama

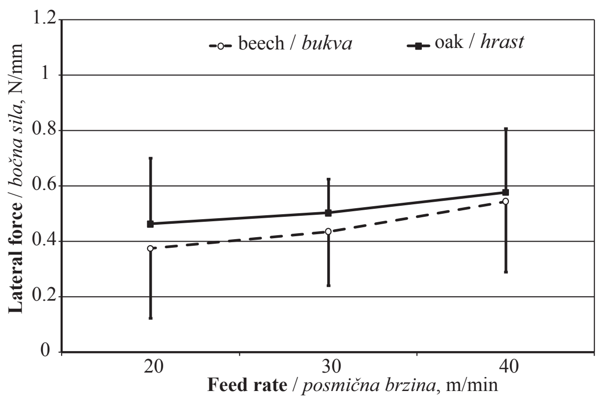

Figure 11 Behaviour of lateral force during bandsawing at different feed rates
Slika 11. Promjene bočne sile tijekom piljenja tračnom pilom pri razičitim posmičnim brzinama

4 CONCLUSION
4. ZAKLJUČAK

The main purpose of the present research was to accurately measure the orthogonal wood cutting forces, including lateral, normal and parallel ones for different cutting speeds (20, 30 and 40 m·s^{-1}) and feed rates (20, 30 and 40 m·min^{-1}) using piezoelectric dynamometer. On the whole, it was established that all cutting forces depended on the cutting speed and feed rate over the analysed range. However, little dependence was observed for lateral force.The forces increased with the increase of the feed rate. Both parallel and normal forces decreased when the cutting speed increased. Overall, oak wood required more cutting forces compared to beech wood. Higher cutting speeds are usually used during wood bandsawing to achieve higher productivity and cutting efficiency. Therefore, further study of higher cutting speeds is recommended to better understand the impact of the cutting speed on the cutting force components. Another suggestion for additional research can be to simultaneously use another method for measuring cutting forces, such as strain gauge dynamometer to make comparison with piezoelectric dynamometer method.

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Review on Lipophilic and Hydrophilic Extractives in Tissues of Common Beech

Pregled lipofilnih i hidrofilnih ekstraktivnih tvari u tkivima obične bukve

Review paper • Pregledni rad
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ABSTRACT • *Common beech (Fagus sylvatica L.) is one of the most widespread and economically important tree species in Europe and, therefore, represents a potential source of high value added extractives. The aim of this paper was, therefore, to review the existing data regarding the composition of lipophilic and hydrophilic extractives of beech tissues, and the extraction systems and analytical techniques used for their examination. The lipophilic extractable fraction of beech is characterized mainly by saturated and unsaturated fatty acids, fatty alcohols and sterols while the hydrophilic extractives of beech consist of soluble sugars, i.e. monosaccharides, oligosaccharides, sugar alcohols and sugar acids, as well as of simple phenols and flavonoids. Chromatography has been recognized as the convenient and most frequently used technique for the chemical analysis of extractives. This overview showed that the information about the composition of low-molecular extractives of beech is satisfactory, but the data on oligomeric extractives are still fragmentary.*

Key words: *beech, extractives, fatty acids, sterols, sugars, phenols, catechin, chromatography*

SAŽETAK • *Obična bukva (Fagus sylvatica L.) jedna je od najrasprostranjenijih i gospodarski najvažnijih vrsta drva u Europi i stoga je potencijalni izvor ekstraktivnih tvari visoke dodatne vrijednosti. Cilj rada bio je preispitati postojeće podatke koji se odnose na sastav lipofilnih i hidrofilnih ekstraktivnih tvari u tkivima bukve te sustave za ekstrakciju i analitičke tehnike koje se primjenjuju za njihovo istraživanje. Lipofilne frakcije koje se mogu ekstrahirati iz bukve uglavnom su zasićene i nezasićene masne kiseline, masni alkoholi i sterol, dok se hidrofilne ekstraktivne tvari iz bukve sastoje od topljivih šećera, tj. monosaharida, oligosaharida, šećernih alkohola i šećernih kiselina, kao i od jednostavnih fenola i flavonoida. Kromatografija je prepoznata kao prikladna i najčešće primjenjivana tehnika kemijske analize ekstraktivnih tvari. Ovaj je pregled pokazao da su podaci o sastavu niskomolekularnih ekstraktivnih tvari iz bukve zadovoljavajući, ali su podaci o oligomernim ekstraktivnim tvarima još uvijek fragmentarni.*

Ključne riječi: *bukva, ekstraktivne tvari, masne kiseline, steroli, šećeri, fenoli, katehin, kromatografija*

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1 INTRODUCTION
1. UVOD

Utilization of hardwood represents one of the main industrial and research issues of the wood sector in Europe. Common beech (*Fagus sylvatica* L.) accounts for approximately one third of the wood stock in Slovenian forests (Report of Slovenian Forest Service for 2011) and represents an economically important tree species with a relatively high potential in wood industry. One of the main deficiencies of this tree species is its tendency to develop discoloured wood in the central part of the tree, also known as the red heart (Bosshard, 1974; Torelli, 1984). Red heart in beech has been investigated from various aspects, ranging from physiology, gross and minute anatomy, chemical composition and physical, mechanical and technological properties (Dietrichs, 1964a; Bauch, 1984; Sachsse, 1991; Torelli *et al.*, 1994; Baum and Schwarze, 2002; Koch *et al.*, 2003; Hofmann *et al.*, 2004; Wernsdörfer *et al.*, 2005; Oven *et al.*, 2008; Mali *et al.*, 2009; Vek *et al.*, 2014; Vek *et al.*, 2015). Generally, if compared to the unaffected wood, the value of discoloured round wood, as well as wood elements on the market, is usually lower (Zell *et al.*, 2004) and, therefore, attempts were made to commercially promote discoloured beech wood (Koch, 2002). In addition to the main structural components of the cell wall, i.e. cellulose, hemicelluloses and lignin, different tissues of a living tree also contain smaller amounts of compounds, which can be removed from the plant tissue with the process of extraction and are, therefore, known as extractives. These are natural low-molecular compounds, the non-structural components of wood, located in the lumina of cells and extraneous to a lignocellulose cell wall. From the physiological aspect of view, the extractive compounds of plant tissue are primary and secondary metabolites (Rowe and Conner, 1979; Fengel and Wegener, 1989; Kai, 1991; Holmbom, 1999). Primary metabolites are present in every plant species, whereas specific secondary metabolites can be found only in some tree species or related group of species. Secondary metabolites were sometimes referred to as accessory compounds (Fengel and Wegener, 1989), because their important ecological functions in the tree have not been understood for a long time. It is known that these in general contribute to protection of plants and against herbivories and microbial pathogens, serve as attractants for pollinators and seed-dispersing animals and function as agents of plant–plant competition and plant-microbe symbioses (Taiz and Zeiger, 2002).

Extractives can be classified according to their chemical similarities, with respect to biochemical paths of their synthesis or regarding the solvent, in which they are soluble. Based on solubility, extractives are divided into classes of lipophilic and hydrophilic extractives (Willför *et al.*, 2006; Jansson and Nilvebrant, 2009).

As proposed by Holmbom (1999), extractives are usually analyzed at three levels, i.e. gravimetric determination of total extractives, determination of different component groups and analysis of individual components. The first level of extractive analysis includes gravimetric and other determination of total extractives. It is generally known that the xylem of tree species in the temperate climate zone contains a relatively small amount of extractives, up to 5 – 10 % (Umezawa, 2000). Anyway, the concentration can be much higher in certain parts of the tree, e.g. in branch bases, bark and roots. Moreover, higher amounts of extractives are also found in some tropical and subtropical woods (Fengel and Wegener, 1989; Holmbom, 1999). As reported by Wagenführ (1996), beech wood consists of 33.7 % to 46.4 % of cellulose, 11.6 % to 22.7 % of lignin, 11.8 % to 25.5 % of hemicelluloses, 3 % to 5 % of extractives, meanwhile the share of inorganic compounds represents 0.3 % to 1.2 %. By applying standardized analytical methods used in wood chemistry, 47.66 % of cellulose, 25.53 % of lignin, 69.01 % of holocellulose, 0.93 % substances soluble in benzene-alcohol, 2 % of substances soluble in hot water, 13.15 % substances soluble in 1 % NaOH and 0.3 % of mineral substances (ash) were determined by Bodirlau *et al.* (2008). The pH value of beech wood ranges from 5.06 up to 5.13 (Hillis, 1987). Fengel and Wegener (1989) stated that the average pH value is 5.4. Even more, authors reported that the pH value of cold water extract is 5.5, while the pH value of hot water extract is slightly lower (5.3). Sixta *et al.* (2004) found 24.2 % of lignin in freshly prepared beech wood chips. Further carbohydrate analysis revealed 41.6 % glucan, 17.9 % xylan, 1.3 % mannan, 1.2 % galactan and 0.5 % arabinan (Sixta *et al.*, 2004). It was reported that intact sapwood contains less lignin (19.75 %) than biologically decayed wood (20.82 %) (Košikova *et al.*, 2008), whereas the origin of decay was not described in this research. Generally, beech wood is characterized by a relatively low amount of extractives (Rowe and Conner, 1979). Furthermore, the information regarding the content and composition of extractives in beech wood is poor. In the case of fresh beech wood chips, Sixta *et al.* (2004) stated that 0.2 % of the compound are extracted with dichloromethane, 1.0 % with acetone, 1.7 % of extractives are soluble in ethanol, while 2.7 % are obtained with water. According to Košikova *et al.* (2008), in comparison to healthy sapwood, from which 1.78 % of extractives were gained, decayed wood contains less extractives soluble in acetone, i.e. 0.98 %. Furthermore, Kubel and Weissmann (1988) report that the amount of extractives, soluble in petrol ether and diethyl ether, is relatively low and it amounts to 0.2% and 0.1%, respectively. More compounds can be extracted by the mixture of alcohols and water, 1.6 % with acetone/water (9:1, v/v) and 1.2 % with ethanol/water (8:2, v/v). A relatively low amount of water soluble extractives (0.3 %) can be attributed to the successive extraction procedure.

