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Sait Dündar Sofuoğlu[1], Ahmet Kurtoğlu[2]

Effects of Machining Conditions on Surface Roughness in Planing and Sanding of Solid Wood

Utjecaj uvjeta obrade na hrapavost površine pri blanjanju i brušenju masivnog drva

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ABSTRACT • *It is important to evaluate the effect of machining and wood machining properties on surface quality to determine and upgrade the data on wood machining properties and to define convenient usage areas for some native wood species of Turkey. European black pine (Pinus nigra Arnold) and cedar of Lebanon (Cedrus libani A. Rich) are two softwood species and sessile oak (Quercus petraea Lieble) and black poplar (Populus nigra L.) are two hardwood species commonly used and grown in Turkey. These trees species were selected as experimental material for the study. Roughness measurements are significant in the determination of wood surface quality for use as a final product. This study evaluated roughness measurements after planing and sanding operations, and found that the highest value for average roughness (Ra) was observed as 6.780 µm. in sessile oak, followed by black poplar at 6.338 µm, cedar of Lebanon at 4.836 µm, and black pine at 4.740 µm. The average roughness values for wood in directions perpendicular to the grain and along the grain from highest to lowest were sessile oak, black poplar, black pine, and cedar of Lebanon.*

Key words: *Wood, surface roughness, planing, sanding*

SAŽETAK • *Istraživanje utjecaja mehaničke obrade i svojstava drva na kvalitetu obrađene površine važno je kako bi se dopunili podaci o svojstvima drva pri mehaničkoj obradi i definirala prikladna područja upotrebe nekih domaćih vrsta drva u Turskoj. Europski crni bor (Pinus nigra Arnold) i libanonski cedar (Cedrus libani A. Rich) dvije su meke vrste drva, a hrast kitnjak (Quercus petraea Lieble) i crna topola (Populus nigra L.) dvije su tvrde vrste drva koje se često upotrebljavaju i uzgajaju u Turskoj. Te su četiri vrste drva odabrane za istraživanje hrapavosti pri mehaničkoj obradi. Mjerenje hrapavosti važno je za određivanje kvalitete površine drva gotovog proizvoda. U ovom se istraživanju ocjenjuje izmjerena hrapavost drva nakon njegova blanjanja i brušenja. Utvrđeno je da je najveća izmjerena vrijednost prosječne hrapavosti (Ra) iznosila 6,780 µm na uzorcima drva hrasta kitnjaka te 6,338 µm na uzorcima drva crne topole, dok je na uzorcima drva libanonskog cedra izmjerena hrapavost od 4,836 µm, a na uzorcima crnog bora 4,740 µm. Izmjerene su vrijednosti prosječne hrapavosti drva u smjeru okomito na vlakanca i uzduž vlakanaca, od najviše do najniže, na uzorcima hrasta kitnjaka, crne topole, crnog bora i libanonskog cedra.*

Ključne riječi: *drvo, hrapavost površine, blanjanje, brušenje*

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1 INTRODUCTION
1. UVOD

In wood finishing, roughness reflects faults on a wood surface as a result of the operations carried out in production. These faults are repeated with a low probability and periodically. Control and monitoring of surface roughness is required to maintain product quality at the same level throughout the production, as this property affects wood adhesion and changes can increase loss. After solid wood undergoes machining by sawing, planing, sanding, etc., it becomes a final product. Wood finishing is an important factor in determining the economic value of the final product. Accordingly, surface roughness is a definitive property for measuring the success of the wood finish.

Surface roughness can be evaluated quantitatively and qualitatively. Each approach has advantages and disadvantages, such as a slower speed, sensitivity, and the accuracy of results (Malkocoglu, 1999). There are various methods of surface roughness measuring in the area of woodworking. Lumber surface roughness can be measured with an airflow method (Porter, 1971). An imaged light and needle-scan can also measure surface roughness (Peters, 1970). It is thought that surface roughness in industrial applications can be easily done with a light-sectioning shadow scanner method (Sandak, 2005). However, the stylus trace method has emerged as the most suitable and applicable method in the measurement of surface roughness (Peters, 1971; Faust, 1987).

Stumbo (1960) mentioned that a decrease in surface roughness will occur with an increase in the cutter speed and number of teeth in cutting saws. An increase in surface roughness will occur with an increase in feeding speed. When planing and milling softwood species compared to hardwood species, roughness is greater when cutting perpendicular to the grain than when cutting along the grain. In general, worn cutters increase surface roughness. With regards to average roughness values, approximately the same values are obtained in directions perpendicular to the grain and along the grain (Steward, 1970).

Roughness of various tree species has been investigated. Gurleyen (1998) studied surface roughness in the planing of beech (*Fagus orientalis* L.), scotch pine (*Pinus sylvestris* L.), sessile oak (*Quercus petreae* L.), and black locust (*Robinia pseudoacacia* L.). Demirci (1998) studied oriental beech (*Fagus orientalis* L.), scotch pine (*Pinus sylvestris* L.), oak (*Quercus petreae* L.), and black locust (*Robinia pseudoacacia* L.) in the machining of massive wooden material with circular saws. Ors *et al.* (1999) studied the planing and sanding operations of planed and sanded massive wooden material using oriental beech and Scotch pine. Kantay *et al.* (2001) studied the surface roughness of sliced veneer boards from tree species of walnut (*Juglans regia* L.) and oriental beech (*Fagus orientalis* L.) in Turkey. Ünsal *et al.* (2002) studied the surface roughness of massive parquets from oak and oriental beech in Turkey using a stylus trace method. Ilter *et al.* (2002) studied surface roughness in planing and sanding of Uludag fir (*Abies bornmülleriana* Mattf.). Efe *et al.* (2003) carried out surface roughness measurements in planing experiments conducted under various conditions on black locust (*Robinia pseudoacacia* L.) and walnut (*Juglans regia*). Kilic *et al.* (2003) studied surface roughness in the sawing of wood from Scotch pine (*Pinus sylvestris* L.) and chestnut (*Castania sativa* mill.). Ors *et al.* (2003) determined surface roughness in the sanding of wood from black locust (*Robinia pseudoacacia* L.) and oak (*Quercus petrea* L.) using a stylus trace method. Aslandogan (2005) determined the surface roughness after planing and sanding experiments of European black pine (*Pinus nigra* Arnold) that were artificially grown. Sogutlu (2005) determined surface roughness in sanding of black locust (*Rubinia pseudoacacia* L.), European pear (*Pirus communis* L.), chestnut (*Castanea sativa* Mill.), oak (*Quercus petrea* Lieble) and cedar of Lebanon (*Cedrus libani* A.Rich) grown in Turkey. Sonmez *et al.* (2005) determined surface roughness in the planing of wood from Black locust (*Rubinia pseudoacacia* L.), European pear, chestnut, oak and cedar of Lebanon.

Aras *et al.* (2007) evaluated surface roughness in the turning of walnut (*Juglans regia* L.), oriental beech (*Fagus orientalis* L.), largeleaf linden (*Tilia grandifolia* Ehrh.) and aspen (*Populus tremula* L.) with a stylus trace method. Malkocoglu (2007) investigated planing properties and surface roughness of oriental beech (Fagus orientalis Lipsky.) grown in the Eastern Black sea region, Anatolian chestnut (*Castenea sativa* Mill.), black alder (*Alnus glutinosa*), Scots pine (*Pinus sylvestris* L.) and oriental spruce (*Picea orientalis* (L.). It was observed that using veneer with tough surfaces in plywood production reduced adhesion quality (Faust, 1986). Hiziroglu *et al.* (2013) determined surface roughness in the sanding of pine (*Pinus strobus*), borneo camphor (*Dryobalanops* spp.) and meranti (*Shorea* spp). Zhong *et al.* (2007) evaluated surface roughness in various commercially produced composite panels including particleboard, medium density fibreboard (MDF), and plywood in addition to ten different solid wood species which are commonly used in furniture production. Skaljic *et al.* (2009) determined surface roughness values of planed beech-wood (*Fagus L.*), oak - wood (*Quercus L.*) and fir-wood (*Abies alba* Mill.) specimens.

This study investigated and evaluated surface roughness through planing and sanding experiments for several hardwood and softwood species commonly used in Turkey.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Wood material
2.1. Uzorci drva

Various species of softwoods and hardwoods were used for the experiments. European black pine (*Pinus nigra* Arnold) and cedar of Lebanon (*Cedrus libani* A. Rich), as two softwood species, and Sessile Oak (*Quer-*

Table 1 Machining conditions of planing experiments
Tablica 1. Uvjeti obrade tijekom provedbe eksperimenta pri blanjanju

	Number of knives *Broj noževa*	**Feed rate** *Posmična brzina* m/min	**Number of knife marks per cm** *Broj prolazaka noža po 1 cm*	**Cutting angles, °** *Kut rezanja, °*
Run 1 / *Prolazak 1.*	4	8.6	4.72	25
Run 2 / *Prolazak 2.*	4	18	2.36	25
Run 3 / *Prolazak 3.*	2	8.6	4.72	15
Run 4 / *Prolazak 4.*	2	8.6	4.72	20

cus petraea Lieble) and black poplar (*Populus nigra* L.), as two hardwood species commonly used and grown in Turkey, were selected as experimental material for the study. The samples were all randomly selected from naturally grown wood in Istanbul and Kutahya in Turkey. The wood was conditioned at a temperature of 20 ± 2 °C and 65 ± 5 % to a moisture content of about 12 %. 30 specimens (25 x 102 x 910 mm) were used for each planing and sanding test according to ASTM standard D 1666 (2004) (ASTM International, 2004).

2.2 Performance of planing and sanding experiments
2.2. Provedba eksperimenta pri blanjanju i brušenju

Planing experiments were carried out using a TORK brand K500-X250 model thickness planer at the facility of the Istanbul University, Forestry Faculty of Furniture and Wood Machining. Thirty test samples with the dimensions 25 x 102 x 910 mm and a wood moisture content of 12 % were made from each tree species. As stated in the above said standard (ASTM D-1666), the cutting depth was 1.6 mm for all the cuts. The properties of the cutting tools used in the planing tests are presented in Table 1.

A wide-belt caliber sander, Melkuc Kombi 650 model, for calibrating and sanding of wood based panels was used for the sanding experiments. The cutting speed in sanding operation was set to 5.5 m/min. The samples previously used in the planing experiments with dimensions of 20 x 102 x 910 mm were first sanded with 80 grain sandpaper and then with a 120 grain.

2.3 Roughness measurement
2.3. Mjerenje hrapavosti

The measurement of surface roughness was done according to protocols in TS 6956 EN ISO 4287, TS 971, and TS 2495 EN ISO 3274. An instrument for measuring surface roughness, Mitutuyo Surfjet SJ 301, was used for the determination of surface roughness by a contact stylus trace method.

Measurements were made in two different directions, perpendicular and along the grain. Gaussian filter type was used. Sampling length was 2.5 mm and the evaluation length was L_t= 12.5 mm. Cut-off length was 2.5 mm. Surface roughness values were measured with a sensitivity of ± 0.01 μm. Tool measurement speed was 10 mm/min, the diameter of the measurement needle was 4 μm, and the needle tip 90°. Care was taken to have a measurement environment around 18 °C -22 °C, away from noise sources, and without vibration. The tool was calibrated before the measurement and the calibration was checked at established intervals.

2.4 Statistical methods used
2.4. Statističke metode

Arithmetic mean and standard deviation were used for the evaluation of the specific gravity and the number of annual rings per cm. In the evaluation of roughness results, correlation analysis, analysis of variance (ANOVA), and also a t-test were employed to investigate whether there is a significant difference between the roughness values with respect to the applied measurement directions.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Wood species with various specific gravity were selected: European black pine (0.6526 g/cm^3), cedar of Lebanon (0.5019 g/cm^3), sessile oak (0.7767 g/cm^3), black poplar (0.3412 g/cm^3). The mean for the number of rings per cm was also calculated for each species: European black pine (3.484), cedar of Lebanon (1.768), sessile oak (4.660), and black poplar (0.780).

A total of 8 roughness measurements were conducted on 4 fixed points established on each machine in directions perpendicular to the grain and along the grain on 30 planed samples. A *R*a (average roughness) value was used in the evaluation of results of roughness measurement.

There is a very weak correlation between roughness, a dependent variable, and the number of annual rings per cm and the specific weight, an independent variable, at 0.097 and –0.038, respectively. However, a strong positive correlation is observed between the number of annual rings per cm and the specific weight, an independent variable at 0.804. The data obtained from the experiments is given in Table 2.

Figure 1a below shows roughness values along the grain for various machining conditions and tree species. Figure 1b shows the roughness perpendicular to the grain. Figure 1c provides the mean of the roughness values perpendicular to the grain and along the grain in the form of a graph.

Table 3 provides average roughness values, standard errors based on tree species, and lower and upper limits based on a 95 % confidence limit.

With respect to tree species, oak had the highest roughness average with 6.780 μm, followed by black poplar with 6.338 μm. With regards to the upper and lower limits of tree species based on a 95 % confidence level, the confidence ranges of pine and cedar of Lebanon intersect. When roughness values are studied based on machining conditions, the highest average

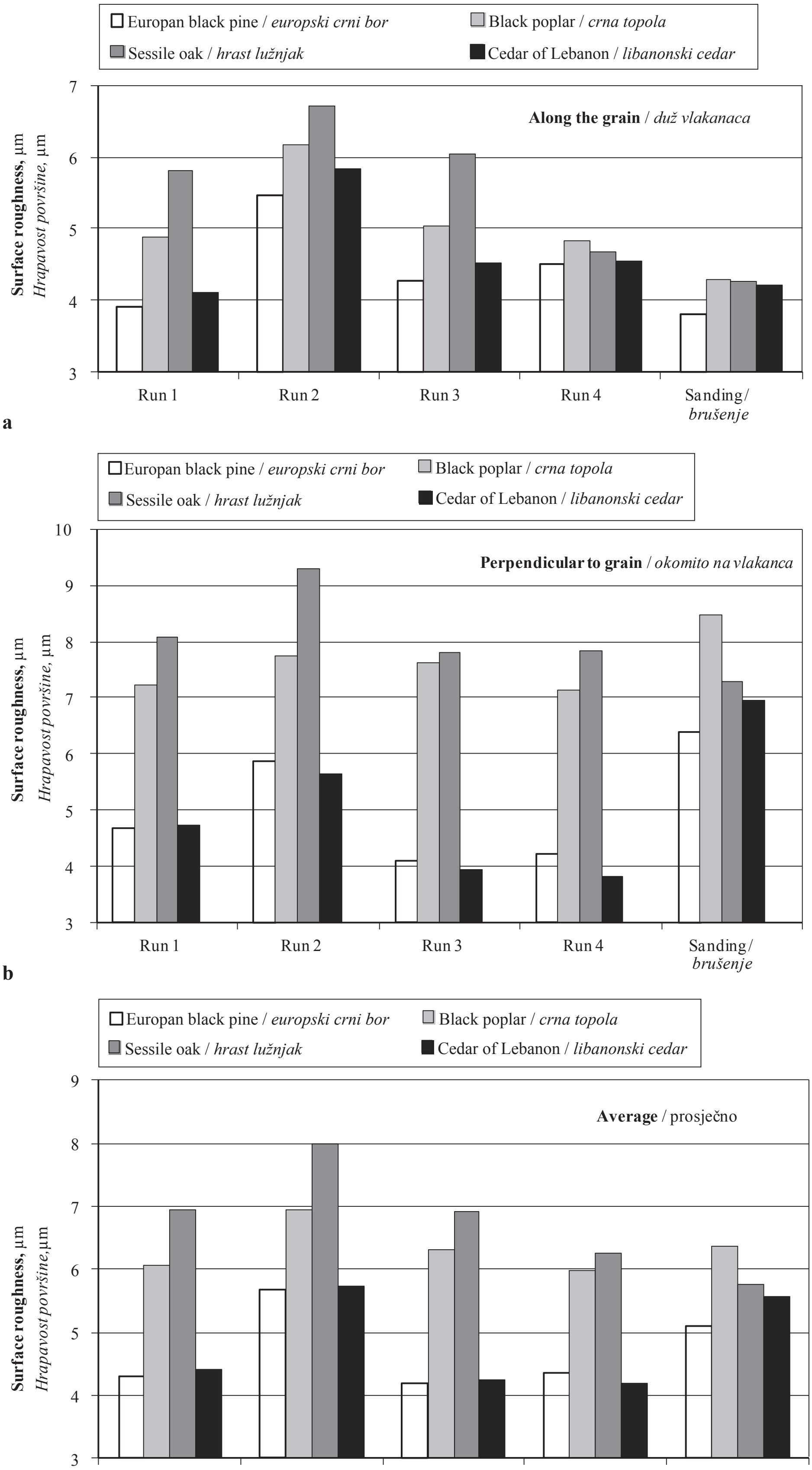

Figure 1a Roughness values along the grain for various machining (cutting type) conditions and tree species **1b** Roughness values perpendicular to grain for various machining (cutting type) conditions and tree species **1c** Mean Roughness values for various machining (cutting type) conditions and tree species
Slika 1. a) Vrijednosti hrapavosti uzduž vlakanaca za različite uvjete obrade i različite vrste drva; b) vrijednosti hrapavosti okomito na vlakanca za različite uvjete obrade i različite vrste drva; c) prosječne vrijednosti hrapavosti za različite uvjete obrade i različite vrste drva

Table 2 General results for the measured roughness
Tablica 2. Rezultati izmjerene hrapavosti

Wood species *Vrsta drva*	**Surface roughness** / *Hrapavost površine*, µm														
	Run 1 *Prolazak 1.*			Run 2 *Prolazak 2.*			Run 3 *Prolazak 3.*			Run 4 *Prolazak 4.*			Sanding *Brušenje*		
	Along the grain	Perpendicular to the grain	Average	Along the grain	Perpendicular to the grain	Average	Along the grain	Perpendicular to the grain	Average	Along the grain	Perpendicular to the grain	Average	Along the grain	Perpendicular to the grain	Average
Europan black pine *europski crni bor*	3.91	4.70	4.31	5.46	5.89	5.68	4.28	4.12	4.20	4.51	4.25	4.38	3.82	6.41	5.11
Black poplar *crna topola*	4.87	7.22	6.05	6.17	7.73	6.95	5.03	7.61	6.32	4.83	7.14	5.98	4.29	8.46	6.37
Sessile oak *hrast kitnjak*	5.81	8.08	6.95	6.70	9.30	8.00	6.03	7.79	6.91	4.68	7.82	6.25	4.26	7.28	5.77
Cedar of Lebanon *libanonski cedar*	4.09	4.73	4.41	5.83	5.65	5.74	4.51	3.96	4.24	4.55	3.84	4.19	4.20	6.94	5.57

Table 3 Average roughness values, standard errors based on tree species and lower and upper limits based on 95 % confidence limit
Tablica 3. Prosječne vrijednosti hrapavosti, standardna pogreška za pojedinu vrstu drva, donja i gornja granica za interval pouzdanosti od 95 %

Wood species *Vrsta drva*	**Arithmetic average** *Aritmetička sredina*	**Standard error** *Standardna pogreška*	**95 % confidence limits** *95 %-tni interval pouzdanosti*	
			Lower limits *Donja granica*	**Upper limits** *Gornja granica*
Black poplar / *crna topola*	6.338	0.072	6.196	6.480
Europen black pine / *europski crni bor*	4.740	0.073	4.597	4.884
Sessile oak / *hrast kitnjak*	6.780	0.072	6.638	6.922
Cedar of Lebanon / *libanonski cedar*	4.836	0.073	4.693	4.978

roughness values were found in Run 1 and sanding, and the average roughness values for Run 3 and Run 1 exhibited close values when the upper and lower limit values of the Run 3 and Run 1 are studied based on a 95 % confidence level, the limit values for both runs overlap. It was determined that the machining conditions of Run 4 had the lowest roughness average.

With regards to measurement direction, there was a significant difference between the measurement values along the grain and measurement values perpendicular to the grain (the average of the roughness values perpendicular to the grain is 1.553 µm higher than the roughness value along the grain). Figure 2 shows the average roughness values (*R*a) along and perpendicular to the grain based on tree species in the form of graphs.

*R*a of poplar is 1.6077 µm higher than that of pine. The average roughness value *R*a of poplar is also 1.5048 µm higher than that of cedar of Lebanon. However, *R*a of oak is 0.4417 µm units higher than that of black poplar. The *R*a of pine is 2.0494 µm less than that of oak. Although the *R*a of pine is 0.1029 µm less than that of cedar of Lebanon, there is no significant difference between the two. In other words, pine and cedar of Lebanon may

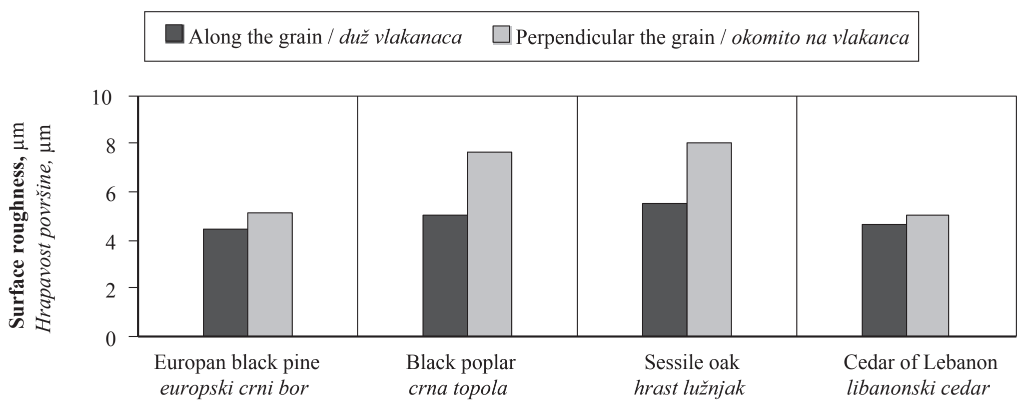

Figure 2 Graphs of average surface roughness along and perpendicular to the grain based on tree species
Slika 2. Prosječna hrapavost površine istraživanih vrsta drva uzduž vlakanaca i poprečno na njih

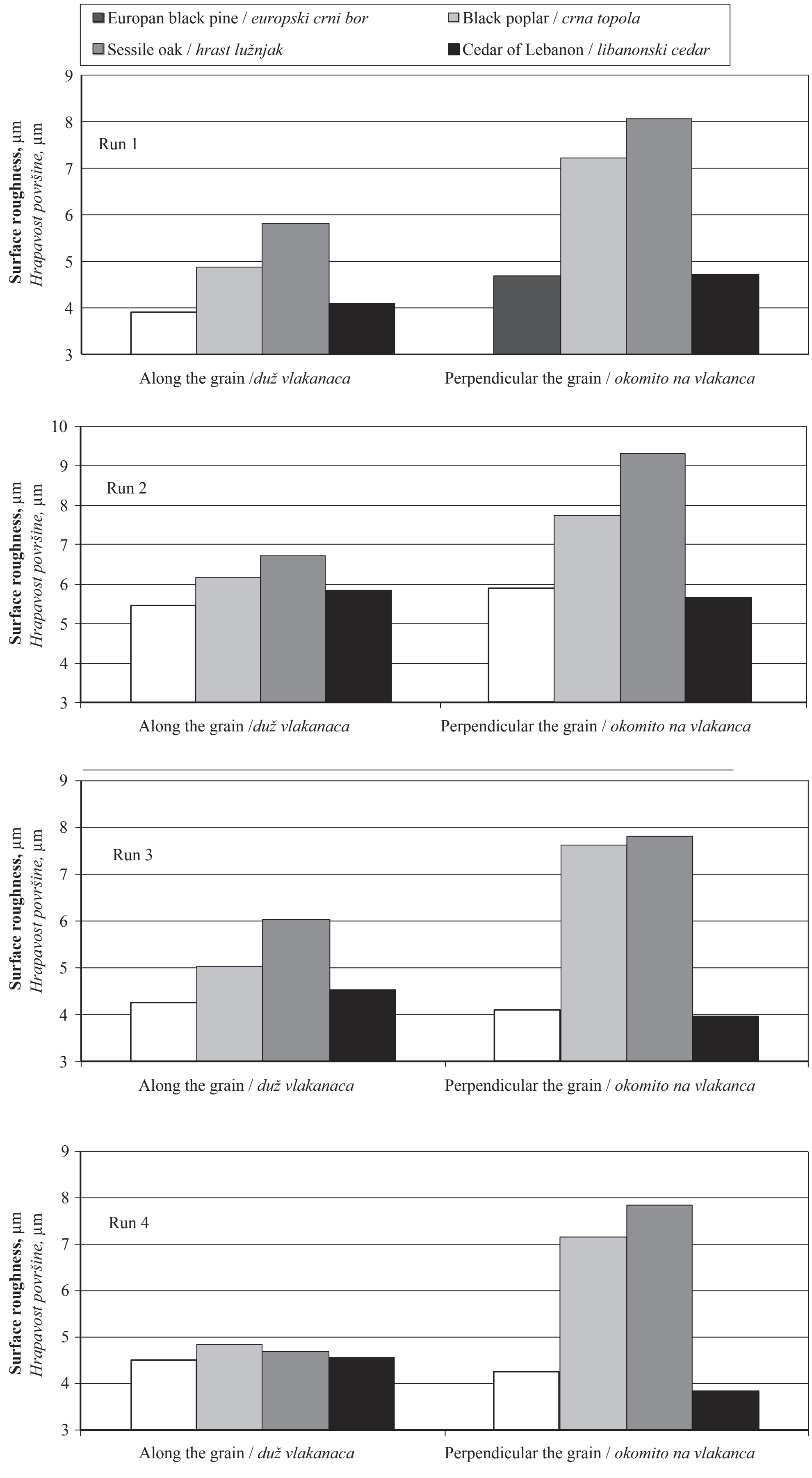

Figure 3 Average roughness values under machining conditions of runs 1, 2, 3, and 4 based on measurement directions and tree species
Slika 3. Prosječne vrijednosti hrapavosti u uvjetima obrade nakon 1., 2., 3. i 4. prolaska noža za različite smjerove mjerenja hrapavosti i različite vrste drva

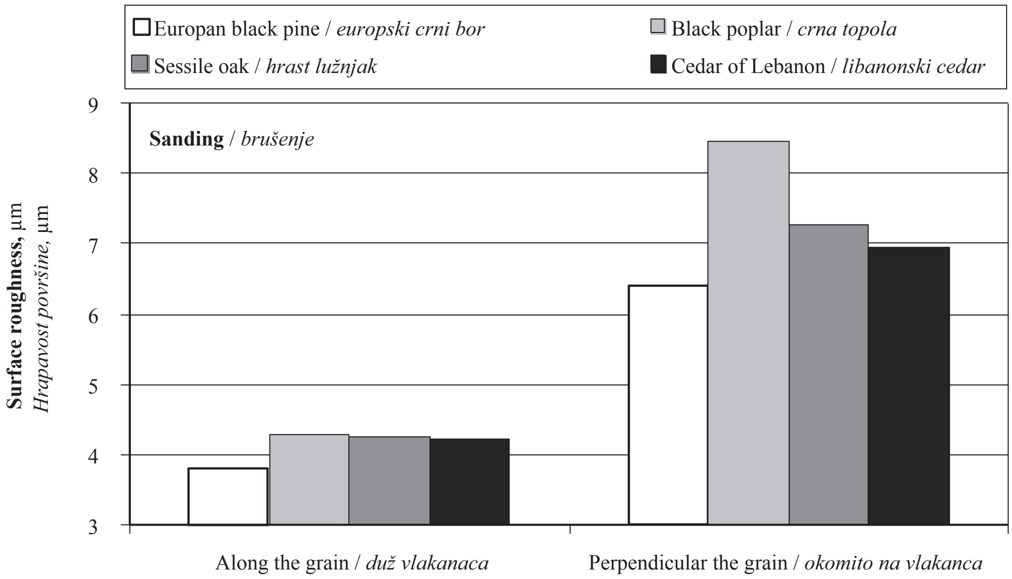

Figure 4 Roughness graph for sanding operation (cut type) based on measurement directions and tree species
Sika 4. Izmjerena hrapavost nakon brušenja za različite smjerove mjerenja hrapavosti i za različite vrste drva

be gathered together under the same group with regards to roughness value. The *R*a values for black poplar and oak are higher than those for the other tree species.

According to statistical analysis results, the *R*a for Run 2 was by 1.1737 µm higher than for Run 1. Although *R*a for Run 1 was by 0.0218 µm higher than for Run 3, there was no significance between them (Sig: 1,000) and Run 1 and Run 3 can be put into the same group with regards to roughness averages. While the value of *R*a for Run 1 was by 0.2375 µm higher than for Run 4, it is by 0.2677 µm less for sanding. The *R*a for Run 2 exhibited a significant difference since they were higher compared to all the other machining conditions. The *R*a for sanding conditions have a slightly higher *R*a compared to all the other machining conditions except for Run 2. Sanding machining condition can be shown as a separate group with regards to *R*a. At the same time, although *R*a for Run 3 was by 0.2158 µm higher than for Run 4, these two machining conditions are shown under the same group with regards to roughness averages.

According to the statistical analysis results, there was no significant difference in roughness with regards to measurement directions. Figures 3a, 3b, 3c, and 3d show the roughness graphs under machining conditions for Runs 1, 2, 3, and 4 based on measurement directions and tree species.

Figure 4 presents a roughness graph under sanding condition based on measurement directions and tree species.

4 CONCLUSIONS
4. ZAKLJUČAK

As a result, Sessile Oak showed the roughest surface in wood machining operations. According to the roughness measurement results for black poplar, surfaces with the highest faults and the roughest surfaces occurred in the sanding operation. Although it was expected that black poplar would have smoother surfaces during sanding, since the machining method affects surface quality, an increase in the roughness was observed. It is believed that this result is significantly affected by the type of procedure. Cedar of Lebanon exhibited values close to black pine with regards to average roughness, displaying the lowest average roughness values amongst the tree species studied. The values for black poplar and sessile oak were found to be higher. Cedar of Lebanon was in the same group as black pine in regards to surface roughness and exhibited the highest roughness value.

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5 REFERENCES
5. LITERATURA

1. Aras, R.; Budakçı, M.; Özışık, O., 2007: The effect of wood turning techniques on surface roughness of wood material. Journal of Polytechnic, 10: 325-330.
2. Aslandoğan, C., 2005: Research on determination of surface roughness of crimean pine (*Pinus nigra* Arnold) wood. MSc thesis, Hacettepe University, Ankara/Turkey.
3. ASTM International, 2004: Standart methods for conducting machining tests of wood and wood – base materials (Vol. ASTM D 1666–87 (Reapproved 2004)). West Conshohocken, United States.
4. Efe, H.; Gürleyen, L., 2003: Effects of the cutting direction the number of cutter and the rotation value on surface smoothness for some wood species. The Journal of the Industrial Arts Education Faculty of Gazi University, 11: 34-44.
5. Faust, D. T., 1987: Real time measurement of veneer surface roughness by image analysis, Forest Products Journal, 37: 34-40.

6. Faust, D. T.; Rice, J. T., 1986: Effect of veneer surface roughness on the bond quality of Southern pine plywood, Forest Products Journal, 36: 57-62.
7. Gürleyen, L., 1998: A comparison on the surface smoothness in wood materials, Master Thesis, Gazi University, Institute of Science, Ankara.
8. Hiziroglu, S.; Zhong, Z. W.; Tan, H. L., 2013: Measurement of bonding strength of pine, kapur and meranti wood species as function of their surface quality. Measurement 46: 3198-3201. http://dx.doi.org/10.1016/j.measurement.2013.05.005.
9. İlter, E.; Çamlıyurt, C.; Balkız, O. D., 2002: Researches of the determination of the surface roughness values of bornmullerian fir (*Abies bornmülleriana* Mattf.). Central Anatolia Forestry Research Institute, Turkey.
10. Kantay, R.; Ünsal, Ö.; Korkut, S., 2001: Investigation of surface roughness of sliced walnut and beech veneers produced in Turkey. Review of the Faculty of Forestry, University of İstanbul, 51: 15-31.
11. Malkocoglu, A., 2007: Machining properties and surface roughness of various wood species planed in different conditions. Building and Environment, 42: 2562-2567 http://dx.doi.org/10.1016/j.buildenv.2006.08.028.
12. Malkocoglu, A.; Ozdemir, T., 1999: Surface roughness of the historical development. Furniture decoration 32: 60-68.
13. Örs, Y.; Baykan, İ., 1999: The effect of planing and sanding on surface roughness of massive wood. Turkish Journal of Agriculture and Forestry, 23: 577-582.
14. Örs, Y.; Demirci, S., 2003: The effect of cutting direction and sanding on the surface roughness of the acacia (*Robinia pseudoacacia* L.) and oak (*Quercus petraea* L.) Woods, Journal of Polytechnic, 6: 491-495.
15. Peters, C.; Mergen, A., 1971: Measuring wood surface smoothness: A proposed method, Forest Products Journal, 21: 28-30.
16. Peters, C. C.; Cumming, J. D., 1970: Measuring wood surface smoothness: A rewiew, Forest Products Journal, 20: 40-43.
17. Porter, A. W.; Kusec, D. J.; Sonders, J. L., 1971: Air - flow method measures lumber surface roughness, Canadian Forest Industries.
18. Sandak, J.; Tanaka, C., 2005: Evaluation of surface smoothness using a light - sectioning shadow scanner. Journal of Wood Science, 51: 270-273. http://dx.doi.org/10.1007/s10086-004-0637-z
19. Škaljić, N.; Beljo Lučić, R.; Čavlović, A.; Obučina, M., 2009: Effect of feed speed and wood species on roughness of machined surface. Drvna industrija, 60: 229-234.
20. Söğütlü, C., 2005: The effect of some factors on surface roughness of sanded wood material. Journal of Polytechnic, 8: 345-350 http://dx.doi.org/10.2339/y2005.v8.n4.p345-350.
21. Sönmez, A.; Söğütlü, C., 2005: The effect of planning on the surface roughness in wood material. Teknoloji, 8: 287-293.
22. Steward, H. A., 1970: Cross grain knife planing, hard maple produces high quality surfaces and flakes. Forest Products Journal, 20: 39-42.
23. Stumbo, D. A., 1960: Surface texture measurement for quality and production control. Forest Products Journal, 10: 122-124.
24. Ünsal, O.; Kantay, R., 2002: Investigation of surface roughness of oak and beech wood parquets produced in Turkey. Review of the Faculty of Forestry, University of İstanbul, 52: 81-94.
25. Zhong, Z. W.; Hiziroglu, S.; Chan, C. T. M., 2013: Measurement of the surface roughness of wood based materials used in furniture manufacture. Measurement, 46: 1482-1487 http://dx.doi.org/10.1016/j.measurement.2012.11.041.

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Water Uptake of Thermally Modified Norway Spruce

Upijanje vode toplinski modificirane norveške smreke

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ABSTRACT • *Thermal modification of wood has been commercially available for almost twenty years but the complete mechanism of improved durability is still not completely understood. It is known that the temperature and duration of the modification influences the properties of the final products. There are several potential reasons for the increased durability of the modified wood. In recent research in particular, water exclusion efficiency has been identified as one of the key mechanisms. In order to elucidate this presumption, specimens made of Norway spruce heartwood were thermally modified at 6 different temperatures (160 °C, 180 °C, 190 °C, 200 °C, 210 °C and 230 °C) for three hours according to the Silvapro® procedure. Control specimens were left unmodified. Three sets of tests were performed: (a) samples were soaked in water for 4 days and then positioned on load cells and allowed to dry until a constant mass was achieved; (b) short term water uptake was determined with a tensiometer and (c) wood-water interactions were verified using constant gravimetric moisture measurement during outdoor exposure. As expected, the degree of modification was reflected in the moisture content of the wood during testing. Short and medium term water uptakes correlated quite well with the performance of wood in outdoor applications. On the other hand, long term tensiometer measurements were not in line with either short term water uptake or outdoor measurements.*

Key words: *load cell, Picea abies, tensiometer, thermal modification, water uptake, field testing*

SAŽETAK • *Toplinski modificirani drvo dostupno je na tržištu već gotovo dvadeset godina međutim, potpuni mehanizam poboljšane trajnosti drva još uvijek nije sasvim razjašnjen. Poznato je da temperatura i trajanje modifikacije utječu na svojstva konačnog proizvoda. Nekoliko je razloga za povećanje trajnosti toplinski modificiranog drva. U recentnim istraživanjima učinkovito je odstranjenje vode identificirano kao jedan od ključnih mehanizama za poboljšanje trajnosti drva. Kako bi se razjasnila ta pretpostavka, uzorci drva srži norveške smreke toplinski su modificirani pri šest različitih temperatura (160, 180, 190, 200, 210 i 230 °C) tijekom tri sata prema postupku Silvapro®. Kontrolni su uzorci ostali nemodificirani. Provedena su tri ciklusa ispitivanja: a) uzorci su namakani u vodi tijekom četiri dana, zatim su postavljeni na senzor težine da se osuše do konstantne mase; b) kratkoročno upijanje vode određeno je tenziometrom i c) interakcije drva i vode provjeravane su stalnim gravimetrijskim mjerenjem sadržaja vode pri izlaganju uvjetima na otvorenome. Kao što se očekivalo, stupanj modifikacije ogleda se u sadržaju vode u drvu tijekom ispitivanja. Kratkoročno i srednjoročno upijanje vode dobro korelira s ponašanjem drva u vanjskim uvjetima. Nasuprot tome, dugoročna mjerenja tenziometrom nisu bila u skladu s kratkoročnim vezanjem vode ili s mjerenjem pri izlaganju uvjetima na otvorenome.*

Ključne riječi: *senzor težine, Picea abies, tenziometar, toplinska modifikacija, upijanje vode, terenska ispitivanja*

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1 INTRODUCTION
1. UVOD

Thermal modification is one of the most commercially important modification procedures (Rapp and Sailer, 2001; Esteves and Pereira, 2009; Lacić *et al.,* 2014). The properties of the treated products depend on the temperature and duration of modification (Altgen *et al.,* 2012). In spite the fact that this procedure has been on the market for almost two decades, the complete mechanism of improved durability has not been fully elucidated. The increased durability has been explained by the lower equilibrium moisture content, better dimensional stability and formation of new toxic compounds (Hakkou *et al.,* 2006). In recent research, another aspect has attracted considerable attention: water exclusion efficiency. The purpose of this study was to elucidate the correlation between the degree of modification and water exclusion efficiency, as determined by different experimental procedures.

Although there is no standardised method for determining water exclusion efficiency, several techniques are available. The majority of them are based on gravimetric measurements after longer or shorter periods of exposure to water (Humar and Lesar, 2013). These methods are fairly simple to perform but time consuming and the size of the specimens is limited. However, especially when considering the time and effort, manual weighing of the samples is not the best solution for outdoor testing, particularly if working with a larger number of specimens. Furthermore, if the specimens are weighed manually once per week, the moistest periods might be overlooked, since the specimens are not usually weighed immediately after rain. In order to speed up the test procedure, there are two possibilities: to determine the moisture content through measurements of electrical resistance (Brischke *et al.,* 2013) or to apply single load cells for automated measurements (Van den Bulcke and Van Acker, 2008). The second method is more correlated to laboratory-gravimetric based measurements, and hence continuous monitoring of weight on single load cells was also applied in the present research.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

Samples made of Norway spruce (*Picea abies*) were heat treated according to the Silvapro® commercial procedure (Rep *et al.,* 2012). Two types of sample were used: large ones (2.5 × 5.0 × 50.0 cm) and small ones (1.5 × 2.5 × 5.0 cm). Samples were thermally modified at six temperatures, as shown in Table 1. The time of modification at the target temperature for all specimens was 3 hours. The mass loss of the samples after modification was determined gravimetrically. After modification, samples were stored in laboratory for 4 weeks (24 °C; 65 %). The conditioned samples were then subjected to various short and long term water uptake analyses.

Short term water uptake was determined on small specimens. The measurements were carried out at room temperature (20 °C), at RH of 50±5 % on a Krüss Processor Tensiometer K100MK2. The specimens were positioned in the device in such a way that the axial surfaces of the specimens were in contact with the test liquid (water) and their masses were subsequently measured at 2-s intervals for 200 s. Other parameters used were: velocity before contact 6 mm/min, sensitivity of contact 0.005 g and depth of immersion 0.5 mm.

The medium term water uptake test was based on the ENV 1250-2 (1994) leaching procedure. Smaller specimens were used for this test. The water uptake study was completed in four days. Modified samples were placed in the vessel and positioned with weights to prevent them from floating. One hundred grams of distilled water were added per specimen. The water was replaced six times in four subsequent days, as prescribed by the standard (the cumulative periods of leaching were: 1 h, 3 h, 7 h, 23 h, 31 h, 47 h, 95 h). The mass of the samples was determined after each period and the moisture content of the samples was calculated.

Long term water uptake was determined on larger samples. Similarly as reported for short term water uptake measurements, samples were positioned so as to be in contact with the water and their masses were subsequently measured at 20-s intervals for the following 160 h. Samples were placed on single point load cells (HBM precix 6), with a maximum capacity of 7 kg. Data was acquired with the PMX data acquisition system and recorded and analysed with Catman Easy software.

There are two important processes during weathering, drying and wetting. Short, medium and long term leaching procedures were designed to simulate wetting events. In this laboratory experiment, the focus was on the drying phase. The larger samples were, therefore, immersed in distilled water for 4 days. They were then mounted on HBM precix single point load cells and their mass was continuously recorded through the drying process (sampling rate = 0.02 Hz).

In the last experiment, the actual moisture content of the samples was continuously monitored during outdoor exposure (sampling rate = 0.02 Hz). The test set up was located in the field test site of the University of Ljubljana (latitude: +46.0489°; longitude: +14.4787). Samples were placed in a horizontal position on single point load cells and their masses were continuously monitored, as described previously. Samples were exposed in the period Nov. 30, 2013 to March 6, 2014 for 105 days.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Thermal modification resulted in changes in the overall properties of the Norway spruce wood. Mass loss is one of the most reliable indicators of the effectiveness of thermal modification (Hill, 2006; Altgen *et al.,* 2013). The mass loss of the specimens increased with the modification temperature as shown in Table 1. The obtained data are in line with the literature data (Esteves and Pereira, 2009; Rep *et al.,* 2012).

The short term water uptake test is a fast and efficient method for quick estimation of hydrophobicity.

Table 1 Influence of modification temperature on mass loss after thermal modification and short term water uptake (STWU); different letters represent different homogeneous groups within the same exposure
Tablica 1. Utjecaj temperature modifikacije na gubitak mase nakon toplinske modifikacije i kratkoročnog upijanja vode (STWU); različita slova predočuju različite homogene skupine unutar iste izloženosti

Modification temperature, °C *Temperatura modifikacije, °C*	**Mass loss, %** *Gubitak mase, %*	**STWU, g/mm²** *Kratkoročno upijanje vode, g/mm²*
0	0.0 (a)	0.00169 (b)
160	1.9 (b)	0.00218 (a)
180	2.3 (b)	0.00120 (b)
190	3.2 (c)	0.00068 (c)
200	4.4 (d)	0.00073 (c)
210	6.0 (e)	0.00081 (c)
230	11.7 (f)	0.00150 (b)

The limitation of this test is that tests are performed on axial surfaces only. The ratio of axial surfaces in the specimens compared to real case applications is fairly small. However, axial surfaces often represent the weakest point of wooden objects in above ground applications. Unmodified spruce wood samples retained approximately 0.00169 g/mm^2 of water in 200 seconds. The modification of spruce at low temperature (160 °C) resulted in higher water uptake (0.00218 g/mm^2). The reason for the increased water uptake is linked to certain anatomical changes, such as the destruction of tracheid walls, ray tissues, pit de-aspiration due to heat treatment and thus an increase in the wood cell wall porosity (Awoyemi and Jones, 2011). In contrast, higher temperatures of modification resulted in lower short term water uptakes. Heat treatment of wood slightly increases the free energy of wood (Kutnar *et al.,* 2012). Furthermore, the contact angles for water in contact with wood modified at different temperatures showed greater variation but without a clear trend; only spruce treated above 210 °C exhibited a considerably higher value (96,6°) than non-modified wood (Kutnar *et al.* 2012). However, in spite of the increased hydrophobicity of the specimens treated at 230 °C, short term water uptakes again increased. We presume that the small cracks in the axial surface are the primary reason for increased water uptake. They act as capillaries and increase the short term water uptake. This should be elucidated in one of the future studies.