The basic gravimetrical estimation of the amount of total extractives is usually upgraded by the second and third level of analyses, i.e. determination of the component groups in extracts and evaluation of composition of individual extractives. For the determination of groups of extractives in wood extracts, e.g. total phenols, flavonoids or proanthocyanidins, a spectrophotometric analysis (UV-Vis) represents a quick and reliable technique (Baum and Schwarze, 2002; Albert *et al.*, 2003; Brighente *et al.*, 2007; Vek *et al.*, 2013a; Vek *et al.*, 2013b). The lack of semi-qualitative evaluation is that UV-Vis analysis gives relative and not absolute results as a consequence that the amount of component group is estimated towards the component of external standard, e.g. gallic acid, quercetin of catechin. Therefore, more precise chromatographic techniques are used, i.e. thin-layer chromatography (TLC), gas chromatography (GC) or high performance liquid chromatography (HPLC). Qualitative determination is possible by the ^{13}C NMR and eventually with Furrier transform infrared spectroscopy (FTIR) as well. Furthermore, for the determination of different groups of extractives by means of HPLC, both the size-exclusion (HPLC-SEC) and reversed-phase (RP) modes can be applied. Precise qualitative evaluation of individual compounds separated by chromatographic techniques (GC or HPLC) is most conveniently made by mass spectrometry (MS). Therefore, GC/MS and HPLC/MS represent an adequate technique for the identification of extractives in complex mixtures such as plant extract.

The aim of the present work was to review the literature on extractives, which have been qualitatively evaluated as the extracts of beech tissue so far. In the following, the results of various chemical analyses of extractives occurring in different types of beech tissue are presented separately for lipophilic and hydrophilic components (Holmbom, 1999; Naczk and Shahidi, 2007).

2 EXTRACTIVES OF BEECH
2. EKSTRAKTIVNE TVARI U TKIVIMA BUKVE

2.1 Lipophilic extractives
2.1. Lipofilne ekstraktivne tvari

Lipophilic extractives are referred to as the compounds which are soluble in nonpolar organic solvents, e.g. pentane, hexane, petroleum ether, dichloromethane, chloroform or toluene. It is well known that lipophilic extractives can have a negative influence and may disturb the analysis of more polar compounds. Moreover, they may have a deleterious effects on chromatographic instrumentation due to column clogging (Slanina and Glatz, 2004). Therefore, it is recommended first to remove the lipophilic extractives from the sample before further extraction with polar solvents (Naczk and Shahidi, 2004; Willför *et al.*, 2006). Waxes, fats, fatty alcohols, fatty acids, terpenoids, sterols and steryl esters are known as the characteristic representatives of lipophilic extractives. Some of them were also identified in the nonpolar extractible fraction of beech.

In the case of beech wood dust, extracts were characterized by a relatively low amount of lipophilic

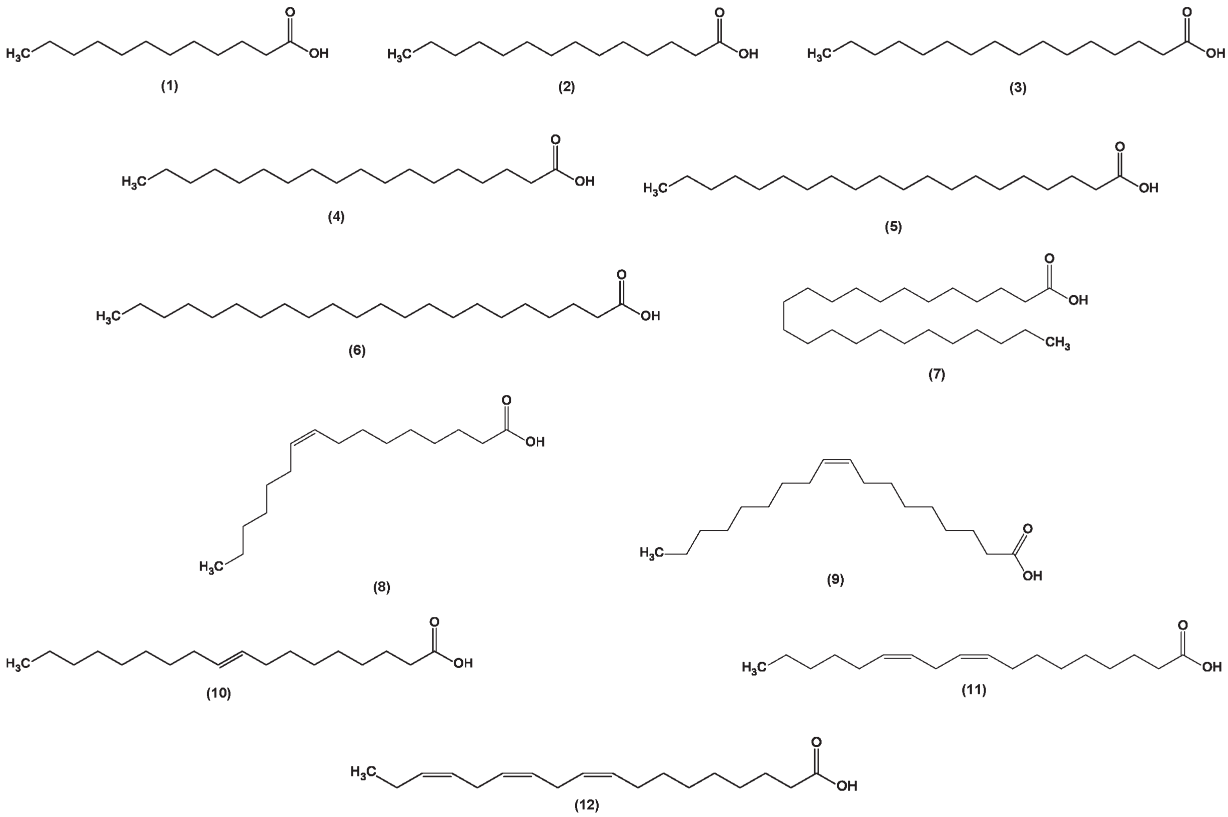


Figure 1 Structure formulas of saturated and unsaturated fatty acids identified in the extracts of beech: (1) Lauric C12:0 acid; (2) Myristic C14:0 acid; (3) Palmitic C16:0 acid; (4) Stearic C18:0 acid; (5) Arachidic C20:0 acid; (6) Behenic C22:0 acid; (7) Lignoceric C24:0 acid; (8) Palmitoleic C16:1 acid; (9) Oleic C18:1 acid; (10) Elaidic C18:1 acid; (11) Linoleic C18:2 acid; (12) Linolenic C18:3 acid

Slika 1. Strukturne formule zasićenih i nezasićenih masnih kiselina identificiranih u ekstraktivnim tvarima bukve: (1) laurinska C12:0 kiselina; (2) miristinska C14:0 kiselina; (3) palmitinska C16:0 kiselina; (4) stearinska C18:0 kiselina; (5) arahidonska C20:0 kiselina; (6) behenska C22:0 kiselina; (7) lignocerinska C24:0 kiselina; (8) palmitoleinska C16:1 kiselina; (9) oleinska C18:1 kiselina; (10) elaidinska C18:1 kiselina; (11) linolna C18:2 kiselina; (12) linolenska C18:3 kiselina

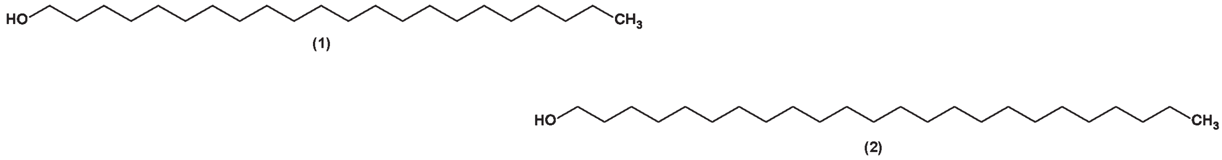


Figure 2 Structures of fatty alcohols found in the cyclohexane extracts of beech wood: (1) Behenyl C22:0 alcohol; (2) Lignoceryl C24:0 alcohol
Slika 2. Strukture masnih alkohola pronađenih u cikloheksanskim ekstraktima bukovine: (1) behenil C22:0 alkohol; (2) lignocerinski C24:0 alkohol

extractives (Kubel and Weissmann, 1988). In the non-polar extracts of sapwood and wood chips of beech, saturated and unsaturated fatty acids were identified as the palmitic (C16:0), stearic (C18:0), oleic (C18:1) and linoleic (C18:2) acid by means of different chromatographic techniques (Kubel and Weissmann, 1988; Zule and Može, 2003). Moreover, a saturated lauric (C12:0), myristic (C14:0), arachidic (C20:0), behenic (C22:0) and lignoceric acid (C24:0) and unsaturated palmitoleic (C16:1), elaidic (C18:1), linolenic (18:3), dehydroabietic and unsaturated hydroxyoctadecadiene acid were identified in the extracts of sapwood as well (Figure 1 Structure formulas of saturated and unsaturated fatty acids identified in the extracts of beech: (1) Lauric C12:0 acid; (2) Myristic C14:0 acid; (3) Palmitic C16:0 acid; (4) Stearic C18:0 acid; (5) Arachidic C20:0 acid; (6) Behenic C22:0 acid; (7) Lignoceric C24:0 acid; (8) Palmitoleic C16:1 acid; (9) Oleic C18:1 acid; (10) Elaidic C18:1 acid; (11) Linoleic C18:2 acid; (12) Linolenic C18:3 acid (Figure 1) also represent a part of the aliphatic fraction in suberin (Perra *et al.*, 1993), a hydrophobic biopolymer, whose occurrence is characteristic for wound response of wood in beech (Pearce, 1996; Torelli and Oven, 1996; Oven *et al.*, 1999; Pearce, 2000; Schwarze and Baum, 2000). The presence of fatty alcohols, i.e. behenyl C22:00 alcohol and lingoceryl C24:0 (Figure 2 Structures of fatty alcohols found in the cyclohexane extracts of beech wood: (1) Behenyl C22:0 alcohol; (2) Lignoceryl C24:0 (Figure 2), has been recently proven in the cyclohexane extracts of wood of red hearted beech by the long-column GC/MS analysis (Vek *et al.*, 2014). Besides fatty acids, the extracts of beech knots are also characterized by a low concentration of resin acids (Lindberg *et al.*, 2004).

In addition to fatty acids and alcohols, numerous glycerides, sterols and steryl esters were identified as the lipophilic extractives of beech wood. An acyclic triterpenoid squalene (Figure 3) and cyclic cycloartenyl acetat, β-amyrin acetate, acetyl methyl betulinate and dihydrositosterol were extracted from dried wood by Pišova and Souček (1973). Furthermore, relatively low levels of β-carotene and lutein were found in the

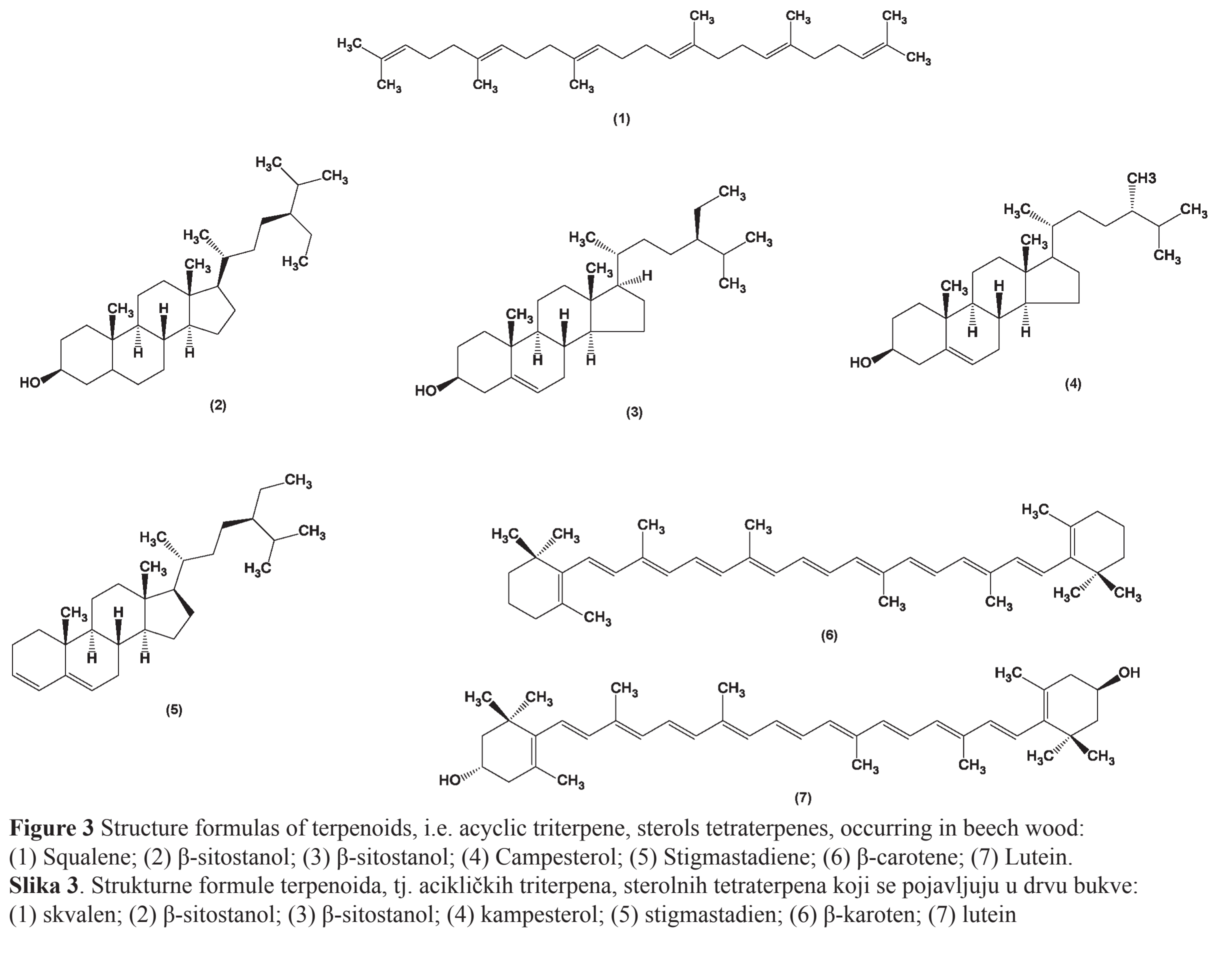


Figure 3 Structure formulas of terpenoids, i.e. acyclic triterpene, sterols tetraterpenes, occurring in beech wood: (1) Squalene; (2) β-sitostanol; (3) β-sitostanol; (4) Campesterol; (5) Stigmastadiene; (6) β-carotene; (7) Lutein.
Slika 3. Strukturne formule terpenoida, tj. acikličkih triterpena, sterolnih tetraterpena koji se pojavljuju u drvu bukve: (1) skvalen; (2) β-sitostanol; (3) β-sitostanol; (4) kampesterol; (5) stigmastadien; (6) β-karoten; (7) lutein

sapwood extracts of beech by Masson *et al.* (1997). This was actually the first report about the presence of carotenoids in wood tissue (Figure 3). As shown in Figure 3, a β-sitosterol, dihydrositosterol (β-sitostanol) and campesterol were qualitatively evaluated as the free sterols occurring in various beech materials, i.e. sapwood dust, wood chips and dried wood (Pišova and Souček, 1973; Kubel and Weissmann, 1988; Zule and Može, 2003). Furthermore, Zule and Može (2003) described β-sitosterol as the most important unesterified sterol in beech wood with a very significant physiological function in wood. Sterols were also found in beech knots (Lindberg *et al.*, 2004). As recently reported (Vek *et al.*, 2014), a characteristic compound of the nonpolar fraction of extractives in beech wood is also stigmasta-3,5-diene (Figure 3) that belongs to the group of sterenes, known as the dehydration compounds of sterols (Gallina Toschi *et al.*, 1996; Amelio *et al.*, 1998). Lindberg *et al.* (2004) reported on the presence of sterols in the extract of beech knots.

2.2 Hydrophilic extractives
2.2. Hidrofilne ekstraktivne tvari

After removing lipophilic extractives, the hydrophilic compounds are usually further extracted by means of more polar solvents, such as methanol, acetone, ethanol, water, etc. Soluble sugars and various phenolic extractives, e.g. simple phenolics, stilbenes, lignans, flavonoids and tannins are known as the characteristic representatives of hydrophilic extractives. In a broader sense, inorganic compounds are also known as hydrophilic extractives and they can be extracted by water (Fengel and Wegener, 1989). The yield of hydrophilic extractives from beech wood is usually much larger than that of lipophilic extractives (Kubel and Weissmann, 1988).

Various monosaccharides and oligosaccharides, sugar alcohols and acids, simple phenolics, flavonoids, both oligomeric units of tannins have been determined as the hydrophilic substances of beech wood. Among the monosaccharides, glucose, galactose, arabinose, fructose, xylose, mannose and rhamnose were identified in the wood extracts and wood condensate of beech (Dietrichs, 1964b; Kubel and Weissmann, 1988; Irmouli *et al.*, 2002). Furthermore, disaccharides saccharose and trehalose as well as trisaccharide raffinose were identified in the extracts of beech wood (Dietrichs, 1964b; Vek *et al.*, 2014). The presence of both tetrasaccharide stachyose and polysaccharide starch was reported for the sapwood and wood condensate of beech, respectively (Dietrichs, 1964b; Irmouli *et al.*, 2002). Sugar alcohols, i.e. erytritol, arabitol, sorbitol, mannitol, xylitol