In the next step, we compare the values of the short term water uptake tests with the results of continuous immersion in water. The same specimens as used for the short term water uptake tests were immersed in water according to leaching protocol ENV 1250-2 (1994).The differences between the materials were most prominent after one hour of immersion (Table 2). The moisture content of the control specimens reached almost fibre saturation point (28.5 %). Similarly as reported for the short term tests, modification of the specimens at 160 °C resulted in higher moisture contents, while higher modification temperatures resulted in lower MC of modified specimens compared to the controls (Table 2). The only difference in wood moisture performance with medium term immersion compared to the short term water uptake was with specimens modified at the highest temperature. The moisture content of these samples after medium term immersion was the lowest among all of the specimens (Table 2). It seems that the cracks on the surface of the specimens have an influence on the uptake from the axial planes but not on the overall medium term uptake of water. With continuous immersion, the moisture content of the specimens began to increase. The influence of the modification was still evident even after 47 h of immersion and was similar to that already described. However, after 95 h of immersion, all specimens had similar MC, with the exception of the samples treated at 160 °C. The MC of these specimens was approximately 15 percentage points higher than the MC of other specimens (Table 2). Consequently, it can be concluded that thermally modified wood is not suitable for use in applications with permanent moisture load, like in ground contact.

In order to obtain more representative data, experiments were also repeated with larger specimens in the laboratory. Since EN 252 sized specimens (2.5 × 5.0 × 50 cm) performed well in past moisture related studies (Humar in Lesar, 2013), this size of specimen was chosen for the second part of the research. Firstly, we tried to simulate the tensiometer measurements with larger samples that were in contact for a longer period. The axial planes of the samples were thus positioned in contact with the water and the mass of the samples was monitored for 160 hours. Water uptake continuously increased during the overall testing period. However, visual inspections of the specimens clearly showed that the properties of not only the axial planes but other surfaces contribute to the water up-

Table 2 Moisture content of Norway spruce samples heat treated at different temperatures, after continuous immersion in water
Tablica 2. Sadržaj vode u uzorcima drva norveške smreke toplinski obrađenima pri različitim temperaturama, nakon kontinuiranog namakanja u vodi

Modification temperature, °C *Temperatura modifikacije, °C*	**Moisture content, %** / *Sadržaj vode, %*						
	1 h	3 h	7 h	23 h	31 h	47 h	95 h
0	28.5	41.4	50.6	62.5	64.4	69.3	72.6
160	38.9	51.2	71.5	79.8	80.7	85.7	87.8
180	19.5	34.5	41.5	55.8	59.0	65.5	72.1
190	15.0	28.1	38.1	51.9	55.5	62.7	70.4
210	13.6	28.0	35.6	48.7	51.8	59.3	67.6
230	12.7	25.4	34.6	48.4	52.4	60.5	71.0

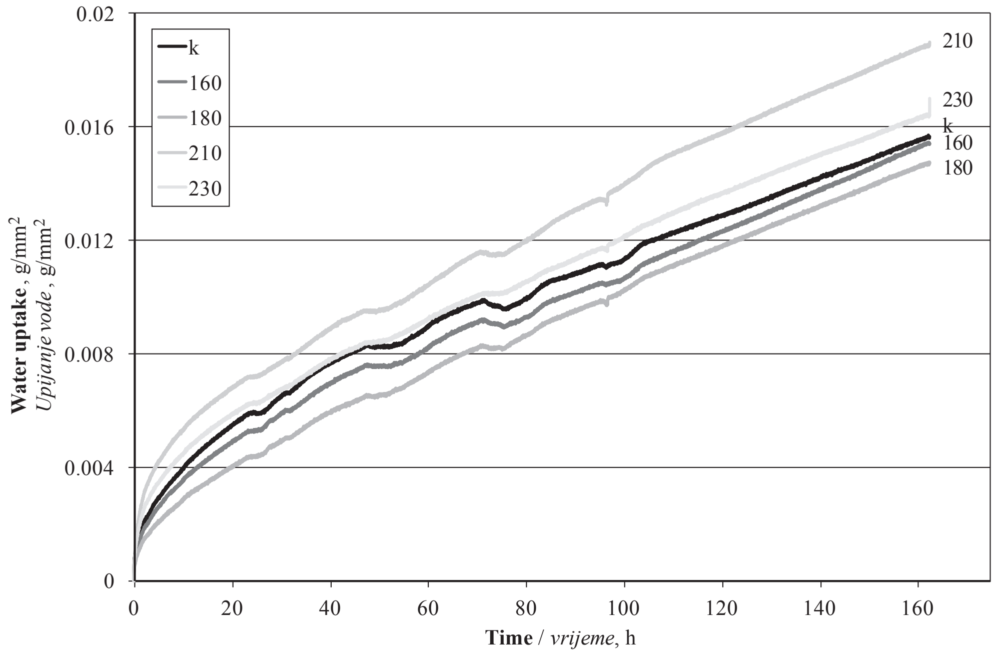

Figure 1 Water uptake from axial surfaces of EN 252 sized samples in contact with water
Slika 1. Upijanje vode aksijalne površine uzoraka drva izrađenih prema EN 252 u dodiru s vodom

take. Water was also rising through the longitudinal planes, which was evident from the dark colour of the wet wood. The results presented in Figure 1 show that the specimens modified at lower temperatures (160 °C and 180 °C) took up less water than the control specimens, while the specimens modified at higher temperatures (210 °C and 230 °C) took up more water than the control specimens. Not all the reasons for this phenomenon can be elucidated but it is suspected that the prime reason for this is formation of the small cracks in the surface of the specimens modified at higher temperatures, which act as capillaries and increase the water uptake into the specimens.

In addition to water uptake, drying is another important phenomenon that influences the moisture content of wood during outdoor exposure. In order to elucidate this phenomenon, samples were first immersed in water for 4 days and then positioned on single point load cells in order to monitor their mass during drying. As shown in Figure 2, the initial moisture content reflects the modification temperature. Although all specimens were immersed for 4 days, the starting moisture content varied between 25.6 % (control) and 16.9 % (modification at 210 °C). This is in line with the immersion studies performed on the smaller specimens. Wood modified at higher temperatures took up less wa-

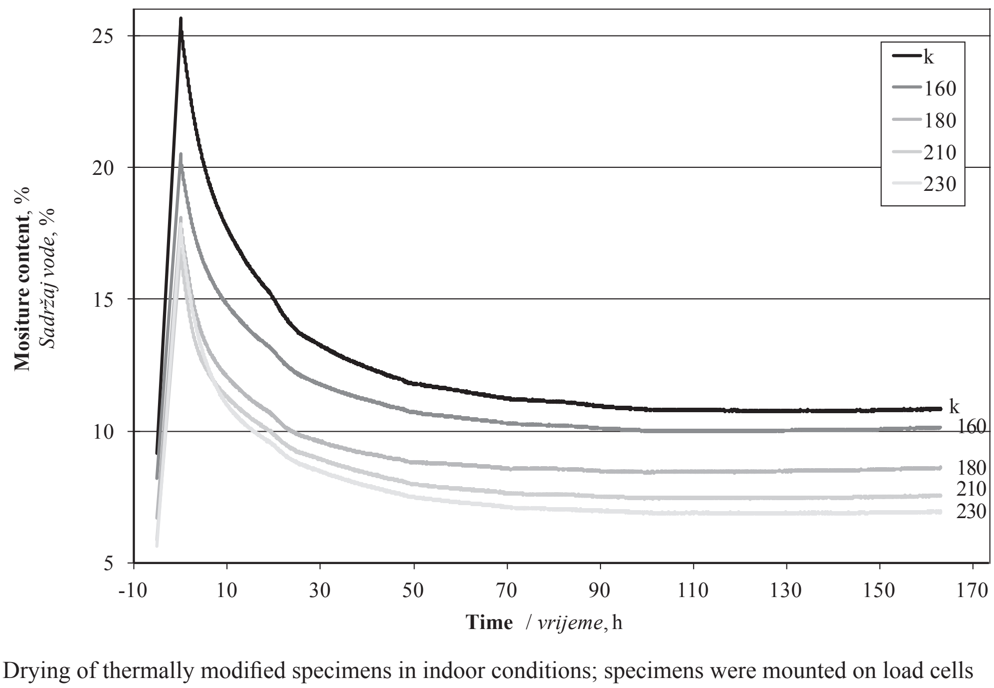

Figure 2 Drying of thermally modified specimens in indoor conditions; specimens were mounted on load cells
Slika 2. Sušenje uzoraka toplinski modificiranog drva u uvjetima zatvorenog prostora; uzorci su bili postavljeni na senzore težine

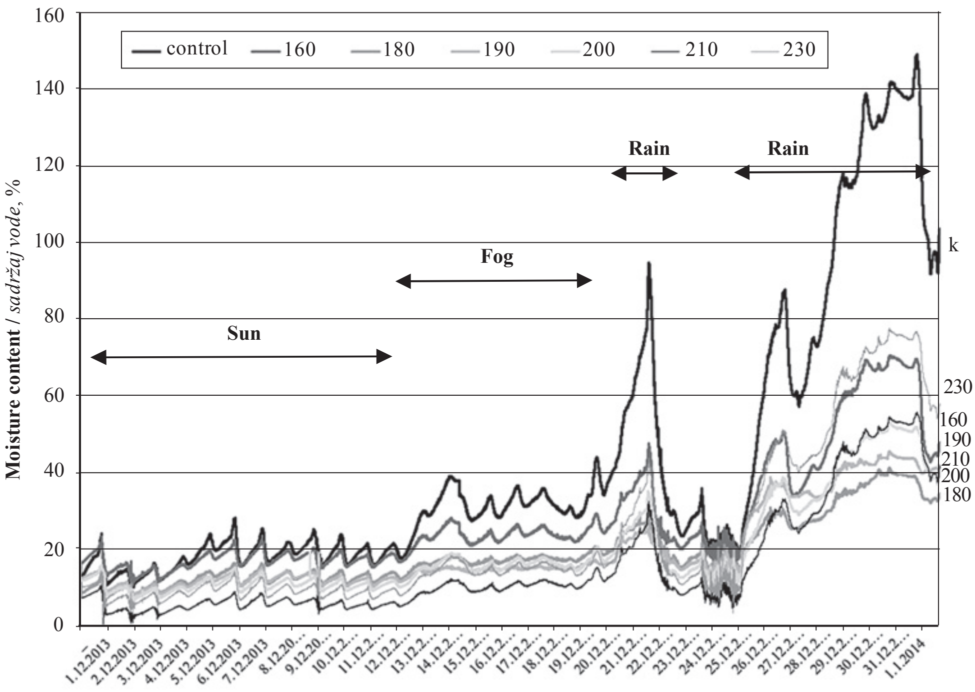

Figure 3 Influence of modification temperature on moisture content of thermally modified Norway spruce during the first month of outdoor exposure
Slika 3. Utjecaj temperature modifikacije na sadržaj vode toplinski modificiranog drva norveške smreke tijekom prvog mjeseca izlaganja na otvorenome

ter than wood modified at lower temperatures and control (unmodified) wood. The final MC at the end of the drying process clearly correlated with the temperature of the modification. A higher modification temperature resulted in a lower MC at the end of the drying period. Regardless of the modification temperature, the final MC was determined after 100 h of drying.

In the last part of the experiment, moisture monitoring was performed during outdoor exposure. During the first ten days of exposure, there was no rainfall. This was clearly reflected in the MC of the samples (Figure 3). The average MC of the samples varied between 6 % (210 °C) and 18 % (control). With the exception of the highest modification temperature, a higher modification temperature resulted in a lower MC during the initial days of exposure. This was expected, since in the absence of rainfall, only sorption and desorption influence the MC of the exposed samples. Similar relations were determined during a foggy period, with the only significant difference being that the average MC was considerably higher: 17 % for specimens modified at 210 °C and 33 % for control specimens. However, during a rainy period, MC relationships changed considerably. The highest average value was again determined on control specimens, while specimens modified at 180 °C and 190 °C had the lowest average MC. This result indicates that not only the sorption properties but other physical properties of the modified wood reflect its performance during outdoor exposure, predominantly during and after extensive rain. Moisture performance is a function of the sorption properties, surface properties and permeability and thus cannot be assessed with a single laboratory test (Figure 3). Furthermore, it should be considered that different mechanisms are responsible for capillary water uptake and sorption.

Comparison of the daily rainfall and moisture content revealed that intensive rain events considerably influence the moisture content (Figure 4). There were 31 days with a moisture content of the control specimens above 100 %. There are two reasons for such a high moisture content. Firstly, in total there were 520 mm of rain during the 100 days of exposure, in 53 rain events, of which 17 days were snow that was deposited on the specimens and afterwards slowly melted and wet the specimens more effectively than rain. Further information shown in Figures 3 and 4 concerns the velocity of drying. Although the specimens were very wet, they dried very fast. For example, the moisture content of control specimens was reduced from 100 % to 20 % in two to three days (Figure 4). However, it should be born in mind that the constructions contained no water trap and the specimens were positioned on two fasteners only, which allowed good circulation of air and thus resulted in fast drying. This drying was significantly faster than drying of green timber.

However, long term data are fairly difficult to analyse and compare. Data presented in Figure 4 are, therefore, summarised in Table 3. It is evident from these results that control specimens had the highest average MC (69 %) and specimens treated with 210 °C (35 %) the lowest. These results are in line with laboratory data obtained in this study (Table 1 and 2). Similar relationships were determined with other statistical aggregates. However, from an application point of view, the days with a moisture content above 25 % are the most important data since this is accepted to be the limit for effective fungal decay (Welzbacher *et al.,* 2009). There are some fungi that can grow at a lower MC but decay caused by such fungi is not likely out-

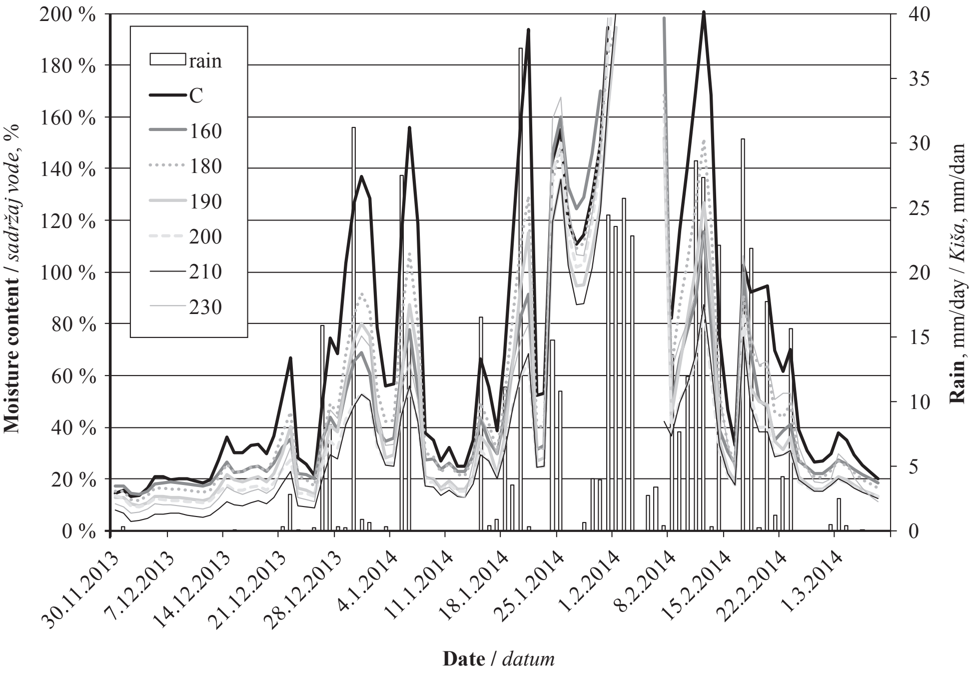

Figure 4 Influence of modification temperature on the correlation between the average daily moisture content of wood specimens and daily rainfall
Slika 4. Utjecaj temperature modifikacije na korelaciju između prosječnoga dnevnog sadržaja vode u uzorcima drva i dnevne količine oborina

Table 3 Influence of modification temperature on mean, median and maximum values of the specimens. Number of days above 20 %, 25 % and 30 % wood moisture content (MC) during 105 days of natural weathering; MC was determined gravimetrically and recorded once per minute. Days when specimens were under snow were not considered as maximum values.
Tablica 3. Utjecaj temperature modifikacije na srednje vrijednosti, medijan i maksimalne vrijednosti sadržaja vode u uzorcima; broj dana sa sadržajem vode (MC) u uzorcima drva većima od 20, 25 i 30 % tijekom 105 dana izlaganja na otvorenome; sadržaj vode određen je gravimetrijski i bilježen jedanput u minuti; dani kada su uzorci bili pod snijegom nisu uzeti u obzir pri određivanju maksimalne vrijednosti sadržaja vode

Moisture content, % *Sadržaj vode, %*	**Modification temperature,** °C / *Temperatura modifikacije, °C*						
	control	160	180	190	200	210	230
Mean, % / *Srednja vrijednost, %*	69	52	55	45	40	35	48
Median, % / *Medijan, %*	54	35	41	29	26	25	33
Max (%) / *Maksimalna vrijednost, %*	201	160	152	136	150	136	168
# days MC > 20 % / *Broj dana s MC > 20 %*	87	84	80	64	56	53	64
# days MC > 25 % / *Broj dana s MC > 25 %*	82	65	64	53	50	47	58
# days MC > 30 % / *Broj dana s MC > 30 %*	70	54	55	47	43	40	54

doors. During the exposure period of 105 days, the MC of the control specimens was higher than 25 % on 82 days. On the other hand, there were only 47 days on which the MC of the specimens modified at 210 °C was above 25 %. This indicates sufficient moisture performance of modified wood if not in permanent contact with liquid water. The reasons for this have already been discussed and can be summarised as a lower hemicellulose content, fewer OH groups and lower surface energy.

4 CONCLUSIONS
4. ZAKLJUČAK

Thermal modification of wood considerably improves its performance against wetting. The highest level of correlation between laboratory and outdoor testing was determined between short term tests and outdoor moisture monitoring on single point load cells. However, it is evident from the presented results that a single laboratory procedure is not enough for prediction of the moisture performance outdoors. In order to determine a comprehensive moisture performance, multiple techniques have to be applied.

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5 REFERENCES
5. LITERATURA

1. Altgen, M.; Welzbacher, C.; Humar, M.; Willems, W.; Militz, H., 2012: Bestimmung der Behandlungsqualität von Thermoholz mithilfe von Schnellverfahren. Holztechnologie, 53 (6): 44-49. [in German language].

2. Awoyemi, L.; Jones, I. P., 2011: Anatomical explanations for the changes in properties of western red cedar (*Thuja plicata*) wood during heat treatment. Wood science and technology, 45: 261-267 http://dx.doi.org/10.1007/s00226-010-0315-9.
3. Brischke, C.; Meyer, L.; Bornemann, T., 2013: The potential of moisture content measurements for testing the durability of timber products. Wood science and technology, 47 (4): 869-886 http://dx.doi.org/10.1007/s00226-013-0548-5.
4. ENV 1250-2, 1994: Wood preservatives – Methods for measuring losses of active ingredients and other preservative ingredients from treated timber – Part 2: Laboratory method for obtaining samples for analysis to measure losses by leaching into water or synthetic sea water. European Committee for Standardization, Brussels.
5. Esteves, B. M.; Pereira, H. M., 2009: Wood modification by heat treatment: A review. Bioresources, 4 (1): 370-404.
6. Hakkou, M.; Pétrissans, M.; Gérardin, P.; Zoulalian, A., 2006: Investigations of the reasons for fungal durability of heat-treated beech wood. Polymer degradation and stability, 91 (2): 393-397 10.1016/j.polymdegradstab.2004.04.042.
7. Hill, C., 2006: Wood Modification-Chemical, Thermal and Other Processes. Wiley, UK, pp. 260 http://dx.doi.org/10.1002/0470021748.
8. Humar, M.; Lesar, B., 2013: Efficacy of linseed- and tung-oil-treated wood against wood-decay fungi and water uptake. International biodeterioration and biodegradation, 85: 223-227 http://dx.doi.org/10.1016/j.ibiod.2013.07.011.
9. Kutnar, A.; Kričej, B.; Pavlič, M.; Petrič, M., 2013: Influence of treatment temperature on wettability of Norway spruce thermally modified in vacuum. Journal of adhesion science and technology, 27 (9): 963-972 http://dx.doi.org/10.1080/01694243.2012.727168.
10. Lacić, R.; Hasan, M.; Trajković, J.; Šefc, B.; Šafran, B.; Despot, R., 2014: Biological durability of oil heat treated alder wood. Drvna industrija, 65 (2): 143-150 http://dx.doi.org/10.5552/drind.2014.1256.
11. Rapp, A. O.; Sailer, M., 2001: Oil-heat-treatment of wood – process and properties. Drvna industrija, 52 (2): 63-70.
12. Rep, G.; Pohleven, F.; Košmerl, S., 2012: Development of the industrial kiln for thermal wood modification by a procedure with an initial vacuum and commercialisation of modified Silvapro wood. In: The sixth European conference on wood modification. Jones, D. (ed.); Militz, H. (ed.); Petrič, M. (ed.); Pohleven, F. (ed.); Humar, M. (ed.); Pavlič, M. (ed.); University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology, Ljubljana, Slovenia, pp. 11-17.
13. Van den Bulcke, J.; Van Acker, J., 2008: Time resolved analysis of the moisture dynamics of plywood. Cost Action E37 Final Conference in Bordeaux, Socio-economic perspectives of treated wood for the common European market. pp. 65-75.
14. Welzbacher, C. R.; Brischke, C.; Rapp, A. O.; Koch, S.; Hofer, S., 2009: Performance of thermally modified timber (TMT) in outdoor application – durability, abrasion and optical appearance. Drvna industrija, 60 (2): 75-82.

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Evaluating the Competitiveness of Wood Processing Industry

Vrednovanje konkurentnosti drvoprerađivačke industrije

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ABSTRACT • *Wood processing industry (WPI) is a sector based on renewable natural resources of wood raw material. It can, therefore, provide sustainable growth and be competitive on the international markets. The interest of the European Union is to build economy based on renewable natural resources, meaning that it is necessary to pay increased attention to the development and support of the WPI. The aim of the article is to evaluate and compare the level and development of competitiveness of WPI in the Czech and Slovak Republics for a ten year period through the establishment of indicators based on foreign trade data of industry using mathematical and statistical methods. To reach the goal, a system of indicators measuring sectoral competitiveness was set up under the hypothesis: in the WPI the potential of competitiveness is used deficiently. The resulting indicators have confirmed the hypothesis and shown that, despite the fact that the WPI creates active foreign trade balance and contributes to surplus balance of the country, it achieves low values of indicators implying comparative advantage with a negative, decreasing trend, consequently meaning that industry gradually loses its competitive ability. The analysis also showed that the reason for low competitive ability of WPI is low specialization of the country in the commodity group, which was confirmed by statistical method of correlation analysis.*

Key words: *competitiveness, Revealed Comparative Advantage, foreign trade balance, wood processing industry*

SAŽETAK • *Drvoprerađivačka industrija (WPI) industrijski je sektor koji se temelji na drvnoj sirovini kao obnovljivome prirodnom resursu, zbog čega je moguće ostvariti održivi rast i razvoj te međunarodnu konkurentsku prednost. Interes je Europske unije graditi gospodarstvo utemeljeno na obnovljivim prirodnim resursima, što će rezultirati pojačanom pozornošću prema razvoju i potpori WPI-a. Cilj ovog rada jest vrednovati i usporediti razinu razvijenosti konkurentnosti WPI-a u Češkoj i Slovačkoj Republici u razdoblju od deset godina, i to uspostavom pokazatelja utemeljenih na podacima međunarodne trgovine sektora primjenom matematičkih i statističkih metoda. Kako bi se to postiglo, uspostavili smo sustav pokazatelja kojima se mjeri sektorska konkurentnost. Postavili smo hipotezu da je potencijal konkurentnosti WPI-a nedovoljno iskorišten. Rezultati dobiveni uz pomoć tih pokazatelja potvrdili su hipotezu i pokazali da, usprkos činjenici da WPI ima pozitivnu vanjskotrgovinsku bilancu i unatoč činjenici da znatno pridonosi pozitivnoj bilanci države, još uvijek ima niske vrijednosti pokazatelja, što upućuje na negativne trendove komparativnih prednosti, a posljedica toga je gubitak komparativnih mogućnosti. Analiza je također pokazala da je razlog niske konkurentnosti WPI-a niska specijaliziranost pojedine države u pojedinoj grupaciji proizvoda, što je potvrđeno statističkom metodom korelacijske analize.*

Ključne riječi: *konkurentnost, komparativne prednosti, vanjsko trgovinska bilanca, drvoprerađivačka industrija*

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1 INTRODUCTION
1. UVOD

According to EU, the competitiveness is defined as the ability of the firms, industries, regions, nations and transnational regions to generate a high level of income and employment, while exposed to foreign competition. Today, competitiveness of countries and industries on the world markets is the basis for the theory of international trade and economic growth, while in comparison with classical and neoclassical economic theory of international trade, it highlights innovative, realistic sources of trade and economic development. In professional literature, however, there is no universally valid and generally accepted definition for the competitiveness of the sector. In the case of sectoral competitiveness, the macro-economic evaluation of competitiveness is applied, thus there is an overlap of macro and meso level view of competitiveness. The balance of foreign trade is used for better understanding of competitiveness and it is, therefore, based on analyzing comparative advantages of the industry. At the sectoral level, an international trade is also taken into account.

The article deals with the analysis of competitiveness of wood processing industry (WPI) in the Czech Republic, Slovak Republic and comparison with EU WPI as a whole. The article is focused on WPI for several reasons. The WPI is extremely multi-functional and provides a wide range of products and materials. It provides economic, environmental and social contribution based on use of renewable resources. Wood-based products are recyclable, re-usable either as new products or energy. They are biodegradable and can be used to replace materials from non-renewable resources. The WPI is an important part of developing economies and provides a new prospective direction based on biotechnology. Production of wood-based products in the Czech and Slovak Republics has, in regard to sufficient supply of input wood material, long tradition and, as one of the options for obtaining renewable resources, it is closely connected with many sectors of the national economy (Jelačić *et al*., 2012). Wood processing industry is one of the sectors in which the Czech and Slovak economies can affect European markets by maximum use of their own resources. The need to deal with the theme of the article is mainly due to the fact that the EU puts emphasis on the economic development based on renewable resources. WPI, therefore, belongs to the supported and prospective industries and it is in the EU interest to make this sector highly competitive on the world market. The competitiveness of the WPI is, therefore, highly topical and important. Despite these facts, insufficient attention is paid to the analysis of competitiveness development of WPI, and so far no study of the subject has been published.

The aim of this article is to evaluate, based on competitiveness analysis, the competitiveness development of the wood processing industry in the Czech and Slovak Republics in a ten-year period, to identify competitive advantages of the industry and to suggest possibilities for increase of sectoral competitiveness within EU.

2 MATERIAL AND METHODS
2. MATERIJALI I METODE

The material required for achieving the relevant outputs from a secondary research was obtained on the basis of an analysis of available scientific literature dealing with competitiveness problem of sectors and countries and on the basis of processing the foreign trade statistics of the wood processing industry.

The present research of competitiveness is based on using statistical methods to assess revealed and anticipated comparative and competitive advantages. In fact, there is not only one indicator comprehensively expressing the level of competitiveness. Some indicators are applicable only to the whole economy; some may measure competitiveness at the level of a country as a whole as well as at lower levels of economic structure (Bobáková and Hečková, 2007). In practice, several indicators for identifying and measuring competitiveness, which can be combined, characterize competitiveness of the selected industrial sector or even country (Han *et al*., 2009). The indicators can be classified into two basic groups, to result-oriented and determinant-oriented indicators (Dieter and Englert, 2007).

Result-oriented indicators enable to detect a competitive situation in ex-post perspective and they are used for determining competitiveness in the sector and in international markets. Based on the study of literature and methodologies of international organizations dealing with the evaluation of competitiveness at the macro and meso levels, a system of indicators was developed for evaluating the competitiveness of the sector and its internal structure:

- Revealed Comparative Advantage (RCA) is the most used indicator and exists in several modifications:
  - RCA indicator (Aiginger and Landesmann, 2002) expresses competitiveness at national level.
  - Competitiveness Growth Index (RCA1) allows to determine the competitiveness of industry in the international and world market.
  - Index of Net Business Performance RCA 2 (Balassa, 1965, p. 90- 124) expresses the rate of the industry contribution to establish active trade balance.
  - RCA index of cross-sectoral specialization (in accordance with the methodology ITC - International Trade Center UNCTAD and WTO) analyzes the difference between observed net exports, existing specialization, trade deficit and the theoretical net exports.
- Index of Contribution to Trade Balance CTB (Melíšek, 2012) measures the contribution made by the industry to the national trade balance.
- Michaely Index (Michaely, 1962) enables to demonstrate certain rate of specialization of the country in the commodity group, or in the industry.
- Grubel-Lloyd Index (GLI) analyzes the level of representation of commodities with intrasectoral character of foreign trade, higher levels of representation is symptomatic of higher level of national competitiveness.

- Index of Kilogram Export and Import Prices (KPI) highlights the relationship between price and qualitative competitiveness of the product or commodity group.
- Indicator of revealed price elasticity (REVELAST approach) developed by Aiginger and Landesmann (2002) analyzes competitiveness in price and qualitative distinction.

The real competitiveness of wood processing industry, its sections and commodities was analyzed by applying the above mentioned methods for measuring competitiveness at the level of industry with the aim to validate correctness of the achieved results and the relevance of characteristics.

Indicators found in literature were modified and their calculation was adjusted in order to provide the analysis of sectoral competitiveness. For their calculation, the following abbreviations are used:

x_{ij} - export value of commodity group „i“ within industry „i“ in country „j“
m_{ij} - import value of commodity group „i“ within industry „i“ in country „j“
X_j - value of total export from country „j“
M_j - value of total import to country „j“
X_i - world export or export of integration group (e.g. EU) in commodity group „i“
X - total world export or total EU export

RCA indicator presents comparative advantage or disadvantage of export and its competitive ability. The formula for its calculation is:

$$\text{RCA} = \ln\left[(x_{ij} / m_{ij}):(X_j / M_j)\right] \qquad (1)$$

The following applies to variable RCA:
RCA < 0 induces revealed comparative disadvantages in the commodity.
RCA > 0 indicates that there are revealed comparative advantages in the country for exported commodities of that industry or commodity group.
RCA > 1 identifies the commodity and industry as internationally competitive.

Index of Competitiveness Growth (RCA1) is calculated as follows:

$$\text{RCA1} = \frac{x_{ij}}{X_j} / \frac{X_i}{X} \qquad (2)$$

If RCA1 > 1 there is comparative advantage of industry in the worldwide market
If RCA1 < 1 a commodity group has no competitive ability in the relevant market

Indicator of net trade performance (RCA 2) evaluates a comparative advantage of export of industry or commodity and its competitive ability. The formula for calculating RCA2 is:

$$\text{RCA2} = \frac{x_{ij} - m_{ij}}{x_{ij} + m_{ij}} \qquad (3)$$

The following applies to variable RCA2:
RCA2 = -1 means that there is no export (x_{ij} = 0),
-1 < RCA2 < 0 induces comparative disadvantage,
RCA2 = 0 export = import
0 < RCA2 <1 induces comparative advantage,
RCA2 = 1 means that there is no import (m_{ij} = 0).

Michaely Index (MI) highlights the degree of specialisation, or the lack of specialisation in specific commodity groups. Calculation of the index is as follows:

$$\text{MI} = \frac{x_{ij}}{\sum_{i=1}^{n} X_j} - \frac{m_{ij}}{\sum_{i=1}^{n} M_j} \qquad (4)$$

The following applies to Michaely Index:
0 < MI < 1 points to a certain degree of specialisation of the country in the commodity group,
-1< MI < 0 indicates insufficient specialisation of the country in the commodity group.

Index of Contribution to Trade Balance (CTB) is calculated by the formula:

$$\text{CTB} = \frac{x_{ij} - m_{ij}}{X_j + M_j} - \frac{X_j - M_j}{X_j + M_j} \cdot \frac{x_{ij} + m_{ij}}{X_j + M_j} \cdot 100 \qquad (5)$$

The left part of the equation represents the real balance of trade industry based on its share in the total foreign trade of the country, which is a cross-sectoral trade, and the right part of the equation measures the expected trade balance in the sector (commodity group) provided that each commodity contributes to the overall trade balance according to their weight in total trade. The difference between the actual and the expected trade balance defines a specific contribution to the total trade balance.

The following applies to CTB:
CTB > 0 means that actual surplus is higher than expected and the relative trade deficit is less than expected, the industry has a positive contribution to the overall trade balance,
CTB < 0 industry has a negative contribution to the total trade balance, the actual results are in accordance with the expected negative or insufficient results.

The original **Grubel-Lloyd Index (GLI)** measures export ability on the macroeconomic level. It has been modified for the evaluation at the industry level, and its calculation indicates the level of commodity representation in intrasectoral foreign trade of the country. The formula for its calculating is:

$$\text{GLI} = 1 - \frac{\frac{x_{ij}}{X_j} - \frac{m_{ij}}{M_j}}{\frac{x_{ij}}{X_j} + \frac{m_{ij}}{M_j}} \qquad (6)$$

Values of GLI are in interval from 0 to 1 (0 < GLI< 1). Comparing value should be an average value of GLI for all industries in the country or GLI value of EU or world trade in the commodity group.

To simplify the comparison of the results of the sector in different countries, as well as for the purpose of implementing benchmarking, a new indicator has been suggested: **Trade Coverage Index (TCI)**. Its calculation is presented in the section - Results.

Calculation of individual indicators was applied in the wood processing industry of the Czech Republic, the Slovak Republic and the EU 27. A characteristic feature of the WPI is processing of raw wood and wood products production at various stages of finalization. Within the classification of business activities of the EU (NACE), WPI consists of the following sections:

- NACE 16: primary mechanical wood processing (timber industry),
- NACE 17: primary chemical wood processing (pulp and paper industry)
- NACE 31: secondary wood processing (production of furniture)

Input data for evaluating the competitiveness of WPI was obtained from the database of Statistics Bureaus, the Ministries of Economy of the Czech and Slovak Republics (www.cso.cz; www.slovak.statistics.sk) and Eurostat (epp.eurostat.ec.europa.eu) with annual data on foreign trade of countries and commodity structure divided according to statistical classification of products by activity (CPA 2008) in million Euro (FOB/FOB) for the period 2003 – 2012. The selected database enabled to exclude the trade in timber used as raw material from export and import values. Thus it was possible to analyze competitiveness of WPI according to the NACE.

To reach the goal of the paper, the hypothesis "WPI potential of competitiveness is used deficiently" was tested.

For appropriate applications of statistical methods, the application was created in MS Excel and competitiveness of WPI and its individual sections was analyzed at several levels: at international EU level, at national level and intrasectoral competitiveness of individual sections by calculating statistical variables to measure competitiveness. Then, the results obtained in the Czech and Slovak Republics were compared with the EU WPI as a whole. Moreover, a trendline analysis of competitiveness development has been performed.

Dependences among the selected data were analyzed using statistical method of correlation analysis. Strength of mutual dependence between selected relations was determined by calculating the coefficient of correlation (r).

3 RESULTS
3. REZULTATI

The starting point in evaluating the competitiveness at the sector level was the definition that competitiveness of the industry can be characterized as the success of the industry in a competitive battle with other equivalent sectors in other economies in placing their products on the domestic and foreign markets, provided that production factors are efficiently used.

The status of wood processing industry (WPI) in the foreign trade of the country is characterized by the proportion of the sector in the foreign trade of the country, and its success in foreign markets is presented by export performance of the industry. The analyzed statistical data showed that in a ten year period (2003–2012) WPI in the Slovak and Czech Republics had an active role in the balance of trade; the export performance in Slovakia being much higher. The share of the Slovak WPI in the import of SR is lower than in the export and it gradually decreased from 4 % to 2.9 %. In the Czech Republic the situation is similar, and the proportion of WPI in the Czech Republic is almost at the same level as in Slovakia. As for export performance of the industry, it can be concluded that in Slovakia it is high and amounting to an average of 77 % of revenues and 95 % of production. In the Czech Republic the export performance of WPI compared to SR is lower but with an increasing trend; the share of exports in sales gradually increased from 31.2 % to 64.5 % and in the production of WPI from 53.8 % to 66.7 %.

3.1 Analysis of Competitiveness of Wood Processing Industry
3.1. Analiza konkurentnosti drvoprerađivačke industrije

The choice of indicators of competitiveness at the sectoral level was inspired by efforts to determine whether the wood processing industry and its sections have succeeded in the domestic and foreign markets. Evidence of success is a higher volume of products placed by the domestic industry on the foreign market than the volume of products placed by the same foreign sectors on the domestic market. Based on the information on these facts via the coefficient of RCA and its various modifications, coefficients CTB, GLI and Michaely Index were achieved. The achieved results of individual parameters are shown in Table 1.

Values of the indicators in Table 1 show that wood processing sector has a comparative advantage within the industry of the country, as well as on international markets. Positive values of RCA index mean a comparative advantage of the industry at the national level. However, over the analyzed period this advantage is gradually decreasing in both countries and approaching zero. In Slovakia it is associated with decreased net export of the sector, but in the Czech Republic, despite an increase in net exports, the comparative advantage decreases. Index of Competitiveness Growth (RCA1) is much higher than the value; in both countries it is almost at the same level and presents a high competitiveness of Czech and Slovak industry within the EU.

Positive values of net trade performance indicator (RCA2) say that WPI contributes to the positive trade balance of the sector, in Slovakia at a much higher rate than in the Czech Republic at the beginning of the period. However, in 2012 the situation was reversed due to a steep decrease in the Slovak Republic - up to three times, while in the Czech Republic, the level of indicator is almost at the same level. The indicator RCA2 is related to index of Contribution to Trade Balance (CTB) indicating the contribution of the sector to the national trade balance. The negative CTB values achieved in WPI as a whole and also in its subsectors since 2005 show that the contribution of the sector to the overall trade balance is negative and that there is no real surplus, which is quite the contrary of what was expected. This in turn means that the relative trade deficit is smaller than expected. Significantly worse results of this indicator were observed in the Czech Republic, where negative values have been recorded since 2005. Positive values of Michaely Index confirmed the competitiveness of WPI, but showed a very low rate of country specialization in the commodities

Table 1 Indicators of Competitiveness of Wood Processing Industry
Tablica 1 Pokazatelji konkurentnosti drvoprerađivačke industrije

indicator/ year *pokazatelj / godina*	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
WPI SR / *WPI Slovačka*										
RCA	0.666	0.553	0.605	0.430	0.367	0.451	0.514	0.395	0.329	0.208
RCA1	1.984	1.953	1.965	1.949	1.763	1.712	1.940	1.695	1.642	1.527
RCA2	0.310	0.252	0.266	0.189	0.175	0.208	0.248	0.194	0.166	0.131
MI	0.038	0.029	0.029	0.020	0.016	0.017	0.022	0.015	0.011	0.007
GLI	0.679	0.731	0.706	0.788	0.819	0.778	0.748	0.805	0.837	0.897
CTB	0.091	0.113	0.161	0.118	0.035	0.063	0.026	0.013	-0.005	-0.087
WPI ČR / *WPI Češka*:										
RCA	0.406	0.358	0.346	0.330	0.306	0.230	0.148	0.239	0.230	0.197
RCA1	1.895	1.812	1.793	1.707	1.659	1.613	1.659	1.621	1.614	1.587
RCA2	0.177	0.170	0.182	0.173	0.169	0.128	0.110	0.143	0.148	0.150
MI	0.021	0.017	0.016	0.014	0.013	0.009	0.006	0.009	0.008	0.007
GLI	0.800	0.823	0.829	0.836	0.848	0.886	0.926	0.881	0.886	0.902
CTB	0.137	0.044	-0.040	-0.033	-0.069	-0.051	-0.152	-0.089	-0.119	-0.181

and a decreasing trend in the post-crisis period. On the other hand, the values of the Grubel-Lloyd Index (GLI) show a high degree of representation commodities of intrasectoral character of foreign trade and an increasing share of individual WPI subsectors. GLI values of WPI are higher when compared with the average values of the processing industry of SR (0.835), CR (0.868) and EU-27 (0.776), which implies WPI contribution to the competitiveness of economy as a whole.

Development trend of competitive abilities of wood processing industry based on the most important indicators are shown in Figures 1 and 2.