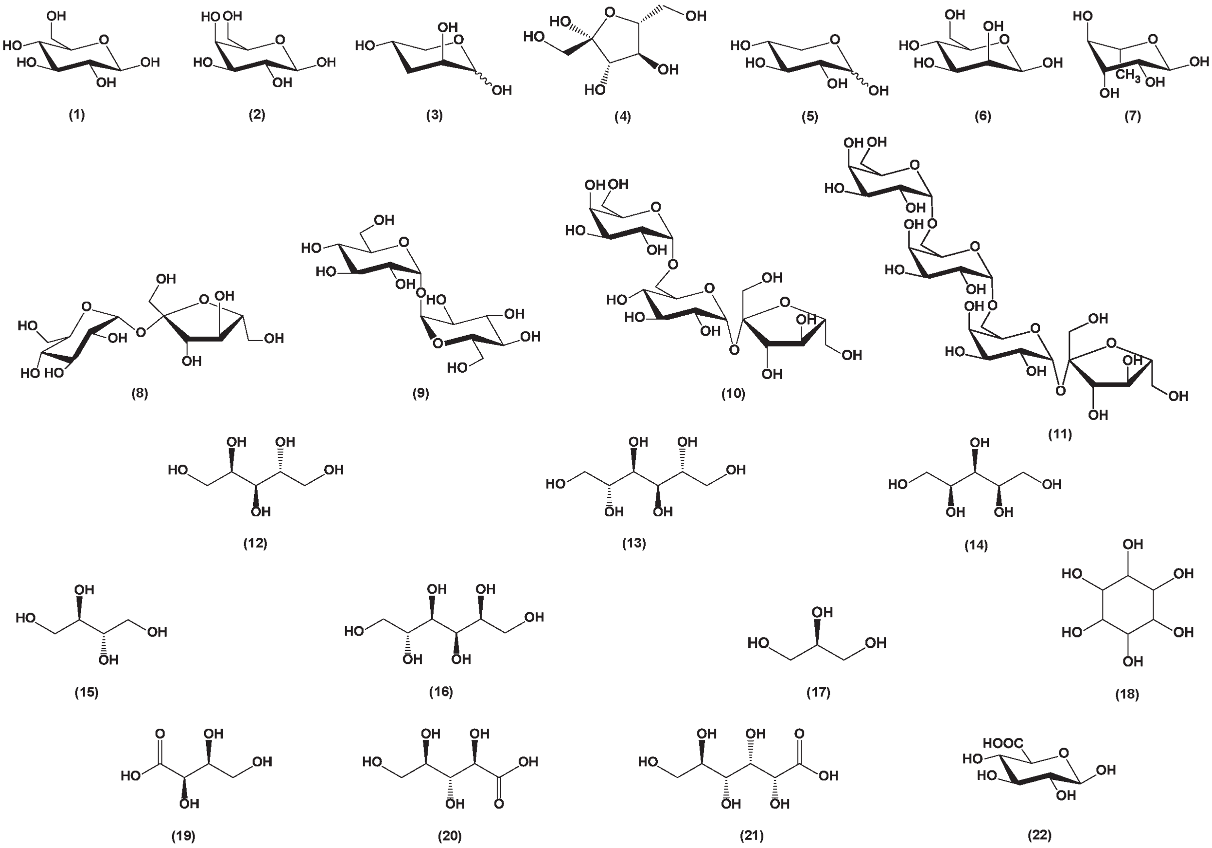


Figure 4 Chemical structures of monosaccharides, oligosaccharides, sugar alcohols and sugar acids identified in beech wood: (1) Glucose; (2) Galactose; (3) Arabinose; (4) Fructose; (5) Xylose; (6) Mannose; (7) Rhamnose; (8) Saccharose; (9) Trehalose; (10) Raffinose; (11) Stachyose; (12) Arabitol; (13) Mannitol; (14) Xylitol; (15) Erytritol; (16) Sorbitol; (17) Glicerol; (18) Inositol; (19) Threonic acid; (20) Ribonic acid; (21) Gluconic acid; (22) Glucuronic acid
Slika 4. Kemijska struktura monosaharida, oligosaharida, šećernih alkohola i šećernih kiselina identificiranih u drvu bukve: (1) glukoza; (2) galaktoza; (3) arabinoza; (4) fruktoza; (5) ksiloza; (6) manoza; (7) ramnoza; (8) saharoza; (9) trehaloza; (10) rafinoza; (11) stahioza; (12) arabitol; (13) manitol; (14) ksilitol; (15) eritritol; (16) sorbitol; (17) glicerol; (18) inozitol; (19) treonska kiselina; (20) ribonska kiselina; (21) glukonska kiseline; (22) glukuronska kiselina

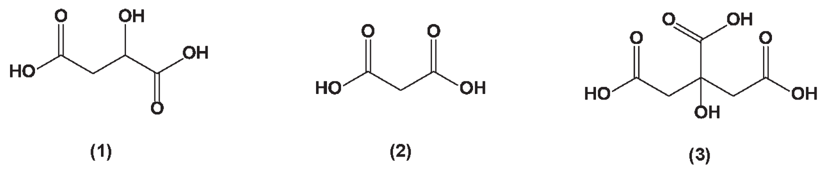


Figure 5 Structure formulas of carboxylic acids identified in methanolic extracts of beech wood: (1) Malic acid; (2) Malonic acid; (3) Citric acid
Slika 5. Strukturne formule karboksilnih kiselina identificiranih u metanolnim ekstraktima iz bukovine: (1) jabučna kiselina; (2) malonska kiselina; (3) limunska kiselina

and glycerol, as well as inositols were qualitatively evaluated in extracts of wound-associated tissues and knots of beech (Zule and Može, 2003; Vek *et al.*, 2014). In addition to sugar alcohols, the occurrence of several sugar acids (ribonic, threonic, gluconic and glucuronic acid) has been proven for the methanol extracts of stem wood by means of GC/MS (Figure 4). Our recent chromatographic study has also shown the presence of low-molecular carboxylic acids in the extracts of both stem wood and knots of beech, i.e. malic, malonic and citric acid (Figure 5) (Vek *et al.*, 2014).

Numerous simple phenols have been extracted from beech wood as well. Challinor (1996) applied gas chromatography coupled with mass spectrometry for the qualitative evaluation of extractives in the wood shavings/turnings of intact beech. As the characteristic compounds in the tetramethylammonium hydroxide extracts, 5-hydroxy, 2-hydroxymethyl pyranone (triv. kojic acid), 3,4-dimethoxybenzaldehyde, 3,4-dimethoxybenzoic acid methyl ester, 3,4,5-trimethoxybenzaldehyde and 3,4,5-trimethoxybenzoic acid methyl ester were found. From thermal treated wood, i.e. steamed and dried beech wood, a sinapyl alcohol, coniferyl alcohol, 2,6-dimethoxybenzoquinone, protocatechuic acid, vanillic acid, vanillin, syringic acid, coniferaldehyde, siringalydehide synapic acid, gallic acid, p-hy-

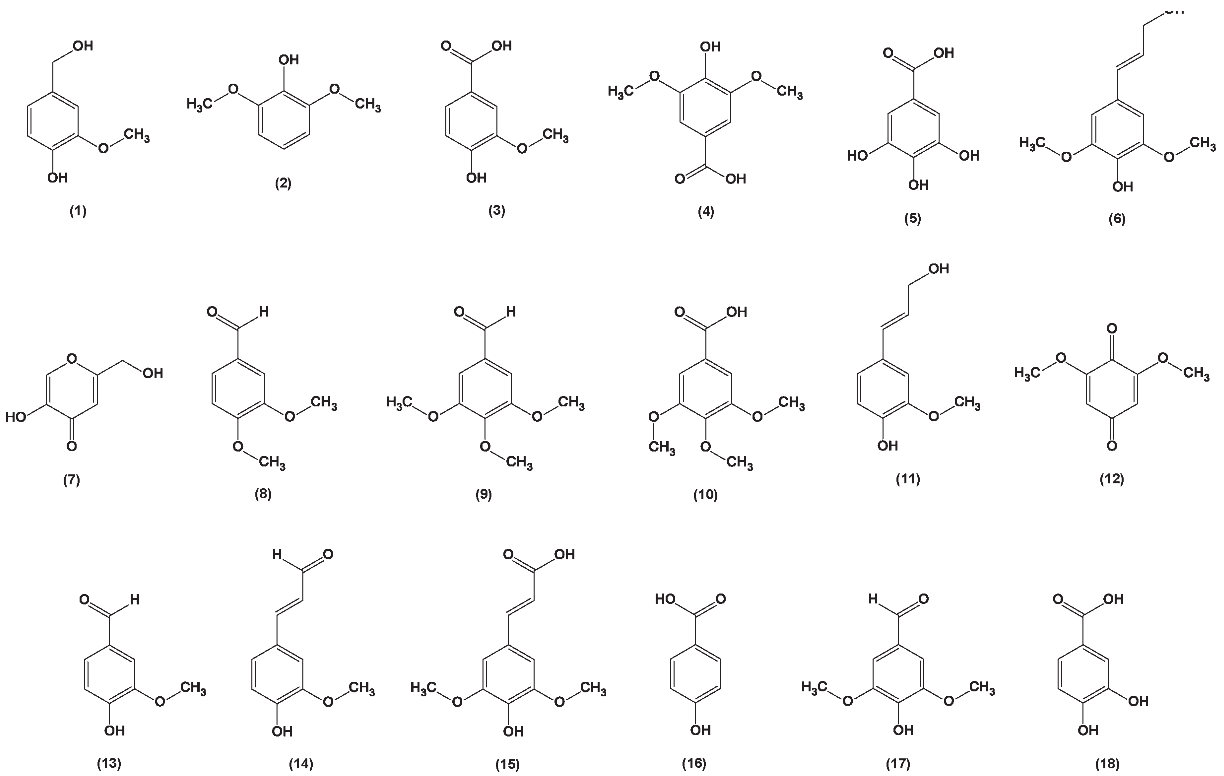


Figure 6 Structure formulas of simple phenolics identified in beech wood extracts: (1) Vanilyl alcohol; (2) Syringol; (3) Vanillic acid; (4) Syringic acid; (5) Gallic acid; (6) Sinapyl alcohol; (7) Kojic acid; (8) 3,4-Dimethoxybenzaldehyde; (9) 3,4,5-Trimethoxybenzaldehyde; (10) 3,4,5-trimethoxybenzoic acid; (11) Coniferyl alcohol; (12) 2,6-Dimethoxybenzoquinone; (13) Vanilin; (14) Coniferaldehyde; (15) Synapic acid; (16) p-Hydroxybenzoic acid; (17) Syringaldehyde; (18) Protocatechuic acid
Slika 6. Strukturne formule jednostavnih fenola identificiranih u ekstraktima iz bukovine: (1) vanilil alkohol; (2) siringol; (3) vanilinska kiselina; (4) siringijska kiselina; (5) galna kiselina; (6) sinapil alkohol; (7) Kojić kiselina; (8) 3,4-dimetoksibenzaldehid; (9) 3,4,5-trimetoksibenzaldehid; (10) 3,4,5-trimetoksibenzojeva kiselina; (11) koniferil alkohol; (12) 2,6-dimetoksibenzokinon; (13) vanilin; (14) koniferaldehid; (15) sinapik kiselina; (16) p-hidroksibenzojeva kiselina; (17) siringaldehid; (18) protokatehična kiselina

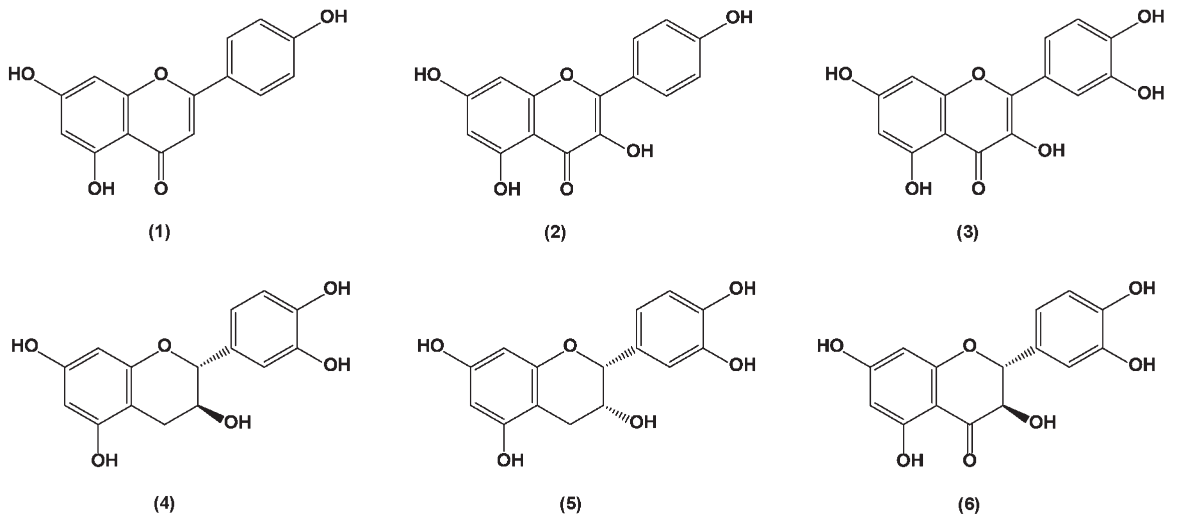


Figure 7 Flavonoids found in the extracts of functional wood, discoloured wood, dried wood, leaves, bark and roots of beech: (1) Apigenin; (2) Kaempferol; (3) Quercetin; (4) Catechin; (5) Epicatechin; (6) Taxifolin
Slika 7. Flavonoidi pronađeni u ekstraktima funkcionalnog drva, izbijeljenog drva, osušenog drva, lišća, kore i korijena bukve: (1) apigenin; (2) kempferol; (3) kvercetin; (4) katehin; (5) epikatehin; (6) taksifolin

droxybenzoic acid were successfully extracted and qualitatively evaluated (Irmouli *et al.*, 2002; Koch *et al.*, 2003; Mounguengui *et al.*, 2007; Vek *et al.*, 2014). Moreover, vanillin, vanillic acid and syringic acid are also known as the constituents of phenolic fraction of a depolymerized suberin in beech (Perra *et al.*, 1993). In addition to simple phenols, the presence of aromatic dimeric structures, i.e. lignin-type compounds, was also proven in beech wood extracts (Koch *et al.*, 2003; Vek *et al.*, 2014). These dimers made up of coniferyl and sinapyl alcohol were referred to as the precursors of a lignin biosynthesis accordingly to Koch *et al.* (2003), but they can represent another group of phenolic extractives, called lignans. Lignans were found in extracts of beech knot by Lindberg *et al.* (2004). Furthermore, they reported about the presence of small amounts of stilbenes, generally known as bioactive compounds with the 1,2-diphenylethene structure (Lindberg *et al.*, 2004). Some of simple phenolic compounds that have been shown as the extractives of beech wood are presented in Figure 6.

Flavonoids are commonly referred to as both the most important and abundant group of extractives of beech tissue (Brignolas *et al.*, 1995; Pearce, 1996; Torelli, 2003; Vek, 2013). Catechin is the most frequently reported flavonoid that can be extracted from the beech wood (Figure 7). A few research groups reported on the presence of catechin in the sapwood and discoloured wood (Kubel and Weissmann, 1988; Baum and Schwarze, 2002; Koch *et al.*, 2003; Zule and Može, 2003; Hofmann *et al.*, 2004; 2008). Catechin was also found in the extracts of thermally treated and decayed beech wood (Mounguengui *et al.*, 2007; Lekounougou *et al.*, 2008). It was reported that the amount of catechin in discoloured tissues decreases due to its participation in the process of formation of colour chromophores (Hofmann *et al.*, 2004). It was also suggested that, during thermal treatment of beech wood, the condensation of catechin contributes to a brown stain pigment, whereas other extractives, e.g. a 2,6-dimethoxybenzoquinone (Figure 6) and taxifolin (Figure 7), contribute to the final colour of discoloured tissues (Koch *et al.*, 2003). Therefore, the discolouration mechanism in beech wood can be understood as a condensation of catechin monomers to polymer forms. Besides wood, the presence of flavonoids has also been shown for the extracts of other parts of beech tree, e.g. leaves, knots, roots and bark (Beyeler and Heyser, 1997; Dubeler *et al.*, 1997; Feucht *et al.*, 1997; Lindberg *et al.*, 2004; Pietarinen *et al.*, 2006; Pirvu *et al.*, 2010). In addition to the catechin, its diastereomer epicatechin was also found both in beech wood and in roots and leaves (Beyeler and Heyser, 1997; Feucht *et al.*, 1997; Hofmann *et al.*, 2004). As reported by Pirvu *et al.* (2010), a flavone apigenin, flavonols kaempferol and quercetin and various caffeic acid derivates can be extracted with ethanol from beech leaves (Figure 7). Recently, a comprehensive investigation, with the high-performance liquid chromatography and multistage mass spectrometry, has shown the presence of catechin and epicatechin in beech bark extracts (Hofmann *et al.*, 2015).

Phenolic compounds frequently occur as glycosides as the core aglycone in plant tissues. According to Sherwood and Bonello (2013), the sugar unit of phenolic glycoside serves to improve solubility for storage in cell organs, e.g. vacuoles. Some research groups described the presence of flavonoid glycosides as characteristic for beech extracts (Figure 8). Catechin glucoside and taxifolin glucoside were found in the extracts of both normal and thermally treated beech wood (Kubel and Weissmann, 1988; Koch *et al.*, 2003). Numerous glycosides, i.e. taxifolin-*O*-pentoside, taxifolin-*O*-hexoside, quercetin-*O*-pentoside and quercetin-*O*-hexoside were proven to occur in the methanol extracts of wood dust by Mammela (2001). The presence of glycosides was confirmed in the extracts of beech bark as well. Thus, *cis*-coniferin, *cis*-syringin,

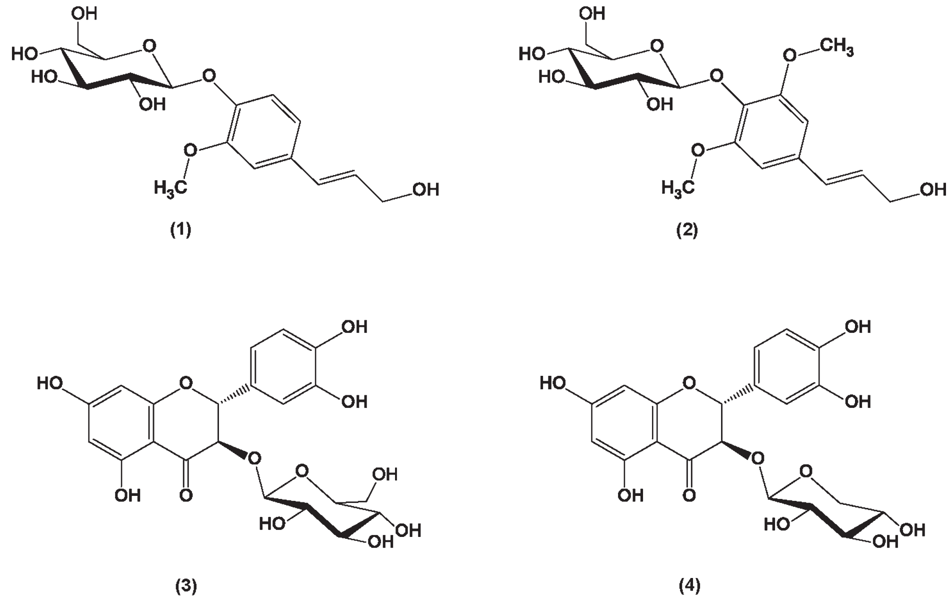


Figure 8 Chemical structures of determined flavonoid glycosides occurring in beech tissues: (1) Coniferin; (2) Syringin; (3) Taxifolin-3-glucopyranoside; (4) Taxifolin-3-xylopyranoside
Slika 8. Kemijska struktura utvrđenih flavonoida glikozida koji se pojavljuju u tkivima bukve: (1) koniferin; (2) siringin; (3) taksifolin-3-glukopiranozid; (4) taksifolin-3-ksilopiranozid

cis-isoconiferin, (2*R*,3*R*)-(+)-glucodistylin, (2*S*,3*S*)-(–)-glucodistylin and 2*R*,3*R*-taxifolin-3-*D*-*β*-xylopyranosid were identified and completely assigned by 2D NMR techniques (Dubeler *et al.*, 1997). More isomers of taxifolin-O-hexosides as well as taxifolin-O-pentosides have been qualitatively and quantitatively evaluated in beech bark by means of HPLC-MS/MS analysis (Hofmann *et al.*, 2015). Authors report about the presence of syringin, coniferins, quercetin-O-hexoside, coumaric acid di-O-hexoside, syringic acid-di-O-hexosides, coniferyl alcohol-O-hexoside-O-pentoside in beech bark extracts as well (Hofmann *et al.*, 2015).