The development of the main indicators shows higher competitiveness of wood processing industry in

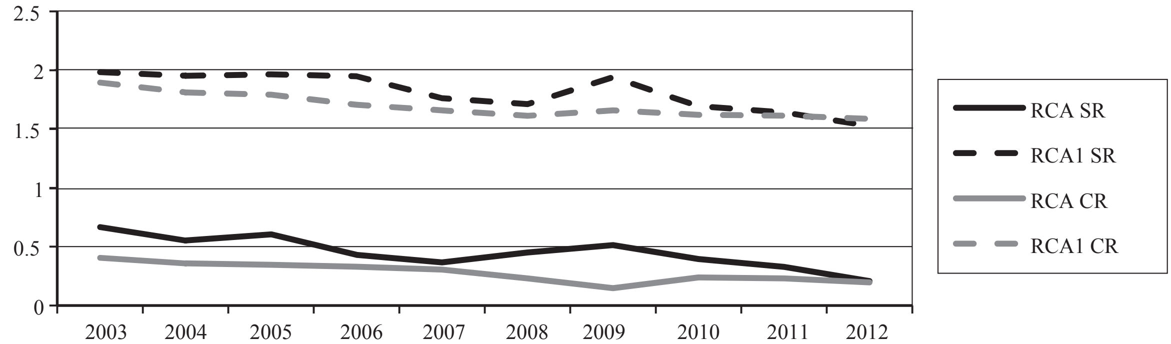

Figure 1 Trend of Revealed Comparative Advantage (RCA and RCA1)
Slika 1. Trend RCA, RCA1

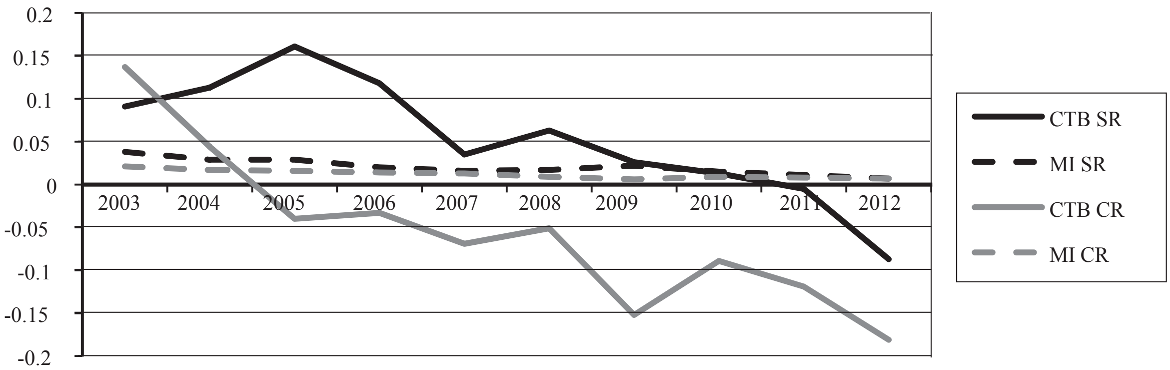

Figure 2 Trend of Contribution to Trade Balance Index (CTB) and Michaely Index (MI)
Slika 2. Trend CTB, MI

Table 2 Correlation coefficients
Tablica 2. Koeficijenti korelacije

X/Y	RCA	RCA1	RCA2	CTB
MI	0.9428	0.7815	**0.9319**	**0.9572**
GLI	**0.9998**	0.7959	**0.9666**	0.8132
trade balance of WPI / *trgovinska bilanca WPI-a*	**0.9576**	0.7428	**0.9263**	0.765
share of WPI in national export *udio WPI-a u nacionalnom izvozu*	0.8598	0.8098	0.8362	**0.9501**

Slovakia than in the Czech Republic. However, Slovak sector is losing competitiveness on foreign markets. If such trend continues, it can cause uncompetitiveness of Slovak WPI. Considering the development of CTB indicator, a negative trend can be seen. Despite higher values of RCA2 of WPI in SR compared to CR, the level of indicators was gradual falling and came under the EU average. A decreasing trend is also seen by Michaely Index, which is near zero.

In further analysis, findings of dependency between the selected indicators were analyzed using statistical correlation method to determine the factors affecting the competitiveness of wood processing industry. Dependences based on the correlation coefficients are shown in Table 2.

The results show that the sector´s competitiveness is strongly influenced by the following factors:

- specialization of the country for commodities of the sector,
- high rate of intrasectoral foreign trade of the country,
- export performance of the sector at the national level,
- share of the sector in the country´s export affecting mainly a positive contribution of the sector to active trade balance of the country.

3.2 Comparative and Trendline Analysis of Competitiveness of Wood Processing Industry
3.2. Analiza konkurentnosti drvoprerađivačke industrije komparacijom i na osnovi trendova

To compare the competitiveness of the sector in several countries, a new indicator Trade Coverage Index (TCI) has been proposed. The formula for its calculation is:

$$TCI = \ln\left[\frac{X_{ia}}{X_{ib}} / \frac{M_{ia}}{M_{ib}}\right] \quad (7)$$

Where: X_{ia} is export of sector „*i*“ and M_{ia} import of sector „*i*“ in country „*a*“
X_{ib} is export of sector „*i*“ and M_{ia} import of sector „*i*“ in country „*b*“

The following applies to TCI:

- if TCI > 0 the higher competitiveness of the sector is in country „*a*“
- if TCI < 0 the higher competitiveness of the sector is in country „*b*“

Results of TCA indicator calculated for comparison of Slovak and Czech wood processing industry are shown in Table 3. The values of Trade Coverage Index observed for WPI in Slovakia and the Czech Republic show that higher competitiveness of the sector was reached in Slovakia until 2011. However, this advantage was gradually decreasing until 2012 when the CR became more competitive. The low TCI values of 0.5 further indicate a small difference between competitiveness of the sector in Slovakia and the Czech Republic.

Competitiveness of the wood processing industry of the Czech and Slovak Republics at EU level was further evaluated by comparing the average values of indicators to WPI of EU as a whole. Results are shown in Table 4 and Figure 3. The comparison showed that, except indicators RCA2 and GLI, the Czech and Slovak WPI show lower competitiveness than WPI of EU. The most important indicators of competitiveness: RCA, MI and CTB are considerably below the EU average.

4 DISCUSSION
4. RASPRAVA

Evaluating the competitiveness of wood processing industry was based on the findings of previous studies in which the authors (Sujová, 2011, 2012, 2013; Hlaváčková and Šafařík, 2014) and other professionals (Parobek, 2014; Grladinović *et al*., 2006; Šafařík and Badal, 2013) dealt with qualitative analysis of com-

Table 3 Trade Coverage Index in wood processing industry of SR and CR
Tablica 3. Indeksi trgovinske pokrivenosti drvoprerađivačke industrije u Slovačkoj i Češkoj

Years / *Godine*	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
TCI SR/CR *TCI Slovačka/Češka*	0.284	0.174	0.179	0.034	0.012	0.165	0.287	0.105	0.037	-0.038

Table 4 Average values of indicators
Tablica 4. Prosječne vrijednosti pokazatelja

Indicator / *Pokazatelj*	RCA	RCA1	RCA2	GLI	CTB	MI
WPI SR / *WPI Slovačka*	0.452	1.813	0.214	0.779	**0.053**	0.020
WPI CR / *WPI Češka*	0.279	1.696	0.155	0.862	-0.055	0.012
WPI EU 27	1.070	-	0.159	0.776	0.154	1.028

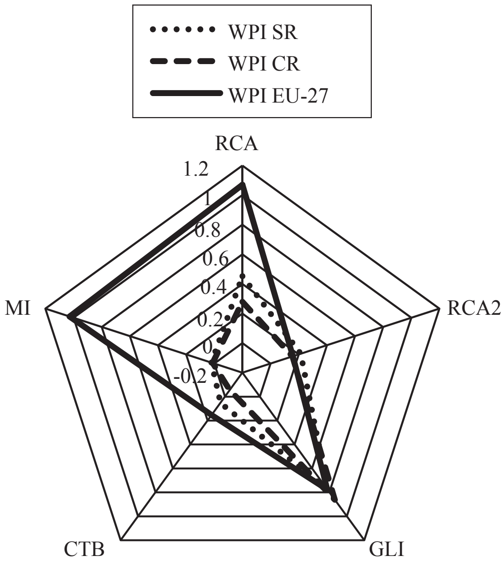

Figure 3 Comparison of competitiveness of WPI of SR, CR and EU 27
Slika 3. Komparacija konkurentnosti drvoprerađivačke industrije Slovačke, Češke i EU-a

petitive factors of wood processing industry. Previous analyses led to conclusions that wood processing industry has a high export performance compared to other sectors of industry and a significant share in production of processing industries. It is an independent industry based on imported raw wood material, but the use of wood raw material is not effective and the main competitive advantage of the industry is in the price and lower costs.

Quantitative analysis of the evolution of competitiveness of wood processing presented in this paper showed that the industry is competitive on a national and international level as well as at EU level. This is the result of the industry´s ability to generate trade balance surplus. On the other hand, however, its real contribution to the national trade balance is negative. Previous qualitative studies confirmed the competitive ability of WPI and potential to be successful on the international market by increasing its performance and thus contributing to the sustainable growth of the national economy. According to the presented quantitative analysis, the competitiveness of an industry increases with the growth of positive net exports. However, the Slovak WPI has been losing this capability, and this may be caused by several factors: lower prices, decrease in the exported commodities or increase in imports of commodities of WPI.

In the way of achieving and demonstrating competitiveness, there is a conflict between the desire of the Government to maximize the utilization of domestic timber commodities and competitiveness on international markets based on foreign trade. To solve this problem, the country should specialize in foreign trade to create positive balance by means of sector´s products with the highest added value.

Wood processing industry includes three subsectors. Production occurs in all stages of wood processing from the lowest up to the highest added value. The subject of further scientific study will, therefore, be intrasectoral analysis of competitive abilities of individual WPI sections allowing to suggest and optimize the structure of foreign trade in wood processing industry to increase competitiveness of the sector.

5 CONCLUSION
5. ZAKLJUČAK

The wood processing industry has the potential to achieve high competitiveness on international markets, create an active trade balance and contribute to economic growth of the sector and country. The system of indicators established to analyze the level and evolution of competitiveness of the industry in a ten-year period enabled to determine the achieved comparative advantages and the ability to create a positive trade balance by wood processing industry. However, this cannot be applied in defining the active trade balance of the country, where the contribution is much lower than expected. At the beginning of the analyzed period, wood processing industry achieved higher competitiveness in Slovakia than in the Czech Republic, but after gradual decreasing indicators in Slovakia, at the end of the period in question the level was equal in both countries. It can be expected that competitiveness of wood processing industry in the Czech Republic will be kept at a low level, while the industry in Slovakia will be at risk of losing comparative advantage.

As for the competitiveness level of wood processing industry, the analysis showed existing comparative advantages but the achieved level of competitiveness is at a low level, lower than the EU average and the potential of the industry. The analysis confirmed very low specialization of countries in the WPI foreign trade and inability of industry to actively contribute to national trade balance, resulting in a decrease of existing comparative advantages of industry on international markets.

In order to influence trade balance in a positive way, it is necessary to optimize the structure of intrasectoral foreign trade, to increase attention to supporting export of wood-based products with the highest added value and exploit the potential of the industry to create a competitive advantage based on quality and innovation. Success of wood processing industry, therefore, lies in the active development of new comparative advantages because, as shown by the results of the analysis, the original comparative and competitive advantages based on cost and price are disappearing.

5 REFERENCES
5. LITERATURA

1. Aiginger, K.; Landesmann, M., 2002: Competitive Economic Performance: The European View [WIFO Working Papers 179/2002]. Wienna: Austrian Institute of Economic Research.
2. Balassa, B., 1965: Trade Liberalisation and Revealed Comparative Advantage. Manchester: Manchester School of Economics and Social Studies.

3. Bobáková, V.; Hečková, J., 2007: Analýza konkurencieschopnosti slovenského spracovateľského priemyslu. Politická ekonómie, IV (4): 490-507 http://dx.doi.org/10.18267/j.polek.610.
4. Dieter, M.; Englert, H., 2007: Competitiveness in the global forest industry sector: an empirical study with special emphasis on Germany. Springer Link, 126 (3): 401-412 http://dx.doi.org/10.1007/s10342-006-0159-x.
5. Grladinović, T.; Jelačić, D.; Motik, D.; Drabek, J., 2006: Modelling of the Material Flows IN Wood Industry Companies. Wood research, 51 (2): 63-75.
6. Han, X.; Wen, Y.; Kant, S., 2009: The global competitiveness of the Chinese wooden furniture industry. Forest Policy and Economics, 11 (8): 561-569 http://dx.doi.org/10.1016/j.forpol.2009.07.006.
7. Hlaváčková, P.; Šafařík, D., 2014: Problémy českých dřevozpracujících podniků a indikátory konkurenceschopnosti. Manažment podnikov, 4 (1): 3-8.
8. Jelačić, D.; Moro, M.; Drábek, J.; Sujová, A., 2012: Motivation factors in wood processing plants. Wood Research, 57 (2): 317-330.
9. Melíšek, I., 2012: Meranie a hodnotenie makroekonomických výsledkov zahraničného obchodu. Ekonomické rozhľady, 41 (4): 439-451.
10. Michaely, M., 1962: Concentration in International Trade, Contributions to Economic Analysis. Amsterdam: North-Holand Publishing Company.
11. Parobek, J.; Kalamárová, M., 2014: Kvantitatívne metódy konkurencieschopnosti zahraničného obchodu s drevom a výrobkami z dreva. Manažment podnikov, 4 (1): 9-14.
12. Sujová, A., 2011: Process restructuralization and its importance by increasing a competitiveness of an enterprise. Acta Univ. Agric. Silvic. Mendelianae Brunensis, 59 (2): 319-324 http://dx.doi.org/10.11118/actaun201159020319.
13. Sujová, A.; Rajnoha, R., 2012: Evaluation of competitive factors in Slovak woodprocessing enterprises as the base for business performance management. In: Wood and Furniture Industry in times of change – new trends and challenges: proceedings of the International Scientific Conference WoodEMA, Trnava: University of st. Cyril and Mehod in Trnava, pp. 1-6.
14. Sujová, A., 2013: Business Process Performance Management - A Modern Approach to Corporate Business Management. In: Liberec Economic Forum 2013: proceedings of scientific papers. Liberec: TU Liberec, pp. 542-550.
15. Šafařík, D.; Badal, T., 2013: The economic efficiency of forest energy wood chip production in regional use – A case study. Acta Univ. Agric. Silvic. Mendelianae Brunensis, 61 (2): 1391-1398 http://dx.doi.org/10.11118/actaun201361051391.
16. *** Czech Statistical Office. © 2014. [online]. Available at: <http://www.czso.cz>. [Accessed: 2014, March, 14].
17. *** EUROSTAT. © 2014. [online]. Statistics Database. European Commission. Available at: <http://epp.eurostat.ec.europa.eu/>. [Accessed: 2014, March, 10].
18. ***Statistical Office of the Slovak Republic. © 2014. [online]. Available at: <http:// slovak.statistics.sk> [Accessed: 2014, March, 20].

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Proizvodni troškovi kao osnovni čimbenik konkurentnosti pilanske prerade četinjača

Production Costs as a Basic Factor of Competitiveness of Softwood Sawmilling

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SAŽETAK • *Bogatstvo šuma na prostorima Republike Hrvatske uvjetovalo je razvoj pilanske prerade drva koja ima već stoljetnu tradiciju. S određenim zakašnjenjima u usporedbi s europskim zemljama, pilanska je prerada drva pratila razvoj tehnologije, zapošljavala stručnu radnu snagu te uz šumarstvo bila prva faza razvoja prerade drva. Troškovi su „u srcu" mnogih poslovnih odluka. Nije dovoljno proučavati troškove za pojedino ili za ograničeno poslovno područje, već ih je nužno promatrati za cijeli lanac poslovnog procesa, tj. od dobavljača do kupca proizvoda ili usluga. Cilj ovog istraživanja bio je usporediti čimbenike u proizvodnji uz pomoć kojih se mogu uspoređivati proizvodnje domaćih i inozemnih poduzeća kako bi se dobila slika konkurentnosti pilanarstva u Republici Hrvatskoj. Čimbenici koji su se uspoređivali jesu trošak po jedinici proizvoda, trošak sirovine s prijevozom, trošak energije, trošak kapitala (u ovom primjeru amortizacije) te trošak radne snage. Radi dodatnog povećanja i održavanja konkurentnosti, potrebno je više ulagati u tehnologiju kako bi se smanjili troškovi po jedinici proizvoda. Također treba utvrditi optimalnu tehnologiju s obzirom na kvalitetu, kvantitetu i vrstu drva.*

Ključne riječi: *prerada drva, troškovi, konkurentnost, kalkulacije, trupci, piljena građa*

ABSTRACT • *Abundance of forests in the territory of the Republic of Croatia was the reason for the development of sawmill industry that has a century long tradition. Although lagging behind the European countries, the Croatian sawmilling industry, along with forestry, represents the first phase of wood processing development, which is based on high manufacturing technology, trained employees and skilled workers. Costs are the core of many business decisions. It is, however, not enough to analyze the costs of a specific or restricted business area, but the costs of the entire business process – from supplier to product/service buyer. The aim of this paper was to compare the selected production process factors so as to make comparison between the Croatian and foreign companies, in order to get an idea of competitiveness of the Croatian sawmilling industry. Factors that were compared were: output cost per unit, costs of raw material including transportation, energy costs, cost of capital (in this case amortization), and the cost of labor. In order to further increase and maintain competitiveness of sawmill industry, it is necessary to make higher investments into technology with the aim to reduce the unit production costs. It is also necessary to determine the optimal technology in terms of quality, quantity and wood species.*

Key words: *wood processing, costs, competitiveness, calculations, logs, sawn wood*

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1. UVOD
1 INTRODUCTION

Bogatstvo šuma na prostorima Republike Hrvatske uvjetovalo je razvoj pilanske prerade drva koja danas ima već stoljetnu tradiciju. U proteklom razdoblju, s određenim zakašnjenjima u odnosu prema europskim zemljama, taj je dio industrije pratio razvoj tehnologije, obučavao je i zapošljavao stručnu radnu snagu te uz šumarstvo bio prva faza razvoja prerade drva. Krajnji produkt pilana završavao je kao proizvod u građevinarstvu ili kao sirovina za daljnju preradu u drvnoj industriji. Troškovi su u „srcu“ mnogih poslovnih odluka. Tvrtke za preradu drva moraju stalno nastojati poboljšati ili barem zadržati svoj tržišni udio (Oblak i Glavonjić, 2014.). Postoji nekoliko načina da se to postigne (Oblak i Glavonjić, 2014.), npr. tvrtke moraju paziti na troškove jer svaka kuna više u trošku smanjuje profite poduzeća, odnosno poduzeće koje vodi brigu o profitu strogo će paziti na svoje troškove da bi održalo profitabilnost (Motik, 2004.). Za svaku poslovnu situaciju vrijedi pravilo da poduzeće mora biti dugoročni ponuđač s najnižim troškovima, da njegovi troškove moraju imati tendenciju snižavanja te imati potpunu sliku o troškovima i dobiti za svaki proizvod u svako vrijeme. Nije dovoljno proučavati troškove za pojedino ili za neko ograničeno poslovno područje, već ih treba pratiti u cijelom lancu poslovnog procesa, tj. od dobavljača do kupca proizvoda ili usluga. Na taj se način upravlja troškovima u cijelom poslovnom procesu (Figurić, 2003.).

Neprekidno traženje poboljšanja i težnja smanjenju troškova proces je koji se prema izvorniku naziva Kaizen (Figurić, 2003.). To je poslovno razmišljanje koje prati stalno snižavanje troškova i rast kvalitete. Bitan je timski rad menadžmenta, a i svih zaposlenika u traženju boljih rješenja kojima bi se mogao poboljšati proizvod ili usluga te racionalizirati poslovanje. Upravljanje troškovima neprekidna je aktivnost usporedbe troškova s tržištem i konkurencijom, jer poticaji za poboljšanje dolaze upravo od kupaca i konkurencije. Troškovima se mogu smatrati svi oni poslovni rashodi koji se mogu ukalkulirati u cijenu proizvoda odnosno u cijenu usluge (Santini, 2006.). Za troškove možemo ukratko reći da su novčano izrađena cijena utroška (Motik i Figurić, 1998.). Prema toj definiciji, ako je prikažemo putem proizvodnje, troškovi su količine potrošenih elemenata proizvodnje pomnožene njihovim cijenama. Na osnovi toga, ukupni se troškovi poduzeća mogu prikazati kao zbroj umnožaka količina i cijena svih utrošaka, odnosno ako je u proizvodnji potrošena određena količina materijala koja je nabavljena po određenoj nabavnoj cijeni, tada je trošak materijala umnožak količine proizvoda i nabavne cijene materijala utrošenoga u taj proizvod. Na taj način dobivamo i formulu koja će biti korištena u ovom radu, a u kojoj se navodi da količina rada pomnožena cijenom rada daje trošak rada, odnosno da su prosječni troškovi jednaki ukupnim troškovima podijeljenim s količinom proizvoda (Matić, 2000.). Cilj svakog poduzeća jest da uz što manje troškove ostvari što veću proizvodnju, odnosno da ostvari što veći profit (Škrtić, 2005.).

Potrebno je poznavati troškove da bismo mogli odrediti cijenu koštanja, a samim time i prodajnu cijenu proizvoda i vidjeti kako se ona ponaša s obzirom na konkurentske cijene na domaćemu i stranom tržištu (Škrtić, 1995.).

Cijene su egzogeni činitelji kada se promatraju s aspekta poslovne politike poduzeća. Cijene, dakle, pomažu proizvođačima da odrede koliko će sredstva alocirati na pojedine proizvodne faktore da bi ostvarili maksimalnu količinu proizvodnje (Babić, 2000.). Troškovi pripadaju unutrašnjim, a ostali vanjskim činiteljima politike cijena. Cijena je posljedica odnosa ponude i potražnje, ali i uzrok ponude i potražnje te ima svoje sastavne elemente. Odnos elemenata unutar cijene čini strukturu cijene. Pojedini elementi strukture cijene koštanja za proizvodno poduzeće jesu materijal izrade, amortizacija, troškovi rada, strane usluge, opći troškovi uprave i prodaje, dakle, troškovi proizvodnje (Gulin, 2003.). Jednako tako, na strukturu prodajne cijene utječu i korisnost nekog proizvoda, troškovi transporta, trgovine, kapitala, distribucije, a može postojati i utjecaj države putem poreza, carina, prireza i raznih taksi. Osnovni su činitelji politike poduzeća troškovi, potražnja, konkurencija, politika i društvene mjere.

Strukturu cijene određuje ponuda, mjesto ponude te potrebe i kupovna moć potrošača. Zato se razlikuju različite strukture cijena: cijena proizvodnje (cijena koštanja i prosječni profit), cijena ponude (iznos za koji je prodavatelj voljan prodati robu) i cijena potražnje ili nabavna cijena (iznos koji je voljan platiti kupac). Struktura cijene nije samo računski postupak izračunavanja udjela pojedinih elemenata u cijeni robe nego ona odražava tehnički odnos i odnos između rada i kapitala. Računski postupak utvrđivanja strukture cijena naziva se kalkulacijom. Metoda kalkulacije uvjetuje način izražavanja elemenata cijena. Za utvrđivanje cijena postojećih proizvoda primjenjuju se dvije skupine metoda: a) metode utvrđivanja cijena na temelju troškova (troškovno načelo) i b) metode utvrđivanja cijena na temelju ponude i potražnje (tržišno načelo).

1.1. Metode utvrđivanja cijena na temelju troškova (troškovno načelo)
1.1 Methods for determining prices based on costs (cost principle)

Određivanje cijena na temelju troškova obuhvaća sve troškove poduzeća uvećane za odgovarajuću dobit. Svako bi poduzeće trebalo obavljati određenu kontrolu svojih prodajnih cijena što znači: a) utvrditi osnovicu cijena za svoj proizvod; b) utvrditi različite cijene za različite modele; c) utvrditi različite cijene za različite uvjete prodaje s obzirom na količinu, područje itd.; d) utvrditi cijene za posebne narudžbe (specifikacije) ili posebne uvjete u kojima se poduzeće može naći (razne usluge piljenja).

Kada je riječ o troškovima kao podlozi za utvrđivanje cijena, nužno je analizirati troškove s obzirom na:

1. reagibilnost i remanenciju troškova – za velika poduzeća remanencija troškova ima veliko značenje zbog strukture njihovih ukupnih troškova. U kapitalno intenzivnim, velikim poduzećima, kao i u radno intenzivnima, fiksni troškovi imaju znatan udio

u ukupnim troškovima. Odluku o smanjenju proizvodnje nije lako donijeti ako se ne želi smanjiti dobit i, eventualno, stvoriti gubitak. Bitno je utvrditi način ponašanja prosječnih ukupnih troškova, prosječnih varijabilnih troškova, prosječnih fiksnih troškova i graničnih troškova pri povećanju i smanjenju proizvodnje;

2. način ponašanja troškova proizvodnje i troškova prodaje s obzirom na količinu proizvodnje; obično se troškovi proizvodnje po jedinici proizvoda smanjuju ako proizvodnja raste, a troškovi prodaje rastu s povećanjem prodanih količina;
3. metode obračuna troškova materijala, amortizacije i dr.;
4. stupanj realnosti (stvarni, planski, standardni troškovi);
5. način izračunavanja troškova po jedinici proizvoda (direktni i indirektni ili posredni troškovi).

Cijene ovise o visini troškova proizvodnje i prodaje, a troškovi ovise o količini, kvaliteti i cijenama utrošenog materijala, primijenjenoj tehnologiji, utrošenoj energiji te raznim društvenim obvezama. Jednako tako, troškovi ovise i o metodi njihova obračuna.

1.2. Metode utvrđivanja cijena na temelju ponude i potražnje (tržišno načelo)
1.2 Methods for determining prices based on supply and demand (market principle)

Cijena nije jednom zauvijek dana fiksna veličina. Ona ima svoju donju i gornju granicu. O manjem ili većem rasponu cijena ovisi i manja ili veća akumulativnost proizvoda. Gornja granica predstavlja potražnju, sredina ukupne troškove, a donja granica varijabilne troškove. Raspon cijena upućuje na zaključak da često nije ispravno promatrati cijene na temelju samo jednog kriterija (troška) već je potrebno uzeti u obzir više kriterija (troškove, potražnju, konkurenciju i sl.). U tržišnom su gospodarstvu ponuda i potražnja bitni činitelji politike cijena. Bitni činitelji tržišne politike cijena jesu veličina tržišta, tip tržišta, oblik tržišta, struktura tržišta, odnos ponude i potražnje, položaj proizvoda na tržištu, elastičnost ponude i potražnje s obzirom na cijene i dobit itd. U svom najjednostavnijem obliku metoda utvrđivanja cijena na temelju ponude i potražnje sastoji se u tome da se istraži opći sustav cijena u pojedinoj grani ili grupaciji te se na temelju toga određuju cijene vlastitih proizvoda. Kad se jednom tako utvrde cijene, troškovi se moraju držati u granicama definirane vrijednosti ako se želi ostvariti planirana dobit. Po pravilu, problemi se uvijek pojavljuju pri pronalaženju mogućih ušteda u troškovima. Bitno je, međutim, da postoji ravnoteža između potrebe za utvrđivanjem odgovarajućih cijena unutar uske mogućnosti konkurencijskih cijena i potrebe da se proizvede proizvod koji je konkurentan s obzirom na dizajn i kvalitetu.

Cilj ovog istraživanja bio je usporediti čimbenike u proizvodnji uz pomoć kojih se mogu uspoređivati proizvodnje domaćih i inozemnih poduzeća kako bi se dobila slika konkurentnosti pilanarstva u Republici Hrvatskoj. Uspoređivani su trošak po jedinici proizvoda; trošak sirovine s prijevozom; trošak energije, trošak kapitala (u ovom primjeru amortizacije) te trošak radne snage.

Jedna od pretpostavki jest da pilane u Republici Hrvatskoj svojom produktivnošću i troškovima ne mogu konkurirati na tržištu piljene građe u Europi te mogu proizvoditi samo za domaće tržište.

H1: Ako se ne poveća produktivnost pilanske prerade drva u Republici Hrvatskoj, onda pilane u našoj zemlji neće biti konkurentne na međunarodnom tržištu.

H2: Ako se smanje troškovi proizvodnje primarne prerade drva, tada će poduzeća koja se bave proizvodnjom piljene građe biti konkurentna na europskome i svjetskom tržištu.

2. MATERIJALI I METODE
2 MATERIAL AND METHODS

Podaci o troškovima proizvodnje i podaci o samoj proizvodnji koji su radi istraživanja prikupljeni iz poduzeća A (u daljnjem tekstu: poligon A), poduzeća B (u daljnjem tekstu: poligon B) i poduzeća C (u daljnjem tekstu: poligon C) uvrštena su u dva modela obrade podataka kako bi se izračunao trošak po jedinici proizvoda. Da bi se dobio trošak po jedinici proizvoda, trebalo je razvrstati troškove prema vrsti i mjestu nastanka te prema proizvodnim jedinicama. Troškovi su dobiveni iz završnog računa na kraju godine. Za samo istraživanje, a kasnije i za usporedbu s drugim poligonima i državama bilo je potrebno utvrditi trošak sirovine bez prijevoza i s njim, iskorištenje, trošak energije, trošak amortizacije, trošak radne snage, troškove održavanja i ostale troškove kako bismo njihovim uvrštenjem u odgovarajuću formulu mogli izračunati trošak dobivene građe po jedinici proizvoda, u ovom primjeru trošak građe po m^3.

Prikupljeni podaci, dobiveni dnevnim praćenjem proreza trupaca i izmjerom dobivene građe te izračunanim koeficijentom iskorištenja, uvršteni su u mjesečne tablice, a na kraju godine u ukupnu godišnju tablicu ispiljene sirovine. U godišnjoj tablici ispiljene sirovine prikazana je količina ispiljene sirovine prema vrstama drva, trošak sirovine, trošak prijevoza sirovine, iskorištenje prema vrstama drva i prema ukupnoj količini. Analiza podataka provedena je primjenom sljedećih dvaju modela.

I. Model obrade podataka. Dobivanje troška piljene građe po jedinici proizvoda u prvom primjeru za sva tri poligona počinje izradom tablice građe s podacima dobivenim iz proizvodnje i iskorištenja trupaca te izračunom dnevnog troška rada. Dnevni je trošak rada u tablici ukupnih troškova izračunan za pojedini poligon, a dobiven je tako da su zbrojeni pojedini godišnji troškovi radnih jedinica i podijeljeni brojem radnih dana u godini.

II. Model obrade podataka. Model zamišljenoga (fiktivnog) poduzeća sadržava izračun troška proizvodnje po jedinici za Njemačku i Austriju. Svjetsku konkurentnost pilanske prerade izložila je tvrtka Jaakko Pöyry 2004. godine. Postavljen je zamišljeni (fiktivni) model pilane koja preradi 600 000 m^3 trupaca u godini, i to 100 % jele i smreke. Pretpostavljeno je da cijena i kvaliteta sirovine iznose 20 % za podrazred 1B, 40 % za podrazred

Tablica 1. Analiza cijena pilanske prerade u „zamišljenom" poduzeću
Table 1 Price analysis of sawmill processing in 'model' company

Kalkulacija za 600 000 m³: pilana, dvije smjene, četinjače (u EUR/m³) Calculation (600 000 m³, sawmill, two shifts, coniferous (in EUR per m³)		
	Njemačka / *Germany*	**Austrija** / *Austria*
Trupci / *Logs*		
Sirovina / *Raw material*	63,4	65,8
Radnici / *Employees*	9	6,5
Kapital/ *Equity*	10,5	10,5
Ostalo / *Other*	7,3	6,9
Ukupno / *Total*	90,2	89,7
Piljena građa / *Sawn wood*		
Sirovina / *Raw material*	103,9	105,2
Radnici / *Employees*	16,3	11,7
Kapital/ *Equity*	19,1	19,2
Ostalo / *Other*	13,3	12,5
Ukupno /*Total*	152,6	148,6

Izvor: COST Action E44: A European wood processing strategy: Country reports, 2008

2A, 30 % za podrazred 2B i 10 % za podrazred 3AB, što odgovara našoj prosječnoj pilanskoj sirovini I. – III. klase (COST Action E44, 2008.). U prvom dijelu tablice 1. cijena trupaca zbrojena je s cijenom prijevoza i za pojedinu zemlju uvrštena u stavku SIROVINA. U tablicu su također uvršteni i podaci o kapitalu te ostali troškovi. U drugom dijelu tablice SIROVINA je dobivena na temelju iskorištenja pri piljenju trupaca i za Njemačku iznosi 61,5 %, a za Austriju 62,5 %. Zbrajanjem podataka iz drugog dijela tablice dobije se trošak proizvodnje po jedinici proizvoda za proizvodnju iz svake od tih zemalja. Trendovi cijena trupaca i piljenje građe prikazani su u tablici 2.

3. REZULTATI I RASPRAVA
3 RESULTS AND DISCUSSION

3.1. Odnos troškova promatranih poduzeća u Republici Hrvatskoj (I. model)
3.1 Costs ratio between companies in the Republic of Croatia (Model I)

Prema podacima iz tablice 3., najskuplja sirovina u 2011. i 2010. godini bila je u poligonu A, i to u 2010. oko 9 % viša nego u ostala dva poligona, a u 2011. za oko 4,5 % viša nego u preostala dva poligona. Nasuprot tome, u poligonu A trošak drvne sirovine za 2009. godinu bio je oko 12 % niži, odnosno oko 8 % niži u 2008. nego u poligonima B i C. Razlika u cijeni sirovine bitno utječe na trošak građe po jedinici proizvoda jer, osim što je trošak veći za 10 %, iz tablice udjela troškova proizvodnje vidi se da je trošak sirovine trošak s najvećim udjelom u ukupnim troškovima istraživanih poligona. Troškovi rada vrlo često čine velik udio u troškovima proizvodnje te u odnosu prema ostalim troškovima dobivaju sve veće značenje (Polimeni i dr., 1999.). Drugi trošak s najvećim udjelom jest trošak radnika. Troškovi radnika najveći su u poligonu C, i to 37 % veći nego u druga dva poligona. Iz toga možemo zaključiti da su plaće radnika veće nego u druga dva istraživana poligona ili je broj radnika veći u poligonu C pa je stoga potrebno izdvojiti i veću količinu novca za plaće radnika. U ovom radu trošak kapitala jest trošak amortizacije. Amortizacija je svojevrsni dugoročni izvor financiranja poslovanja i ekspanzije poduzeća te je postupna transformacija dugoročno imobilizirane imovine u novčani oblik. Sama transformacija imovine iz jednog oblika u drugi ne mijenja strukturu kapitala poduzeća. Trošak kapitala od amortizacije ukupan je trošak kapitala (Orsag, 2002.). Troškovi kapitala podjednaki su u poligonima A i B, dok su u poligonu C znatno niži, i to zato što je u poligonu C amortizacija obračunana po najnižoj obračunskoj stopi od 2,5 %.

Troškovi energije također su podjednaki za sva tri istraživana poligona i ne utječu bitno na trošak građe, a troškovi energije u ukupnim troškovima sudjelu-

Tablica 2. Trendovi cijena jelovih trupaca *(Abies alba Mill.)* (I. – III. klasa) i jelove piljene građe u odabranim zemljama (u EUR/m³)
Table 2 Price trends of fir logs *(Abies alba Mill.)* (I. – III. Class) and fir sawn wood in selected countries (in EUR per m³)

	2008.	**2007.**	**2006.**	**2005.**
Njemačka/ *Gremany*				
Trupci / Logs	80,0	78,0	65,0	63,4
Piljena građa / Sawn wood	186,9	183,6	161,9	159,3
Austrija/ *Austria*				
Trupci / Logs	80,0	86,0	75,0	65,8
Piljena građa /Sawn wood	181,1	191,1	172,8	157,5

Izvor: COST Action E44: A European wood processing strategy: Country reports, 2008

Tablica 3. Odnos troškova poligona A, B i C (u EUR/m^3)
Table 3 Costs ratio of polygons A, B, and C (in EUR per m^3)

Poligon A / *Polygon A*					
	Obračunska jedinica *Currency unit*	**2011.**	**2010.**	**2009.**	**2008.**
Trošak piljene građe / *Cost of sawn wood*	EUR	139	141	117	122
Sirovina s prijevozom *Raw material (including transportation)*	EUR	66	60	51	51
Radnici / *Employees*	EUR	14	14	13	15
Kapital / *Equity*	EUR	4	4	3	5
Energija / *Energy*	EUR	4	4	4	4
Produktivnost po zaposleniku *Productivity per employee*	m^3/radnici *m^3 per employees*	725	744	767	685
Poligon B / *Polygon B*					
	Obračunska jedinica *Currency unit*	**2011.**	**2010.**	**2009.**	**2008.**
Trošak piljene građe / *Cost of sawn wood*	EUR	135	138	135	131
Sirovina s prijevozom *Raw material (including transportation)*	EUR	55	54	54	55
Radnici / *Employees*	EUR	17	18	17	14
Kapital / *Equity*	EUR	6	6	8	9
Energija / *Energy*	EUR	5	4	4	3
Produktivnost po zaposleniku *Productivity per employee*	m^3/radnici *m^3 per employees*	713	706	712	723
Poligon C / *Polygon C*					
	Obračunska jedinica *Currency unit*	**2011.**	**2010.**	**2009.**	**2008.**
Trošak piljene građe / *Cost of sawn wood*	EUR	132	118	129	109
Sirovina s prijevozom *Raw material (including transportation)*	EUR	60	56	53	49
Radnici / *Employees*	EUR	22	15	21	20
Kapital / *Equity*	EUR	3	2	3	3
Energija / *Energy*	EUR	4	3	4	4
Produktivnost po zaposleniku *Productivity per employee*	m^3/radnici *m^3 per employees*	439	597	426	426

je u prosjeku s 10 %. Nadalje, trošak građe prosječno je jednak za sva tri istraživana poligona, a na nj jedino bitno utječe svaka promjena troška sirovine te trošak radnika, koji i u ukupnim troškovima čine najveći udio.

Proizvodnost ili produktivnost općenito označava omjer proizvedenih dobara i potrebe za čimbenicima proizvodnje ili uspješnost pri obavljanju nekog posla s obzirom na upotrijebljene resurse (Bizjak, 1993.). Produktivnost po radniku podjednaka je za istraživane poligone A i B, dok je za poligon C u prosjeku niža za 40 %. Razlog tome je da prva dva poligona raspolažu modernijom tehnologijom pa im je potreban manji broj zaposlenih u proizvodnji, što nije točno jer sva tri istraživana poligona posjeduju jednako zastarjelu tehnologiju, ili da poligon C ne prerađuje dovoljno trupaca s obzirom na broj zaposlenih.

3.2. Odnos troškova zamišljenog modela poduzeća i troškova istraživanih poligona A, B i C (II. model)
3.2 Costs ratio between the model company and polygons A, B, and C (Model 2)

Prema tablicama 4. i 5. trošak sirovine je 20 % veći u Njemačkoj i Austriji od troška sirovine u Republici Hrvatskoj. Zbog udjela od 50 % u ukupnim troškovima, trošak sirovine ima i najveći utjecaj na promjenu troška građe po jedinici proizvoda. Iz podataka se vidi da je odnos troškova radnika u hrvatskim poduzećima 20 – 30 %, a u Njemačkoj i Austriji iznosi 6,5 – 9 % za trupce te 13 – 18 % za piljenu građu.

Iz modela opisanog poduzeća (tabl. 5.) može se zaključiti da se u proizvodnom procesu primjenjuje novija tehnologija velikog kapaciteta piljenja koja ne zahtijeva velik broj radnika kao u hrvatskim poduzećima sa zastarjelom tehnologijom, što povećava troškove. Budući da je u hrvatskim poduzećima tehnologija zastarjela, i odnos troškova kapitala od 6 % manji je od 10 % ukupnih troškova Njemačke i Austrije, te kao trošak ne utječe bitno na povećanje troška građe, odnosno daje mogućnost konkurencije.

Jednako je tako utvrđeno da su ostali troškovi za 50 – 60 % manji u odnosu prema ostalim troškovima u poligonima A, B i C. S obzirom na to koji troškovi u ovom primjeru čine ostale troškove (troškovi održavanja, troškovi energije…), jedan od zaključaka može biti da zbog zastarjele tehnologije rastu troškovi održavanja i kupnje rezervnih dijelova.

Tablica 4. Usporedba troškova prema modelu „zamišljenog“ poduzeća za poligone A, B i C (u EUR/m³)
Table 4 Comparison of costs according to the model company for polygons A, B, and C (in EUR per m³)

Kalkulacija za 22 000 m³: pilana, dvije smjene, četinjače (u EUR/m³) Calculation 22000 m³, sawmill, two shifts, coniferous (in EUR per m³)				
Poligon A / *Polygon A*	**2011.**	**2010.**	**2009.**	**2008.**
Trupci / *Logs*				
Sirovina / *Raw material*	66,1	59,0	50,9	50,9
Radnici / *Employees*	21,2	14,2	13,1	14,9
Kapital/ *Equity*	5,1	3,6	13,1	14,9
Ostalo / *Other*	11,1	8,1	9,3	9,8
Ukupno / *Total*	103,5	85,0	76,3	80,3
Piljena građa / *Sawn wood*				
Sirovina / *Raw material*	94,4	84,3	72,6	72,7
Radnici / *Employees*	35,3	23,7	21,9	24,9
Kapital/ *Equity*	8,5	6,1	5,1	7,9
Ostalo / *Other*	18,4	13,5	15,5	16,3
Ukupno /*Total*	156,7	127,6	115,1	121,7
Kalkulacija za 60 000 m³: pilana, dvije smjene, četinjače (u EUR/m³) Calculation 60000 m³, sawmill, two shifts, coniferous (in EUR per m³)				
Poligon B / *Polygon B*	**2011.**	**2010.**	**2009.**	**2008.**
Trupci / *Logs*				
Sirovina / *Raw material*	55,3	53,3	54,4	55,1
Radnici / *Employees*	17,1	18,4	17,2	14,3
Kapital/ *Equity*	6,0	6,1	7,5	8,8
Ostalo / *Other*	13,0	16,1	13,4	11,8
Ukupno / *Total*	91,5	93,9	92,5	90,0
Piljena građa / *Sawn wood*				
Sirovina / *Raw material*	85,1	82,0	83,7	84,7
Radnici / *Employees*	28,6	30,7	28,7	23,9
Kapital/ *Equity*	10,0	10,1	12,4	14,7
Ostalo / *Other*	21,7	26,8	22,3	19,6
Ukupno /*Total*	145,4	149,6	147,1	142,9
Kalkulacija za 22 000 m³: pilana, dvije smjene, četinjače (u EUR/m³) Calculation 22000 m³, sawmill, two shifts, coniferous (in EUR per m³)				
Poligon C / *Polygon C*	**2011.**	**2010.**	**2009.**	**2008.**
Trupci / *Logs*				
Sirovina / *Raw material*	59,9	56,2	53,4	48,8
Radnici / *Employees*	21,6	15,0	21,0	19,6
Kapital/ *Equity*	2,5	1,8	2,5	2,5
Ostalo / *Other*	10,6	6,9	8,5	9,5
Ukupno / *Total*	94,6	79,9	85,4	80,4
Piljena građa / *Sawn wood*				
Sirovina / *Raw material*	92,2	86,4	82,1	75,0
Radnici / *Employees*	36,0	25,0	35,0	32,7
Kapital/ *Equity*	4,1	3,0	4,2	4,2
Ostalo / *Other*	17,7	11,5	14,2	15,8
Ukupno /*Total*	150,1	125,9	135,5	127,6

4. ZAKLJUČCI
4 CONCLUSIONS

Na osnovi istraživanja odnosa troškova zamišljenog poduzeća u promatranim zemljama Europe i stvarnih troškova u promatranim hrvatskim pilanama, može se istaknuti sljedeće.