Flavonoids can also occur in wood extracts as the aglicon polymers (Fengel and Wegener, 1989). The latter are known as the condensed tannins or proanthocyanidins. It has to be mentioned that the term proanthocyanidins describes bioflavonoids, leucoantocyanidins as well as condensed tannins. The building blocks of most proanthocyanidins are the flavanols catechin and epicatechin (Dixon et al., 2005), i.e. the characteristic compounds of flavonoid fraction of beech wood extracts. Regarding the inter flavanol linkages as well as the degree of polymerization, the proanthocyanidins are generally divided into A-, B- or C-type proanthocyanidins (Figure 9). Proanthocyanidins were spectrophotometrically evaluated in extracts of intact sapwood as well as in reaction zone of beech by Scalbert *et al.* (1989) and Baum and Schwarze (2002). This semi-quantitative technique has also been applied for the determination of proanthocyanidins in the stem and knot samples of red hearted beech (Vek *et al.*, 2014). Koch *et al.* (2003) also reported about the presence of oligomeric flavonoids in acetone-water and methanol-water extracts of beech wood. A relatively large amount of oligomeric polyphenols is characteristic for beech knotwood (Lindberg *et al.*, 2004; Vek *et al.*, 2014). Just recently, Hofmann *et al.* (2015) have identified and quantified a large number of dimeric and trimeric procyanidins in beech bark by

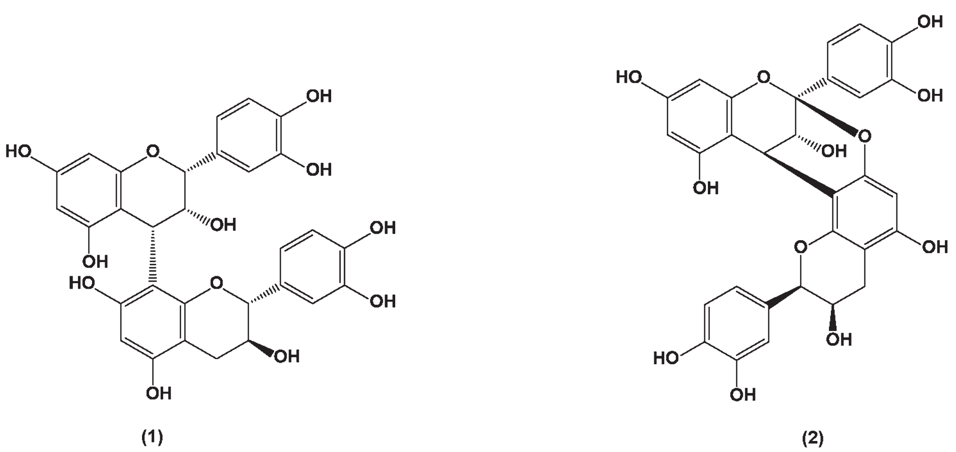
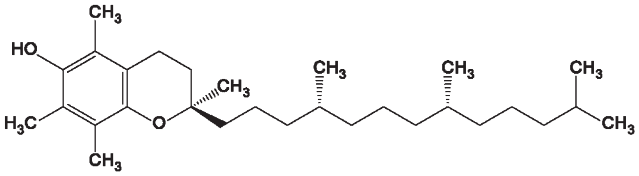


Figure 9 Chemical structures of simple dimeric units of type B1 (1) and type A2 (2) proanthocyanidins
Slika 9. Kemijska struktura jednostavnih dimernih jedinica tipa B1 (1) i tipa A2 (2) proantocianidina


(1)

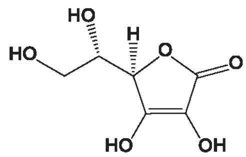

(2)

Figure 10 α-tocopherol (Vitamin E) (1) and Ascorbic acid (Vitamin C) (2) as identified in the extracts of beech for leaves and wood
Slika 10. (1) α-tokoferol (vitamin E) i (2) askorbinska kiselina (vitamin C), kao što je identificirano u ekstraktima bukve, u listovima i u drvu

HPLC-MS/MS. Further on, proanthocyanidins were also identified in the extracts of roots and leaves (Feucht *et al.*, 1994; Beyeler and Heyser, 1997; Feucht *et al.*, 1997). Condensed tannins, present in beech leaves, were investigated by Behrens *et al.* (2003). The authors demonstrated that proanthocyanidins of beech leaves are built up of procyanidin (catechin and epicatechin) and prodelphinidin units (gallocatechin and epigallocatechin).

Different antioxidants were identified in the beech leaf extracts, i.e. vitamin C (ascorbic acid) and vitamin E (α-tocopherol) (Kunert and Ederer, 1985). Structural formulas for both compounds are presented in Figure 10. It was shown that vitamin E also occurs in the tissues at the bases of living and dead breaches of beech. Furthermore, it can be extracted from these tissues by means of non-polar solvent, i.e. cyclohexane (Vek *et al.*, 2014). Further to the above, vitamin E could be classified as the lipophilic extractive as well.

After all, some of characteristic hydrophilic extractives occurring in tissues of beech trees are biologically active compounds, which make this forest biomass interesting for extraction and further utilization. For instance, antifungal properties against some basidiomycetes were found for catechin and taxifolin by Malterud *et al.* (1985). Some years later, epicatechin was also reported as the compound with antifungal activity (Ardi *et al.*, 1998; Baum and Schwarze, 2002). In addition to flavonoids, aglycones of *cis*-coniferin *and cis*-syringin, i.e. coniferyl alcohol and syringic acid, identified in the methanolic extracts of beech bark were reported as fungicides by Dubeler *et al.* (1997). Not only pure compounds, but also acetone extract of a beech knot, which was reported to be composed mainly of catechins and flavonoids, showed evident antibacterial properties (Välimaa *et al.*, 2007). Wood and bark extractives of various tree species have attracted much attention due to their possible application in various fields, including nutritional, cosmetic, medical and pharmaceutical industry, as natural biocides, feed additives or in industry of adhesives and leather production etc. Replacement of synthetic, artificial chemicals with more benign natural products, whose recovery has only little or no impact on human health and environment, is one of the important challenges in the field of biorefining forest biomass (Holmbom, 2011).

3 CONCLUSION
3. ZAKLJUČAK

It can be summarized that successive extraction using the non-polar and polar solvent, respectively, represents the most frequently used and appropriate way of extraction of different beech material. The extractives can be obtained from grinded samples by using magnetic stirrer, whereas, more aggressive extraction techniques are recommended, e.g. conventional Soxhlet apparatus or various subcritical systems for accelerated extraction (Thurbide and Hughes, 2000; Vek, 2013). From the analytical aspect of view, chromatography in combination with mass spectrometry has been found as the convenient technique for the qualitative and quantitative analysis of extractives. Since stem-wood of beech is generally characterized by the relatively low amounts of extractable compounds, there is a strong need to recognize the appropriate source for extraction. Knots of trees have been presented more times as a very rich source of different polyphenols, perhaps the richest in all of nature as reported by Holmbom (2011) and beech is not an exception (Vek, 2013). Furthermore, a very important step for recovering the target compounds from different parts of a beech tree is the optimization of appropriate and efficient extraction systems (i.e. extraction techniques and solvents) as it was recently demonstrated for beech bark (Hofmann et al. 2015). This short review revealed that the composition of low-molecular fraction of lipophilic and hydrophilic extractives is relatively well investigated, whereas the data on oligomeric fraction of extractable compounds are extremely sparse and require further research efforts.

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PROMOCIJA SVEUČILIŠNOG PRIRUČNIKA KVALITETA I TEHNIČKI OPISI PROIZVODA OD DRVA,

svezak I. Opremanje zgrada za odgoj i obrazovanje

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doc. dr. sc. Danijela Domljan, prof. dr. sc. Ivica Grbac, prof. dr. sc. Vlatka Jirouš Rajković, doc. dr. sc. Zoran Vlaović, doc. dr. sc. Vjekoslav Živković, doc. dr. sc. Ivica Župčić
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Šumarski fakultet Sveučilišta u Zagrebu, Hrvatska gospodarska komora, Zagreb, srpanj 2015.