1. Cijena sirovine u promatranom je razdoblju u europskim zemljama bila viša nego u Hrvatskoj. Za točnu usporedbu trebalo bi provesti i analizu kvantitativnog iskorištenja trupaca jednakih klasa jer standardi razvrstavanja trupaca nisu identični. U Hrvatskoj se trupci razvrstavaju na I., II. i III. klasu, a u Europi na A, B, C i D.
2. Struktura dobivene sirovine u Austriji i Njemačkoj bitno je drugačija, što uvjetuje i primjenu različitih tehnologija piljenja trupaca. U navedenim su zemljama dobiveni trupci manjeg promjera i ujednačene kvalitete, pa se mogu piliti na jarmačama, tračnim pilama trupčarama u paru ili na linijama kružnih pila uz mogućnost velike automatizacije i produktivnosti. U Hrvatskoj trupci imaju velik raspon promjera, a velike su i razlike u kvaliteti, pa je radi pravilnoga kvalitativnog i kvantitativnog

Tablica 5. Usporedba troškova prema modelu „zamišljenog“ poduzeća za Njemačku i Austriju (u EUR/m^3)
Table 5 Comparison of costs according to the model company for Germany and Austria (in EUR per m^3)

Kalkulacija za 600 000 m^3: pilana, dvije smjene, četinjače (u EUR/ m^3) Calculation (600 000 m^3, sawmill, two shifts, coniferous (in EU per m^3)				
Njemačka / *Germany*	**2011.**	**2010.**	**2009.**	**2008.**
Trupci / *Logs*				
Sirovina / *Raw material*	80,0	78,0	65,0	63,4
Radnici / *Employees*	9	9	9	9
Kapital/ *Equity*	10,5	10,5	10,5	10,5
Ostalo / *Other*	7,3	7,3	7,3	7,3
Ukupno / *Total*	103,5	85,0	76,3	90,2
Piljena građa / *Sawn wood*				
Sirovina / *Raw material*	133,3	130,0	108,3	105,7
Radnici / *Employees*	18,0	18,0	18,0	18,0
Kapital/ *Equity*	21,0	21,0	21,0	21,0
Ostalo / *Other*	14,6	14,6	14,6	14,6
Ukupno /*Total*	186,9	183,6	161,9	159,3
Kalkulacija za 600 000 m^3, pilana, dvije smjene, četinjače (u EUR/m^3) Calculation 600 000 m^3, sawmill, two shifts, coniferous (in EUR per m^3)				
Austrija / *Austria*	**2011.**	**2010.**	**2009.**	**2008.**
Trupci / *Logs*				
Sirovina / *Raw material*	80,0	86,0	75,0	65,8
Radnici / *Employees*	6,5	6,5	6,5	6,5
Kapital/ *Equity*	10,5	10,5	10,5	10,5
Ostalo / *Other*	6,9	6,9	6,9	6,9
Ukupno / *Total*	103,9	109,9	98,9	89,7
Piljena građa / *Sawn wood*				
Sirovina / *Raw material*	133,3	143,3	125,0	109,7
Radnici / *Employees*	13,0	13,0	13,0	13,0
Kapital/ *Equity*	21,0	21,0	21,0	21,0
Ostalo / *Other*	13,8	13,8	13,8	13,8
Ukupno /*Total*	181,1	191,1	172,8	157,8

iskorištenja trupce nužno piliti na tračnim pilama trupčarama. Stoga je otežana primjena procesne tehnologije i automatizacije.

3. Iako su plaće zaposlenika u Republici Hrvatskoj niže nego u europskim zemljama, cijena rada po jedinici proizvoda zbog niske je produktivnosti viša nego u europskim zemljama. Prijeko je potrebno novim investicijama unaprijediti tehnologiju u našim pilanama i povećati produktivnost.
4. U europskim se zemljama u pilansku proizvodnju ulaže mnogo više kapitala nego u nas, pa je i trošak kapitala veći. Međutim, veća ulaganja rezultiraju boljom tehnološkom opremljenošću, a time i većom proizvodnjom po radniku, boljim uvjetima rada i većom sigurnošću na radu.
5. Analizom ukupnih troškova može se zaključiti da pilane u Gorskom kotaru mogu konkurirati europskim pilanama. Prednost su manji ukupni troškovi po m^3 građe.

Radi dodatnog povećanja konkurentnosti i njezina održavanja, potrebno je više ulagati u tehnologiju kako bi se smanjili troškovi po jedinici proizvoda. Također treba utvrditi optimalnu tehnologiju s obzirom na kvalitetu, kvantitetu i vrstu drva. Ovim je radom istraženo koji čimbenici bitno utječu na trošak piljene građe, te su time dane smjernice za buduća istraživanja, što bi u konačnici rezultiralo smanjenjem troškova poslovanja i povećanjem konkurentnosti poduzeća.

5. LITERATURA
5 REFERENCES

1. Babić, M., 2000: Mikroekonomska analiza, Mate, Zagreb.
2. Bizjak, F., 1993: Zbirka vaj za ekonomiko podjetja. Univerza v Ljubljani, Biotehniška fakulteta, Nova Gorica.
3. Figurić, M., 2003: Menadžment troškova u drvnotehnološkim procesima, Zagreb.
4. Gulin, D., 2003: Obračun troškova proizvodnje po radnom nalogu, RIF 11/2003. Zagreb.
5. Motik, D., 2004: Price calculation in multiphase production of wooden products, International science conference “Current questions and development tendencies in woodworking industry”. Ohrid, Macedonia.
6. Motik, D.; Figurić, M., 1998: Calculation methods and their influence upon the business of a company. 1. Vedecká konferencia s medzinárodnou účast’ou nové trendy v systémoch riadenia podnikov, Herl’any.
7. Oblak, L.; Glavonjić, B., 2014: A Model for the Evaluation of Radio Advertisements for the sale of Timber Products. Drvna industrija, 65 (4): 303-308 http://dx.doi.org/10.5552/drind.2014.1357.
8. Orsag, S., 2002: Budžetiranje kapitala – Procjena investicijskih projekata. Masmedia, Zagreb.

9. Polimeni, S.; Handy, A.; Cashin, A., 1999: Troškovno računovodstvo. Faber&Zgombić Plus, Zagreb.
10. Santini, I., 2006: Troškovi u poslovnom odlučivanju. Hibis, d.o.o., Centar za ekonomski consalting, Zagreb.
11. Škrtić, M., 1995: Smanjenje troškova u funkciji povećanja konkurentnosti, RRIF, br. 7, opseg 1,1 a.a., Zagreb.
12. Škrtić, M., 2005: Upravljanje troškovima s ciljem povećanja konkurentnosti. Zbornik radova: Upravljanje troškovima – povećanje konkurentnosti i uspješnosti poslovanja; Zagreb – Zadar, M.A.K. – Golden.
13. ***COST Action E44: A European wood processing strategy: Country reports, 2008.

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Effect of Heat Treatment of Wild Cherry Wood on Abrasion Resistance and Withdrawal Capacity of Screws

Utjecaj toplinske obrade drva divlje trešnje na otpornost na habanje i čvrstoću držanja vijaka

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ABSTRACT • *In its wise use, many properties of wood are important. Among these properties, wood abrasion resistance (AR) and withdrawal capacity of screws (WCS) are deemed to be relatively significant. It is well know that heat treatment changes the resistance features of wooden materials by changing the structural characteristics of wood. Within the scope of this study, the effects were investigated of the temperature and duration of heat treatment of Wild Cherry (Cerasus avium (L.) Monench) on its AR and its WCS in the radial direction and tangential direction. The test results indicated that weight loss (WL) and thickness reduction (TR) remained almost the same in the radial direction specimen, but there was significant TR in the tangential direction specimen. As a result of these changes, the abrasion effect of the S-42 abrader diminished based on the increase in the number of cycles. However, in both the radial and tangential direction, the WCS decreased to a significantly greater extent in the heat-treated specimens than in the control specimens.*

Key words: *Heat treatment, ThermoWood, abrasion resistance, withdrawal capacity of screws, Wild Cherry wood*

SAŽETAK • *Za brojne uporabe drva bitna su mnoga njegova svojstva, a među važnijima su otpornost na habanje (AR) i čvrstoća držanja vijaka (WCS). Dobro je poznato da toplinska obrada drva zbog promjene obilježja građe drva mijenja njegova svojstva otpornosti. U sklopu ovog rada istraživani su učinci temperature i trajanja toplinske obrade drva divlje trešnje (Cerasus avium (L.) Monench) na njegovu otpornost na habanje i čvrstoću držanja vijaka u radijalnome i tangencijalnom smjeru. Rezultati istraživanja pokazali su da se gubitak mase (WL) i smanjenje debljine (TR) uzoraka ne pojavljuju u radijalnom smjeru, ali je značajno smanjenje debljine zabilježeno u tangencijalnim uzorcima. Kao rezultat tih promjena, učinak abrazije primjenom S-42 abraziva smanjuje se*

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s povećanjem broja ciklusa. Međutim, i u radijalnome i u tangencijalnom smjeru znatno se smanjuje čvrstoća držanja vijaka toplinski obrađenih uzoraka u usporedbi s kontrolnim uzorcima.

Ključne riječi: *toplinska obrada, ThermoWood, otpornost na habanje, čvrstoća držanja vijaka, drvo divlje trešnje*

1 INTRODUCTION
1. UVOD

Wooden material has certain undesirable features, such as the change of dimensional stability, biological degradation, and color change, but wooden materials are still used extensively in many products. These adverse features reduce the lifetime and value of wooden material. Currently, it is possible to extend the lifetime and increase the value of wooden materials by various methods that upgrade the features of the materials. Heat treatment of wood is one such method (Kocaefe *et al.,* 2008; Gunduz *et al.,* 2008).

ThermoWood is one of the heat treatment methods developed in the 1990s by VTT Technical Research Centre of Finland. In this method, wooden material is heated at a minimum of 190 °C in steam. The ThermoWood treatment method enhances the properties of wooden material, e.g., the color of the wooden material darkens and becomes more stable against the exchange of moisture. Moreover, the wooden material gains the value of thermal isolation. If a sufficiently high temperature is used in the treatment, the wooden material becomes more resistant to decomposition. However, the bending resistance of the wooden material decreases (Anonymous, 2003).

From this perspective, the identification of the resistance for various kinds of woods treated by the ThermoWood method can be significant in determining appropriate areas for using the wood. For instance, ThermoWood treated wood can be used as a facade lining for such areas as saunas, bathrooms, and garden furniture (Anonymous, 2003). For use in such areas, AR and WCS, as well as the physical and mechanical properties of the wood, are taken into consideration.

The AR, both heat-treated and untreated, wood is important for such areas as wooden floors, decks, and staves. Abrasive forces on wooden materials result in various effects. There are various methods and devices to measure the resistance of wooden materials to abrasion. However, this issue has been studied extensively because of certain difficulties in the measurement of the resistance of wooden material to abrasion (Berkel, 1970).

Therefore, it is necessary to identify the resistance of wooden material to abrasion and classify it for related areas of use. Despite these difficulties, it has been possible to predict the abrasion levels of various types of wooden materials based on other properties of the materials, such as weight loss, volume reduction, surface roughness, and energy consumption for a defined level of abrasion (Brischke *et al.,* 2004).

Abrasion resistance is determined for various materials according to weight loss during an abrasion test. For example, the Taber Abrasor Method (TAM) was developed to determine the abrasion resistance of high Pressure-Laminated (HPL) panels (DIN EN 438-2, 2005). The abrasion resistance of any solid wooden material can be measured by this method. Obviously, the principle of this testing method is not suitable for testing solid wood and thermally treated materials, even if it is possible to get board-like specimens of at least 120 x 120 mm². Additionally, the wastage of sandpaper is very high due to plugging (Brischke *et al.,* 2004).

Swaczyna *et al.* (2011) measured abrasion resistance compared to TR and WL with TAM, according to PN-EN ISO 5470-1:2001 standards and published the results. In the study, they found that TR was 0.17 mm and WL was 0.25 g in untreated Cherry Wood.

Taking into consideration the connecting techniques applied on products made of wooden material, it seems that similar methods are used in heat-treated and untreated wooden material. From this perspective, connecting with screws would be better in heat-treated materials. A sinker and a tap hole must be prepared on hardwood, medium-density fiberboard, and other fragile materials. Stainless steel screws and embedding screw heads are preferred for outdoor usage and other humid conditions. Stove bolts give best connecting-resistance results. Self-locking screws can be used without a tap hole on ThermoWood (Anonymous, 2003).

Kariz *et al.* (2013) measured the withdrawal of screws in radial direction and tangential direction on heat-treated spruce wood at 150, 170, 190, 210, and 230 °C. The results indicated that there was a greater reduction in WCS for thermal modification conditions, and they concluded that deformation increased at higher temperatures based on the analysis of the images of the deformed surface left by the screws. In their study, in which they suggested the use of larger diameter screws and deeper penetration for connecting heat-treated materials, they also recommended that the distance between screws be increased to attain sufficient resistance compared with wooden material that was not heat-treated.

Wild Cherry, a valuable wood in the forest products industry, is used extensively in cabinet making and wood turning. Recently, the use of wild cherry wood has grown in popularity in Turkey and surrounding countries due to high demand for this species. A relatively small amount of research information is available concerning Wild Cherry tree ecology, biology, and genetics of Turkish forestry resources and increased efforts are being encouraged by economic incentives and other benefits (Eşen *et al.,* 2005).

Heat treated wooden materials, unlike products made available by conventional methods, can be evaluated without any protective surface treatment in places where the changes of temperature and relative humidity are intense or in the areas where contact with water is expected. Therefore, the determination of AR is of great importance. It is also important to consider the issue of the performance and quantity of fasteners for heat treated wood in furniture production for similar places. A large number of tree species relative to both issues has not been adequately researched. Thus, in this study, efforts were made to determine the values of AR and WCS in heat treated Wild Cherry Wood. The results should fill both of the mentioned information gaps and form a basis for future studies in this important area. In this way, when determining the values of AR and WCS, the applicability of the chosen method was also evaluated.

Tests for AR and WCS were performed in radial and tangential directions. For the determination of AR, both WL and TR were measured in the test samples. This study was also focused on the applicability of the Taber method. The machine was stopped in the loop of 0-250 to determine the effect of the S-42 abrader, and, after cleaning the piece with a brush, its weight was measured, and the test was continued. Depending on the results found in the loops of 0-250 and 250-500 in TR and WL for AR, the effects of aging of the abrasive material were also assessed.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Five Wild Cherry trees with a breast height diameter of 30 to 50 cm were obtained from Duzce Forest Enterprises. Trees were chosen according to TS 4176, 1984 and cut to specimens according to TS 2470, 1976. Later, the wood was heat treated in accordance with the ThemoWood method in the Novawood Factory in Gerede/Bolu at 190 and 212 °C for 1 and 2 hr. Five variations along with an untreated group were formed, i.e., untreated (UT); 190 °C and 1 hr (HT_1); 190 °C and 2 hr (HT_2); 212 °C and 1 hr (HT_3); and 212 °C and 2 hr (HT_4). In order to determine AR, specimens with the dimensions of 100 x 100 x 10 mm were prepared according to TS EN 15185, 2013 and to determine WCS, specimens with the dimensions of 50 x 50 x 20 mm were prepared according to TS EN 320, 1999.

2.2 Method
2.2. Metode

The number of test samples was determined according to TS EN 15679, 2010. Following the heat treatment of 100 specimens, 20 for the radial and tangential tests repeated five times, were prepared to be used in the AR and WCS tests. Later, the specimens prepared for AR and WCS were kept at the temperature of 20±2 °C and the relative humidity of 60±5 % until their weights became stable.

2.2.1 Determination of abrasion resistance
2.2.1. Određivanje otpornosti na habanje

The AR values of the control and heat treated specimens were determined by using a Taber® Rotary Abraser 5135. The test specimens were mounted on a platform turning on a vertical axis against the sliding rotation of two abrading wheels, with one wheel rubbing the specimen toward the periphery, and the other wheel rubbing inward toward the center. The test specimens were abraded using loads of 1000 g. After every 250 cycles, the devices were stopped and the specimens were weighed, after which the devices resumed, and, at 500 cycles, both the weights and thicknesses of the specimens were determined. The test results were used to calculate the percentages changes in WL and TR by equations (1) and (2). S-42 sandpaper was used as the abrasive, and it was changed after every 500 test cycles.

$$WL = \frac{(W_E - W_1)}{W_1} \cdot 100 \tag{1}$$

WL = Weight loss (%), W_1 = Initial weight (g), W_E = Final weight (g)

$$TD = \frac{(T_E - T_1)}{T_1} \cdot 100, \tag{2}$$

where TD = decrease in thickness (%), T_1 = initial thickness (mm), and T_E = final thickness (mm).

Figs. 1a and b show images of radial and tangential specimens after 500 cycles.

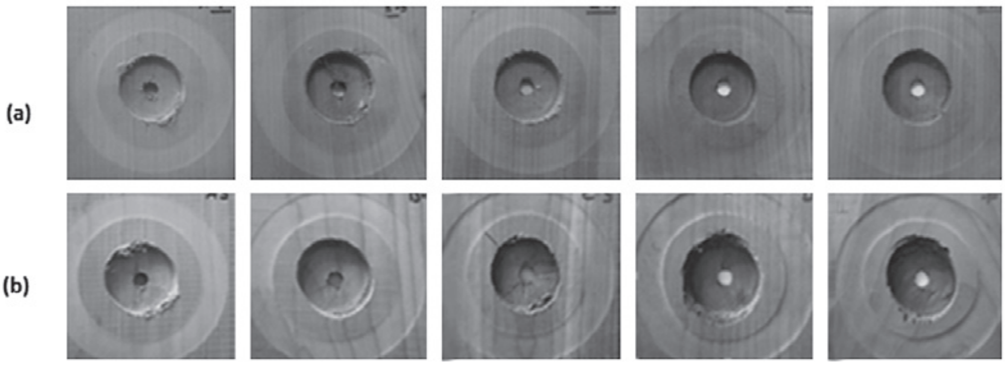

Figure 1 Images of specimens after the experiment: (a) radial specimens; (b) tangential specimens
Slika 1. Fotografije uzoraka nakon eksperimenta: a) radijalni uzorci, b) tangencijalni uzorci

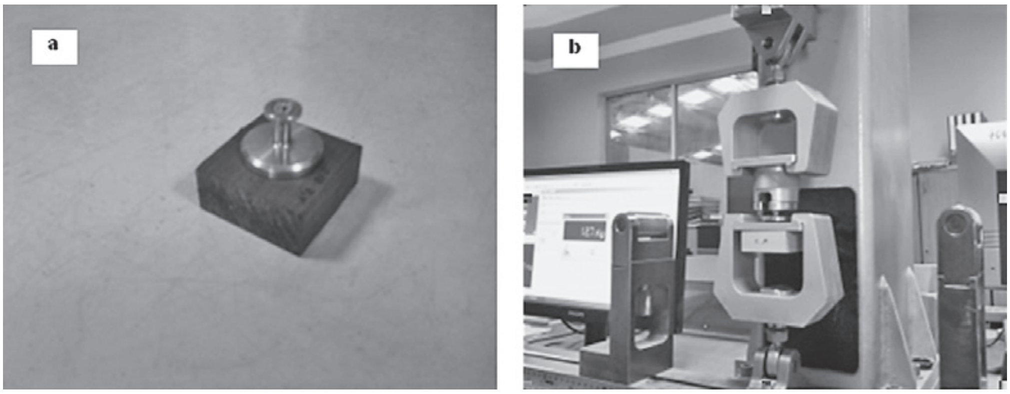

Figure 2 (a) Preparation of the specimen; (b) conducting the experiment on the IMAL IB600 test device
Slika 2. a) Priprema uzorka, b) provođenje ispitivanja na uređaju IMAL IB600

2.2.2 Determination of withdrawal capacity of screws
2.2.2. Određivanje čvrstoće držanja vijaka

Specimens used to assess the withdrawal capacity of screws were prepared according to TS EN 320, 1999. In order to determine WCS, specimens with the dimensions of 50 x 50 x 20 mm were prepared according to TS EN 320. The tests were conducted using the Laboratory Testing Machine, IMAL IB600. The IB600 has been designed to conduct a series of laboratory tests on wood-based samples, particleboard samples, MDF, OSB or similar. Simple operations enable the operator to programme and perform the tests required for board quality control (Anonymous, 2014). The machine consists of (Anonymous, 2014):

- A motorised column capable of highly accurate speed control, fitted with a two-way (push and pull) load cell, on which it is possible to mount special utensils to perform the individual tests,
- A precision weighing scale,
- A dimensions gauge,
- PC, monitor and printer,
- Utensils for conducting the tests.

Figs. 2a and b show the screw placed in the WCS test specimen and the test being conducted, respectively.

In this experiment, the nominal size of the screw was 4.2 x 38 mm, according to TS 432-1 EN ISO 1478, and steel screws with a pitch of 1.4 mm were used without drilling the wood (Fig. 3).

For the abrasion resistance and withdrawal capacity of screws, all multiple comparisons were first subjected to an analysis of variance (ANOVA), and significant differences between mean values of control and treated samples were determined using Duncan's multiple range test. The experimental values obtained were evaluated with SPSS 15.0 for Windows Evaluation Version.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Abrasion resistance
3.1. Otpornost na habanje

Standard deviation (SD), Duncan test results (D), and arithmetic mean (M) for WL and TR caused by the abrasion in the radial and tangential test samples are given in Table 1.

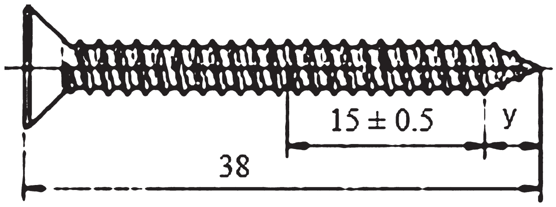

Figure 3 Dimensions of screws used in the experiment
Slika 3. Dimenzije vijka rabljenog u eksperimentu

As shown in Table 1, it was found that TR and WL did not change; however, UT for both the 0-250 and the 250-500 loops in the radial test samples changed and WL was also greater in the 0-250 loop than in the 250-500 loop in all variations. The maximum WL occurred in UT, whereas the minimum WL occurred in the variation of HT4; WL in the HT4 samples was about 30 % less than in the UT samples. The maximum WL in all experimental designs of radial test samples occurred in the UT samples. The percentage changes in WL that occurred in HT compared to those in UT in the total amount of loops of the radial test samples are given in Figs. 4a and b.

Unlike the radial samples, statistically significant differences in WL were determined in all groups except for HT1 in the 0-250 loop and in all heat treated test samples in the 0-250 loop in the tangential test samples. WL occurred in the 0-250 loop samples to a greater extent than that of the 250-500 loop in all variations of tangential surfaces. In the tangential test samples, the maximum WL of tangential direction occurred in HT4, while the minimum WL occurred in UT. The WL changes in the total loop amount that occurred on tangential surfaces are given in Fig. 4b.

Welzbacher *et al*. (2009) reported that there were no difference in resistance to abrasion between beech and thermally modified beech timber, whereas a significantly higher mass loss by abrasion of thermally modified beech timber compared to controls was determined by the Shaker test. However, in both cases the abrasion in terms of mass loss of thermally modified beech timber was significantly lower compared to larch heartwood, which represents a commonly used decking material.

The TR values are also shown in Table 1 along with the WL results. Accordingly, it was determined

Table 1 Weight loss (WL) and thickness reduction (TR) as percent
Tablica 1. Gubitak mase (WL) i smanjenje debljine (TR) izraženo u postocima

Test samples ↓ *Uzorci*		WL				TR	
		Radial *radijalno*		**Tangential** *tangencijalno*		**Radial** *radijalno*	**Tangential** *tangencijalno*
	Cycle →	0-250	250-500	0-250	250-500	0-500	
UT	M	0.80 A*	0.36 A	0.50 A	0.23 A	2.02 A	1.53 A
	SD	0.24	0.3	0.05	0.03	0.37	0.39
HT_1	M	0.55 AB	0.30 A	0.46 A	0.34 B	1.69 A	2.13 AB
	SD	0.07	0.05	0.07	0.8	0.55	0.39
HT_2	M	0.67 A	0.39 A	0.76 B	0.56 C	1.80 A	2.44 AB
	SD	0.02	0.02	0.03	0.06	0.07	1.18
HT_3	M	0.59 A	0.37 A	0.75 B	0.63 BC	1.82 A	3.25 B
	SD	0.11	0.03	0.09	0.09	0.01	1.03
HT_4	M	0.50 A	0.31 A	0.85 B	0.73 D	1.82 A	2.99 B
	SD	0.08	0.07	0.17	0.10	0.00	1.24

(*) The letters express the homogeneity groups according to Duncan test results. / *Slova označuju homogene grupe prema Duncanovu testu.*

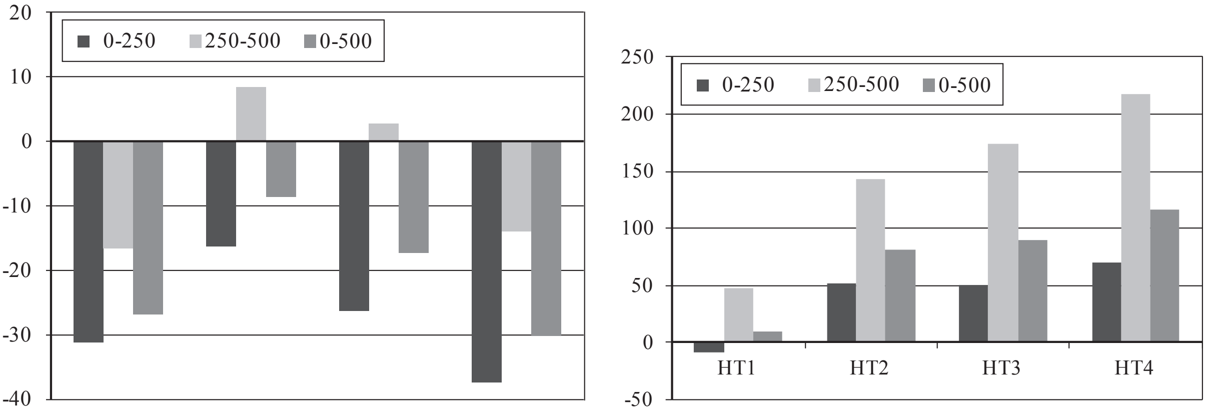

Figure 4 (a) Percentage change of WL in the radial samples; (b) Percentage change in the tangential test samples according to UT
Slika 4. a) Postotna promjena WL-a radijalnih uzoraka, b) postotna promjena WL-a tangencijalnih uzoraka u odnosu prema kontrolnom uzorku

that, although there is no statistically significant difference between UT and all heat treated test samples in terms of TR in radial test samples, there were differences between HT variations and UT in the tangential test samples. The variations in thickness that occurred in the total loop are shown in Fig. 5.

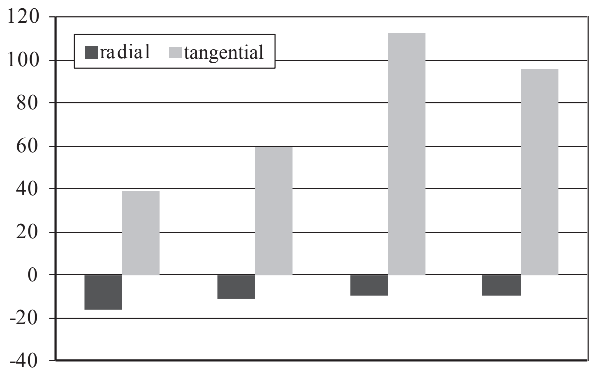

Figure 5 Change of TR on radial and tangential surfaces according to UT
Slika 5. Promjena smanjenja debljine radijalnih i tangencijalnih uzoraka u odnosu prema kontrolnom uzorku

According to the results of WL and TR obtained from the heat treated Wild Cherry Wood, the following can be concluded:

1. In terms of both WL and TR, more abrasion occurred in the HT tangential test samples than in the UT samples. It is noteworthy that the results of HT were lower than those of UT in terms of both WL and TR in all loop groups of the radial test samples.
2. The abrasion of the I. loop was higher than the abrasion of the II. loop in all variations. This probably stems from the decrease of the abrasive feature of the sandpaper (S-42) depending on the increase of the loop. Some decrease in this feature of abrasive grains would inevitably occur as the number of loops increased. Thus, the abrasive etches, but it also puts pressure on the surface and compresses the surface as a result of the effect of the applied force.

3.2 Withdrawal capacity of screws
3.2. Čvrstoća držanja vijaka

Arithmetic mean values of the WCS results, the change of WCS according to UT, SD and Duncan test

Table 2 Values and change of WCS, density values and variations
Tablica 2. Vrijednosti promjene WCS-a, vrijednosti gustoće i varijacije

Test samples *Uzorci* ↓		**Radial surface** *Radijalna površina*			**Tangential surface** *Tangencijalna površina*		
		WCS N/mm^2	**Reduction** *Smanjenje* %	**Density** kg/m^3	**WCS** N/mm^2	**Reduction** *Smanjenje* %	**Density** kg/m^3
UT	M	16.76 C*	-	585 D	15.5 C	-	579 C
	SD	1.72	-	-	0.63	-	-
HT_1	M	13.18 B	21.3	559 C	15.16 C	2.1	565 BC
	SD	1.43	-	-	1.33	-	-
HT_2	M	12.58 B	24.9	558 C	12.71 BC	18.0	546 BC
	SD	0.57	-	-	2.96	-	-
HT_3	M	8.40 A	49.8	510 B	10.59 AB	31.6	533 AB
	SD	1.02	-	-	1.52	-	-
HT_4	M	8.15A	51.37	469 A	9.26 A	40.2	491 A
	SD	1.53	-	-	0.7	-	-

(*) The letters express the homogeneity groups according to Duncan test results. / *Slova označuju homogene grupe prema Duncanovu testu.*

results are given with the density of the test samples in Table 2.

As shown in Table 2, WCS decreases more than the UT in both radial direction and tangential direction, heat treated. Compared to UT, the highest decrease of WCS occurred in HT4, and the lowest occurred in the HT1 test samples.

Heat treatment resultes in a decrease in the density, and this reduction in density became even more pronounced as the duration and the temperature of the heat treatment increased. So, a relationship was observed between the decrease in density and the decrease in WCS. Kariz *et al*. (2013) and Percin and Ayan (2012) outlined that heat treatment affects the screws withdrawal capacity of wooden material because of various factors, one of which was the decrease in density that resulted from heat treatment.

Fig. 6 shows the effects of heat treatment on the withdrawal capacity of screws and the changes in wood density.

Fig. 6 shows that the withdrawal capacity of screws was compatible with decrease in the density during the heat treatment, and the extension of the duration of the treatment affected both radial and tangential surfaces.

4 CONCLUSIONS
4. ZAKLJUČAK

1. In heat treated Wild Cherry Wood, weight and thickness losses that occurred in 500 loops on the radial surfaces were less than the losses on the tangential surfaces. Although it is not very important for wall and ceiling coverings, it will be suitable to use the material primarily with a radial surface if it is heat-treated wooden material for floor coverings.
2. The differences of weight loss and thickness reduction between the 0-250 loop and the 250-500 loop indicated that careful consideration should be given to the applicability of the Taber method. In this regard, the loop numbers should be determined carefully to obtain objective results. Also, the S-42 sandpaper should be replaced after completing each sample process.

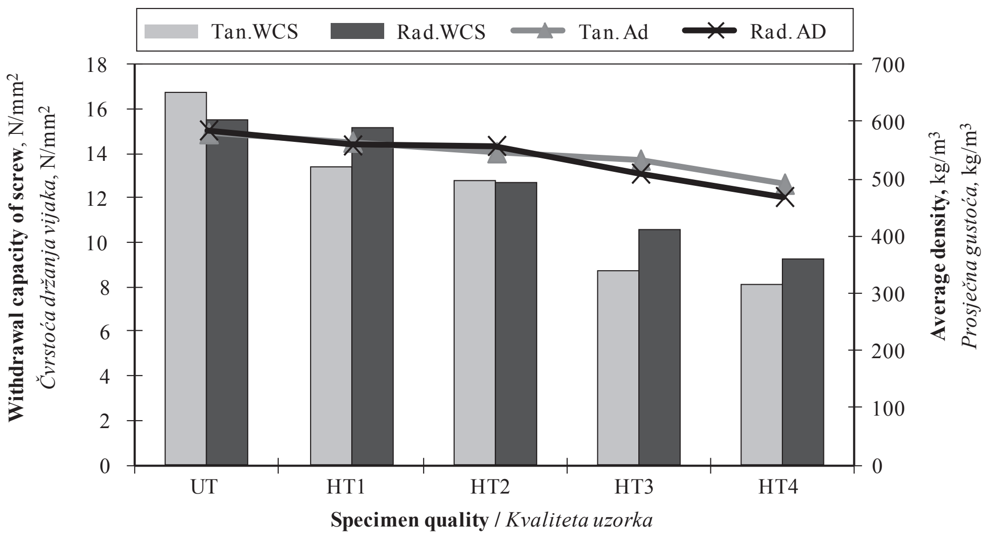

Figure 6 The effects of heat treatment on the withdrawal capacity of screws and changes in density
Slika 6. Utjecaj toplinske obrade drva na čvrstoću držanja vijaka i promjenu gustoće

3. In practice, both temperature and duration have negative effects on the withdrawal capacity of screws of heat treated Wild Cherry Wood, but the effect of temperature has a greater effect than the duration. The withdrawal capacity of screws was reduced by 50 % in the trials with flat head screws in heat treated Wild Cherry Wood.

5 REFERENCES
5. LITERATURA

1. Anonymous, 2003: ThermoWood Handbook, Finish ThermoWood Association, Helsinki- Finland.
2. Anonymous, 2014: http://www.imalpal.com/en/scheda.php?pr=114.
3. Brischke, C.; Welzbacher, C. R.; Rapp, A. O., 2004: A new method for testing the abrasion resistance of thermally modified wood, Workshop COST Action E37 'Managing the Environmental Risk' Reinbek – Germany, 8th – 9th November Federal Research Centre of Forestry and Forest Products (BFH), Leuschnerstr. 91, D-21031 Hamburg.
4. Berkel, A., 1970: Wood Technology (First volume), Istanbul University, Kurtulmuş Printing House.
5. DIN EN 438-2, 2005. High-pressure decorative laminates (HPL) - Sheets based on thermosetting resins (usually called laminates) - Part 2: Determination of properties, German.
6. Eşen, D.; Yıldız, O.; Kulaç, Ş.; Sarginci, M., 2005: Neglected valuable leafy of Turkey forest's: Wild Cherry (*Cerasus avium* (L.) Monench). J Chamber of Forest Engineer (TBMMO), 2: 18-22.
7. Gunduz, G.; Korkut, S.; Korkut, D. S., 2008: The effects of heat treatment on physical and technological properties and surface roughness of Camiyanı Black Pine (*Pinus nigra* Arn. subsp. pallasiana var. pallasiana) wood. Bioresource Technology, 99 (7): 2275-2280 http://dx.doi.org/10.1016/j.biortech.2007.05.015
8. Kocaefe, D.; Poncsak S.; Boluk, Y., 2008: Effect of thermal treatment on the chemical composition and mechanical properties of birch and apsen. Bioresources, 3 (2): 517-537.
9. Kariz, M.; Kuzman, M. K.; Sernek, M., 2013: The Effect of Heat Treatment on the Withdrawal Capacity of Screws in Spruce Wood. Bioresources, 8(3): 4340-4348 http://dx.doi.org/10.15376/biores.8.3.4340-4348.
10. Perçin, O.; Ayan, S., 2012: Determination of screw withdrawal strength in heat treated wood material, Journal of Advanced Sciences, 1 (1): 57-68.
11. Swacyna, I.; Kedzierski, A.; Tomusiak, A.; Cichy, A.; Rozanska, A., 2011: Hardness and wear resistance tests of the wood species most frequently used in flooring panels, Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology, 76: 82-87.
12. ***TS EN 15185, 2013: Furniture – Assessment of the surface resistance to abrasion, Turkish Standart Institution.
13. ***TS EN 320, 1999: Determine of withdrawal capacity of screw for Fiberboards, TSE, Ankara.
14. ***TS 432-1 EN ISO 1478, 2000: Tapping screws thread, Turkish Standard Institution.
15. ***TS 4176, 1984: Wood - Sampling Sample Trees and Long for Determination of Physical and Mechanical Properties of Wood in Homogeneous Stands, Turkish Standard Institution.
16. ***TS 2470, 1976: Wood-Sampling Methods And General Requirements For Physical And Mechanical Tests, Turkish Standard Institution.
17. ***TS EN 15679, 2010: Thermal Modified Timber - Definitions and characteristics. Turkish Standard Institution.
18. Welzbacher, C. R.; Brischke, C.; Rapp, A. O.; Koch, S.; Sabine Hofer, S., 2009. Performance of thermally modified timber (TMT) in outdoor application – durability, abrasion and optical appearance. Drvna industrıja, 60 (2): 75-82.

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Steaming chamber projects

Establishing and modification of kiln drying schedules

Consulting in selection of kiln drying technology

Introduction of drying quality standards

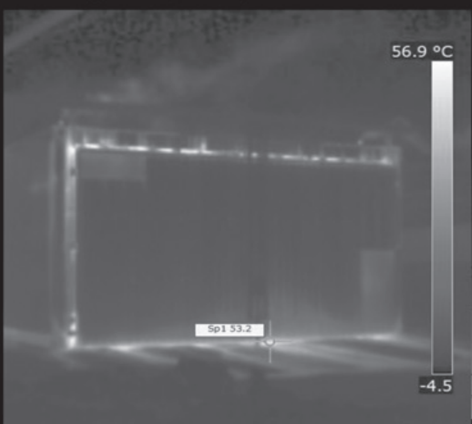
Determination of wood bending parameters

Detection and reducing of hydrothermal processes wood defects

Reducing of kiln drying time

Drying costs calculation

Kiln dryer capacity calculation



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Lipophilic Extractives in Heartwood of European Larch (*Larix decidua* Mill.)

Lipofilni ekstraktivi srži europskog ariša (*Larix decidua* Mill.)

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ABSTRACT • *The heartwood of two European larch trees was examined for the content of lipophilic extractives. Hexane was used as a solvent for extractions, while gas chromatography with flame ionisation detection and gas chromatography coupled to mass spectrometry were applied for analyses. Different lipophilic groups of compounds, such as fatty acids, resin acids, diterpenoids, sterols, steryl esters and triglycerides were identified and quantitatively evaluated as well as individual low molecular mass components. Distribution of heartwood lipophilics in relation to the trunk heights was also determined and their most likely biological function in wood tissues discussed. The content of hexane extract increased with stem height. Various fatty and resin acids as well as diterpenoid alcohols and sterols were characterized. The predominating lipophilic compounds identified were isopimaric acid and diterpenoid alcohol larixyl acetate. Their average concentrations in examined samples was between 2.0 and 2.5 mg/g. Higher molecular mass lipophilics, e.g. steryl esters and triglycerides, were also present with concentrations between 0.5 and 2.2 mg/g.*

Key words: *European larch, heartwood, lipophilic extractives, chromatographic techniques*

SAŽETAK • *U radu je prikazan rezultat istraživanja lipofilnih ekstraktivnih tvari u srži dvaju stabala europskog ariša. Kao otapalo za ekstrakciju primijenjen je heksan, a plinska kromatografija s plameno-ionizacijskim detektorom i plinska kromatografija povezana s masenom spektrometrijom primijenjene su za kemijske analize. Različite lipofilne grupe spojeva, kao masne kiseline, smolne kiseline, diterpenoidi, steroli, sterolni esteri i trigliceridi, identificirane su u uzorcima i kvantitativno su procijenjene. Također su identificirani i procijenjeni pojedini spojevi niskih molekularnih masa. Određena je i raspodjela lipofilnih tvari u srži s obzirom na visinu stabala i objašnjena njihova najvjerojatnija biološka uloga u drvnim tkivima. Sadržaj ekstrakta heksana povećava se s visinom stabla. Različite masne i smolne kiseline, kao i diterpenoidni alkoholi i steroli, također su zastupljeni u srži europskog ariša. Dominantni identificirani lipofilni spojevi jesu isopimarična kiselina i diterpenoidni alkohol. Njihove prosječne koncentracije u ispitivanim uzorcima kreću se između 2,0 i 2,5 mg/g. Lipofilni spojevi veće molekularne mase, npr. sterolni esteri i trigliceridi, također su otkriveni u koncentracijama između 0,5 i 2,2 mg/g.*

Ključne riječi: *europski ariš, srž, lipofilni ekstraktivi, kromatografske tehnike*

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1 INTRODUCTION
1. UVOD

Different nonstructural wood components with relatively low molecular masses, which are well soluble in nonpolar organic solvents are classified as lipophilic extractives. Their content is much smaller than that of the main building elements, e. g. polysaccharides and lignin and averagely amounts up to only a few percents of dry plant material. Types and concentrations of wood lipophilics depend on tree species, tissue types, geographic position of growing site, climatic conditions, felling season, age and tree health. A function of lipophilic extractives in living trees is not yet fully understood, however it is well known that some compounds, such as sterols and steryl esters are components of cell membranes and take an active part in different biochemical processes, while others, e.g. triglycerides and diglycerides represent food reserve. The most important function of extractives is most probably mechanical and chemical protection of wood tissues against microbial, fungal and insect attack. Resin and wax components form typical mechanical protective layer or hydrophobic barrier while more polar phenols (lignans, flavonoids, stilbenes) exhibit biocidal properties and are as such very toxic for numerous organisms (Hawley *et al*., 1924; Scheffer and Cowling, 1966; Fengel and Wegener, 1984; Schultz *et al*., 1990, 1995).

The genus *Larix* is represented by about ten species that are mainly distributed across the cooler regions of the northern hemisphere. European larch (*Larix decidua* Mill.) is the most frequent representative of this genus in Europe. It is growing on its natural habitat or on reforested areas. It is appreciated for its timber, with good mechanical properties, attractive colour and high natural durability of its heartwood (Gierlinger *et al*., 2004). The heartwood of European larch is usually composed of about 39 % of cellulose, 30 % of hemicellulose (mannan and xylan), 28 % of lignin with the remaining portion being ash and extractives (Fengel and Wegener, 1984). Chemical composition of larch wood is variable, which is e.g. reflected in variable durability of larch heartwood, reported to range from nondurable to moderately durable (class 5 to 3, European Standard EN 350-1) (Gierlinger *et al*., 2003).

Several authors have so far reported on the content of lipophilic extractives in different larch species. Nair and von Rudloff (1959, 1960) studied and compared chemical composition of heartwood extractives of Tamarack (*Larix laricina*) and Alpine larch (*Larix lyalii*). Norin and coauthors (1965) determined the structures and configurations of the diterpenoids larixol, larixyl acetate and 13-epimanool, which were isolated from the oleoresin of European larch. Larixol was reported to be one of the main neutral constituents of Siberian larch (*Larix sibirica*) as well. Mills (1973) analysed oleoresin of most larch species growing in England. He found out that European larch contained large quantities of larixyl acetate together with lesser amounts of the free diol larixol and epimanool. The neutral fraction was composed of aldehydes including dehydroabietal and isopimaral. Siberian larch contained epimanool and epitorulosol, as well as hydrocarbons such as monocyclic thunbergene and biformene and compounds abietadiene, abietal and abietol. All investigated larches also contained resin acids of abietic and pimaric type. The most striking feature was that two species, namely European and Japanese larch (*Larix gmelinii*) contained large amounts of larixol and larixyl acetate, which were not detectable in the others. Western larch and Japanese larch (*Larix kaempferi*) had high amounts of thunbergol, while the latter was completely absent from Tamarack and Alpine larch. Giwa and Swan (1975) studied extractives of Western larch, isolated from the heartwood by the help of solvents of different polarity. The lipophilic portion was composed of sandaracopimaric, isopimaric, abietic and dehydroabietic acid, β-sitosterol, larixol and larixyl acetate. Viitanen and coauthors (1997) examined durability of European, Siberian and Japanese larch against brown-rot fungi and found out that it was related to the extractives content. They analysed diethylether extracts and proved that some resin acids inhibited the growth of certain fungi, in spite of the fact that their content was as small as about 0.1 %. Staccioli and colleagues (1997) compared heartwood extractives of living and subfossil European larch and established different age dependent, structural changes. Krutov and co-workers (1988) examined extractives of Siberian larch in which they identified numerous neutral diterpenoid components. Babkin and coauthors (2001) also analysed resinous substances in Siberian and Japanese larch. The latter were a complex mixture of neutral diterpenoids and resin acids. Ohtsu and co-workers (1998a, 1998b, 1998c) identified some interesting diterpenes in cones of Japanese larch as well as tetracyclic triterpenes in needles and bark of the same tree species, while Xue (2004) reported about identification of two new diterpenoids of labdane type in Chinese larch (*Larix chinensis*). Most authors analysed heartwood samples at the representative height of 1.2 to 1.5 m, while there is practically no data on the content of extractives at different positions along the trunk.