Na Šumarskom fakultetu Sveučilišta u Zagrebu 2. prosinca 2015. održana je promocija sveučilišnog priručnika *Kvaliteta i tehnički opisi proizvoda od drva, svezak I. Opremanje zgrada za odgoj i obrazovanje.*

Promociji su nazočili brojni uzvanici, od kojih je, nakon pozdravnoga govora dekana Fakulteta prof. dr. sc. Vladimira Jambrekovića, uvodnu riječ o aktualnoj Strategiji obrazovanja znanosti i tehnologije dao prof. Neven Budak, posebni savjetnik predsjednika Vlade Republike Hrvatske za znanost i predsjednik Posebnoga stručnog povjerenstva za provedbu Strategije. Potom su se skupu obratili prof. dr. sc. Ružica Beljo Lučić, pomoćnica za visoko obrazovanje ministra znanosti, obrazovanja i sporta; Domagoj Križaj, pomoćnik ministra poljoprivrede za šumarstvo, lovstvo i drvnu industriju, Božica Marković, direktorica Sektora za poljoprivredu, prehrambenu industriju i šumarstvo pri Hrvatskoj gospodarskoj komori, koja je govorila i u ime projekta *Drvo je prvo*, te Silvija Zec, tajnica Komore inženjera šumarstva i drvne tehnologije, koja je također poduprla nastanak i izdavanje toga sveučilišnog priručnika. U nastavku promocije prisutnima se obratila urednica priručnika doc. dr. sc. Danijela Domljan i pregledno iznijela kronološki slijed nastanka priručnika. Doc. Domljan ujedno je bila i voditeljica projekta *Izrada knjige tehničkih opisa proizvoda do drva – odgojno obrazovne ustanove* (2012. - 2013.), u sklopu kojega je 2013. godine objavljen prvi stručni *Priručnik za kvalitetu – izradu tehničkih opisa – proizvoda od drva – Svezak I – odgojno-obrazovne zgrade*, nastao kao dio projekta *Drvo je prvo,* što ga financiraju i potiču Hrvatska gospodarska komora, Ministarstvo poljoprivrede i Hrvatske šume d.o.o. Nakon recenzija djelo je preraslo u sveučilišni priručnik pod nazivom *KVALITETA I TEHNIČKI OPISI PROIZVODA OD DRVA, svezak I. Opremanje zgrada za odgoj i obrazovanje*, čime je uz stručnu dobio i najvišu znanstvenu potvrdu kvalitete. U ime recenzenata (recenzenti Boris Ljuljka profesor emeritus, Stjepan Tkalec, redoviti profesor u mirovini, te Martina Bertina, d.i.a., viša predavačica) profesor Ljuljka je auditoriju obrazložio razloge dobivanja znaka *Manualia Universitatis studiorum Zagrabiensis.* Na kraju je doc. dr. sc. Zoran Vlaović, urednik i suautor djela, prezentirao sadržaj priručnika i načela njegova razumijevanja i primjene.

Ovim putem autori zahvaljuju svim uzvanicima i sudionicima skupa koji su svojom prisutnošću uveličali događaj te svim imenovanim predstavnicima koji su se u ime svojih institucija i u svoje ime obratili nazočnima. Posebnu zahvalu upućuju kolegici dr. sc. Aidi Kopljar i kolegi Igoru Barbariću, koji su kao koordinatori projekta *Drvo je prvo* u ime svojih ustanova – Ministarstva poljoprivrede i Hrvatske gospodarske komore, pratili, poticali i omogućili da priručnik bude realiziran i predstavljen na Šumarskom fakultetu.

KRATAK SADRŽAJ PRIRUČNIKA

Priručnik se sastoji od tri dijela.

I. DIO obuhvaća dva poglavlja. U tekstu prvog poglavlja – O PRIRUČNIKU – uz osnovne napomene objašnjava se svrha, cilj i očekivani rezultati projekta. Drugo poglavlje – SUVREMENE SPOZNAJE – uvodi čitatelja u problematiku opremanja odgojno-obrazovnih zgrada; navode se postojeći dokumenti Republike Hrvatske te analiziraju rezultati znanstvenih i stručnih istraživanja u području suvremenoga odgojno-obrazovnog procesa, dizajna predmetnog okruženja, opremanja te, općenito, utjecaja namještaja i opreme na zdrav rast i razvoj djece i mladih u vrtićima te osnovnim i srednjim školama.

II. DIO priručnika zapravo je njegov glavni dio. Sadržava tri poglavlja, koja se nastavljaju na prethodna. Treće poglavlje – UVOD U KVALITETU PROIZVODA OD DRVA – opisuje opće uvjete i čimbenike kvalitete, objašnjava osnovne pojmove i navodi važeće norme u području kvalitete namještaja, opreme, površinske obrade i proizvoda za graditeljstvo. U četvrtom poglavlju – NAMJEŠTAJ I OPREMA – obrađuju se glavni zahtjevi i preporuke o dizajnu namještaja i opreme te obuhvaća zahtjeve o općoj i tehničkoj kvaliteti, oblikovno-konstrukcijska rješenja, sigurnost, ergonomsko-antropometrijske zahtjeve i funkcionalne dimenzije namještaja i opreme, pedagoške i estetske zahtjeve, zahtjeve vezane za drvne i nedrvne materijale, površinsku obradu, ojastučene površine i dr. Zatim je opisano više od stotinu proizvoda, glavnih predstavnika namještaja za odlaganje, rad i blagovanje, sjedenje i ležanje, kao i elemenata opreme odgojno-obrazovnih ustanova. Dani su primjeri tehničkih opisa predstavnika svake pojedine vrste namještaja. Peto poglavlje – PROIZVODI ZA GRADITELJSTVO – na isti način kao i prethodno poglavlje navodi zahtjeve i preporuke te opisuje glavne predstavnike te skupine prozivoda – vrata, prozore i podne obloge (parkete).

III. DIO čini šesto poglavlje naziva VIZIJE I NOVI PRIJEDLOZI OPREMANJA, a namijenjeno je svim korisnicima, djeci i mladima, roditeljima i odgojno-nastavnom osoblju te drugim korisnicima, ali najviše onima koji sudjeluju u projektiranju i opremanju odgojno-obrazovnih zgrada i u oblikovanju te proizvodnji namještaja i opreme kojima će se te zgrade opremati (arhitektima, projektantima, dizajnerima, drvnim tehnolozima i drugima). To poglavlje ističe probleme što ih uzrokuje neodgovarajuće dizajniran namještaj i oprema te navodi važnost odgovarajućeg odnosa namještaja i zdravlja korisnika, uz postojeća rješenja i dobre primjere opremanja.

U ZAKLJUČKU je istaknuto kako je u spremanju odgojno-obrazovnih ustanova nužna interdisciplinarna suradnja stručnjaka s brojnih područja te da je *priručnik* doprinos pozitivnim nastojanjima u stvaranju cjelovite i poticajne predmetne okoline u kojima su udobnost, radost boravka i motivacija, komunikacija i dobrobit (engl. *well-being*) ostvareni uz pomoć kvalitetnih i „zdravih" proizvoda od drva.

U priručniku se citira više od 135 naslova domaće i strane LITERATURE koji svakako mogu poslužiti kao preporuka čitateljima za daljnju nadgradnju i proučavanje te tematike.

Format i opseg knjige je 21 × 21 cm, tvrdog uveza na 300 stranica, i sadrži preko 146 ilustracija i 16 tablica.

Sveučilišni priručnik može se nabaviti na Šumarskom fakultetu u Zagrebu putem narudžbenice (osoba za kontakt je gđa Dubravka Cvetan, tel.+385 1 2352 454; fax 00385 1 2352 531; www.sumfak.hr).

IZ RECENZIJE PRIRUČNIKA...

U Republici Hrvatskoj usvojena je politika intenzivnog razvoja institucionalne i društveno organizirane brige, odgoja i obrazovanja djece i mladih, kao i cjeloživotnog obrazovanja odraslih. To potvrđuju i brojni dokumenti u RH. Nažalost, koliko god se radilo na problematici pedagoških standarda, kurikuluma, zakona o odgoju i obrazovanju, malo se učinilo u osuvremenjivanju procesa opremanja obrazovnih objekata suvremenim namještajem i opremom koji bi pratili navedene strukturalne i pedagoške promjene. Proces opremanja odgojno-obrazovnih zgrada u Republici Hrvatskoj u posljednjih je dvadesetak godina doživio znatan kvalitativni pad. Provedba natječaja za opremanje tih zgrada često ne zadovoljava osnovnu kompetentnost o suvremenim potrebama i navikama korisnika. Zbog odredbi Zakona o javnoj nabavi i prihvaćanja najjeftinijeg proizvoda kao najpogodnijega, cijena u potpunosti zasjenjuje ergonomiju, funkcionalnost i kvalitetu, koji pak izravno utječu na zdrav rast i razvoj djece i mladih. Posljedice se očituju u nekvalitetnom i nefunkcionalnom namještaju i opremi koji ne podržavaju navedeno, osobito u smislu primjene funkcionalnih (normiranih) dimenzija namještaja, zdravih i pogodnih materijala, sigurne i stabilne konstrukcije, poticajnoga i kreativnog obličja, kao i brojnih drugih. Zahtjeva znanstvena istraživanja, kao i iskustva iz prakse u RH, pokazuju da postoje znatne nedosljednosti pri opremanju odgojno-obrazovnih objekata, da proizvodi često nisu dizajnirani u skladu sa suvremenim pedagoškim metodama i potrebama korisnika te da nisu izrađeni od kvalitetnih materijala. Pri tome je slabo zastupljeno drvo i drvna sirovina, što se ponajviše uviđa pri sastavljanju i provođenju natječajnih dokumentacija za odabir najpovoljnijeg dobavljača za opremanje odgojno-obrazovnih zgrada.

Autori priručnika objedinili su znanja različitih područja, čime su prezentirali interdisciplinarno djelo namijenjeno široj stručnoj publici. Priručnik je namijenjen studentima šumarskoga, arhitektonskoga, medicinskoga i strojarskog fakulteta, studiju dizajna i drugih srodnih područja, proizvođačima i investitorima namještaja i ostalih proizvoda namijenjenih opremanju odgojno-obrazovnih zgrada, kao i arhitektima, projektantima, dizajnerima, nastavnicima i odgajateljima te svim populacijama korisnika koji dolaze u doticaj s navedenom tematikom.