The purpose of the present research was to make a detailed chemical characterization of lipophilic extractives in the heartwood of European larch, and to determine their variability in longitudinal direction within a tree and between two trees.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Samples
2.1. Uzorci

Two larch trees (*Larix decidua* Mill.) were felled at the end of June, 2009 in the Alpine region of Slovenia at the altitude of 1000 m. They were growing in a mixed forest among beech and spruce trees. Both were about 180 years old, about 30 m high and with a diameter at breast height (DBH) above 50 cm. The trees were healthy and without visible damage.

About 5 cm thick discs were cut from the trunks at the base (50 cm above ground) as well as at the heights of 8, 18 and 28 m. Discs were debarked and representative sections of heartwood were cut into smaller pieces, which were subsequently frozen at -24 °C till analysis.

2.2 Drying and grinding
2.2. Sušenje i mljevenje

Frozen samples were first conditioned at room temperature, after which they were cut into short splinters, freeze-dried for 24 hours (Martin Christ Gefriertrocknungsanlagen GmbH) and ground by means of a Wiley laboratory mill (100 mesh) to wood meal. The latter was freeze-dryed again for 24 hours in order to remove volatile compounds.

2.3 Extraction
2.3. Ekstrakcija

Extractions were conducted by means of an accelerated solvent extraction system (ASE) using the instrument Dionex ASE 200. About 5 g of each freeze-dried powdered sample was weighed into a metal extraction cell and extracted with hexane (V-50 ml) to isolate lipophilic fraction. The temperature of the extraction was 90 ºC, pressure 13.8 MPa and extraction time 10 minutes (2 static cycles with static time of 5 minutes). The extraction was performed under the stream of nitrogen.

2.4 Derivatization of extractives
2.4. Derivatizacija ekstraktiva

All hexane extracts were derivatized prior to chromatographic analyses (GC-FID, GC-MS), by which components with hydroxyl groups, such as alcohols, sterols and acids were converted to the corresponding trimethylsilyl (TMS) derivatives, namely ethers and esters. 2 ml of internal standard solution were added to each extract, containing about 0.5 mg of extractive compounds. Internal standards were heneicosanoic acid (S1), betulinol (S2), cholesteryl heptadecanoate (S3) and 1.3-dipalmitoyl-2-oleyl glycerol (S4) all having concentration of 0.02 mg/ml. The mixture of a sample and standards was dried under the stream of N_2 and in vacuum desiccator at 40 ºC, after which sylilation reagents were added: 80µl BSTFA (bis-trimethylsilyl-trifluoroacetamide) and 20 µl TMCS (trimethylchlorosilane) in 20 µl of pyridine. The reaction mixture was heated for 1 hour at 70 ºC, then it was cooled and injected into gas chromatograph (Willfor, 2007).

2.5 Chromatographic analyses of extractives
2.5. Kromatografska analiza ekstraktiva

2.5.1 GC-FID analysis on short capillary column
2.5.1. GC-FID analiza na kratkoj kapilarnoj koloni

The main extractive groups in hexane extracts were determined by means of gas chromatography with flame ionization detector (GC-FID) on the Perkin Elmer Clarus 500 instrument. The separation was performed on a short capillary column HP-1 (6 m x 0.53 mm x 0.15 µm) using the following experimental conditions – oven temperature program: 100 ºC (1.5 min), 12 ºC/min, 340 ºC (5 min); carrier gas H_2 (7 ml/min, programed flow); PSS injector – temperature program of heating: 80 ºC (0,1 min), 50 ºC/min, 110 ºC, 15 ºC/min, 330 ºC (7 min); FID detector: 340 ºC; injection volume 0.5 µl (on column). Heneicosanoic acid (S1) was used for quantification of free fatty and resin acids as well as diterpenoids, while betulinol (S2) was applied for determination of sterols. Steryl esters were quantified against cholesteryl heptadecanoate (S3) and triglycerides against 1.3-dipalmitoyl-2-oleyl glycerol (S4). No correction factor was applied for the calculation of lipophilics. The concentrations of individual extractive groups were expressed as mg per gram of dry sample weight where the quantification limit was about 0.01 mg/g (Willfor, 2007).

2.5.2 GC-FID analysis on long capillary column
2.5.2. GC-FID analiza na dugoj kapilarnoj koloni

The determination of individual fatty and resin acids, diterpenoids and sterols was accomplished by means of GC-FID on the Perkin Elmer AutoSystem XL instrument. HP-1 (25 m x 0.20 mm x 0.11 µm) capillary column was used for separation of compounds under the following experimental conditions: temperature program of column heating: 120 ºC, 6 ºC/min, 300 ºC (10 min); carrier gas H_2 (0,8 ml/min); split injector (1:20) – 160 ºC, 8 ºC/min, 260 ºC (15 min); FID detector: 320 ºC; injection volume 1 µl. Heneicosanoic acid (S1) was used as internal standard for quantification of individual acids and diterpenoids, while betulinol (S2) was used as standard in determination of sterols. All results are expressed as mg per gram of dry sample weight where the limit of quantification was about 0.01 mg/g (Willfor, 2007).

2.5.3 Identification of extractive compounds by GC-MS
2.5.3. Identifikacija ekstraktivnih spojeva uz pomoć GC-MS-a

Characteristic components of the selected hexane extracts were identified by means of gas chromatography coupled to mass spectroscopy (GC-MS). The analyses were performed on the HP 6890-5973 GC-MSD instrument. The separation was carried out on the HP-1 (30 m x 0.25 mm x 0.25 µm) capillary column under the following experimental conditions: temperature program of column heating 80 ºC, 8 ºC/min, 290 ºC; carrier gas He (0.9 ml/min); split injector (1:15) – 260 ºC; MS-EI detector (source temp. 280 ºC, 70 eV, quadrupole temp. 180 ºC). Mass range (m/z) was between 10 and 1050. For positive identification of individual compounds the mass spectra of their chromatographic peaks were compared with spectra of pure compounds from the Wiley Registry NIST 2008 Mass Spectral Library. On both GC-FID and GC-MS chromatograms there was practically the same sequence of chromatographic peaks of individual compounds as similar long capillary columns were used, by which reliability of identification was ensured and quantitative work facilitated (Willfor, 2007).

2.6 Gravimetric determination of the content of lipophilic extractives
2.6 Gravimetrijsko određivanje sadržaja lipofilnih ekstraktiva

10 ml aliquots of selected hexane extracts were dried under the stream of N_2 and in vacuum desiccator at 40 ºC until a constant weight was reached. The gravimetric amount of extractives was calculated as mg per gram of dry sample weight.

All quantitative determinations of lipophilic extractives in the samples of heartwood were performed in two parallels. The present results are average values of individual determinations.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Gravimetric determination of hexane extracts
3.1. Gravimetrijsko određivanje heksanskih ekstrakata

Hexane, as one of the most nonpolar solvents, was selected for extraction and separation of lipophilic fraction from more polar components, e.g. polyphenols, which are not soluble in it.

The content of hexane extract in the heartwood samples increased with stem height. The measured values were between 8 and 16 mg/g, calculated on dry mass of wood. There was no significant difference be-

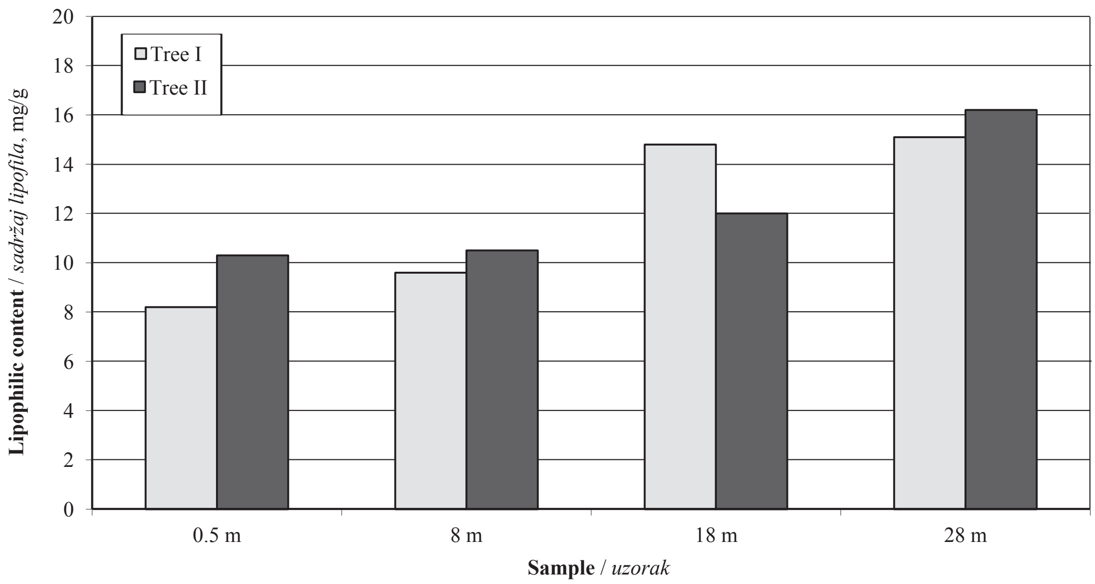

Figure 1 Hexane extract content in heartwood at different heights of two larch trees
Slika 1. Sadržaj heksanskog ekstrakta srži stabla 1 i 2 na različitim visinama

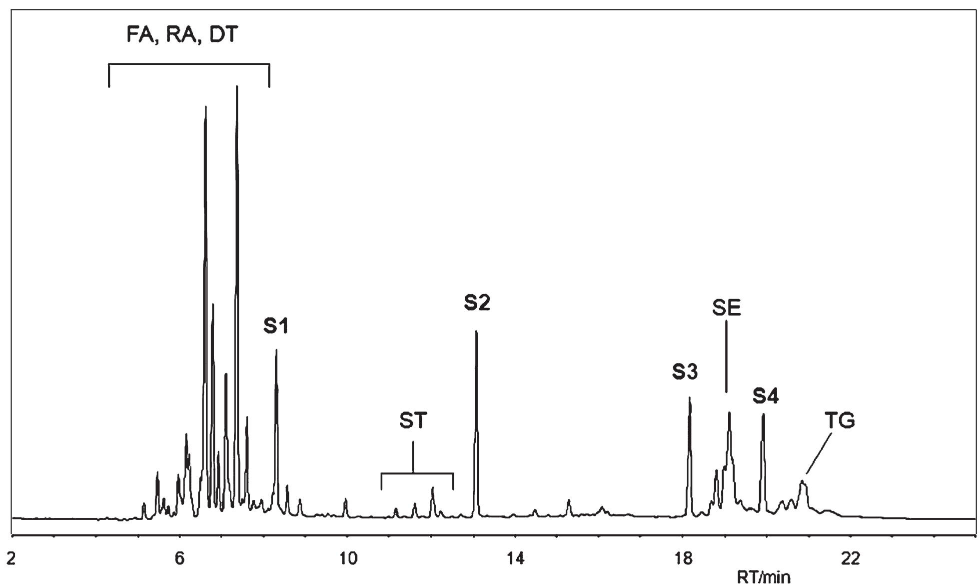

Figure 2 GC-FID (short column) chromatogram of heartwood hexane extract (tree 1 – 0.5 m stem height) (FA – fatty acids, RA – resin acids, DT – diterpenoids, ST – sterols, SE – steryl esters, TG – triglycerides, S1-S4 – internal standards)
Slika 2. GC-FID kromatogram (kratka kolona) heksanskog ekstrakta srži (stablo 1 – 0,5 m visina stabla) (FA – masne kiseline, RA – smolne kiseline, DT – diterpenoidi, ST – steroli, SE – sterolni esteri, TG – trigliceridi, S1-S4 – interni standardi)

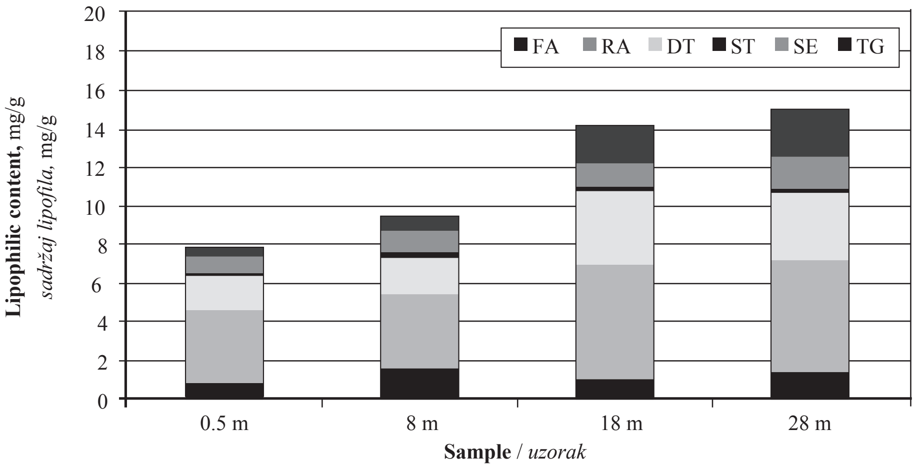

Figure 3 Content and composition of lipophilic fraction of heartwood of tree 1 at different heights (FA – fatty acids, RA – resin acids, DT – diterpenoids, ST – sterols, SE – steryl esters, TG – triglycerides)
Slika 3. Sadržaj i sastav lipofilne frakcije srži stabla 1 na različitim visinama (FA – masne kiseline, RA – smolne kiseline, DT – diterpenoidi, ST – steroli, SE – sterolni esteri, TG – trigliceridi)

tween the two trees. The amount of hexane extract vs. stem height is presented in Figure 1.

The average concentration of hexane extract in the heartwood of tree 1 was calculated to be 11.6 ± 3.5 mg/g and in the heartwood of tree 2 it was 12.0 ± 2.8 mg/g, respectively.

3.2 Determination of typical compound groups (GC-FID)
3.2. Određivanje tipičnih grupa spojeva (GC-FID)

The composition of lipophilic groups in hexane extracts was determined by GC-FID using short capillary column. A typical short column chromatogram of a heartwood hexane extract is shown in Figure 2.

The analysis on a short capillary column (5 m) with relatively high carrier gas flows and use of temperature programmable injection, supported by a relevant computer program for calculation of complex peak areas, enables separation and detection of a series of compounds with very different volatilities and chemical properties on a single chromatographic column. The most significant property of these short column chromatograms is somewhat worse separation of peaks, meaning that compounds are separated as characteristic groups (broad, overlapping peaks) and not as sharp peaks, representing individual compounds. In this way, it is possible to qualitatively and quantitatively determine the composition of various lipophilic groups in wood extracts in a single chromatographic analysis (Sjöstrom and Alen, 1999).

The content and composition of lipophilic fraction in the heartwood of trees I and II related to the stem height is presented in Figures 3 and 4.

Chromatographically determined total concentration of lipophilics (the sum of individual lipophilic group concentrations) increased with the height in both trees just the same as gravimetrically determined content of hexane extract. Concentrations of free fatty acids ranged between 0.9 and 1.8 mg/g, while the con-

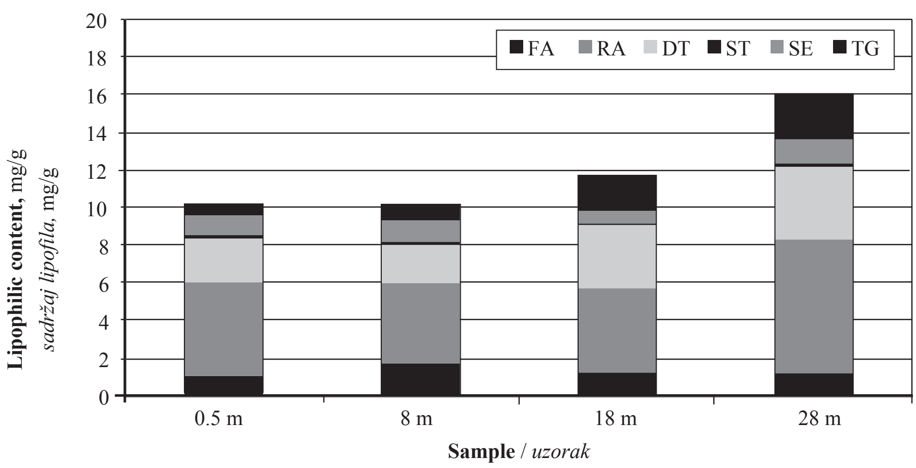

Figure 4 Content and composition of lipophilic fraction of heartwood of tree 2 at different heights (FA – fatty acids, RA – resin acids, DT – diterpenoids, ST – sterols, SE – steryl esters, TG – triglycerides)
Slika 4. Sadržaj i sastav lipofilne frakcije srži stabla 2 na različitim visinama (FA – masne kiseline, RA – smolne kiseline, DT – diterpenoidi, ST – steroli, SE – sterolni esteri, TG – trigliceridi)

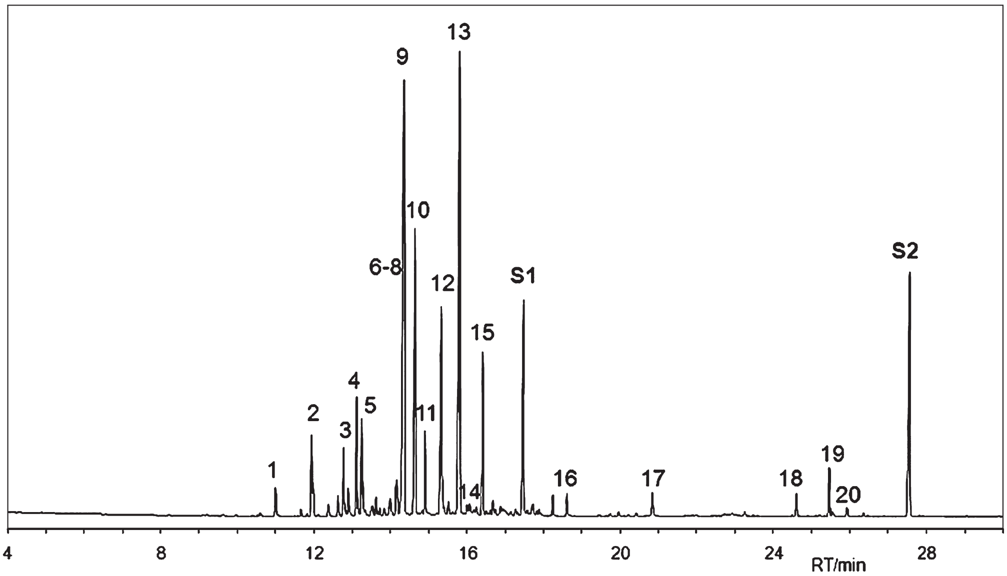

Figure 5 GC-FID (long column) chromatogram of heartwood hexane extract (tree 1 – 0.5 m height) (1 – palmitic, 2 – epimanool, 3 – pinolenic, 4 – linoleic, 5 – oleic, 6 – stearic, 7 – pimaric, 8 – sandaracopimaric, 9 – isopimaric, 10 – palustric, 11 – dehydroabietic, 12 – abietic, 13 – larixyl acetate, 14 – arachidic, 15 – neoabietic, 16 – behenic,17 – lignoceric, 18 – campesterol, 19 – β-sitosterol, 20 – cycloartenol, S1 and S2 – internal standards)
Slika 5. GC-FID kromatogram (duga kolona) heksanskog ekstrakta srži (stablo 1 – 0,5 m visina stabla) (1 – palmitinska, 2 – epimanol, 3 – pinolenska, 4 – linolna, 5 – oleinska, 6 – stearinska, 7 – pimarna, 8 – sandarakopimarna, 9 – isopimarna, 10 – palustrinska, 11 – dehidroabietinska, 12 – abietinska, 13 – lariksil acetat, 14 – arašidna, 15 – neoabietinska, 16 – behenska, 17 – lignocerinska, 18 – kampesterol, 19 – β-sitosterol, 20 – cikloartenol, S1 i S2 – interni standardi)

centrations of resin acids and other diterpenoids were much higher, which was between 5.6 and 11 mg/g. Concentrations of free sterols in no case exceeded 0.3 mg/g, while the contents of higher lipophilics, e.g. steryl esters and triglycerides, were comparable and in the range between 0.5 and 2.2 mg/g. High increase of triglycerides was the most distinctive in the heartwood of both trees at 28 m, which was the top position. The measured quantities were 5 times bigger than at the base of the tree at 0.5 m. The most important fact is that the concentrations of all lipophilic groups exhibited increasing trend in respect to the stem height.

3.3 Identification of individual compounds (GC-MS)
3.3. Identifikacija pojedinačnih spojeva (GC-MS)

For accurate and unambiguous identification of individual low molecular mass components, as for example free fatty acids, diterpenoids, sterols and fatty alcohols in hexane extracts, a selected sample of heartwood at 0.5 m from tree I was analysed by GC-MS technique. Among fatty acids unsaturated oleic, linolenic and pinolenic predominated, while isopimaric acid and larixyl acetate were the most abundant components among resin acids and diterpenoids. β-sitosterol proved to be the most abundant sterol in all heartwood samples.

3.4 Determination of individual compounds (GC-FID)
3.4. Određivanje pojedinih spojeva (GC-FID)

All samples were later chromatographed on a similar long capillary column using similar experimental conditions as in the case of the GC-MS analysis in order to analyse qualitative and quantitative composition of free fatty acids, resin acids, diterpenoid compounds, free sterols and fatty alcohols. A typical long capillary column chromatogram of a heartwood hexane extract is presented in Figure 5. Steryl esters, waxes and triglycerides were not eluted at the applied conditions as they were not volatile enough to be determined directly in this way.

The examined samples had practically the same chemical composition, however they differed accord-

Table 1 Composition of free fatty acids in heartwood of tree 1 at different heights
Tablica 1. Sastav jednostavnih masnih kiselina srži stabla 1 na različitim visinama

Sample *Uzorak*	**16:0** mg/g	**18:0** mg/g	**18:1** mg/g	**18:2** mg/g	**18:3** mg/g	**20:0** mg/g	**22:0** mg/g	**24:0** mg/g	**Total** *Ukupno* mg/g
0.5 m	0.06	0.02	0.26	0.29	0.16	0.02	0.04	0.01	0.86
8 m	0.14	0.03	0.48	0.57	0.29	0.03	0.07	0.02	1.6
18 m	0.09	0.03	0.31	0.31	0.14	0.07	0.11	0.02	1.1
28 m	0.12	0.04	0.54	0.37	0.16	0.08	0.11	0.01	1.4
Average *Prosječ.*	0.10	0.03	0.40	0.38	0.19	0.05	0.08	0.01	1.2

16:0 – palmitic, 18:0 – stearic, 18:1 – oleic, 18:2 – linoleic, 18:3 – pinolenic, 20:0 – arachidic, 22:0 – behenic, 24:0 – lignoceric / 16:0 – palmitinska, 18:0 – stearinska, 18:1 – oleinska, 18:2 – linolna, 18:3 – pinolenska, 20:0 – arašidna, 22:0 – behenska, 24:0 – lignocerinska

Table 2 Composition of free fatty acids in heartwood of tree 2 at different heights
Tablica 2. Sastav jednostavnih masnih kiselina srži stabla 2 na različitim visinama

Sample *Uzorak*	**16:0** mg/g	**18:0** mg/g	**18:1** mg/g	18:2 mg/g	**18:3** mg/g	**20:0** mg/g	**22:0** mg/g	**24:0** mg/g	**Total** *Ukupno* mg/g
0.5 m	0.07	0.02	0.33	0.35	0.19	0.03	0.06	0.01	1.1
8 m	0.10	0.02	0.48	0.68	0.38	0.03	0.05	0.01	1.8
18 m	0.09	0.03	0.32	0.34	0.19	0.08	0.15	0.02	1.2
28 m	0.06	0.02	0.53	0.29	0.17	0.08	0.10	0.01	1.2
Average *Prosječ.*	0.08	0.02	0.42	0.42	0.23	0.05	0.09	0.01	1.3

16:0 – palmitic, 18:0 – stearic, 18:1 – oleic, 18:2 – linoleic, 18:3 – pinolenic, 20:0 – arachidic, 22:0 – behenic, 24:0 – lignoceric / 16:0 – palmitinska, 18:0 – stearinska, 18:1 – oleinska, 18:2 – linolna, 18:3 – pinolenska, 20:0 – arašidna, 22:0 – behenska, 24:0 – lignocerinska

Table 3 Composition of resin acids and diterpenoids in heartwood of tree 1 at different heights
Tablica 3. Sastav smolnih kiselina i diterpenoida srži stabla 1 na različitim visinama

Sample *Uzorak*	**PI** mg/g	**SA** mg/g	**IZ** mg/g	**PA** mg/g	**DeAB** mg/g	**AB** mg/g	**NeAB** mg/g	EPI mg/g	**LAc** mg/g	**Total** *Ukupno* mg/g
0.5 m	0.05	0.09	1.3	0.65	0.15	0.52	0.34	0.14	1.3	4.6
8 m	0.06	0.14	1.8	0.62	0.30	0.65	0.23	0.47	1.4	5.7
18 m	0.12	0.18	3.0	0.95	0.56	0.79	0.27	1.2	2.6	9.7
28 m	0.14	0.15	3.0	0.87	0.63	0.76	0.26	0.70	2.8	9.3
Average *Prosječ.*	0.1	0.1	2.3	0.8	0.4	0.7	0.3	0.6	2.0	7.3

PI – pimaric, SA – sandaracopimaric, IZ – isopimaric, PA – palustric, DeAB – dehydroabietic, AB – abietic, NeAB – neoabietic, EPI – epimanool, LAc – larixyl acetate
PI – pimarna, SA – sandarakopimarna, IZ – izopimarna, PA – palustrinska, DeAB – dehidroabietinska, AB – abietinska, NeAB – neoabietinska, EPI – epimanol, LAc – lariksil acetat

Table 4 Composition of resin acids and diterpenoids in heartwood of tree 2 at different heights
Tablica 4. Sastav smolnih kiselina i diterpenoida u srži stabla 2 na različitim visinama

Sample *Uzorak*	**PI** mg/g	**SA** mg/g	**IZ** mg/g	**PA** mg/g	**DeAB** mg/g	**AB** mg/g	**NeAB** mg/g	**EPI** mg/g	**LAc** mg/g	**Total** *Ukupno* mg/g
0.5 m	0.08	0.15	2.1	0.95	0.26	0.83	0.54	0.22	2.1	7.3
8 m	0.06	0.09	1.8	0.93	0.21	0.72	0.43	0.45	2.0	6.7
18 m	0.09	0.13	2.1	0.51	0.96	0.60	0.15	0.70	2.7	7.9
28 m	0.11	0.19	3.8	0.99	0.60	1.1	0.29	0.93	2.9	11
Average *Prosječ.*	0.1	0.1	2.5	0.8	0.5	0.8	0.4	0.6	2.4	8.2

PI – pimaric, SA – sandaracopimaric, IZ – isopimaric, PA – palustric, DeAB – dehydroabietic, AB – abietic, NeAB – neoabietic, EPI – epimanool, LAc – larixyl acetate
PI – pimarna, SA – sandarakopimarna, IZ – izopimarna, PA – palustrinska, DeAB – dehidroabietinska, AB – abietinska, NeAB – neoabietinska, EPI – epimanol, LAc – lariksil acetat

Table 5. Composition of free sterols in heartwood of tree 1 at different heights
Tablica 5. Sastav jednostavnih sterola srži stabla 1 na različitim visinama

Sample *Uzorak*	**Camp-esterol** mg/g	**β-sitosterol** mg/g	**Cycloartenol** mg/g	**Total** *Ukupno* mg/g
0.5 m	0.04	0.08	0.02	0.14
8 m	0.09	0.18	0.03	0.30
18 m	0.07	0.15	0.02	0.24
28 m	0.06	0.14	0.02	0.22
Average *Prosječ.*	0.07	0.14	0.02	0.23

Table 6. Composition of free sterols in heartwood of tree 2 at different heights
Tablica 6. Sastav jednostavnih sterola srži stabla 2 na različitim visinama

Sample *Uzorak*	**Camp-esterol** mg/g	**β-sitosterol** mg/g	**Cycloartenol** mg/g	**Total** *Ukupno* mg/g
0.5 m	0.05	0.11	0.02	0.18
8 m	0.05	0.10	0.02	0.17
18 m	0.02	0.05	0.01	0.08
28 m	0.06	0.11	0.02	0.18
Average *Prosječ.*	0.04	0.09	0.02	0.15

ing to the concentrations of individual low molecular lipophilic components. Qualitative and quantitative composition of free fatty acids, resin acids, diterpenoids and sterols is presented in Tables 1 to 6.

Unsaturated fatty acids C18 with one or more double bonds prevailed. The group was represented by oleic (C18:1), linoleic (C18:2) and pinolenic (C18:3) acids, having concentrations in the range between 0.14 and 0.68 mg/g, while the contents of saturated higher fatty acids (C16:0 – C24:0) were much lower and ranged between 0.01 and 0.12 mg/g.

The samples also contained resin acids typical for conifers, among which isopimaric acids predominated with concentrations between 1.3 and 3.8 mg/g. The concentrations increased with the height of both stems. Palustric, dehydroabietic and abietic acids were also abundant with concentrations between 0.15 and 1.1 mg/g. Other less important resin acids, in terms of quantity, such as pimaric, sandaracopimaric and neoabietic, were also detected. In addition, specific diterpenoids, typical of larch wood, which formed quite a significant portion of lipophilic fraction were also observed. The identified diterpenoid alcohols or labdans were epimanool, larixol and larixyl acetate. The concentrations of the latter were the highest and ranged between 1.3 and 2.9 mg/g. larixol eluted together with dehydroabietic acid, so it was impossible to determine its exact concentrations.

In addition to the main lipophilic groups, low amounts were also detected of several diterpenoids and fatty alcohols, which did not belong to any of the presented extractive groups. Their total amount in no case exceeded 5 % of the dry mass of the hydrophobic extractive fraction.

β-sitosterol was the main free sterol, however campesterol and cycloartenol were also detected. Total sterol concentrations ranged between 0.08 and 0.30 mg/g and no increase was observed related to the stem height.

Qualitative lipophilic composition of all examined samples in both larch trees was essentially the same with isopimaric acid and larixyl acetate as the most abundant compounds. On the other hand, the amounts of the total hexane extract as well as the concentrations of most components increased with trunk heights. This increase was most pronounced at the top of both trees at the height of 28 m, where the growth was very intensive and the observed tissues much younger and vulnerable. Relatively high amounts of triglycerides represented substantial food reserve, while resin acids and diterpenoids are known to provide physical and chemical protection against deterioration.

4 CONCLUSIONS
4. ZAKLJUČAK

A detailed chemical characterisation of the lipophilic fraction of larch heartwood was performed by means of modern chromatographic techniques, such as GC-FID and GC-MS. It was established that heartwood contained some characteristic compounds (epimanool, larixyl acetate) that could not be found in other conifer genera as for example pine (*Pinus*), spruce (*Picea*) and fir (*Abies*). All heartwood samples from different height positions of two healthy larch trees exhibited the same qualitative composition of the lipophilic fraction, however the overall concentrations of the lipophilics increased with the height of the trunk. The same held for the most important extractive groups, e.g. triglycerides, resin acids and diterpenoids, which were found to be especially abundant in the younger tissues at the top of the trees. It could be assumed that lipophilic compounds are distributed in the heartwood within a living tree in such a way as to ensure storage of food and protection against deterioration. Our study may contribute to better understanding of the chemistry and its variation within living trees.

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5 REFERENCES
5. LITERATURA

1. Babkin, V. A.; Ostroukhova, L. A.; Malkov Yu, A.; Babkin, D. V.; Onuchina, N. A.; Ivanova, S. Z., 2001: Isolation of biologically active compounds from larch wood. 11th ISWPC International Symposium on Wood and Pulping Chemistry, Nice, June 11-14, pp. 119-122.
2. Fengel, D.; Wegener, G., 1989: Wood chemistry, ultrastructure, reactions. Walter de Gruyter, Berlin-New York, 812 pp.
3. Gierlinger, N.; Jacques, D.; Schwanninger, M.; Wimmer, R.; Hinterstoisser, B.; Paques, L. E., 2003: Rapid prediction of natural durability of larch heartwood using FT-NIR spectroscopy. Canadian Journal of Forest Research, 33 (9): 1727-1736 http://dx.doi.org/10.1139/x03-092.
4. Gierlinger, N.; Jacques, D.; Schwanninger, M.; Wimmer, R.; Paques, L. E., 2004: Heartwood extractives and lignin content of different larch species (*Larix* sp.) and relationships to brown-rot decay-resistance. Trees 18: 230-236 http://dx.doi.org/10.1007/s00468-003-0300-0.
5. Giwa, S. A. O.; Swan, E. P., 1975: Heartwood extractives of a western larch tree *(Larix occidentalis* Nutt.). Wood and Fiber, 7 (3): 216-221.
6. Hawley, L. F.; Fleck, L. C.; Richard, C. A., 1924: The relation between natural durability and chemical composition in wood. Ind. Eng. Chem., 16: 699-706 http://dx.doi.org/10.1021/ie50175a015.
7. Krutov, S. M.; Kovolev, V. E.; Roshchin, V. I., 1988: Wood extractives. 5th European Workshop on Lignocellulosics and Pulp, Aveiro, Aug 30 - Sept 2, pp. 245-248.
8. Mills, J. S., 1973: Diterpenes of *Larix* oleoresins. Phytochemistry, 12: 2407-2412 http://dx.doi.org/10.1016/0031-9422(73)80447-9.
9. Nair, G. V.; Von Rudloff, E., 1959: Chemical composition of the heartwood extractives of tamarack (*Larix laricina*). Canadian Journal of Chemistry, 37: 1708-1713 http://dx.doi.org/10.1139/v59-232.

10. Nair, G. V.; Von Rudloff, E., 1960: Chemical composition of the heartwood extractives of *Larix lyallii*. Canadian Journal of Chemistry, 38: 177-181 http://dx.doi.org/10.1139/v60-023.
11. Norin, T.; Oloff, G.; Willhelm, B., 1965: The structure and configurations of larixol and larixyl acetate. Tetrahedron Lett., 39: 3523-3528 http://dx.doi.org/10.1016/S0040-4039(01)89336-9.
12. Ohtsu, H.; Tanaka, R.; Matsunaga, S., 1998a: 18-nor-Abietatrienes from the cones of *Larix kaempferi.* Journal of Natural Products, 61 (3): 406-408 http://dx.doi.org/10.1021/np9704720.
13. Ohtsu, H.; Tanaka, R.; Matsunaga, S., 1998b: Abietane diterpenoids from the cones of *Larix kaempferi*. Journal of Natural Products, 61 (10): 1307-1309 http://dx.doi.org/10.1021/np980159d.
14. Ohtsu, H.; Tanaka, R.; Michida, T.; Shingu, T.; Matsunaga, S., 1998c: Tetracyclic triterpenes and other constituents from the leaves and bark of *Larix kaempferi.* Phytochemistry, 49 (6): 1761-1768 http://dx.doi.org/10.1016/S0031-9422(98)00302-1.
15. Scheffer, T. C.; Cowling, E. B., 1966: Natural resistance to microbial deterioration. Annual Review of Phytopathology, 4: 147-170 http://dx.doi.org/10.1146/annurev.py.04.090166.001051.
16. Schultz, T. P.; Hubbard, T. F.; Fisher, J. L.; Nicholas, D. D., 1990: Role of stilbenes in the natural durability of wood: fungicidal structure-activity relationships. Phytochemistry, 29: 1501-1507 http://dx.doi.org/10.1016/0031-9422(90)80109-T.
17. Schultz, T. P., Harms, W. B.; Fisher, T. H.; McMurtrey, K. D.; Minn, J.; Nicholas, D. D., 1995: Durability of angiosperm heartwood: the importance of extractives. Holzforschung, 49: 29-34 http://dx.doi.org/10.1515/hfsg.1995.49.1.29.
18. Staccioli, G.; Sturaro, A.; Parvoli, G., 1997: GC/MS investigation on the dichloromethane extract from subfossil larch. Holzforschung, 51 (2): 107-110 http://dx.doi.org/10.1515/hfsg1997.51.2.107.
19. Viitanen, H.; Paajanen, L.; Saranpää, P.; Viitaniemi, P., 1997: Durability of larch (*Larix* spp) wood against brown-rot fungi. 28th Annual Meeting of the IRG, Whistler, BC, Canada, 26-30 May, 1-8.
20. Willför, S., 2007: Modern analytical tools for pulp and paper, Turku, 5-9 Nov., COST E41 Course.
21. Xue, J. J.; Fan, C. Q.; Dong, L.; Yang, S. P.; Yue, J. M., 2004: Novel antibacterial diterpenoids from *Larix chinensis* Beissn. Chemistry & Biodiversity, 1: 1702-1707 http://dx.doi.org/10.1002/cbdv.200490128.

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TEMATSKI PRILOZI

STRUČNI ČASOPIS

Richard Hrčka[1]

Finite Changes of Bound Water Moisture Content in a Given Volume of Beech Wood

Promjene konačnog sadržaja vezane vode u određenom volumenu drva bukve

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ABSTRACT • *The undesired wood instabilities are connected with the changes of bound water moisture content. The rates of finite changes of bound water moisture content in a given volume of wood were determined in the frame of the specimen dimensions. The derivation is based on the 1st Fick's law and diffusion equation solution in three dimensions. The inverse solution of diffusion equation provided the diffusion coefficients in the principal anatomical directions. Beech wood was tested. The nonlinear regression is involved in the inverse solution. Therefore, the starting values of diffusion coefficients were computed according to the proposed three dimensional square root scheme. The evaluation of data revealed the random character of transport characteristics. The sufficient condition for the slowest finite change of bound water moisture content in a given volume of beech wood is the ratio 8.7:1.5:1.0 of dimensions in longitudinal, radial and tangential directions.*

Key words: *beech wood, diffusion coefficient, moisture content*

SAŽETAK • *Nepoželjna pojava nestabilnosti drva povezana je s promjenom sadržaja vode vezane u drvu. Promjene konačnog sadržaja vode vezane u određenom volumenu drva određene su u ovisno o dimenzijama uzorka. Derivacija se temelji na 1. Fickovu zakonu i rješenju jednadžbe difuzije u tri dimenzije. Inverzna rješenja jednadžbe difuzije daju koeficijente difuzije u glavnim anatomskim smjerovima. Test je proveden na uzorcima bukovine. Nelinearna je regresija uključena u inverzna rješenja, stoga su početne vrijednosti koeficijenata difuzije izračunane prema predloženoj shemi trodimenzionalnoga kvadratnog korijena. Ocjena rezultata otkrila je svojstvo slučajnosti kretanja vode. Dovoljan uvjet za najsporiju promjenu konačnog sadržaja vode vezane u određenom volumenu bukovine omjer je dimenzija 8,7 : 1,5 : 1,0 u uzdužnome, radijalnome i tangencijalnom smjeru.*

Ključne riječi: *bukovina, difuzijski koeficijent, sadržaj vode*

1 INTRODUCTION
1. UVOD

The wood products should be used in an environment that can ensure constant moisture content. Otherwise, the undesired mass and dimensional changes can occur. It is hard to maintain the constant moisture content for a long wood product life cycle; this proved inevitable in most observations and experiments. Wood equilibrates the bound water moisture content when it is in contact with humid air. The humid air should have constant parameters, namely relative humidity and

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temperature (Langmuir, 1918; Brunauer *et al.*, 1938; Dent, 1977). From the view point of drying, there is a lot of humid air with given parameters inside a drying kiln or inside a climatic chamber. The change of the equilibrium moisture content is accompanied with the change of the humid air parameters. The change can be infinitesimal or finite. The infinitesimal changes are connected with the phenomenon of the sorption isotherm. The finite changes only deal with the diffusion of the bound water as far as humid air has never been saturated and free water has not been present in wood. Then bound water mass flux $\vec{q}$ is induced, which is proportional to the concentration gradient as the 1st Fick's law states:

$$\vec{q} = -\bar{\bar{D}}\, grad(c) \qquad (1)$$

Where c is concentration defined as the water mass in wood volume, D is diffusion coefficient as the second order tensor.

Diffusion equation describes the finite changes of the bound water moisture content and introduces the time of the diffusion in its solution. Also solutions introduce the diffusion coefficient D and methods of its measurement can be arranged when the particular solutions of diffusion equation are known (Hrčka and Babiak, 1999):

1. zero time derivative of concentration – steady diffusion – King's method (Skaar, 1954), cup methods (Choong, 1965; Siau, 1995)
2. nonzero time derivative of concentration – unsteady diffusion
   1. variable initial condition – moment method (Cunningham *et al.*, 1989)
   2. constant initial condition – sorption method

I. kind boundary condition (Dirichlet condition)

1. constant boundary concentration – solution from Fourier series (log scheme, half-time scheme (Skaar, 1954; Chen *et al.*, 1994)); solution from Laplace transform (square root scheme (Comstock, 1963; Stamm, 1964))
2. variable boundary concentration – relaxation time method (Babiak et al., 1989)

II. kind boundary condition (Newman condition) – average concentration or flux method (Babiak *et al.*, 1989)

III. kind boundary condition (Robin condition) – including mass transfer coefficient - half-time method (Alpatkina, 1968; Choong and Skaar, 1969; Choong and Skaar, 1972; Liu, 1989); other approaching methods (Söderström and Salin, 1993; Dincer and Dost, 1996).

There are some methods for analyzing the constancy of diffusion coefficient – Egner's method (Skaar, 1954), Rosenkilde and Arfvidsson (1997), and methods based on the wood drying data (Dekrét and Trebula, 1999) if moisture field is known, or numerical methods for evaluating the sorption measurements if the dependency of diffusion coefficient on moisture content is prescribed (Olek *et al.*, 2005). Siau (1984) published the exponential function of the diffusion coefficient on moisture content and Stamm (1964) and Choong (1963) found out its increasing dependence on temperature according to Arhenius equation. Also Kang and Hart (1997) confirmed such relationship experimentally. Olek *et al.* (2011) showed that the application of the diffusion coefficient function on water content improved only insignificantly the prediction of change of the average bound water moisture content in time and the process was modeled by modified convective boundary condition. Yeo and Smith (2005) proved the existence of convective mass transfer coefficient based on the experiment. The infinite slab hypothesis was defeated by Droin-Josserand *et al.* (1989), who investigated the process of moisture adsorption in three dimensions by wood samples of cubic and parallelepiped shapes. Baronas *et al.* (2001) guarantee a better prediction with a two-dimensional model than with a one-dimensional model in the case of extremely long specimen if the ratio of the width to thickness of the specimen is less than 10; otherwise some edges should be heavily coated. The computational disadvantages of three dimensional models in comparison with two dimensional models are reported by Da Silva *et al.* (2014).

The water flux enters wood volume modeled as continuum, through the wood surface. A given volume can have different surface areas. Therefore, there is a lot of ways how to equilibrate the finite change of the wood equilibrium moisture content of a given volume. The hypothesis of this research is the existence of an extreme. Such extreme cannot depend on the duration of the process. The aim of the contribution is the determination of the extreme, non-zero finite equilibrium moisture content change in a given wood volume. The second hypothesis is that if the volume of cube is enveloped by the smallest surface, than the extreme will be minimal.

2 METHOD AND MATERIAL
2. METODA I MATERIJAL

The finite change of moisture content in a given volume of wood can be found using solution of diffusion equation in the form:

$$D_1\frac{\partial^2 c}{\partial x_1^2} + D_2\frac{\partial^2 c}{\partial x_2^2} + D_3\frac{\partial^2 c}{\partial x_3^2} = \frac{\partial c}{\partial t} \qquad (2)$$

Where i=1, 2, 3; xi are spatial coordinates of the range $\langle -L_i, L_i \rangle$, Di is diffusion coefficient in the i^{th} principal anatomical direction (1–longitudinal, 2-radial, 3-tangential), t is time.

The boundary and initial conditions are of the form:

$$\left(-L_i\right)\frac{\partial c}{\partial x_i}\bigg|_{x_i=L_i} = Bi\left(c\big|_{x_i=L_i} - c_\infty\right) \qquad (3)$$

$$\frac{\partial c}{\partial x_i}\bigg|_{x_i=0} = 0 \qquad (4)$$

$$c\left(x,0\right) = c_0 \qquad (5)$$

Where Bi is Biot number; c_∞ is equilibrium concentration; c_0 is the initial, constant concentration.

The particular solution is found in the form:

$$\frac{c-c_\infty}{c_0-c_\infty}=\sum_{n=1}^{\infty}\prod_{i=1}^{3}A_{in}cos\left(\mu_{in}\frac{x_i}{L_i}\right)e^{-\left(\mu_{1n}^2\frac{D_1}{L_1^2}+\mu_{2n}^2\frac{D_2}{L_2^2}+\mu_{3n}^2\frac{D_3}{L_3^2}\right)t} \quad (6)$$

Where $A_{in}=\frac{2sin\left(\mu_{in}\right)}{\mu_{in}+sin\left(\mu_{in}\right)cos\left(\mu_{in}\right)}$, $\mu_n tg\left(\mu_n\right)=Bi_i$

are the roots of characteristic equation and other quantities as previously defined.

A similar solution can be found for heat transfer in the study of Luikov (1968). The moisture content w of the parallelepiped is proportional to the integral of concentration over the wood volume:

$$w=\frac{8}{m_0}\iiint_{000}^{L_1\,L_2L_3}c\,dx\,dy\,dz \quad (7)$$

Where m_0 is the specimen oven dry mass.

The model (6) contains six unknown parameters (three diffusion coefficients and three Biot numbers). It is, therefore, desired to use three specimens of different dimensions as far as the function of moisture content in time is used for their estimation. Then, the least square method and nonlinear regression techniques can be applied. Therefore, starting values for six unknown parameters must be provided. The three dimensional square root scheme was developed to find the staring values of diffusion coefficients.

$$\begin{pmatrix}\frac{1}{L_{11}} & \frac{1}{L_{21}} & \frac{1}{L_{31}}\\ \frac{1}{L_{12}} & \frac{1}{L_{22}} & \frac{1}{L_{32}}\\ \frac{1}{L_{13}} & \frac{1}{L_{23}} & \frac{1}{L_{33}}\end{pmatrix}^{-1}\begin{pmatrix}\frac{\sqrt{\pi}}{2\sqrt{t}}\frac{w_1}{w_{\infty1}}\\ \frac{\sqrt{\pi}}{2\sqrt{t}}\frac{w_2}{w_{\infty2}}\\ \frac{\sqrt{\pi}}{2\sqrt{t}}\frac{w_3}{w_{\infty3}}\end{pmatrix}=\begin{pmatrix}\sqrt{D_1}\\ \sqrt{D_2}\\ \sqrt{D_3}\end{pmatrix} \quad (8)$$

where wi, $wi\infty$ are values of the i^{th} specimen's moisture content at time t and at equilibrium, Lik are the i^{th} specimen's half of the total dimension in the k^{th} anatomical direction, i, k=1, 2, 3. Initial values of the Biot number were set to the value of 10 on the basis of previous analysis and experiments (Babiak, 1996; Hrčka, 2008). The precision of moisture content estimation was evaluated according to the residual standard deviation σres:

$$\sigma_{res}=\sqrt{\frac{\sum_{j=1}^{N}\left(w_{j\,theoretical}-w_{j\,experimental}\right)^2}{N-K}} \quad (9)$$

Where K is the number of estimated parameters (K=6).

Beech wood (*Fagus sylvatica, L.*) was selected as the experimental material. The specimens were free of visible defects. Beech is the most abundant and harvested tree species (32.7 % of total trees) in Slovakia (Green report, 2014). The experiment was conducted in the climatic chamber with controlled temperature and relative humidity. Mass was determined on the same balances, with the use of tare before every mass measurement. The mass was recorded to 1 mg. The dimensions were measured with calliper in millimetres to two decimal places. The beech specimens with dimensions of 5, 10, 15, 20, 25, 30 mm (denoted as A, B, C, D, E, F) in radial and tangential directions and 150 mm in longitudinal direction were used as experimental material. The specimens were cut by sharp circular saw from radial board initially located in the outer part of the stem. Six replicates represented every dimension. Zero moisture content was the initial condition and the experiment was stopped when the mass of every specimen started to slightly oscillate in the humid air at the temperature of 20±0.4 °C and relative humidity of 85±3 %.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The diffusion coefficient and Biot number, evaluated from adsorption experiment of beech wood in humid air are random variables (Comstock, 1963; Dekrét and Kurjatko, 1986; Hrčka, 2008; Sonderegger *et al.*, 2011). The critical p-level value was set to 5 % as a variability of data can be assumed. Even though the parameters are only positive numbers, they fulfil the requirement of the normal distribution. The volume was the factor in ANOVA with 5 degrees of freedom. The Cochran test proved non-significant differences between variances and one-way ANOVA, 7-times repeated, proved non-significant influence of volume on transport characteristic values. The residual standard deviation was the only exception, and Duncan's test marked the value of A group significantly different (*p*-level 0.04).

The anatomical direction is the significant factor for the diffusion coefficient. It has the largest average value in longitudinal direction and the smallest value in tangential one. The null hypothesis (H0) for Biot numbers cannot be refused on the bases of experimental data, the averages differed on the fifth decimal place, and therefore unique average value is assumed for it. Table 1 shows statistical data of bound water diffusion characteristics of beech wood obtained on the basis of the experiment.

Additional results are also shown in Figure 1.

The residual standard deviation reached the value of 0.194 % and its individual values for different volumes are embedded in Table 2.

The change in moisture content is proportional to fluxes through the surfaces. The areas of surfaces are

Table 1 Statistical data of bound water diffusion characteristics of beech wood obtained by the experiment (1–longitudinal, 2-radial, 3-tangential)
Tablica 1. Statistički podaci obilježja difuzije vode vezane u uzorcima bukovine dobiveni eksperimentom (1 – longitudinalni smjer, 2 – radijalni smjer, 3 – tangencijalni smjer)

	$D_1\cdot10^{-12}$ $m^2\cdot s^{-1}$	$D_2\cdot10^{-12}$ $m^2\cdot s^{-1}$	$D_3\cdot10^{-12}$ $m^2\cdot s^{-1}$	**Bi**
Average *Prosječno*	1510	45.3	20.0	20.9
Stand. deviation *Standardna devijacija*	1.9	8.1	6.3	0.5
No. of observations *Broj mjerenja*	60	60	60	60

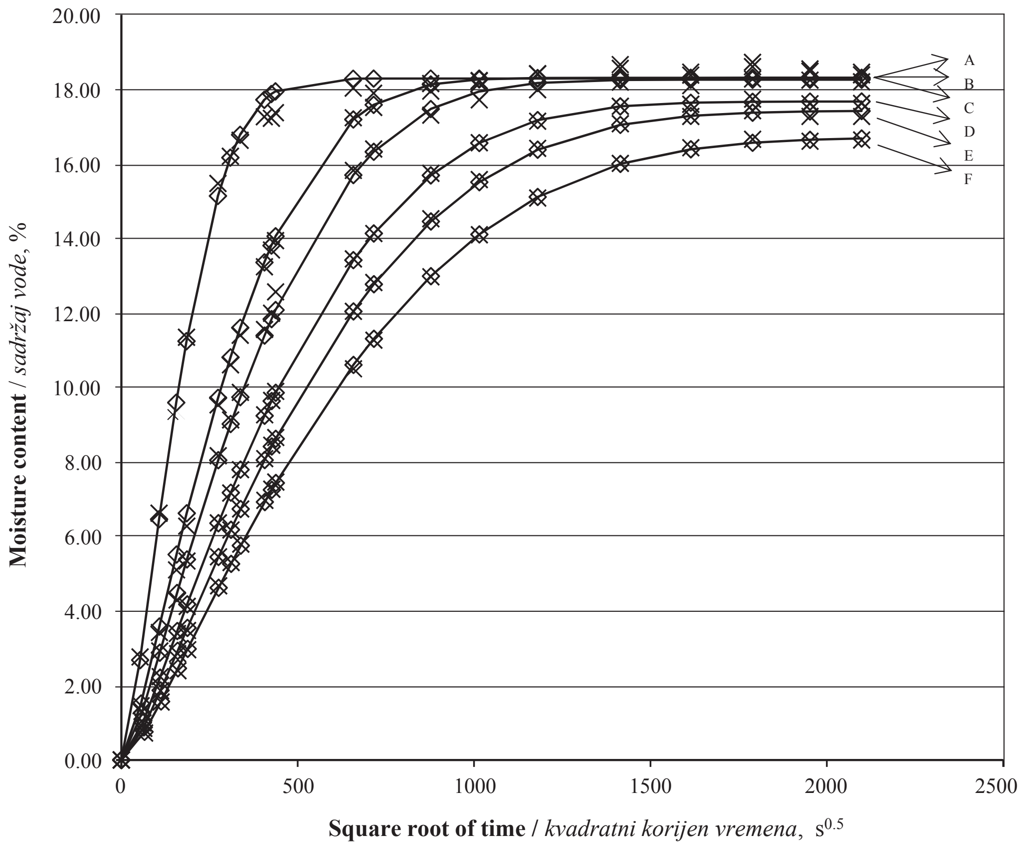

Figure 1 Graphs of bound water moisture content as function of square root of time for different beech wood cross sections, the experimental data are marked as crosses (thicknesses: A – 5 mm, B – 10 mm, C – 15 mm, D – 20 mm, E – 25 mm, F – 30 mm)
Slika 1. Prikaz funkcije sadržaja vezane vode u ovisnosti o drugom korijenu vremena za različite poprečne presjeke bukova drva (debljine: A – 5 mm, B – 10 mm, C – 15 mm, D – 20 mm, E – 25 mm, F – 30 mm)

the proportionality factor for such change. The volume can be enclosed with different surface areas. The extreme values of areas must fulfil the following conditions:

$$\frac{\partial^2 w}{\partial L_j \partial t} = 0 \quad (10)$$

Where L_j denotes the dimension in the j^{th} anatomical direction (for example in radial, and then in tangential).

Then the following relationship is valid for linear orthotropic material such as radial board (and also for cylindrical orthotropic material such as wood):

$$\frac{D_1}{L_1^2} = \frac{D_2}{L_2^2} = \frac{D_3}{L_3^2} \quad (11)$$

Where L_1, L_2 and L_3 are half of the total dimensions of the wood specimen in longitudinal, radial and tangential directions. The determinant ($i \neq j$):

$$\begin{vmatrix} \frac{\partial^3 w}{\partial L_i^2 \partial t} & \frac{\partial^3 w}{\partial L_i \partial L_j \partial t} \\ \frac{\partial^3 w}{\partial L_j \partial L_i \partial t} & \frac{\partial^3 w}{\partial L_j^2 \partial t} \end{vmatrix} \quad (12)$$

is positive and extremes will occur. If sorption occurs as diffusion, the first term is negative; then the conditions (11) are sufficient to characterize the local minimum of the moisture content change in time during bound water diffusion in wood. If desorption occurs as diffusion, then the gradient is opposite to the outside normal of the surface and its absolute value must be involved in determinant (12) instead of the actual value. Also, the local minimum occurs. Once the wood volume is set and diffusion coefficients for wood are determined, the dimensions are determined for the slowest finite change of bound water moisture content.

Table 2 Values of residual standard deviations for different volumes (thicknesses: A – 5 mm, B – 10 mm, C – 15 mm, D – 20 mm, E – 25 mm, F – 30 mm)
Tablica 2. Vrijednosti rezidualne standardne devijacije za različite volumene (A – 5 mm, B – 10 mm, C – 15 mm, D – 20 mm, E – 25 mm, F – 30 mm)

Volume / *Volumen*	**A**	**B**	**C**	**D**	**E**	**F**	**Average** *Prosjek*
Res. stand. deviation, % *Rezidualna standardna devijacija, %*	0.456	0.195	0.199	0.097	0.104	0.117	0.194

The extreme values of dimensions can be computed as follows:

$$L_1^3 = \frac{V}{8}\frac{D_1}{\sqrt{D_2 D_3}} \quad (13)$$

$$L_2^3 = \frac{V}{8}\frac{D_2}{\sqrt{D_1 D_3}} \quad (14)$$

$$L_3^3 = \frac{V}{8}\frac{D_3}{\sqrt{D_2 D_1}} \quad (15)$$

Where *V* is a given wood volume.

The optimal beech wood dimensions of unit volume for the finite change of bound water moisture content fulfil the ratio (longitudinal : radial : tangential):

8.7 : 1.5 : 1.0

Then, due to the finite change of bound water equilibrium moisture content at a given Biot number of 20.9 and temperature of 20 °C, the diffusion exhibits the slowest process in beech wood.

4 CONCLUSIONS
4. ZAKLJUČAK

There were a lot of ways to equilibrate the finite change in the wood equilibrium moisture content of a given volume. The extreme rate of finite change of bound water moisture content in a given volume of wood was found and the hypothesis of this research was confirmed. Such extreme does not depend on the duration of the process. The extreme is unique and minimal. The minimum for a given volume depends solely on diffusion coefficient eigenvalues in the principal anatomical directions. The diffusion coefficient is a random variable and, therefore, the whole procedure can be repeated and the results are reproducible.

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5 REFERENCES
5. LITERATURA

1. Alpatkina, R. P., 1968: Metod issledovanija kojefficijentov vlagoprovodnosti drevesiny. Lesnoj žurnal, 2: 106-111.
2. Babiak, M.; Pavlíková, M.; Jokel, J., 1989: Kinetika a termodynamika vlhkého dreva. [Správa pre priebežnú oponentúru.] ŠDVU, Bratislava.
3. Babiak, M., 1996: Vplyv hraničných podmienok na riešenie rovnice difúzie vody v dreve. In.: interakcia dreva s rôznymi formami energie, 1.sympózium, Zvolen, 55-60.
4. Baronas, R.; Ivanauskas, F.; Sapagovas, M., 2001: The influence of wood specimen geometry on moisture movement during drying. Wood and fiber Science, 33: 166-172.
5. Brunauer, S.; Emmett, P. H.; Teller, E., 1938: Adsorption of Gases in Multimolecular Layers. J. Amer. Chem. Soc. 60: 309-319 http://dx.doi.org/10.1021/ja01269a023.
6. Chen, Y.; Choong, E. T.; Wetzel, D. M., 1994: Optimum average diffusion coefficient: an objective index in description of wood drying data. Wood and Fiber Science, 26: 412-420.
7. Choong, E. T., 1965: Diffusion coefficients of softwoods by steady-state and theoretical methods. Forest Products Journal, 15: 21-27.
8. Choong, E. T.; Skaar, C., 1969: Separating internal and external resistance to moisture removal in wood drying. Wood Science, 1: 200-203.
9. Choong, E. T.; Skaar, C., 1972: Diffusivity and surface emissivity in wood drying. Wood Science, 4: 80-86.
10. Comstock, G. L., 1963: Moisture diffusion coefficients in wood as calculated from adsorption, desorption and steady state. Forest Products Journal, 3: 97-103.
11. Cunningham, M. J.; Keey, R. B.; Kerdemelidis, C., 1989: Isothermal moisture transfer coefficients in Pinus radiata above the fiber-saturation point, using the moment method. Wood and Fiber Science, 21: 112-122.
12. Da Silva, W. P.; Da Silva e Silva C. M. D. P.; Rodrigues, A. F., 2014: Comparison between two- and three-dimensional diffusion models to describe wood drying at low temperature. Eur. J. Wood Prod. 72: 527-533 http://dx.doi.org/10.1007/s00107-014-0812-x.
13. Dekrét, A.; Kurjatko, S., 1986: O povrchových podmienkach pri difúzii vodných pár v dreve. Drevársky výskum, 109: 69-80.
14. Dekrét, A.; Trebula, P., 1999: O jednom odhade závislosti difúzneho koeficienta na vlhkosti a teplote. Acta Facultatis Xylologiae Zvolen – Res Publica Slovaca, 41: 59-65.
15. Dent, R. W., 1977: A Multilayer Theory for Gas Sorption. Part I: Sorption of a Single Gas. Textile Research Journal, 145-152.
16. Dincer, I.; Dost, S., 1996: Determination of moisture diffusivities and moisture transfer coefficients for wooden slabs subject to drying. Wood Science and Technology, 30: 245-251 http://dx.doi.org/10.1007/BF00229347.
17. Droin-Josserand, A.; Taverdet, J. L.; Vergnaud, J. M., 1989: Modelling the process of moisture absorption in three dimensions by wood samples of various shapes: cubic, parallelepipedic. Wood Science and Technology, 23: 259-271 http://dx.doi.org/10.1007/BF00367739.
18. Hrčka, R.; Babiak, M. 1999: Charakteristiky difúzie vody v dreve agáta bieleho zisťované optimálnymi metódami. In. Drevo štruktúra a vlastnosti. TU Zvolen, 47-52.
19. Hrčka, R., 2008: Difúzia vody v dreve vybraných roztrúsenopórovitých drevín v pozdĺžnom smere. Acta Facultatis Xylologiae Zvolen – Res Publica Slovaca, 50: 57-63.
20. Langmuir, I., 1918: The Adsorption of Gases on Plane Surfaces of Glass, Mica and Platinum. J. Amer. Chem. Soc. 40: 1361-1403 http://dx.doi.org/10.1021/ja02242a004.
21. Liu, J. Y., 1989: A new method for separating diffusion coefficient and surface emission coefficient. Wood and Fiber Science, 21: 133-141.
22. Luikov, A. V., 1968: Analytical heat diffusion theory. Academic Press, New York and London.
23. Kang, H. Y.; Hart, C. A., 1996: Temperature effect on diffusion coefficient in drying wood. Wood and Fiber Science, 29 (4): 325-332.
24. Olek, W.; Perré, P.; Weres, J., 2005: Inverse analysis of the transient bound water diffusion in wood. Holzforschung, 59: 38-45 http://dx.doi.org/10.1515/HF.2005.007.
25. Olek, W.; Perré, P.; Weres, J., 2011: Implementation of a relaxation equilibrium term in the convective boundary condition for a better representation of the transient bound water diffusion in wood. Wood Science and Technology, 45: 677-691 http://dx.doi.org/10.1007/s00226-010-0399-2.

26. Rosenkilde, A.; Arfvidsson, J., 1997: Measurement and evaluation of moisture transport coefficients during drying of wood. Holzforschung, 51: 372-380 http://dx.doi.org/10.1515/hfsg.1997.51.4.372.
27. Siau, J. F., 1984: Transport Processes in Wood. Springer, Berlin, Heidelberg, New York http://dx.doi.org/10.1007/978-3-642-69213-0.
28. Siau, J. F., 1995: Wood: Influence of moisture on physical properties. Department of Wood Science and Forest Products, Virginia Polytechnic Institute and State University.
29. Skaar, C. 1954: Analysis of methods for determining the coefficient of moisture diffusion in wood. Forest Product Journal, 4: 403-410.
30. Söderström, O.; Salin, J. G., 1993: On determination of surface emission factors in wood drying. Holzforschung, 47: 391-397 http://dx.doi.org/10.1515/hfsg.1993.47.5.391.
31. Sonderegger, W.; Vecellio, M.; Zwicker, P.; Niemz, P., 2011: Combined bound water and water vapour diffusion of Norway spruce and European beech in and between the principal anatomical directions. Holzforschung, 65: 819-828 http://dx.doi.org/10.1515/HF.2011.091.
32. Stamm, A. J., 1964: Wood and Celullose Science. Ronald, New York.
33. Yeo, H.; Smith, W. B.; Hanna, R. B., 2002: Determination of surface moisture content of wood utilizing a colorimetric technique. Wood and Fiber Science, 34: 419-424.
34. ***2014: "Green report 2014" (on-line), Ministry of Agricultural and Rural Development of the Slovak Republic. http://mpsr.sk/index.php?navID=123&id=8915. Accessed 19 January 2015.

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Effects of Nanosilver-Impregnation and Heat Treatment on Coating Pull-off Adhesion Strength on Solid Wood

Učinci impregnacije nanočesticama srebra i toplinske obrade na čvrstoću prianjanja premaza na drvo

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ABSTRACT • *Effects of impregnation with a silver nano-suspension, as well as of heat-treatment, on pull-off adhesion strengths of the coating system on three commercial solid wood species were studied. The wood species included beech, poplar, and fir. The size range of silver nanoparticles was 30 – 80 nm. The specimens were coated with an un-pigmented sealer and a clear finish on the basis of an organic solvent. The results showed that the highest and the lowest pull-off strengths were found in beech specimens heat-treated at 145 °C (5.7 MPa) and in nanosilver-impregnated poplar specimens heat-treated at 185 °C (2.5 MPa), respectively. Impregnation with nanosilver decreased pull-off strength in the case of all species as a result of formation of micro checks in the cell walls caused by the impregnation under high pressure in vessel. Heat-treatment at the temperature lower than 145 °C increased pull-off strength as to the irreversible hydrogen bonding in the course of water movements within the pore system of the cell walls, resulting in extra bonds among cell wall components and higher mechanical properties. However, heat-treatment at the temperature higher than 185 °C significantly decreased the strength as the degradation of hemicellulose and cell wall wood components caused significant decrease in mechanical strength and cell wall thinning. High thermal conductivity coefficient of silver intensified the impact of heat-treatment by rapid absorption of heat on the surface of the specimens.*

Keywords: *coating, nanotechnology, heat treatment, permeability, porous structure, solid wood.*

SAŽETAK • *U radu su istraživani učinci impregnacije drva srebrnom nanosuspenzijom, kao i učinci toplinske obrade na čvrstoću prianjanja (adhezije) sustava premaza na tri komercijalne vrste masivnog drva. U istraživanjima je analiziran sustav premaza na drvu bukve, topole i jele. Raspon veličine srebrnih nanočestica bio je 30 – 80 nm. Uzorci su obrađeni nepigmentiranim punilom i završnim premazom na osnovi organskog otapala. Rezultati su pokazali da je najveća čvrstoća prianjanja izmjerena na uzorcima od toplinski obrađene bukovine pri 145 °C (5,7 MPa), a najmanja na uzorcima od drva topole impregniranima srebrnim nanočesticama i toplinski obrađenima*

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pri 185 °C (2,5 MPa). Impregnacija srebrnim nanočesticama smanjila je čvrstoću adhezije na svim vrstama drva, što je posljedica stvaranja mikropukotina na staničnim stijenkama uzrokovanima impregnacijom pod visokim tlakom u posudi. Toplinska obrada na temperaturi nižoj od 145 °C povećala je čvrstoću adhezije s obzirom na ireverzibilne vodikove veze u toku kretanja vode u sustavu pora staničnih stijenki, što rezultira dodatnim vezama između komponenti stanične stijenke i boljim mehaničkim svojstvima. Međutim, toplinska obrada na temperaturi višoj od 185 °C bitno smanjuje čvrstoću adhezije jer propadanje hemiceluloze i komponenti stanične stijenke drva uzrokuje znatno smanjenje mehaničke čvrstoće i stanjivanje stanične stijenke. Visoki koeficijent toplinske vodljivosti srebra pojačava učinak toplinske obrade brzom apsorpcijom topline na površini uzorka.

Ključne riječi: *premazivanje, nanotehnologija, toplinska obrada, propusnost, porozna struktura, masivno drvo*

1 INTRODUCTION
1. UVOD

The porous structure in different wood species is one of the root causes of difference in physical and mechanical properties of the wood produced by each species. The size of the pores, the way they are inter-connected or isolated from the neighboring pores, and even the quality of the surface of the pores would all influence the properties. Many factors influence the formation of wood and thereof its structure and porous system; factors such as initial spacing, intercropping with different plants, drying procedures (Oltean *et al*., 2007), growing season, extractive content, and moisture content and hygroscopicity of wood (Borrega and Karenlampi, 2010; Hering *et al*., 2012). Wood is frequently modified by engineering processes to get stiffness or homogeneous mechanical properties because only few species exhibit radial and axial uniformity. Moreover, some surface preparation techniques were used for better adhesion of wood surface (Militz and Viöl, 2008; Militz *et al*., 2013).

Thermal modification is by far the most commercially-advanced wood modification method. The thermal modification of wood has long been recognized as a potentially useful method to improve the dimensional stabilization of wood and increase its decay resistance (Hill, 2006). Although it has negative effects on the strength properties of wood, there are some techniques for mitigating these effects (Awoyemi, 2007). Thermal modification is invariably performed between the temperatures of 180 °C and 260 °C. The temperatures lower than 140 °C result only in slight changes of material properties and higher temperatures result in unacceptable degradation of the substrate (Hill, 2006). Studies of the thermal treatment of wood above 300 °C are of a limited value, due to severe degradation of the material. Modern thermal modification processes are limited to temperatures not higher than 260 °C; in practice, the temperature ranges from 150 °C to 230 °C are generally used, because hydrolysis is very slow at lower temperatures, whereas cellulose degradation begins to occur in the region 210-220 °C (Hill, 2006). Cellulose degradation becomes predominant at 270 °C. A sharp increase in the free-radical content of wood was also found when it was heated to temperatures above 200 °C (Hill, 2006). The reduction of wood swelling with increasing temperature and duration of thermal treatment was often attributed to hemicelluloses destruction (Hill, 2006; Taghiyari *et al.*, 2013). However, structural modifications and chemical changes of lignin were suggested to be also involved in the process (Repellin and Guyonnet, 2005). Furthermore, Borrega and Karenlampi (2010) indicated that reduction in hygroscopicity was not only due to mass loss, but another mechanism also existed. They suggested that this mechanism might be related to irreversible hydrogen bonding in the course of water movements within the pore system of the cell walls.

High thermal conductivity coefficients of metal nanoparticles (Pati, 2012) were used to improve some of the properties of solid woods and wood-composite materials (Taghiyari *et al*., 2013). Both impregnation with nanosilver suspension and heat-treatment were also reported to alter the porous structure of solid woods, significantly changing the gas and liquid permeability (Taghiyari, 2013), and possibly the penetration of coatings and paints into the porous structure, altering their adhesion strength. The effects of different thermal modifications on pull-off adhesion strength of paints were investigated in some studies (Meijer, 2004; De Moura *et al*., 2013; Nejad *et al*., 2013); however, in the literature, the authors could not find any reports on the effects of nanosilver-impregnation and heat-treatment on adhesion strength of paints and finishes on solid woods. The present study was, therefore, aimed at finding the effects of heat-treatment on pull-off adhesion strength in solid woods. In the meantime, considering the previous experience in which changes in physical and mechanical properties of solid wood species were reported by their increased thermal conductivity due to the impregnation with metal nano-suspension (Taghiyari, 2011; Taghiyari *et al*., 2013; Taghiyari, 2013), a separate set of specimens were impregnated with nanosilver suspension to increase the thermal conductivity of the specimens and find out its effects on pull-off adhesion.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Specimen preparation
2.1. Priprema uzoraka

Two hardwoods and one softwood were chosen based on their commercial importance in various industrial and musical applications in Iran - beech (*Fagus orientalis* Lipsky), poplar (*Populus nigra* L.), and fir (*Abies alba* Mill.). From each species, 30 tangential specimens were prepared; the size of each specimen was 250 mm × 150 mm × 10 mm; the specimens were

Table 1 Specifications of the sealer and clear coating used in the present study
Tablica 1. Specifikacija punila i premaza upotrijebljenih u istraživanju

Coating / *Premaz*	**Solids, %** *Čvrsta tvar, %*	**Viscosity (25 °C)** *Viskoznost pri 25 °C* cP	**Density, g/cm³** *Gustoća, g/cm³*	**Appearance** *Izgled*
Sealer / *punilo*	38±1	120±10	0.97	Clear liquid
Clear finish (un-pigmented coating) *završni premaz (nepigmentirani premaz)*	39±1	80±10	0.97	Clear liquid

free from any knots, fissures, and checks; they were kept in conditioning room (25±2) °C, and (40±3) % relative humidity for four weeks. The surface of the specimens was sanded with 100-grit sandpaper; they were then wind-blown to remove the dust and wood floor. All specimens (including the control, the heat-treated, nanosilver-impregnated, and heat-treated + nanosilver-impregnated specimens) were equally coated with an un-pigmented sealer-clear resin with an organic solvent and produced by Pars-Eshen Co., as to its great popularity in the local market; technical specifications of the resins are in Table 1. Nitrocellulose was used as the binder of the clear finish. The coating was applied by spraying in two separate runs by a professional workman. The thickness of the coating was measured to be 150 μm. Four dollies of 20 mm in diameter were fixed to each specimen for testing the coating-adhesion strength. The moisture content of specimens was (8±0.5) % in all treatments, where the pull-off tests were carried out because wood has a thermo-hygromechanical behavior and its deformation properties depend on the combined action of temperature, relative humidity, and mechanical local variations (ASTM D4541-02; Figueroa *et al*., 2012).

2.2 Nanosilver impregnation
2.2. Impregnacija nanočesticama srebra

A 400 ppm aqueous dispersion of silver nanoparticles was produced and applied to the specimens using electrochemical technique (Khaydarov *et al*., 2009; Taghiyari and Norton, 2014). The size range of silver nanoparticles was 30-80 nm. The formation and size of the silver nanoparticles was monitored by transmission electron microscopy, for which samples were prepared by drop-coating on to carbon-coated copper grids. The pH of the suspension was measured to be 6-7; two kinds of surfactants (anionic and cationic) were used in the suspension as stabilizer; the concentration of the surfactants was three times the nano-silver particles. Empty-cell impregnation process (Rueping method) was carried out in pressure vessel under 3 bars of pressure by Mehrabadi Machinery Mfg. Co. (Tehran, Iran). Before and after the impregnation process, all specimens were weighted with a digital scale with 0.01 g precision, and their dimensions were measured by a digital caliper with 0.01 mm precision, to measure the density and the amount of nano-suspension absorption. After the impregnation, all specimens (including the control, heat-treated, nanosilver-impregnated, and heat-treated + nanosilver-impregnated specimens) were kept at room temperature for three months. Once the NS-impregnated specimens were dried under the conditions mentioned in the Specimens Preparation section, they were heat treated.

2.3 Heat-treatment process
2.3. Proces toplinske obrade

All specimens for heat-treatment were randomly arranged in an oven. They were heated at 145 °C for 12 hours. Heat-treated specimens were marked with HT; and specimens impregnated with nanosilver were coded by NS. Then, all HT-145 and NS-HT-145 specimens were taken out of the oven. HT-185 and NS-HT-185 specimens were heated at 185 °C for another four hours for comparison purposes of two temperature levels (145 and 185 °C). Explanation on the abbreviations and the specimen coding are in Table 2.

2.4 Pull-off adhesion strength testing
2.4. Određivanje čvrstoće adhezije

Adhesion strength testing provides the force required to pull a specified test diameter of a coating away from its substrate, using hydraulic pressure. Adhesion tests were carried out in accordance with the ASTM D4541-02. In the present study, an automatic PosiTest® pull-off adhesion tester was used; it is a self-

Table 2 Definition of the abbreviations and coding of the specimens
Tablica 2. Definiranje i skraćeno označivanje uzoraka

Code of the treatment *Oznaka obrade*	**Description of the treatment** / *Opis obrade*
Control	Specimens without any treatment / *uzorak bez obrade*
Control-NSI	Specimens impregnated with silver nano-suspension *uzorak impregniran suspenzijom srebrnih nanočestica*
HT145	Heat-treated specimens at 145 °C / *uzorci toplinski obrađeni pri 145 °C*
NSI-HT145	Nanosilver-impregnated specimens heat-treated at 145°C *uzorci impregnirani srebrnim česticama i toplinski obrađeni pri 145 °C*
HT185	Heat-treated specimens at 185°C / *uzorci toplinski obrađeni pri 185 °C*
NSI-HT185	Nanosilver-impregnated specimens heat-treated at 185°C *uzorci impregnirani srebrnim česticama i toplinski obrađeni pri 185 °C*

Table 3 Density of wood species before the impregnation process and the amount of nano-silver absorption in each species
Tablica 3. Gustoća drvnih uzoraka prije procesa impregnacije i količina nanočestica srebra u uzorcima svake vrste drva

Species / *Vrsta drva*	***Fagus orientalis*** / *Bukva*	***Populus nigra*** / *Topola*	***Abies alba*** / *Jela*
Nano-silver absorption, g/cm^3 *Apsorbcija nanočestica srebra, g/cm^3*	0.37	0.28	0.08
Density, g/cm^3 / *Gustoća, g/cm^3*	0.56	0.34	0.43

aligning spherical dolly-head tester (Type V according to the ASTM standard).

Diameter of the dolly used was 20 mm. The greatest tensile pull-off strength X that the coating could adhere to the substrate was evaluated in MPa (Equation 1). The breaking points, demonstrated by fractured surfaces, occurred along the weakest plane within the system consisting of the dolly, adhesive, coating layers and substrate.

$$X = \frac{4 \cdot F}{\pi \cdot d^2} \qquad (1)$$

Where *F* is the rupture force (N), and *d* is the diameter of the experiment cylinder (mm) (ASTM D4541-02).

The moisture content of the specimens at the time of the pull-off adhesion tests was (8±0.5) %, and the temperature was (25±3) °C.

2.5 SEM Imaging
2.5. SEM fotografije

Scanning Electron Microscope (SEM) imaging was carried out in the thin-film laboratory, FE-SEM lab (Field Emission), School of Electrical & Computer Engineering, University of Tehran; a field-emission cathode in the electron gun of a scanning electron microscope provides narrower probing beams at low as well as high electron energy, resulting in both improved spatial resolution and minimized sample charging and damage.

2.6 Statistical analysis
2.6. Statističke analize

One-way analysis of variance (ANOVA) was conducted to discern significant difference at 95 % level of confidence, using SAS software program (version 9.2) (2010). Grouping was then made between treatments using the Duncan test. Regression and hierarchical cluster analyses, including dendrogram and using Ward methods with squared Euclidean distance intervals, were carried out by SPSS/20 (2011). Cluster analysis was performed to find similarities and dissimilarities between treatments based on more than one property simultaneously (Ada 2013).

3 RESULTS
3. REZULTATI

Results from weighing and measuring the specimens before and after the impregnation process showed that the highest nano-suspension absorption was in beech specimens (0.37 g/cm^3), and the lowest in fir (0.08 g/cm^3) (Table 3).

Visual observation showed that, in nearly all cases, the failure occurred in the damaged woody substrate, not in the coating or the adhesive layers. In fact, the pulled-off dollies showed a great deal of fibril and woody substrate stuck to it. Similar results were reported for eucalyptus and pine woods (De Moura *et al.*, 2013). This indicated that the coating and adhesion procedures were carried out correctly; that is, the surface of the substrate provided suitable anchoring for the finish to be stuck to. The maximum pull-off adhesion strength was observed in beech specimens heat-treated at 145 °C (5.68 MPa); the minimum adhesion strength was seen in nanosilver-impregnated poplar specimens heat-treated at 185 °C (2.46 MPa) (Fig. 1). Impregnation with nanosilver suspension decreased

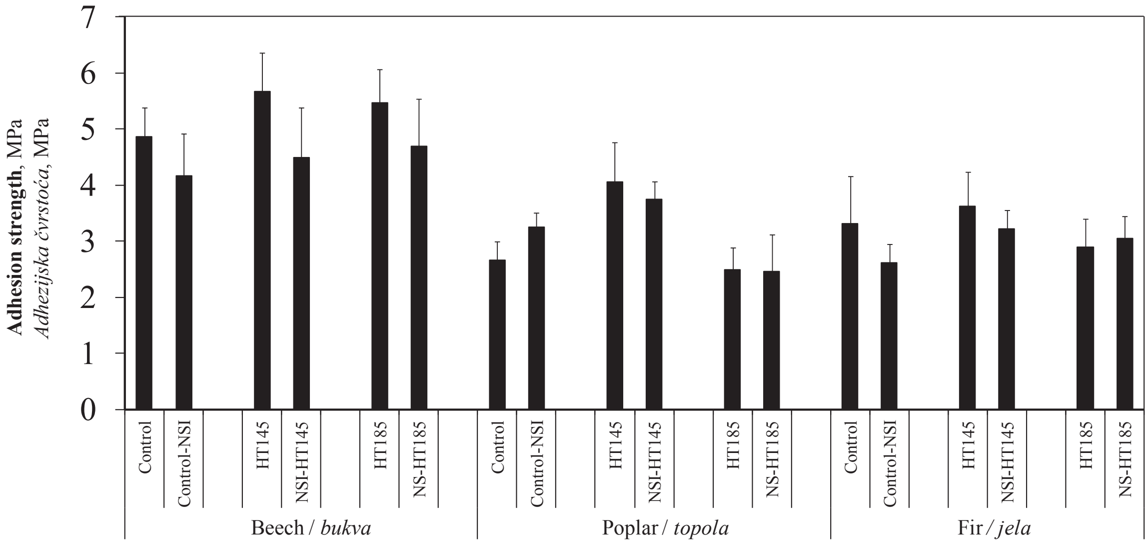

Figure 1. Pull-off adhesion strength (MPa) of three species coated with sealer-clearer
Slika 1. Čvrstoća prianjanja premaza (MPa) izmjerena na uzorcima triju vrsta drva obrađenima sustavom punilo – završni premaz

the pull-off adhesion strength in the case of all treatments of beech specimens; in poplar and fir specimens, however, decrease or increase of the adhesion strength depended on the treatments and species.

Heat-treatment at 145 °C resulted in an increase of the adhesion strength in all three species; in beech and poplar, the increase was significant. Effect of heat-treatment at 185 °C was different according to the species; in beech specimens, it significantly increased the adhesion strength; in fir specimens, it decreased the strength, although not significantly. As to the poplar specimens, the amount of decrease in the adhesion strength was significant.

4 DISCUSSION
4. RASPRAVA

The highest nano-suspension absorption was found in the species with the highest density and permeability (Taghiyari, 2011; 2013). As to the fact that empty-cell process was used for nanosilver impregnation of the specimens, the suspension was absorbed by the cell wall; that is, the cell cavities were ultimately empty at the end of the impregnation process. Therefore, the highest NS-absorption occurred in the case of species that had the highest portion of woody material.

The pull-off adhesion strength of the coating was significantly higher in all treatments of beech specimens. Having significantly higher density in comparison to the other two species, it is shown that the mechanical properties of the substrate significantly affected the pull-off adhesion strength.

Impregnating solid wood species with liquids in pressure vessels was reported to break the cell walls and cause the formation of micro cracks in the cell walls (Taghiyari, 2013; Taghiyari *et al*., 2014), ultimately decreasing the mechanical strength (Taghiyari, 2011). The broken cell parts and distorted perforation plates are shown in Figure 2. The decrease in the pull-off adhesion strengths (statistically significant $P < 0.021$) was related to these micro checks that were formed in the cell walls. On the other hand, the formation of micro checks results in a significant increase in permeability of solid woods (Taghiyari *et al*., 2013); coating pull-off strength was, therefore, expected to increase because coating can more easily penetrate into the texture of the substrate with more permeability, providing mechanical anchoring (Ekstedt, 2002). In fact, two mechanisms were involved in this case. Firstly, the micro checks decreased the mechanical strength of the substrate; secondly, more permeability resulted in possibly better penetration of the coating into the substrate, increasing pull-off strength (Meijer *et al*., 2001a,b). However, in the present case, the decrease in the mechanical properties put the increase in permeability in perspective, eventually decreasing the overall pull-off strength. However, in order to come to a final conclusion, further studies on the depth of penetration of coating into the wood texture of nanosilver-impregnated specimens should be carried out.

Heat-treatment at 145 °C increased the pull-off adhesion strengths in all treatments. This increase was related to the decrease in moisture content (Sönmez *et al*., 2011; Hering *et al*., 2012; Goli *et al*., 2014) as well as the irreversible hydrogen bonding in the course of water movements within the pore system of the cell walls (Borrega and Karenlampi, 2010; Taghiyari *et al*., 2013). To be specific, when water molecules are withdrawn from the cell walls, irreversible bonds are formed among the molecules in the cell wall; these bonds resulted in higher mechanical properties (Taghiyari, 2011). The increase in the mechanical strength of the substrate eventually increased the pull-off adhesion strength due to the fact that all failures actually occurred in the substrate. However, heat-treatment at higher temperatures (higher than 170 °C) was repeatedly reported to decrease the mechanical properties as a result of degradation of hemicelluloses and cell wall components; cell walls are also thinned due to high temperatures (Hill, 2006; Taghiyari, 2011; Taghiyari *et al*., 2013; Taghiyari and Moradi, 2014). The significant decrease of the pull-off adhesion strength of the coating in all three species was related to the degradation of hemicelluloses and the consequent decrease in the mechanical properties of the substrate (Fig. 1).

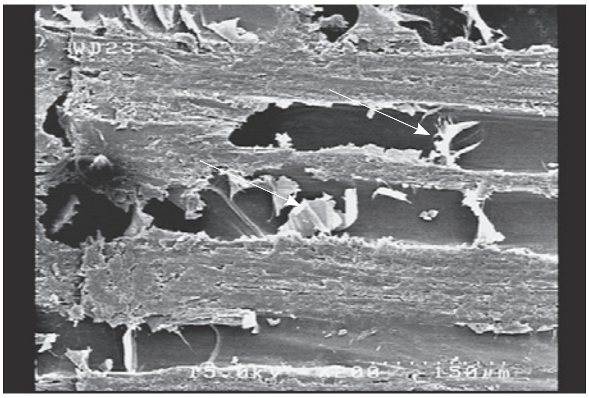

Figure 2 SEM image showing cell parts and perforation plates (↓) distorted along the vessel element
Slika 2. SEM fotografija prikazuje stanične dijelove i perforacije ploče (↓) iskrivljene duž traheje

The lowest pull-off adhesion strength was found in the NS-impregnated specimens heated at 185 °C; this showed the impact of high thermal conductivity coefficient of silver nanoparticles (Saber *et al*., 2013); that is, silver nanoparticles intensified the effects of heat-treatment by rapid absorption of heat. Therefore, the substrate was highly affected by heat-treatment process, especially its surface layer of the specimens to which the pull-off adhesion strength of the coating was most related.