Priručnik je u velikoj mjeri izvorno djelo. Postoji domaća i strana literatura u kojoj se različite discipline bave tom problematikom iz svojih specifičnih perspektiva i koja sadržava dijelove navedene i obrađene u priručniku, međutim nijedno djelo do sada nije ovako spretno znanstveno i stručno objedinilo i saželo različite interdisciplinarne aspekte opremanja odgojno-obrazovnih zgrada.

Priručnik daje analizu sadašnjeg stanja u RH, ali usto daje i vizije i prijedloge razvoja namještaja i opreme koja se rabi u odgoju i obrazovanju. Materija je obrađena dobrim tekstovima koji su obogaćeni grafičkim prikazima što olakšava praćenje sadržaja i daje mu neku vrstu lepršavosti. Osjeća se duh dizajnerske obrade u smislu grafičkog dizajna, jer su tekstovi popraćeni slikama u boji, fotografijama i ilustracijama te tehničkim i dječjim crtežima koji prikazuju stvarno stanje u objektima ili želje korisnika (djece).

Cilj je priručnika uz pomoć opisanih proizvoda, zahtjeva i preporuka ponuditi ujednačenu kvalitetu tehničkih opisa za pojedine proizvode od drva kojima se najčešće opremaju odgojno-obrazovne zgrade. Time se omogućuje zdrava konkurentnost, podiže kvaliteta i percepcija svih korisnika o vrijednostima drva kao prirodnoga i zdravog materijala u interijeru, potiče primjena znanja s područja dizajna, arhitekture, konstrukcija, medicine, ergonomije i brojnih drugih struka, kao i implementacija suvremenih dizajnerskih rješenja koja se pridržavaju tehničkih propisa, preporuka, normi i zahtjeva vezanih za kvalitetu proizvoda. Također je cilj očuvati zdravlje svih korisnika, posebno najmlađih, uvođenjem kvalitetnih, ergonomski, antropometrijski, ekološki te oblikovno-konstrukcijski odgovarajućih proizvoda u navedene objekte.

IZ ZAKLJUČKA...

Važno je imati na umu da proces dizajna (okruženja, namještaja i svih elemenata u odgojno-obrazovnom okruženju) nije statičan već neprestan i dinamičan proces koji se mijenja sukladno potrebama kurikuluma i zahtjevima djece, mladih i odgojno-obrazovnog osoblja, a time i proizvođača. Dosad su istraživači većinu svoje znatiželje, energije i sredstava usmjeravali u istraživanja radnoga, najčešće uredskog okruženja i problema s kojima se susreće radno stanovništvo sjedeći u uredima. Na red su došla djeca i mladi, njihov zdrav rast i razvoj u odgojno-obrazovnim zgradama, u kojima će udobnost, radost boravka i motivacija, komunikacija i dobrobit biti od najvažniji uvjet.

Novi sadržaji, nove tehnologije i načini rada u svim segmentima odgojno-obrazovnih sustava nužno traže promjene. Na nama je, kao na društveno odgovornim osobama, da ih potičemo, usvajamo i primjenjujemo, na dobrobit (naj)mlađih, ali i društva u cjelini.

Priručnik je, nadamo se, doprinos tim nastojanjima.

doc. dr. sc. Danijela Domljan
prof. dr. sc. Vlatka Jirouš Rajković
doc. dr. sc. Zoran Vlaović
doc. dr. sc. Vjekoslav Živković

ILOMBA

UDK: 674.031.757.291.2

NAZIVI

Ilomba je naziv drva botaničke vrste *Pycnanthus angolensis* Exell iz porodice *Myristicaceae*.

Trgovački je naziv te vrste ilomba (Njemačka, Francuska, Velika Britanija, Gabon, Kamerun, Kongo), adria, effoi, hétéré, qualélé walélé (Obala Bjelokosti), otie, etsi (Gana), dihn, dihin (Liberija), abora, akomu, Ekom (Nigerija), bali, bemba, bokondo, ilimba, nesamba, teng, tian (Kamerun), kombo, mulomba (Gabon), bosenga, lolako, lomba, thsimbuku, lusenga senga (Kongo) te mutuje (Angola).

NALAZIŠTE

Stabla ilombe rastu u tropskim šumama zapadne, srednje i južne Afrike, u Liberiji, Obali Bjelokosti, Gani, Nigeriji, Kamerunu, Gabonu, Kongu, Angoli i Ugandi. Glavno su područje rasprostranjenosti tog drveta nizine tropskih prašuma te poluzimzelene i vazdazelene tropske šume.

STABLO

U svojoj domovini ilomba naraste od 30 do 40 metara, dužina debla mu je do 20 metara, a prsni promjer od 0,6 do 1,2 metra. Deblo je pravilnog, cilindričnog oblika. Kora mu je glatka, a sa starenjem i raspuca.

Vanjska kora drveta je pepeljasto siva, a unutarnja crvena. Debljina kore kreće se od 1 do 3 centimetra.

DRVO

Makroskopska obilježja

Srževina i bjeljika drva jedva se razlikuju po boji. Drvo je sivosmeđe do smećkaste boje, s crvenim tonovima nalik na drvo okume. Tekstura drva je jednolična, gruba i sjajna (svjetlucava), slabo dekorativna. Svježe drvo neugodnog je mirisa, koji se sušenjem izgubi. Drvo je rastresito porozno. Granica goda okom je jedva uočljiva. Pore su dobro vidljive okom, a drvni traci vidljivi su povećalom.

Mikroskopska obilježja

Traheje su pojedinačne ili u paru, rjeđe radijalno raspoređene. Promjer traheja iznosi 160...215...280 mikrometara, gustoća im je 0...2...4 na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi 1,4...3,6...6,5 %. Traheje srži nisu ispunjene sržnim tvarima. Aksijalni je parenhim paratrahealan. Volumni udio aksijalnog parenhima iznosi 2,6...4,4...5,4 %.

Drvni su traci heterogeni, visine 180...720...1130 mikrometara, odnosno do 18 stanica; širine 21...44...73 mikrometara, odnosno od 2 do 3 stanice. Gustoća drvnih trakova je 5...6...9 na 1 mm. Volumni je udio drvnih trakova 32,6...33,7...34,8 %. Drvna su vlakanca libriformska, odnosno vlaknaste traheide. Dugačka su 1140...1580...2140 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 1,3...2,1...2,75 mikrometara, a promjer lumena 9,0...20,8...33,4 mikrometara. Volumni je udio vlakanaca oko 55,8...58,3...62,5 %.

Fizikalna svojstva

Gustoća standardno suhog drva, ρ_o	290...410...500 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	420...490...600 kg/m^3
Gustoća sirovog drva, ρ_s	750...800 kg/m^3
Poroznost	oko 73 %
Radijalno utezanje, β_r	3,4...5,5 %
Tangentno utezanje, β_t	7,2...9,6 %
Volumno utezanje, β_v	10,7...14,2 %

Mehanička svojstva

Čvrstoća na tlak	24,5...57,5 MPa
Čvrstoća na vlak, okomito na vlakanca	17...29 MPa
Čvrstoća na savijanje	48...100 MPa
Tvrdoća (prema Brinelu), paralelno s vlakancima	oko 3,2 MPa
Tvrdoća (prema Brinelu), okomito na vlakanca	oko 1,6 MPa
Modul elastičnosti	5,8...12,9 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se strojno i ručno dobro obrađuje. Dobro se ljušti, pili i blanja. Brušenjem i politiranjem lako se površinski obrađuje, a tako obrađena površina lako prima sve vrste boja i lakova. Dobro se lijepi. Čavle i vijke lako prima i dobro drži.

Sušenje

Potrebno je pridati posebnu pozornost sušenju jer je drvo bliže srcu sklono raspucavanju i utezanju. Drvo je pogodna podloga za razvoj gljiva plijesni i za insekte.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva slabo je otporna do otporna na gljive truležnice (razred otpornosti 5) i podložna napadu termita (razred otpornosti S). Srž je vrlo permeabilna (razred 1).

Prema normama, drvo se može upotrebljavati bez kemijske zaštite samo u uvjetima razreda opasnosti 1 (isključivo u unutarnjim prostorima).

Uporaba

Ljušteni furnir ilombe dobro zamjenjuje furnir od drva okume, pa se rabi za proizvodnju šperploča. Kao lako drvo upotrebljava se u interijerima te za izradu namještaja, drvene ambalaže i specijalnih drvenih proizvoda (npr. kutija za cigare, drvenih kućišta, olovaka, rezbarija).

Sirovina

Drvo ilomba isporučuje se u obliku trupaca i piljenica različitih dimenzija.

Napomena

Popularnost upotrebe ilombe počela je rasti nakon Drugoga svjetskog rata, a sredinom 20. stoljeća to se drvo smatralo vrednijim drvom u Centralnoj Africi. Stabla ilombe u Ugandi rade sjenu na plantažama banane i kave. Većina dijelova stabla iskorištava se i u tradicionalnoj afričkoj medicini. U rodu *Pycnanthus* poznato je pet vrsta. Drvo sličnih svojstava imaju i ove vrste drveća: *Cephalosphaera usambarensis* Warb., *Coelocaryum oxycarpum* Stapf., *Virola surinamensis* Warb., *Virola* spp.

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Upute

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

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

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

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

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

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

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

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

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

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

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

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

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

Primjeri navođenja literature

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

Primjer

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

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

Primjeri

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

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

Ostale publikacije (brošure, studije itd.)

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

Web stranice

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

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

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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.

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