Cluster analysis of the three species based on the six treatments studied in the present study (control, NS-impregnated, HT-145, NS-HT-145, HT-185, and NS-HT-185) showed that beech was clustered differently; poplar and fir species were clustered similarly (Fig. 3). Considering the significantly higher density of beech in comparison to the other two species (poplar and fir), it can be concluded that pull-off adhesion strength was significantly influenced by the density of the species; in fact, the high impact of density on other mechanical properties was also repeatedly reported in

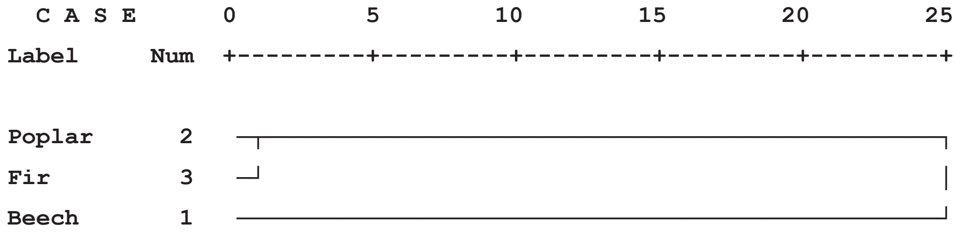

Figure 3 Cluster analysis of three species of beech, poplar, and fir based on pull-off adhesion strengths of six treatments of each species
Slika 3. Klasterska analiza uzoraka triju vrsta drva (bukovine, topolovine i jelovine) na temelju čvrstoće adhezije premaza pri šest različitih obrada tih vrsta drva

many research projects (Taghiyari, 2011; Taghiyari *et al*., 2013).

5 CONCLUSIONS
5. ZAKLJUČAK

1. The pull-off adhesion strength of the coating is closely correlated to the density and mechanical properties of the solid wood substrate.

2. Heat-treatment of solid woods at 145 °C generally tends to increase the pull-off adhesion strength as a result of lower moisture content and irreversible hydrogen bonding in the cell wall. However, heat-treatment at 185 °C significantly decreases the adhesion strength due to degradation of hemi-cellulose in the cell-wall structure of wood.

3. Impregnation with nanosilver suspension significantly decreases pull-off adhesion strength of control and heat-treated solid woods. This decrease is related to the formation of micro checks in cell wall as a result of high pressure in the impregnation vessel, significantly decreasing the mechanical properties of solid woods.

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6 REFERENCES
6. LITERATURA

1. Ada, R., 2013: Cluster analysis and adaptation study for safflower genotypes. Bulgarian Journal of Agricultural Science, 19: 103-109.
2. ASTM D 4541-02, 2006: Standard test method for pull-off strength of coatings using portable adhesion testers.
3. Awoyemi, L., 2007: Determination of Optimum Borate Concentration for Alleviating Strength Loss During Heat Treatment of Wood. Wood Science Technology, 42: 39-45 http://dx.doi.org/10.1007/s00226-007-0139-4.
4. Borrega, M.; Karenlampi, P. P., 2010: Hygroscopicity of Heat-Treated Norway Spruce (*Picea abies*) wood. Eur. J. Wood Prod. 68: 233-235 http://dx.doi.org/10.1007/s00107-0090371-8.
5. De Moura, L. F.; Brito, J. O.; Nolasco, A. M.; Uliana, L. R., 2013: Evaluation of coating performance and color stability on thermally rectified *Eucalyptus grandis* and *Pinus caribaea* Var. *Hondurensis* woods. Wood Research, 58(2): 231-242.
6. Ekstedt, J., 2002: Studies on the barrier properties of exterior wood coatings. Doctoral Thesis at KTH-Royal Institute of Technology, Department of Civil and Architectural Engineering, Division of Building Materials, Stockholm; pp. 75.
7. Figueroa, M.; Bustos, C.; Dechent, P.; Reyes, L.; Cloutier, A.; Giuliano, M., 2012: Analysis of rheological and thermo-hygro-mechanical behaviour of stress-laminated timber bridge deck in variable environmental conditions. Maderas. Ciencia y tecnologia, 14 (3): 303-319.
8. Goli, G.; Cremonini, C.; Negro, F.; Zanuttini, R.; Fioravanti, M., 2014: Physical-mechanical properties and bonding quality of heat treated poplar (I-214) and ceiba plywood. iForest journal 8: 687-692 http://dx.doi.org/10.3832/ifor1276-007.
9. Hill, C., 2006: Wood Modification Chemical, Thermal and Other Processes. John Wiley & Sons, Ltd., pp. 239 http://dx.doi.org/10.1002/0470021748.
10. Hering, S.; Keunecke, D.; Niemz, P., 2012: Moisture-dependent orthotropic elasticity of beech wood. Wood Science and Technology, 46: 927-938 http://dx.doi.org/10.1007/s00226-011-0449-4.
11. Khaydarov, R. A.; Khaydarov, R. R.; Gapurova, O.; Estrin, Y.; Scheper, T., 2009: Electrochemical method for the synthesis of silver nanoparticles. Journal of Nanoparticles Research, 11: 1193-1200 http://dx.doi.org/10.1007/s11051-008-9513-x.
12. Meijer, M.; Thurich, K.; Militz, H., 2001a: Quantitative measurements of capillary coating penetration in relation to wod and coating properties. Holz als Roh und Werkstoff, 59: 35-45 http://dx.doi.org/10.1007/s001070050469.
13. Meijer, M.; Van de Veld, B.; Militz, H., 2001a: Rheological approach to the capillary penetration of coating into wood. Journal of Coatings Technology, 73 (914): 39-51 http://dx.doi.org/10.1007/BF02698437.
14. Meijer, M., 2004: A review of interfacial aspects in wood coatings: wetting, surface energy, substrate penetration and adhesion. European Seminar on High Performance Wood Coatings, Exterior and Interior Performance, 26-27 April, Paris, France.
15. Militz, H.; Viöl, W., 2008: Increased PVA-glue adhesion on particle board and fiber board by plasma treatment. Holz als Roh- und Werkstoff, 66: 143-145 http://dx.doi.org/10.1007/s00107-007-0217-1.

16. Militz, H.; Viöl, W.; Avramidis, G., 2013: Plasma treatment to improve wood surface properties. The 9th Meeting of Northern European Network for Wood Science and Engineering (WSE) Sept. 11-12, Hannover, Germany.
17. Nejad, M.; Shafaghi, R.; Ali, H.; Cooper, P., 2013: Coating performance on oil-heat treated wood for flooring. Bioresources, 8 (2): 1881-1892 http://dx.doi.org/10.15376/biores.8.2.1881-1892.
18. Oltean, L.; Teischinger, A.; Hansmann, C., 2007: Influence of Temperature on Cracking and Mechanical Properties of Wood During Wood Drying – A Review. Bioresources, 2 (4): 789-811.
19. Pati, R., 2012: Molecule for electronics: A myriad of opportunities comes with daunting challenges. Journal of Nanomaterials & Molecular Nanotechnology 1:1. http://dx.doi.org/10.4172/2324-8777.1000e104.
20. Repellin, V.; Guyonnet, R., 2005: Evaluation of Heat Treated Wood Swelling by Differential Scanning Calorimetry in Relation with Chemical Composition. Holzforschung, 59 (1): 28-34 http://dx.doi.org/10.1515/HF.2005.005.
21. Saber, R.; Shakoori, Z.; Sarkar, S.; Tavoosidana, Gh.; Kharrazi, Sh.; Gill, P., 2013: Spectroscopic and microscopic analyses of rod-shaped gold nanoparticles interacting with single-stranded DNA oligonucleotides. IET Nanobiotechnology, 7 (2): 42-49 http://dx.doi.org/10.1049/iet-nbt.2012.0009.
22. Sönmez, A.; Budakci, M.; Pelit, H., 2011: The effect of the moisture content of wood on the layer performance of water-borne varnishes. Bioresources, 6 (3): 3166-3178.
23. ***SPSS Inc. Released 2010. PASW Statistics for Windows, Version 20.0. Chicago: SPSS Inc.
24. Taghiyari, H. R., 2011: Study on the Effect of Nano-Silver Impregnation on Mechanical Properties of Heat-Treated *Populus nigra*, Wood Sci. and Tech., 45: 399-404 http://dx.doi.org/10.1007/s00226-010-0343-5.
25. Taghiyari, H. R., 2013: Effects of heat-treatment on permeability of untreated and nanosilver-impregnated native hardwoods. Maderas-Cienc Tecnol, 15 (2): 183-194 http://dx.doi.org/10.4067/S0718-221X2013005000015.
26. Taghiyari, H. R.; Enayati, A.; Gholamiyan, H., 2013: Effects of nano-silver impregnation on brittleness, physical and mechanical properties of heat-treated hardwoods. Wood Science & Technology, 47 (3): 467-480 http://dx.doi.org/10.1007/s00226-012-0506-7.
27. Taghiyari, H. R.; Moradi Malek, B., 2014: Effect of heat treatment on longitudinal gas and liquid permeability of circular and square-shaped native hardwood specimens. Heat and Mass Transfer, 50 (8): 1125-1136 http://dx.doi.org/10.1007/s00231-014-1319-z.
28. Taghiyari, H. R.; Norton, J., 2014: Effect of silver nanoparticles on hardness in medium-density fiberboard (MDF). iForest 8: 677-680. http://dx.doi.org/10.3832/ifor1188-007.
29. Taghiyari, H. R.; Zolfaghari, H.; Sadeghi, M. E.; Esmailpour, A.; Jaffari, A., 2014: Correlation between specific gas permeability and sound absorption coefficient in solid wood. Journal of Tropical Forest Science, 26 (1): 92-100.

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Process Model of Quality Cost Monitoring for Small and Medium Wood-Processing Enterprises

Model procesa praćenja troškova kvalitete za mala i srednja drvoprerađivačka poduzeća

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ABSTRACT • *Quality is not only a technical category and the system of quality management is not only focused on product quality. Quality and costs are closely interlinked. The paper deals with the quality cost monitoring in small and medium wood-processing enterprises (SMEs) in Slovakia, and also presents the results of the questionnaire survey. An empirical study is aimed to determine the level of understanding and level of implementation of quality cost monitoring in wood-processing SMEs in Slovakia. The research is based on PAF model. A suitable model for quality cost monitoring is also proposed in the paper based on the research results with guidelines for using the methods of Activity Basic Costing. The empirical study is focused on SMEs, which make 99.8 % of all companies in the branch, and where the quality cost monitoring often works as a latent management subsystem. SMEs managers use indicators for monitoring the processe performance and production quality, but they usually do not develop a separate framework for measuring and evaluating quality costs.*

Key words: *quality, quality costs, small and medium wood-processing enterprises, process*

SAŽETAK • *Kvaliteta nije samo tehnička kategorija i sustav upravljanja kvalitetom nije fokusiran samo na kvalitetu proizvoda. Kvaliteta i troškovi međusobno su usko povezani. Ovaj se članak bavi praćenjem troškova kvalitete proizvodnje u malim i srednjim drvoprerađivačkim poduzećima u Slovačkoj. U njemu se ujedno prezentiraju rezultati provođenja istraživanja anketnim upitnikom. Iskustvene se studije temelje na određivanju razine razumijevanja i razine uvođenja praćenja troškova kvalitete u proizvodnji u malim i srednjim drvoprerađivačkim poduzećima u Slovačkoj. Istraživanje je utemeljeno na PAF modelu. U radu se predlaže najprihvatljiviji model praćenja troškova kvalitete s obzirom na dobivene rezultate istraživanja i daju se naputci za primjenu metoda Activity Basic Costing. Istraživanje se temelji na malim i srednjim poduzećima, koja čine 99,8 % svih poduzeća u drvoprerađivačkoj djelatnosti i u kojima se praćenje troškova kvalitete provodi u sklopu podsustava upravljanja. Menadžmenti u malim i srednjim poduzećima najčešće se koriste različitim indikatorima za praćenje proizvodnog sustava i kvalitete proizvodnje, no najčešće ne razvijaju zasebne odrednice za mjerenje i vrednovanje troškova kvalitete.*

Ključne riječi: *kvaliteta, troškovi kvalitete, mala i srednja drvoprerađivačka poduzeća, proces*

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1 INTRODUCTION
1. UVOD

The quality costs are very closely linked to a company's productivity and its performance (**Bekhta** *et al*., 2012). Al-Dujaili (2013) presents a research aimed at discovering a relationship between the quality improvements, quality costs, and productivity. By defying the concept of quality control, referring to the types of quality costs – prevention costs, appraisal costs, internal and external failure costs; and seeking to measure the impact of the quality improvement on productivity and costs, creates an opportunity for the company to improve. J. M. Juran (1987) was one of the first authors to write about quality costs. He describes the Quality Cost Optimum Model, which is a baseline for other models. Same quality costs categories were classified in the study of Su *et al*., (2009) in terms of trade-off relationship (increase of control costs resulting in the decrease of failure costs and vice versa). Integrated time delays in the statistical analysis were used to compute a balanced point of quality costs, which can provide a useful guidance on quality cost savings. Srivastava (2008) used these categories through the DMAIC (Define-Measure-Analyse-Improve-Check) methodology for quality cost analysis, to identify significant quality cost drivers and then to suggest measurements and directions for the next research. Branca and Catalão-Lopes (2011) contributed to the academic research through updating the traditional prevention-appraisal-failure approach by the strategic reaction of other companies, which affects market shares and profits.

The economic effects of quality improvement were reviewed by Eben-Chaime (2013), who demonstrated that the decrease of production costs in order to achieve a lower quality level is not an economic advantage (Freiesleben, 2005; Stasiak-Betlejewska, 2012), but vice versa – production costs could increase extremely due to low quality level. Kajdan (2007) combined the stream performance indicators with quality indicators to optimize the process on the bases of cost minimization. Trade-off relationship between the quality costs was defined in the study by Lin *et al*., (2012) related to a new product development, showing the impact of innovation speed on a project's success is mediated by development cost and product quality (Novakova and Kusy, 2010; Novakova, 2003). Traditionally, design quality and conformance quality are considered separately in the literature. In the paper by Wu (2010), both quality dimensions were integrated into stylized quality decision models for synthesizing quality cost design, conformance to quality cost, and product revenue components. Chiadamrong (2003) presented in his paper an empirical model of quality as a function of traditional cost model (prevention-appraisal-failure expenses) and hidden-opportunities in quality loss costs. This approach provides a view on tracking costs not only associated with production, but additionally with costs associated with quality. A study performed by Lari and Asllani (2013) shows the relationship of quality costs and operational processes and introduces a management support system in order to help the companies to continuously measure, check, and minimize quality costs. Fassoula (2005) addresses processes with a direct or indirect impact on quality costs, with the of implementing the process oriented diagnostic tool followed by assessment procedures for goal setting and action planning.

The main aim of the paper is to present the idea of quality cost monitoring as a framework design based on particular manufacturing conditions of small and medium enterprises in Slovakia. The research was carried out with a selected sample of small and medium manufacturing enterprises focusing on the current state of awareness and potential of quality cost control. The aim of the activity was to answer the basic question: „To what extent and on what level is monitoring of quality costs used in manufacturing in small and medium enterprises in Slovakia?"

2 MATERIAL AND METHODOLOGY
2. MATERIJAL I METODE

Small and medium wood-processing enterprises were the target and objective of the research. There are approximately 23 million SMEs in the European Union that offer approx. 75 million work places that represent 99.8 % of all enterprises. Within Slovakia, SMEs represent about 99.1 % of all registered enterprises. SMEs show flexibility in using progressive technologies and are a driving force for the economy development in creating job opportunities and are the main initiators of the growth of living standards within each country. According to the recent data of the Agency for Small and Medium Enterprise Development, in 2011 there were 153,283 small and medium enterprises (excluding sole traders) registered in Slovakia (Potkány, 2011).

For the purpose of collecting financial data for the research addressing the enterprises, a random sampling of 300 manufacturing wood-processing SMEs was selected from various areas of the national economy of the Slovak Republic. The empirical research was specifically targeted to finding the current level of use of tools for monitoring specific groups of quality costs, its evaluation, and organisational security from the viewpoint of a responsible controller by using process management. The basis for quality cost monitoring in wood-processing SMEs can be found in the implementation of the models and conditions that were created previously. This model should help enterprises create a compact reporting system for monitoring the quality costs and their evaluation.

The research methodology consists of four phases. In the first phase, methods of summary, synthesis, and analogy of the knowledge were used and a short review was prepared. In the second phase, a questionnaire was used to perform an empirical study, which represents the analysis of the situation of the solved practical issues within wood-processing SMEs in Slovakia. When working on the basic part of the questionnaire, the model of quality cost monitoring was based on PAF principles (prevention, appraisal, costs of failure). This questionnaire was evaluated according to graphic and description methods. In the third phase, a model of quality cost monitoring for small and medium manufacturing enterprises was designed**.**

The aim of the empirical research was to discover the level of understanding and the level of implementing the quality cost control in Slovak small and medium manufacturing enterprises, as well as to identify the potential possibilities and interest of implementing this system into an enterprise practice in future. Partial aims of the research were to find out if an enterprise practice in the given area corresponds with modern knowledge of theory, to process data gathered and consequently to formulate the findings and recommendations, which would enrich theory and contribute to a higher quality practice in an enterprise. The basic set of research was represented by small and medium-sized businesses located in Slovakia. According to the Statistical Office of the Slovak Republic, 153,284 small and medium sized enterprises were registered in 2011. Due to the large size of the basic set, it was not possible to include all small and medium enterprises into this research and therefore sampling was made through survey data. To choose the units from the basic set of the sample, one must make a deliberate choice based on the criteria defined by the directive EK No 2003/361/EC. The intended scope of the sample covered 300 enterprises. Determination of the scope of the sample set was the result of the following relation (Scheer, 2007):

$$n = \frac{z_{\alpha/2}^{2} \cdot p.(1-p)}{\Delta_{p^2}} \tag{1}$$

where n is scope of sample set, $z_\alpha/2$ are values of standard random quantity at 95 % reliability, (i.e. the value α = 0.05 corresponds to z = 1.96), $\Delta\, p$ requires exactness, resp. an error of estimation (determined at 5.65 %) and p is ratio (relative frequency) quality sign in the basic set (determined at 50 %). The actual scope of the sample set was at the level of 186 businesses due to the fact that 62 % of the questionnaires were returned. Despite the reduced scope of the sample set, the actual scope of the sample set may be considered as representative. Due to the facts presented by Kozelová *et al*. (2014), it can be stated that with respect to the research of institutions at the national level, the minimum scope of the sample set should be equal to 150 companies. The reduced number of sample set influenced the error of estimation, which rose to 7.18 %.

The ratio of questionnaire return was 62 %, which meant 186 completed questionnaires. When designing the methodology for evaluating the questionnaire, it was important to take into account that the selected surveyed enterprises stood for a relatively small sample to apply statistical methods of the questionnaire survey evaluation. The questionnaire survey was evaluated by a description method, numerically and in percents in tables and graphs. Within the questionnaire evaluation, the correlations between the quality cost control and quality management were established and so the questions were evaluated either individually or in groups of narrowly coherent/related questions. Using the statistical testing method, the level of representation of the sample file of companies was confirmed by the application of Pearson´s chi-squared test (χ^2 - test), which is also known as the 'goodness-of-fit' test. The calculation of the level of representation was done at the level of a statistical significance α = 0.05. The expected values of theoretical distribution were provided from the Statistical Office of the Slovak Republic. The frequencies observed, and the expected (theoretical) frequencies are shown in Table 1. The degree of freedom (k-1) is equal to two, since three categories of business organisation were defined.

The achieved χ^2 value was higher than the critical χ^2 value at the level of statistical significance of α = 0.05 for 2 degrees of freedom (3 - 1), which in particular presents the value of 5.991 (value in statistical tables). Since 40.59>5.991, the null hypothesis cannot be accepted and cannot be stated that the sample file of companies represents their theoretical distribution. Although according to the statistical yearbooks, the ratio of small enterprises in Slovakia is bigger than the ratio of medium size enterprises, in our research there was a dominance of middle size enterprises. It is a given fact that the scope of the research was to find out the level of implementation of quality cost control in enterprises by following the indicators of quality costs. Based on logical judgement, these levels will be higher in the case of medium size enterprises and that is why this research is focused on this area.

Based on the conducted research, 74 % of the questioned enterprises do not consider management of quality and quality cost control as identical areas, while 48 % of those asked think that these two areas still have something in common. These two answers can be considered as correct, which means that most of the respondents have the proper knowledge of the subject matter (Figure 1).

Figure 2 represents the percentage of the answers of enterprises to question Q2 – Do you deal with monitoring individual groups of costs in terms of PAF model methodology? and question Q3 – Do you have your

Table 1 χ^2-test by enterprise size
Tablica 1. χ^2-test vezan za veličinu poduzeća

	np_i (%)	n_i (%)	$(n_i - np_i)^2$	χ^2
Micro enterprises / *Mikro tvrtke*	10	9.56	0.19	0.02
Small enterprises / *Male tvrtke*	50	29.41	423.95	8.48
Medium enterprises / *Srednje velike tvrtke*	30	61.03	962.86	32.09
Σ				40.59

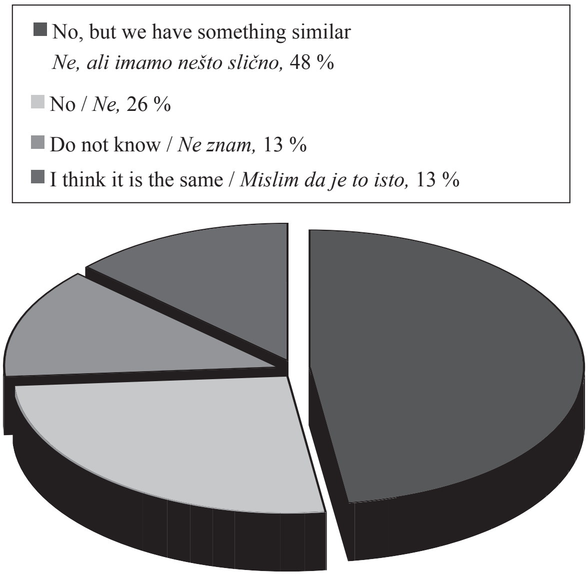

Figure 1 Question 1 – Do you think that quality cost control is the same as the quality management?
Slika 1. Analiza odgovora na pitanje 1.: Mislite li da je kontrola troškova kvalitete isto što i upravljanje kvalitetom?

own methodology for determining costs for quality appraisal?

The present results show that, from the viewpoint of monitoring of individual groups of costs according to the PAF model, enterprises pay bigger attention to monitoring cost entries for external failures (67 %). Our own methodology for cost monitoring has only a small group of respondents (26 %) and it only concerns scoring reclamations/claims. Figure 3 presents the answer structure of the enterprises that, within question Q2, presented a positive viewpoint of monitoring any group of quality costs according to PAF model. It can be stated that companies mostly deal with costs of external and internal failures - the losses caused by poor quality (in total 65 % of answers).

Question Q4 deals with personnel representation from the viewpoint of a quality controller. Figure 4 presents the results among the surveyed enterprises that deal with quality cost control; these have mostly multifunctional jobs (74 % of respondents) and these represent posts of quality managers, agents for quality and manufacturing managers. Therefore, only 4 % of the surveyed enterprises have a job position of quality controller.

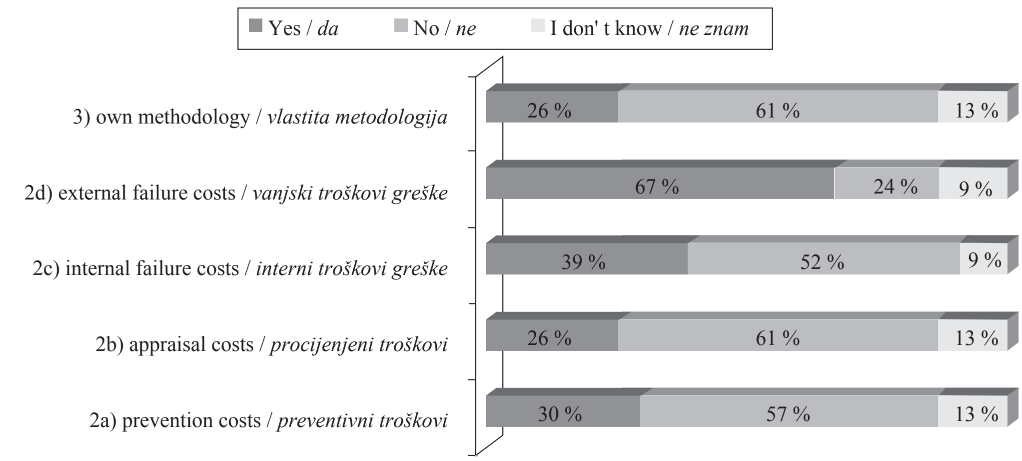

Figure 2 Questions Q2 and Q3
Slika 2. Analiza odgovora na pitanja Q2 (Pratite li pojedine skupine troškova kvalitete prema PAF modelu?) i Q3 (Imate li vlastitu metodologiju za praćenje troškova loše kvalitete?)

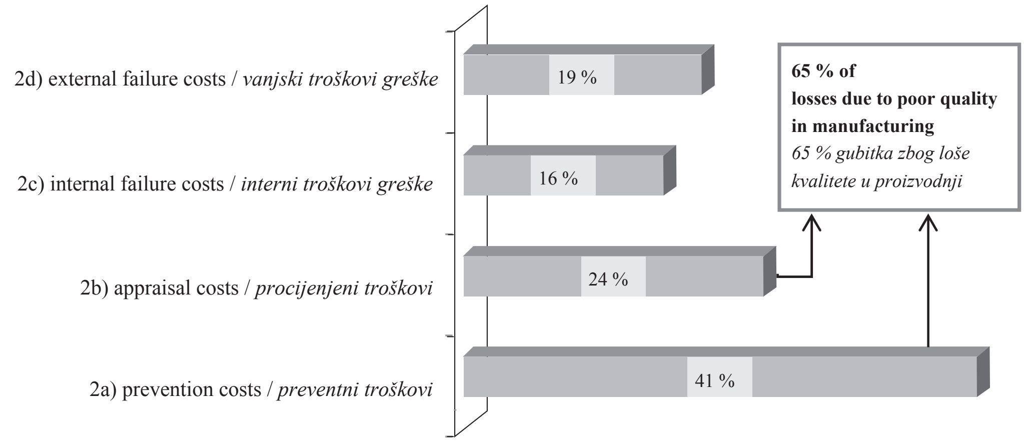

Figure 3 Percentage of individual groups of quality costs
Slika 3. Postotni udio pojedinih promatranih skupina troškova kvalitete

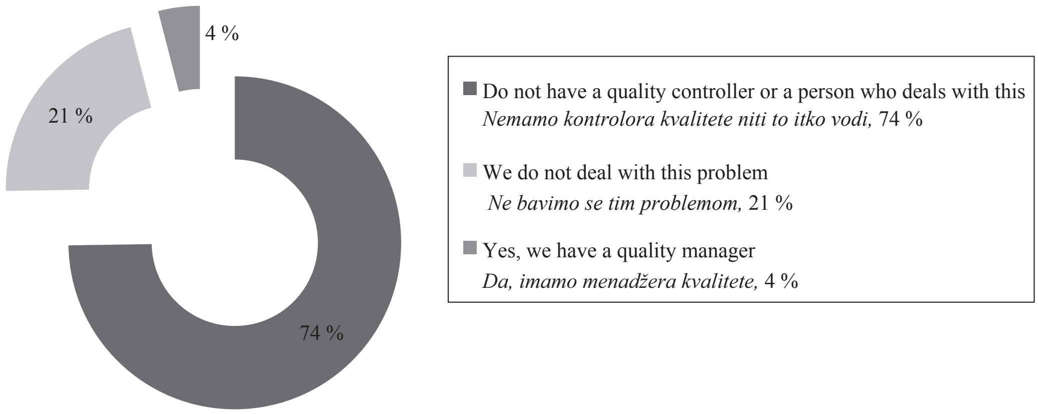

Figure 4 Question 4
Slika 4. Analiza odgovora na pitanje Q4 (Imate li uposlenika koji je zadužen za kontrolu kvalitete u poduzeću?)

ISO standards are mostly focused on the economic aspect of quality; there is a presumption that enterprises, which have implemented the quality management system according to ISO standards and at the same time also the process map, could also deal in more detail with the economics of quality. These results are presented in Figure 5.

Figure 5 results in the following:

- The majority of respondents are certified or are in the certification process according to ISO standards (57 %) and another 37 % are interested in certification in future;
- Also the majority of respondents have set up a process map or will prepare it in a near future (57 % in total);
- Referring to presented data, 65 % of respondents deal with losses due to faulty manufacturing.

In the case of the question that focused on the potential of using quality cost control, it can be stated that 29 % of respondents are interested in implementing quality cost control system into their enterprises, 34 % stated that „yes, but we are not sure“, and the rest, 37 % did not show interest in implementing quality cost control within the enterprise at all.

The summary of the presented findings can be formulated as the results of the conducted survey: Slovak small and medium manufacturing enterprises mostly deal with costs of quality, more precisely with costs for external and internal failures (losses caused by poor quality), which means that from the viewpoint of the level of development of quality cost control, these enterprises are just in their initial phase of such development.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The findings of the empirical research show that wood-processing small and medium enterprises in Slovakia do not actually use a single monitoring methodology and appraisal of quality costs, and in general they do not use further possibilities that can be applied in the

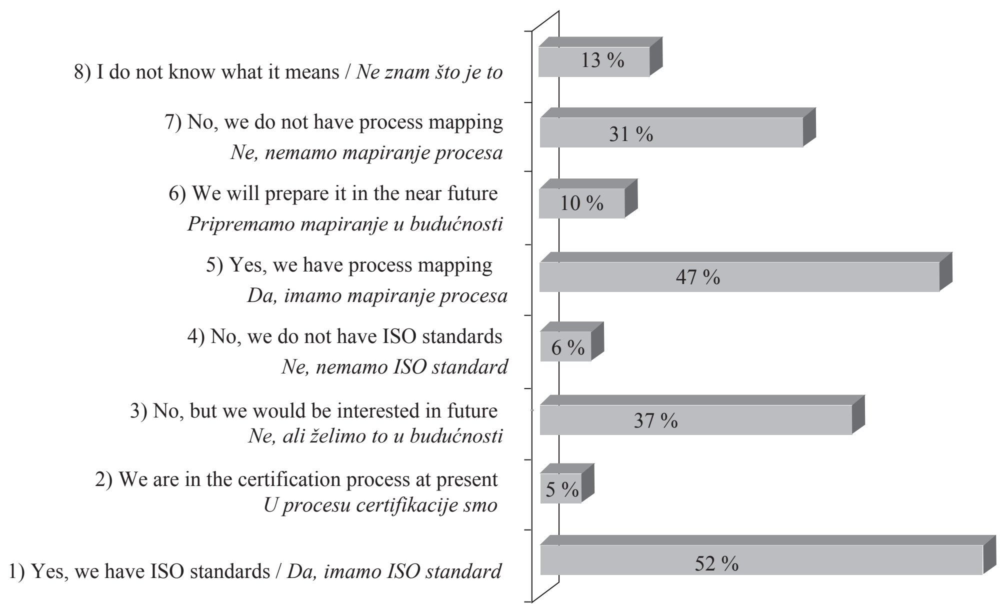

Figure 5 Questions Q5 and Q6
Slika 5. Analiza odgovora na pitanje Q5 (Imate li certifikat prema ISO standardima?) i pitanje Q6 (Obavljate li mapiranje procesa?)

present area. The present process model of quality cost for wood-processing SMEs (steps 1-9 and Figure 7) consists of components that take into consideration the aspects of both process quality and bookkeeping.

1a) Aspect of quality and processes – identification of enterprise quality objectives

To develop a target model of total costs of quality for wood-processing SMEs, the first step is to set objectives in the area of quality that an enterprise wants to reach. These objectives must be a part of strategic aims and future direction of an enterprise. For this purpose, the majority of objectives should be measurable values within the enterprise, as this is a basic feature of the quality cost monitoring.

2a) Aspect of quality and processes – identification of enterprise processes

One of the basic objectives of quality is to identify all company processes listed in an enterprise processes map. For the purpose of monitoring the costs of quality, it is necessary to identify its individual parts of the processes and indicators of their quality measurement.

3a) Aspect of quality and processes – classification of costs for quality

On the bases of the stated measurable quality objectives, identification of enterprise processes, activities and indicators of their quality measurement is another step in the classification of quality costs (model PAF) in individual processes, which will be suitable and possible from the viewpoint of information accessibility in the enterprise in question. Identification of the above listed indicators enables to consider the aspect of quality and processes in the model to be developed.

1b) Aspect of book-keeping – analysis of the nominal ledger, and account content, analysis of departments

For the complex understanding of monitoring the costs of quality, it is necessary to interconnect both areas (book-keeping and quality) and redefine the basic input economic information. This means re-evaluation of content of individual analytic accounts of the nominal ledger, their targeted selection and analysis of departments in relation to quality costs. Data from the nominal ledger will, via the accounting crosswalk, enter the management profit and loss account, which will be in vertical division starting from the structure of ABC calculation.

2b) Aspect of book-keeping – division of costs through Activity Basic Costing

Since management profit and loss account comes from the methodology of the process calculation – ABC, the enterprise costs have to be divided into activities.

3b) Aspect of book-keeping – definition of transfer crosswalk and management profit and loss account

Defining the suitable transfer crosswalk between analytic accounts of nominal ledger and management profit and loss account is considered to be an important and essential part of the given model. The essentials of transfer crosswalk are illustrated in Figure 1 in relation to the definition of work flow. The management of profit and loss account will be the basis for monthly appraisal of enterprise results. We propose the processing of management profit and loss account in gradual classification from the gross revenues via gradual adjustments of individual costs/revenues to overall management result before taxation (EBT). In the following components (step 4-9) there is cross connection of the point of quality and book-keeping.

4) Identification of cost of quality according to analytical accounts and information sources

In order to identify quality costs, it is necessary to determine the information sources that can be used in the enterprise, and also to define particular analytical accounts and corresponding account documents. In case some account documents are not sufficient, considering data from other enterprise record-keeping (reports, statistical indicators, trend analysis) is also recommended.

5) Collection of data about costs of quality i.e. definition of „workflow"

This step is considered to be the most important when designing the model, since it is necessary to set which approach will be the most effective for data collection. Therefore, it is necessary to re-evaluate the content of each chosen item of quality costs from the point of view of secondary division (material, wages, energy, services, etc.) and to find the way how a controller can obtain these data i.e. how, who from, where and when. In this phase, it is also necessary to define a codebook of individual costs of quality. Information about costs of quality can be obtained from bookkeeping and directly from delivered invoices with the identification of the department of the costs of quality (cost of quality = CQ) according to PAF model or the complex enterprise information system.

6) Software support in creating a manager report

Thus obtained information is further evaluated via extension of enterprise information system, which is represented by information system or a dynamic model in the MS Excel environment in the proposed model. This extension of enterprise information system is essential for the formation and use of information database of our designed model in form of a reporting message. In the proposed process model of costs, quality costs will be monitored not only as absolute indices but also as ratio NQ indices, ratio indices to revenues or to overall costs. At the same time, it will be possible to monitor deviations from minimally acceptable phases, and their cumulative sum within the accounting phase also in interim comparison.

7) Suggestion for reporting and communication with users

This phase deals with design of management profit and loss account in its horizontal division to – yearly budget plan, flexible budget (FB – calculation of planned prices and costs for the real capacity of sales), reality, variances, estimates and proposal for correction measures for future. In vertical division, the manager report should be structured from the point of the view of the ABC calculation, meaning that costs should be

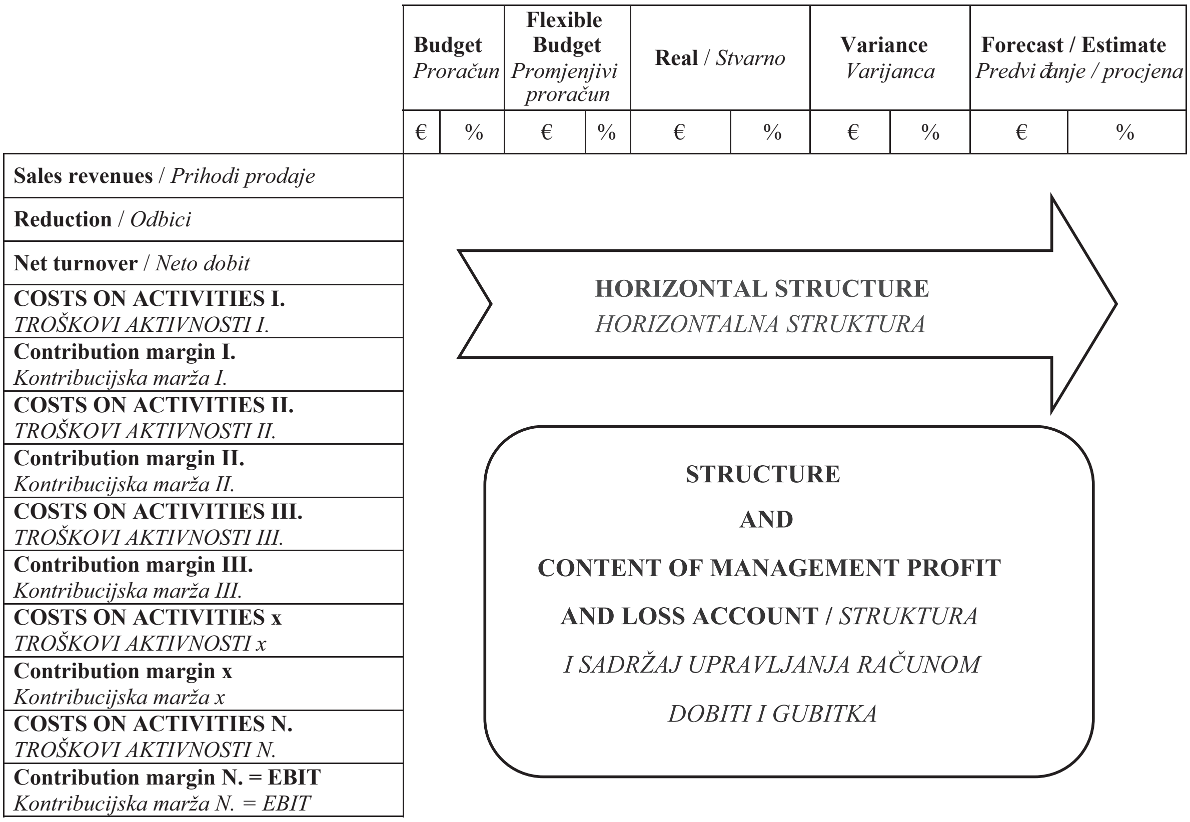

Figure 6 Proposed management profit and loss account based on ABC calculation
Slika 6. Prijedlog za upravljanje računom dobiti i gubitka utemeljen na ABC metodi

allocated on activities. Figure 6 presents the proposed management profit and loss account in its vertical and horizontal division.

8) Analysis, management variance and effects of quality cost monitoring

For the analysis of costs of quality, quality indicators should be amended so as to show the effects of monitoring the costs of quality and these should persuade enterprise managers to focus on the designed subject matter. The detection of savings in costs of quality (in the area of internal errors – non-productive costs of material, energy, work, in the area of external failures – elimination/minimising of claims and other related costs – e.g. costs of transportation and such like) can be an important effect of the quality cost monitoring. External effects of monitoring the costs of quality will also become evident in terms of customers satisfaction and loyalty, in positive references and spreading of enterprise good reputation, which can strengthen its competitiveness in the market.

9) Communication with TOP management in form of monthly manager reports

Detected variances from the planned conditions (positive, negative) are necessary to be discussed on the level of TOP management in form of monthly manager reports and remedial measures should be prepared to eliminate negative variances and to establish how to use the effects of the positive ones.

The proposed process model of quality cost monitoring for wood-processing SMEs interconnects the aspect of processes and the aspect of book-keeping (identification of individual analytic accounts). The proposed model can also partly use the ABC costing methodology, via which it is possible to assign costs of quality (sources) through activities (processes) towards individual cost objects (orders, cost pool, processes) (Vetráková *et al*., 2013). This approach, however, requires the use of ABC costing methodology in enterprise management i.e. in designing calculations and division in enterprise management i.e. in creating calculations and division of overall costs for orders as well as in approving the present state of mind and planning orders. The following figure presents a transparent process model of the quality cost monitoring, which is generally suitable for small and medium manufacturing enterprises from the point of view of versatility of its use.

4 CONCLUSION
4. ZAKLJUČAK

Slovakian small and medium wood-processing companies make 99.8 % of all companies in the branch. As shown in the research, these companies use the methodology for monitoring quality costs that is not sufficient and they do not define their internal guidelines. In this research, the model for monitoring these costs is recommended. Big companies have the methodology for monitoring quality costs, which is also used in their daughter companies. To make small and

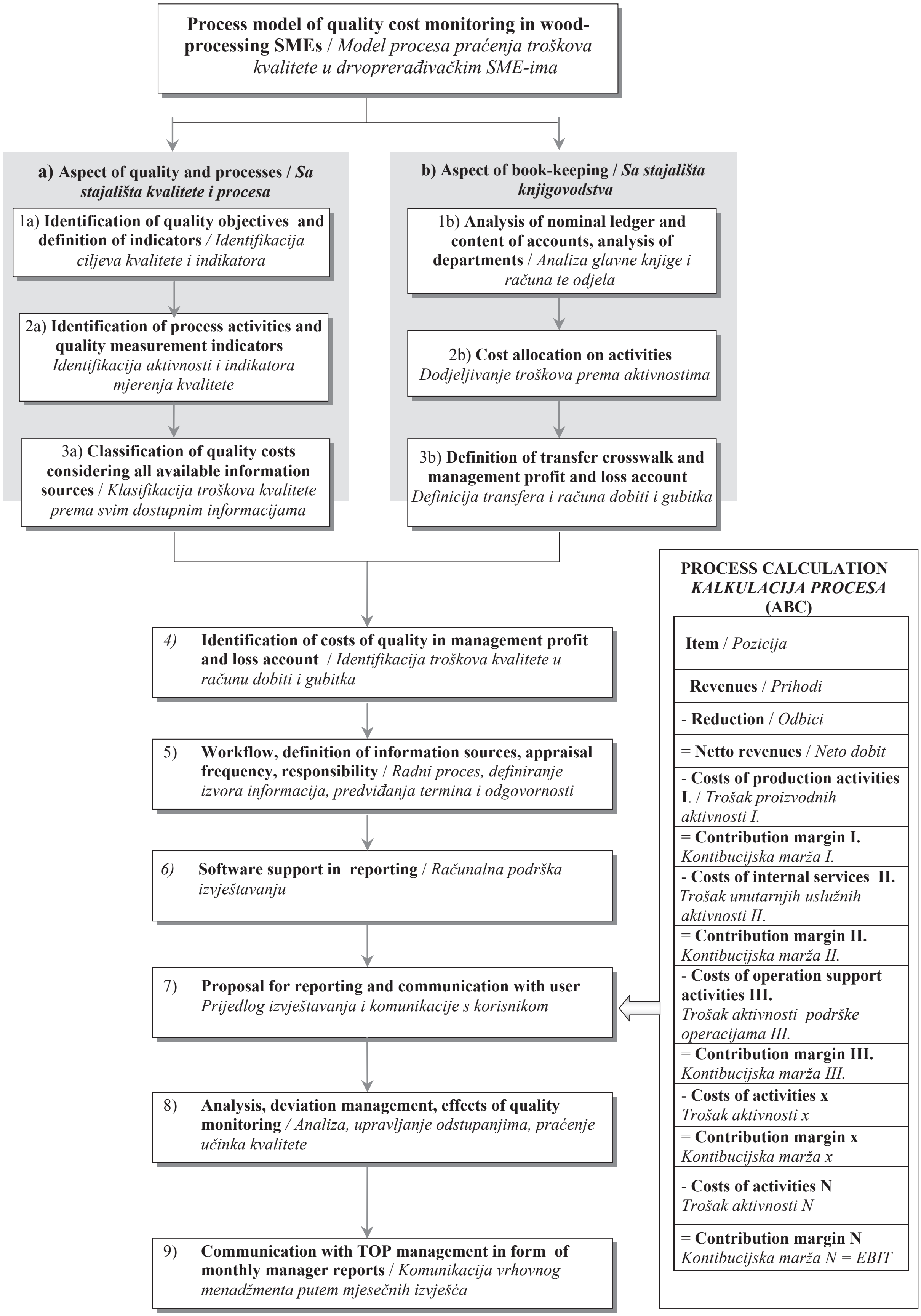

Figure 7 Process model of quality cost monitoring in wood-processing SMEs
Slika 7. Model procesa praćenja troškova kvalitete proizvodnje u malim i srednjim drvoprerađivačkim poduzećima

medium companies able to use the methods of Activity Basic Costing, it is necessary to do as follows:

1. According to standard ISO 9001/2008. Quality management system. Requirements, companies have to create a process map, which is the basis for company process management;
2. Processes have to be divided to management, main and additional (and based on this division activities have to be defined);
3. For particular activities, the size should be defined (Activity Cost Drivers);
4. For particular process, it is necessary to establish measurement criteria NQ, i.e. particular costs divided to fix and variable in groups NP, NH, NI and NE;
5. At this point, it is necessary to create horizontal and vertical structure of reporting.

The aim of each enterprise should be to eliminate the losses, detect weaknesses, and provide preventive measures, i.e. create an effective feedback system, which would signal weaknesses on time and offer the responsible staff valuable information for solving the present problems. The above problems force companies to use modern management tools, one of which is controlling in the area of quality management. Its task is to secure the quality of management by equally relevant information concerning quality with the aim to fulfil the set objectives, detect weaknesses, and identify process defects.

This paper analyses the current state of the subject matter based on the reviewed literature with a focus on quality cost control. Via the questionnaire survey, the level of understanding, implementation, and establishment of quality cost monitoring was determined in Slovak wood-processing SMEs and the complex model for quality cost monitoring was proposed. The essence of the introduced model is to present the sequence of steps necessary for applying a quality control concept in wood-processing SMEs, which is based on the identification of quality aims, processes, costs of quality, collection of data, and definition of information sources aimed at developing the pattern of a manager report. Such reports have their own horizontal and vertical structure. The vertical structure of the manager report is created by individual items of managing the profit and loss account, beginning with revenues through gradual deduction of costs of quality until the economic profit before taxation (EBT). This structure is mainly used for identifying individual costs of quality groups and appraising them through simple relative ratio indicators. The horizontal structure of a manager report creates two basic parameters - time and variant, which create the basis for the so called management system through variances. Time is given by the period of monitoring (month, quarter, and year). This version is based on comparison of a yearly plan, flexible budget, and a real situation in the given month, with comparison of the estimate till the end of year (E - estimate) and plan (B - budget).The proposed model of quality cost monitoring can be helpful for enterprises to create a compact reporting system for monitoring costs of quality and their further evaluation on the basis of controlling principles, which will show the transparent flow of costs and detect hidden reserves and enable their elimination. As small and medium enterprises have proven highly adaptable to receive and use progressive tools in the area of management, it can be stated that our proposal could be used in manufacturing SMEs regardless of the branch of economics.

Controlling is an effective basis of active management of companies and it can be used in different functions such as financial controlling, investment controlling, cost controlling, personnel controlling, and finally also quality controlling. These particular controlling subsystems are not to be used partially, since they make a system with mutual interactions and they support and fulfil each other.

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5 REFERENCES
5. LITERATURA

1. Al-Dujaili, M. A. A., 2013: Study of the relation between types of the quality costs and its impact on productivity and costs: verification in manufacturing industries. Total Quality Management and Business Excellence, 24 (3-4): 397-419 http://dx.doi.org/10.1080/14783363.2012.669552.
2. Bekhta, P.; Niemz, P.; Sedliačik, J., 2012: Effect of prepressing of veneer on the glueability and properties of veneer-based products. European Journal of Wood and Wood Products, 70 (1-3): 99-106 http://dx.doi.org/10.1007/s00107-010-0486-y.
3. Branca, A. S.; Catalão-Lopes, M., 2011: Strategic interaction and quality choice. Total Quality Management and Business Excellence, 22 (3): 265-273 http://dx.doi.org/10.1080/14783363.2010.530809.
4. Chiadamrong, N., 2003: The development of an economic quality cost model. Total Quality Management and Business Excellence, 14 (9): 999-1014 http://dx.doi.org/10.1080/1478336032000090914.
5. Eben-Chaime, M. A., 2013: Note on: the economic effects of quality improvements. Total Quality Management and Business Excellence, 24(3-4): 374-377 http://dx.doi.org/10.1080/14783363.2012.734952.
6. Fassoula, E. D., 2005: Reverse logistics as a means of reducing the cost of quality. Total Quality Management and Business Excellence, 16 (5): 631-643 http://dx.doi.org/10.1080/14783360500077575.
7. Freiesleben, J., 2005: The economic effects of quality improvement. Total Quality Management and Business Excellence, 16 (7): 959-969 http://dx.doi.org/10.1080/14783360500077419.
8. Juran, J. M., 1987: Quality cost optimum model. Quality progress, 20 (4): 7-14.
9. Kajdan, V., 2007: Why Quality, Cost and Business Excellence are Inseparable. Total Quality Management and Business Excellence, 18 (1-2): 147-152 http://dx.doi.org/10.1080/14783360601052139.
10. Kozelová, D., et al. 2014: Analysis of consumer behavior at chocolate purchase. Potravinárstvo, 8 (1): 61-66

http://dx.doi.org/10.5219/325.
11. Lari, A.; Asllani, A., 2013: Quality cost management support system: an effective tool for organisational performance improvement. Total Quality Management and Business Excellence, 20 (3-4): 432-451 http://dx.doi.org/10.1080/14783363.2012.733258.
12. Lin, M. J. J.; Huang, Ch. H.; Chiang, I. Ch., 2012: Explaining trade-offs in new product development speed, cost, and quality: The case of high-tech industry in Taiwan. Total Quality Management and Business Excellence, 23 (9-10): 1107-1123 http://dx.doi.org/10.1080/14783363.2011.637784.
13. Nováková, R.; Kusý, O., 2010: Trends of quality management - quality economy. In: Vysokije technologii, issledovanija, promyšlennosť: Sbornik trudov 9. meždunarodnoj naučno-praktičeskoj konferencii "Issledovanije, razrabotka i primenenije vysokich technologij v promyšlennosti". 22-23. 4. 2010, Sankt-Peterburg, Russia. Tom 4. - Sankt-Peterburg: Izdateľstvo Politechničeskogo universiteta, pp. 6-11.
14. Nováková, R., 2003: Ekonomické náklady a prínosy z certifikačného procesu systémov manažérstva kvality (The economic costs and gains from the certification process in management quality). In: Research papers Faculty of Materials Science and Technology Slovak University of Technology in Trnava. 15: 109-114.
15. Potkany, M., 2011: Outsourcing v podnikoch drevospracujúceho priemyslu na Slovensku. Zvolen: Vydavateľstvo TU vo Zvolene.
16. Vetráková, M.; Potkány, M.; Hitka, M., 2013: Outsourcing of facility management. E+M Ekonomie a Management, 16 (1): 80-92.
17. Scheer, L., 2007: Biometria. Zvolen: Technical university in Zvolen.
18. Srivastava, S. K., 2008: Towards estimating Cost of Quality in supply chains. Total Quality Management and Business Excellence, 19 (3): 193-208 http://dx.doi.org/10.1080/14783360701600605.
19. Stasiak-Betlejewska, R., 2012: Value engineering as the way of quality problems solving in the steel construction management, Manufacturing Technology, 12 (13): 242-247.
20. Su, Q.; Shi, J. H.; Lai, S. J., 2009: Research on the trade-off relationship within quality costs: A case study. Total Quality Management and Business Excellence, 20 (12): 1395-1405 http://dx.doi.org/10.1080/14783360903248922.
21. Wu, L., 2010: Managing design quality and conformance quality: models and insights. Total Quality Management and Business Excellence, 21 (4): 383-389 http://dx.doi.org/10.1080/14783361003606597.

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Application of Reduced Stiffness of Complex Laminate in Finite Elements for Chair Analysis

Primjena reducirane krutosti kompleksnog laminata u konačnim elementima za analizu stolaca

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ABSTRACT • *This paper presents a numerical procedure for the analysis of complex laminate structures. The procedure is based on the application of reduced stiffness of complex laminate. Introduction of reduced stiffness of composite facilitates both linear and nonlinear numerical integration, i.e. the tangential stiffness matrix is translated in the classical plate theory problem. The formulated numerical procedure was implemented in the program system KOMIPS. Special subroutine REDKRUT that calculates reduced stiffness of the laminate was written, and its application in numerical verification of experiments conducted on chairs was presented in (Nestorovic, 2010). At the end of this work, for 3D stress and strain analysis of veneer composites, recommendations were given for experimental determination of all nine independent material constants E_x, E_y, E_z, v_{xy}, v_{xz}, G_{xy}, G_{xz}, G_{yz}, five of which were determined in the previous paper of the author (Nestorović, 2010).*

Key words: *reduced stiffness, finite elements, composite, material constants, shell, chair*

SAŽETAK • *Rad prikazuje numeričku proceduru za analizu struktura izrađenih od kompleksnih laminata. Postupak se temelji na primjeni reducirane krutosti komplesnog laminata. Uvođenjem reducirane krutosti kompozita numerička se integracija, kako linearne, tako i nelinearne, odnosno tangencijalne matrice krutosti, prevodi u problem klasične teorije ploča. Formulirana numerička procedura implementirana je u sklopu programskog paketa KOMIPS. Napisana je posebna subrutina REDKRUT, kojom se proračunavaju reducirane krutosti laminata, a njegova primjena u provjeri numeričkih eksperimenata provedenih na stolcima prikazana je u radu (Nestorovic, 2010.). Za 3-D analizu naprezanja i deformacija furnirskih kompozita na kraju ovog rada dane su preporuke za eksperimentalno određivanje svih devet neovisnih materijalnih konstanti: E_x, E_y, E_z, v_{xy}, v_{xz}, G_{xy}, G_{xz}, G_{yz}, od kojih je pet određeno u prethodnom autoričinu radu (Nestorović, 2010.).*

Ključne riječi: *reducirana krutost, konačni elementi, kompozit, materijalne konstante, ljuska, stolac*

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1 INTRODUCTION
1. UVOD

Theoretical basis of linear elastic anisotropic and orthotropic material is the concept that implies definition of stress-strain as well as reciprocal strain-stress dependencies. From the general 3D state of stress, 2D case that represents conditions of plane state of stress was derived, and for these conditions classical thin plate and shell theory were applied, with the focus on wood composite structures. By introducing reduced stiffness of composites, both linear and nonlinear numerical integrations of respective tangential stiffness matrixes were translated into the problem of classical plate theory.

The aim of this paper was to specify a mathematical model for the calculation of complex laminate, and develop the procedure that applies reduced plate, which can reliably replace the use of complex laminate. We presented a formulation of composite finite plate element in the case of geometrical and material linear and nonlinear treatments by application of reduced stiffness of the composite, concluding with the recommendations and guidelines for further researches. The paper represents an integral part of the research presented in (Nestorović, 2010), certain parts of which, referring to the results of FEM calculations and experimental measurements, were previously published in (Nestorovic *et al.*, 2011, 2012, 2013; Nestorović and Grbac, 2011).

1.1 Laminae as arbitrary layer of laminate
1.1. Lamela kao proizvoljni sloj laminata

The structure of the laminate represents the compound of a number of laminae, whose principal material directions are oriented to enable the laminate structural capability to resist loads in different directions. Application of Classical Lamination Theory (CLT) facilitates the explanation of laminate structure starting from its base building layer - laminae.

CLT in the conditions of bending is based on Kirchhoff-Lowe hypothesis of flat sections before and after deformation. Namely, the linear element orthogonal to the mid-plane of the laminate after deformation remains flat, unchanged in length and perpendicular to the deformed mid-surface of the laminate. This condition will be fulfilled only if all compatibility conditions of overlapping of displacements in all points of the laminae with the adjacent layers are satisfied. Hence, it can be concluded that laminae behaves as a layer with special properties. With this in mind, it is possible to determine the change of dilatation and stress through the thickness of the laminate.

The technical hypothesis of length changelessness and linear element orthogonallity on the mid-plane of the laminate before and after deformation (direction ABCD under deformation, Figure 1), means that dilatations in *z* direction, as well as shear deformations in plans orthogonal to the mid-plane of the laminate, equal zero ($\varepsilon_z = \gamma_{xz} = \gamma_{yz} = 0$).

If displacement is denoted in the x-direction of the point B, which is not the mid-plane of the laminate, with, than the displacement of the arbitrary point C, on equidistance from the middle plane in the same direction, is

$$u_c = u_o + z_c \beta_y \qquad (1)$$

where is rotation of the cross section of laminate around y-axis

$$\beta_y = -\frac{\partial w}{\partial x} \qquad w = w_0 = const. \qquad (2)$$

Let and be displacements of the points on the middle plane in the directions of *x*, *y*, and *z*-axis. Based on the expressions (1) and (2), it can be concluded that displacement in any point through the thickness of the cross section of the laimate is

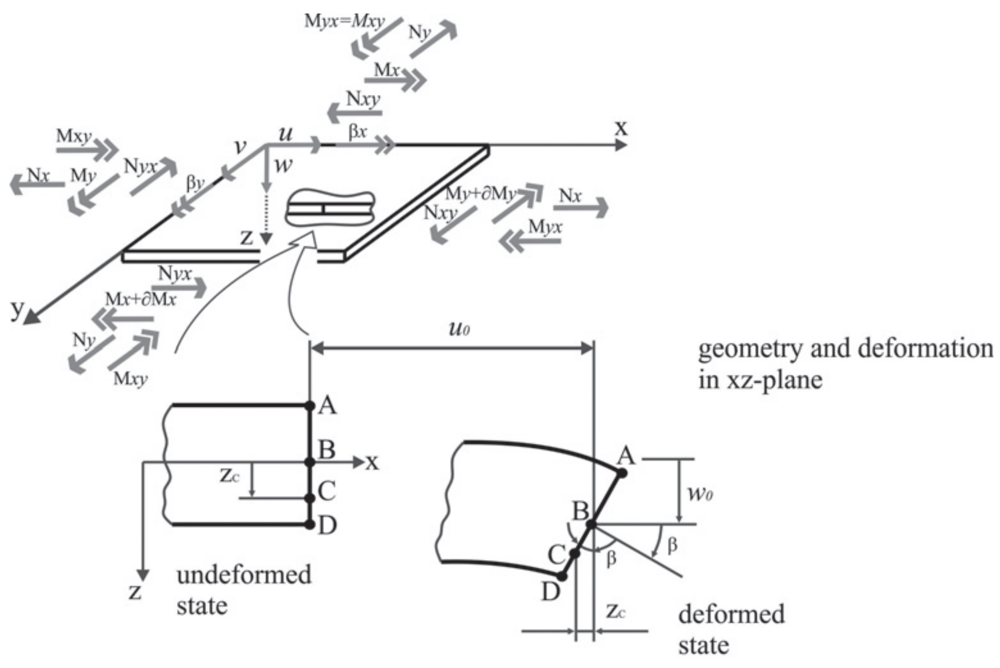

Figure 1 Laminate plate under bending
Slika 1. Laminatna ploča u uvjetima savijanja

$$u = u_o - z\frac{\partial w}{\partial x} \quad (3)$$

Consequently, displacement in the y direction is

$$v = v_o - z\frac{\partial w}{\partial y} = v_0 - z\beta_x, \quad \beta_x = \frac{\partial w}{\partial y} \quad (4)$$

where β_x is rotation of the cross section of the laminate around x-axis.

Having in mind geometrical relations that established dependence between strains and displacements

$$\varepsilon_x = \frac{\partial u}{\partial x}, \ \varepsilon_y = \frac{\partial v}{\partial u}, \ \gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \quad (5)$$

Using matrix notation, the following equation can be expressed:

$$\begin{aligned} \varepsilon_{x0}^T &= [\varepsilon_{x0} \ \ \varepsilon_{y0} \ \ \gamma_{xy0}] = \\ &= [\frac{\partial u_o}{\partial x} \ \ \frac{\partial v_o}{\partial y} \ \ \frac{\partial u_o}{\partial y} + \frac{\partial v_o}{\partial x}] = \varepsilon_{x0} + z\kappa \end{aligned} \quad (6)$$

whereis the mid-plane strain and κ is the vector of second derivatives of the displacement, i.e. curvature

$$\kappa^T = [\kappa_x \ \ \kappa_y \ \ \kappa_{xy}] = -[\frac{\partial^2 w}{\partial x^2} \ \ \frac{\partial^2 w}{\partial y^2} \ \ 2\frac{\partial^2 w}{\partial x \partial y}] \quad (7)$$

The component κ_{xy} is a twisting curvature, stating how the x-direction mid-plane slope changes with y (or equivalently, how the y-direction slope changes with x).

Having in mind that the geometrical relation (5) belongs to the plate theory, Jones (1975) stressed that the more correct designation for the classical lamination theory (CLT) would be the classical theory of laminated plates.

Stress and strain relations in the case of orthotropic laminae, in which the calculated and main material directions do not coincide, in accordance with equation (5), will be expressed as follows

$$\sigma_k = \bar{Q}_k \varepsilon_k \quad (8)$$

where $\bar{Q}$ denotes transformed stiffness matrix in the state of stress.

$$\sigma_x = \bar{Q}_k(\varepsilon_{x0} + z\kappa) \quad (9)$$

Assumed forms of dilatation and stress change across the thickness of the laminate are given as an example in Figure 2.

1.2 Forces and moments in laminate sections
1.2. Sile i momenti u presjecima laminata

Figure 3 shows laminate of the thickness *h* composed of Nlaminae. Z-axis is directed downward from the laminate midd-plane.

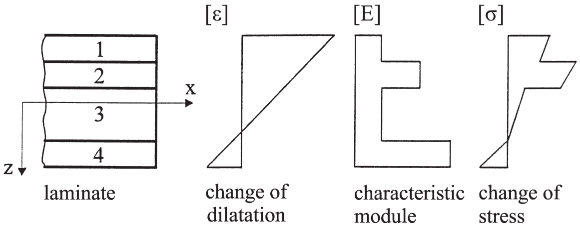

Figure 2 Change in dilatations and stresses across the laminate thickness
Slika 2. Promjena dilatacija i naprezanja po debljini laminata

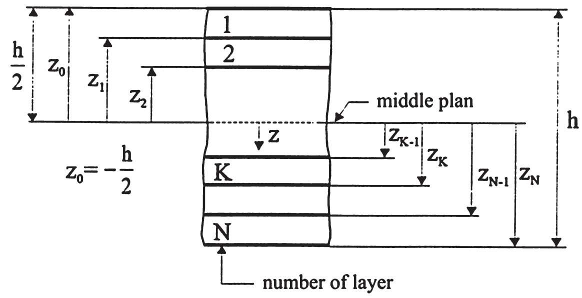

Figure 3 Coordinates and ordinal numbers of laminas in laminate
Slika 3. Koordinate i redni brojevi lamela u laminatu

Components of membrane forces and bending moments will be determined as

$$\begin{aligned} N &= \int_{-h/2}^{h/2} \sigma dz = \sum_{k=1}^{N} \int_{z_{k-1}}^{z_k} \sigma dz \\ M &= \int_{-h/2}^{h/2} z\sigma \, dz = \sum_{k=1}^{N} \int_{z_{k-1}}^{z_k} z\sigma \, dz \end{aligned} \quad (10)$$

while index "$_k$" represents *k*-th laminae (layer) in the laminate.

Integrating the expression (10), it follows that

$$\begin{aligned} N &= \sum_{k=1}^{N} \bar{Q}_k (\int_{z_{k-1}}^{z_k} \varepsilon_{x0} \, dz + \int_{z_{k-1}}^{z_k} z \ \kappa dz) \\ M &= \sum_{k=1}^{N} \bar{Q}_k (\int_{z_{k-1}}^{z_k} z\varepsilon_{x0} \, dz + \int_{z_{k-1}}^{z_k} z^2 \ \kappa dz) \end{aligned} \quad (11)$$

or,

$$N = D_m \ \varepsilon_{x0} + D_{mb} \ \kappa \qquad M = D_{mb} \, \varepsilon_{x0} + D_b \kappa \quad (12)$$

where matrixes

$$\begin{aligned} D_m &= \sum_{k=1}^{N} (z_k - z_{k-1}) \bar{Q}_k \qquad D_{mb} = \frac{1}{2} \sum_{k=1}^{N} (z_k^2 - z_{k-1}^2) \bar{Q}_k \\ D_b &= \frac{1}{3} \sum_{k=1}^{N} (z_k^3 - z_{k-1}^3) \bar{Q}_k \end{aligned} \quad (13)$$

represent laminate stiffness on elongation, banding as well as coupled stiffness.

Based on the (12) and (13), it can be concluded that in general case of anisotropic laminate, membrane forces are not just a function of membrane deformation, but of the change of the curvature as well. On the other hand, it can be easily noted that bending moments and torsion moments in arbitrary laminate section do not only depend on a change of curvature of its mid-plan, but also on membrane deformations. The influence of the curvature change in the membrane section forces as well as the influence of membrane deformations on section bending forces is expressed by coupling stiffness of laminate D_{mb}.

2 STIFNESSES OF THE LAMINATE AND LAMINAE
2. KRUTOSTI LAMINATA I LAMELE

Coupling stiffness D_{mbij} is the consequence of both material characteristics of the laminate and geometrical arrangement of laminas in the laminate. Neglecting the influence of coupling stiffness, in the cases when they are present in the composite structures, could mischief the accuracy of stability calculations of these composite structures. Therefore, attention should be paid to the review of the following groups of composites, in specific laminates.

2.1 Single-layer isotropic "laminate"
2.1. Jednoslojni izotropni laminat

Though the notion laminate implies multilayer structure, Jones (1975) used this name with the intention to demonstrate that laminate stiffness, given by the relations (13), could be reduced to the level of isotropic plate stiffness.

On that basis, from the expression (13), it can be concluded that in the case of isotropic plate there is no coupling between banding and stretching, i.e. expressions for the forces and moments are

$$\begin{bmatrix} N\varepsilon \\ M \end{bmatrix} = \begin{bmatrix} D_m & \\ & D_b \end{bmatrix} \begin{bmatrix} {}^{x0} \\ \kappa \end{bmatrix} \quad (14)$$

whereby stiffness matrixes D_m and D_b have the following values

$$D_m = \begin{bmatrix} D_m & \nu D_m & 0 \\ \nu D_m & D_m & 0 \\ 0 & 0 & \frac{1-\nu}{2} D_m \end{bmatrix}$$
$$D_b = \begin{bmatrix} D_b & \nu D_b & 0 \\ \nu D_b & D_b & 0 \\ 0 & 0 & \frac{1-\nu}{2} D_b \end{bmatrix} \quad (15)$$

where $D_m = \frac{E \cdot h}{1-\nu^2} \quad D_b = \frac{E \cdot h^3}{12 \cdot (1-\nu^2)}$ (16)

2.2 Special orthotropic laminae
2.2. Posebna ortotropna lamela

In the case of special orthotropic laminae of thickness h and stiffness Q_{ij}, given the equation (14), material stiffness matrixes have the following form

$$D_m = \begin{bmatrix} D_{m11} & D_{m12} & 0 \\ D_{m21} & D_{m22} & 0 \\ 0 & 0 & D_{m66} \end{bmatrix}$$
$$D_b = \begin{bmatrix} D_{b11} & D_{b12} & 0 \\ D_{b21} & D_{b22} & 0 \\ 0 & 0 & D_{b66} \end{bmatrix} \quad (17)$$

with the components

$$D_{m11} = Q_{11}h \quad D_{m12} = Q_{12}h \quad D_{m22} = Q_{22}h \quad D_{m66} = Q_{66}h$$
$$D_{b11} = Q_{11}\frac{h^3}{12} \quad D_{b12} = Q_{12}\frac{h^3}{12} \quad D_{b22} = = Q_{22}\frac{h^3}{12} \quad D_{b66} = Q_{66}\frac{h^3}{12} \quad (18)$$

where it can be seen that in the case of laminae, in which geometrical (calculated) main directions coincide with main directions of material characteristics, there is no coupling between bending and membrane stress.

3 EQUILIBRIUM EQUATIONS OF LAMINATED PLATES
3. JEDNADŽBE RAVNOTEŽE LAMELIRANIH PLOČA

In the study of laminated plate theory, inputs are based on the following constraints and assumptions: each laminae in the laminate is orthotropic, linear elastic, of constant thickness, so that laminate (plate) has also constant thickness, which is small compared to the other dimensions; further, there are no internal friction forces, Kirchhoff hypothesis of non-deformable normal on the mid-plan is applicable, displacements u, v, and w are small compared to the plate thickness and dilatations e_x, e_y and g_{xy} are infinitesimal values.

Differential equations of equilibrium of laminate plates under load perpendicular to the mid-plane of laminate p, expressed via resultant forces N_x, N_y and N_{xy} and moments M_x, M_y and M_{xy}, have the following form

$$\frac{\partial N_x}{\partial x} + \frac{\partial N_{xy}}{\partial y} = 0$$
$$\frac{\partial N_{xy}}{\partial x} + \frac{\partial N_y}{\partial y} = 0 \quad (19)$$
$$\frac{\partial^2 M_x}{\partial x^2} + 2\frac{\partial^2 M_{xy}}{\partial_x \partial_y} + \frac{\partial^2 My}{\partial y^2} = p$$

Differential equations of equilibrium are very simplified when it comes to special orthotropic laminates. This leads to differential equations of equilibrium for special orthotropic laminate (plate)

$$D_{m11}u_{,xx} + D_{m66}u_{,yy} + (D_{m12} + D_{m66})v_{,xy} = 0,$$
$$(D_{m12} + D_{m66})u_{,xy} + D_{m66}v_{,xx} + D_{m22}v_{,yy} = 0, \quad (20)$$
$$D_{b11}w_{,xxxx} + 2(D_{b12} + 2D_{b66})w_{,xxyy} + D_{b22}w_{,yyyy} = p(x,y).$$

4 APPLICATION OF FEM FOR STRUCTURAL ELEMENTS OF CHAIRS
4. PRIMJENA METODE KONAČNIH ELEMENATA NA ELEMENTIMA KONSTRUKCIJE STOLACA

Finite element of laminate will be obtainted by integration of finite elements per thickness of the laminate. This integration is not a mathematical problem, and in the finite element methodology, it is known as layered approach. It could be concluded that the laminate element represents a layered finite element. For this reason, in order to formulate the finite element of laminate, it is first necessary to formulate finite laminae element of unit thickness.

4.1 Finite laminate element
4.1. Konačni element laminata

The finite laminate element represents a composite of finite elements of laminaes. Since each laminae

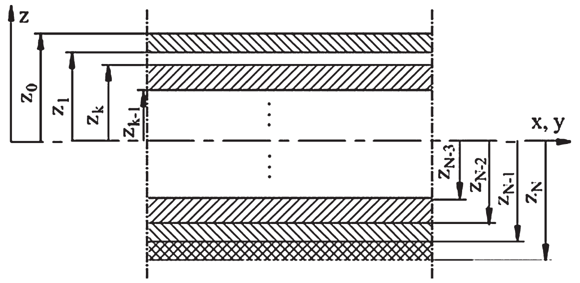

Figure 4. Finite laminae element - thickness cross section
Slika 4. Konačni element laminata - presjek po debljini

in the laminate represents a layer of constant thickness, it follows that the formulation of the finite element of the laminae is subjected to so call layered approach of finite element. Compatibility conditions for displacements and deformations of layers are satisfied not only at nodal points, but in any point within laminae (layer) element. Integration of stiffness matrix per surface of the laminate remains the same as in the case of the single laminae, while thickness integration requires integration of each layer individually in relation to the local coordinate system of the laminate positioned in its middle plane (Figure 4).

Accordingly to this statement, it could be concluded that

$$K_L = \int_z (\int_A \begin{bmatrix} B_m^T & \\ & B_b^T \end{bmatrix} \begin{bmatrix} Q & \\ & z^2 Q \end{bmatrix} \begin{bmatrix} B_m & \\ & B_b \end{bmatrix} dA) dz \quad (21)$$

Where A denotes integration across the surface of the mid-plane of plate, and z integration over its cross section.

Having in mind that surface integrals of laminate represent stiffness matrixes of laminae multiplied by specified multipliers, the final form of the above expression will be as follows:

$$K_L = \sum_{k=1}^{N} \begin{bmatrix} z_k - z_{k-1} & \\ & \frac{z_k^3 - z_{k-1}^3}{3} \end{bmatrix} \begin{bmatrix} \frac{1}{t_k} K_{mk} & \\ & \frac{12}{t_k^3} K_{bk} \end{bmatrix} = \sum_{k=1}^{N} \begin{bmatrix} \frac{z_k - z_{k-1}}{t_k} K_{mk} & \\ & \frac{4(z_k^3 - z_{k-1}^3)}{t_k^3} K_{bk} \end{bmatrix} \quad (22)$$

where K_{mk} and K_{bk} are membrane and stiffness matrixses of banding of k-th laminae.

If the laminate has asymmetry property with respect to the z-axis (Figure 4), its stiffness matrix, like in the case of laminae, could be decomposed on the membrane and stiffness matrix of laminate bending. If the membrane stress is coupled with bending procedure of integration of laminate, stiffness matrix stays the same, with the difference that in the matrix of diagonal blocks, $\mathbf{Q}_k$ also appear out-of-diagonal blocks in accordance with the expressions (13) so that

$$K_L = \int_z (\int_A \begin{bmatrix} B_m^T & \\ & B_b^T \end{bmatrix} \begin{bmatrix} Q & zQ \\ zQ^T & z^2 Q \end{bmatrix} \begin{bmatrix} B_m & \\ & B_b \end{bmatrix} dA) dz \quad (23)$$

4.2 Reduced stiffness of laminate
4.2. Reducirana krutost laminata

In the case when all layers of the laminate are of equal thickness, equal orientation and equal mechanical characteristics, laminate stiffness matrix (22) becomes

$$K_L = \sum_{k=1}^{N} \begin{bmatrix} \frac{z_k - z_{k-1}}{t} K_m & \\ & \frac{4(z_k^3 - z_{k-1}^3)}{t^3} K_b \end{bmatrix} = \begin{bmatrix} N K_m & \\ & \alpha_N K_b \end{bmatrix} \quad (24)$$

where

$$\alpha_N = \frac{4}{t^3} \sum_{k=1}^{N} (z_k^3 - z_{k-1}^3) \quad (25)$$

In accordance with the expression (24), in this case the entire laminate could be viewed as a single layer, whereby multipliers N and α_N are attached to the material stiffnesses, with the aim to encompass integration through the thickness of the laminate, i.e.

$$D_m^r = N D_m \quad D_b^r = \alpha_N D_b \quad (26)$$

Thus, reduced membrane D^r_m and banding stiffness D^r_b are defined. As a result, sub-matrixes of the laminate stiffness matrix were found by integration only per surface of element, i.e.

$$K_{Lm} = \int_A B_m^T D_m^r B_m dA \qquad K_{Lb} = \int_A B_b^T D_b^r B_b dA \quad (27)$$

If laminas do not possess the same mechanical properties, laminate stiffness matrix could also be given by the specified expression, where reduced stiffnesses are defined in the following way, based on the expressions (22):

$$D_m^r = \frac{1}{t} \sum_{k=1}^{N} (z_k - z_{k-1}) D_{mk} \quad D_b^r = \frac{4}{t^3} \sum_{k=1}^{N} (z_k^3 - z_{k-1}^3) D_{bk} \quad (28)$$

In the case when different thickness, different orientation and different mechanical properties of the laminas are assumed, expression (28) becomes

$$D_m^r = \sum_{k=1}^{N} (z_k - z_{k-1}) \bar{Q}_k \quad D_b^r = \sum_{k=1}^{N} \frac{1}{3} (z_k^3 - z_{k-1}^3) \bar{Q}_k \quad (29)$$

where $\bar{Q}_k$ represents constitutive layer matrixes with respect to the computational Cartesian coordinates.

For the general case defined by the expression (23), stiffness matrix of the composite will be expressed as

$$K_L = \begin{bmatrix} K_{Lm} & K_{Lmb} \\ K_{Lbm} & K_{Lb} \end{bmatrix} \quad (30)$$

where

$$K_{Lbm} = \int_A B_m^T D_{mb}^r B_b dA = K_{Lmb}^T \quad (31)$$

is coupling laminate stiffness matrix, while

$$D_{mb}^r = \sum_{k=1}^{N} \frac{1}{2} (z_k^2 - z_{k-1}^2) \bar{Q}_k \quad (32)$$

represents reduced coupling laminate stiffness.

The stiffness matrix of the composite plate (29) includes the effects of coupling of membrane stress and bending of laminate. This kind of coupling occurs in anisotropic and in orthotropic composite plates only if laminas are not symmetrically arranged both per geometry and material in relation to the mid-plane of the plate. Formally, this kind of stiffness matrix form is the same as in the case of isotropic plates, which is the consequence of geometrical or material or both geometric and material nonlinear treatment.

5 SOFTWARE PACKAGE FOR THE ANALYSIS OF LAMINATED STRUCTURES
5. PROGRAMSKI PAKET ZA ANALIZU LAMELIRANIH STRUKTURA

Stress and strain analysis of chair structures was conducted by application of software package KOMIPS for computer modeling and computation of structures, developed by Maneski (1998). This software system is based on the finite element method. It possesses a wide library of elements starting from one-dimensional to general three-dimensional elements that enable modeling of geometry and physical discretization of very complex structures.

For this paper, finite laminate element is of particular importance, since it represents the basis of all our numerical analyses. Finding of stiffness matrix of finite laminate element requires the integration per its volume (23). As mentioned above, the volume integration problem could be translated to the integration per surface of finite element by introduction of the so-called reduced stiffness (26) and (28), which makes stiffness matrix procedure formulation more efficient and identical to the classical plate theory. For this reason, subroutine REDKRUT for KOMIPS, that calculates reduced stiffness of the laminate, was applied.

6 CONCLUSIONS AND RECOMMENDATIONS
6. ZAKLJUČCI I PREPORUKE

On the basis of the above presented teorethical considerations, here are several conclusions and guidelines that were applied in further research (Nestorović, 2010).

1. For the determination of material constants as rheological material model for the conditions of planar stress, three separate uni-axial tension tests were conducted, for complex and uniform composition of laminate. In the tests, four independent elastic orthotropic constants of the modulus of electricity E_x, E_y, Poisson ration ν_{xy} and shear modulus G_{xy} were determined. In these tests, Poisson coefficient ν_{yx} was also determined, but in the case when ν_{xy} is known, it does not represent independent elastic constant. Also, bending tests were conducted, the results of which were elasticity bending modules $E_{fx,}$ E_{fx} and stresses σ_x, σ_y.

2. Laminates with uniform composition of veneer sheets and complex composition of veneer sheets represent two composites, and in terms of rheology, two different material models. However, they are not independent, because material constants of complex composition could be unambiguously determined from the material constants of uniform composite, as shown by experimental results (Nestorovic, 2010).

3. In section 4 the composite plate/shell finite element was formulated. Such finite element is applicable to the problems of membrane stress and bending of composite structures. Volume integration of stiffness matrix was translated in the integration per mid-plane of the plate by introducing of the so-called reduced stiffness of the composite both for membrane stress and bending. Kirchhoff-Love hypothesis of the flat sections of the plate after deformation, implies a linear change of componential deformation through the laminate thickness. Since the mechanical properties of layers are generally disparate, linear change of deformations leads to abrupt changes of componential stresses across the thickness of the composite. This is shown above in Figure 5 for the case of laminate composed of eight 1.5-mm-thick layers.

Having in mind that the cross section of the plate represents the section defined by the unit width and plate thickness, it is clear that the composite section forces are resultants of the componental stresses, i.e. their integrals across the laminate thickness. Provided that the integrals across the thickness are the same at each abrupt change of the stress and fictitious linear change, reduced membrane and reduced bending stiffness of the composite were defined.

4. Theoretical, experimental and numerical researches, and introduction of the reduced stiffness of complex laminate in the finite elements, together with the experiments on chairs (Nestorović, 2010) that were done in order to determine the stiffness of such systems by measurement of real displacements on the selected

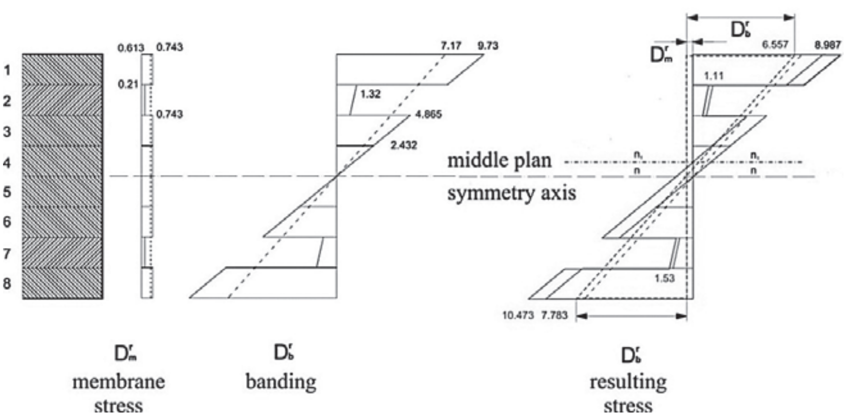

Figure 5 Reduced stiffness
Slika 5. Reducirane krutosti

models, confirmed numerical calculations, enabling design, redesign, construction and dimensioning of not only chairs but of any beam or surface system based on the laminate, by varying material type, combination of diverse materials, layer thickness and fiber orientation.

5. Using the acquired knowledge with the aim of determining material constants of orthotropic composites, the following experimental tests were proposed:

5.1 Production of specimens of massive structure (all fibers oriented in the same direction) in the form of the cube (Figure 6). By uni-axial tensioning in x-direction, it was possible to determine elasticity modulus E_x and Poisson coefficient ν_{xy}, ν_{xz}. Tensioning in the y-direction will result in modulus of elasticity E_y and coefficients ν_{yx}, ν_{yz}. The same test in the z-direction will give E_z and ν_{zx}, ν_{zy}. From here it is clear that, in the case of orthotropic composite, only six out of nine constants are mutually independent E_x, E_y, E_z, ν_{xy}, ν_{xz}, ν_{yz}.

5.2 For the determination of three independent material constants that contain shear modulus in *xy*-, *xz*-, and *yz*- planes, the following experiment was proposed: to make a specimen of the massive structure in the form of the cube with the fibers oriented in the same direction as presented in Figure 6.

Local plan of the lamina is defined by the unit vectors

$$\vec{i}_1 = \frac{1}{\sqrt{2}}\begin{bmatrix}0 & 1 & 1\end{bmatrix} \quad \vec{i}_2 = \frac{1}{\sqrt{3}}\begin{bmatrix}-1 & 1 & -1\end{bmatrix} \tag{33}$$

which implies that its normal equals

$$\vec{i}_3 = \vec{i}_1 \times \vec{i}_2 = \frac{1}{\sqrt{6}}\begin{bmatrix}-2 & -1 & 1\end{bmatrix} \tag{34}$$

In this case, the relation between local *x*, *y* and *z* and global *X*, *Y* and *Z* coordinates is given by the relation

$$\begin{bmatrix}x\\y\\z\end{bmatrix} = \begin{bmatrix}0 & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2}\\ -\frac{\sqrt{3}}{3} & \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3}\\ -\frac{\sqrt{6}}{3} & -\frac{\sqrt{6}}{6} & \frac{\sqrt{6}}{6}\end{bmatrix}\begin{bmatrix}X\\Y\\Z\end{bmatrix} \tag{35}$$

Using the property of stress and strain tensor, components of shear stresses and shear deformations in the local xy-, xz- and yz-planes, due to the tension in all three global directions, are determined by expressions

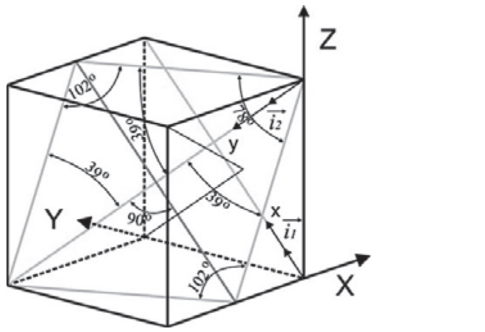

Figure 6 Test cube for determination of shear elasticity constants
Slika 6. Probna kocka za određivanje smičnih konstanti elastičnosti

$$\tau_{xy} = \frac{\sqrt{6}}{6}(\sigma_Y - \sigma_Z) \quad \tau_{xz} = \frac{\sqrt{3}}{6}(\sigma_Z - \sigma_Y)$$
$$\tau_{yz} = \frac{\sqrt{2}}{3}(\sigma_X - \frac{1}{2}\sigma_Y - \sigma_Z) \quad \gamma_{xy} = \frac{\sqrt{6}}{3}(\varepsilon_Y - \varepsilon_Z + \frac{\sqrt{3}}{2}\varepsilon_X) \tag{36}$$
$$\gamma_{xz} = \frac{\sqrt{3}}{3}(\varepsilon_Z - \varepsilon_Y) \quad \gamma_{yz} = -\frac{\sqrt{2}}{3}(\varepsilon_Y + \varepsilon_Z)$$

In accordance with the expressions (36), assuming the uni-axial tension in *Y*-direction, i.e.

$$\sigma_Y \neq 0 \quad \sigma_X = \sigma_Z = 0$$

the equation for the shear stress is

$$\tau_{xy} = \frac{\sqrt{6}}{6}\sigma_Y \quad \tau_{xz} = -\frac{\sqrt{3}}{6}\sigma_Y \quad \tau_{yz} = \frac{\sqrt{2}}{6}\sigma_Y$$

where the resulting shear moduli G_{xy}, G_{xz} and G_{yz} are in the form of

$$G_{xy} = \frac{\tau_{xy}}{\gamma_{xy}} = \frac{\sigma_Y}{2(\varepsilon_Y - \varepsilon_Z + \frac{\sqrt{3}}{2}\varepsilon_X)} \quad G_{xz} = \frac{\tau_{xz}}{\gamma_{xz}} = \frac{\sigma_Y}{2(\varepsilon_Y - \varepsilon_Z)} \tag{37}$$
$$G_{yz} = \frac{\tau_{yz}}{\gamma_{yz}} = \frac{\sigma_Y}{2(\varepsilon_Y + \varepsilon_Z)}$$

In analogue test that assumes tension in the global Z-direction, i.e.

$$\sigma_Z \neq 0 \quad \sigma_X = \sigma_Y = 0$$

components of the shear stress are

$$\tau_{xy} = -\frac{\sqrt{6}}{6}\sigma_Z \quad \tau_{xz} = \frac{\sqrt{3}}{6}\sigma_Z \quad \tau_{yz} = -\frac{\sqrt{2}}{3}\sigma_Z \tag{38}$$

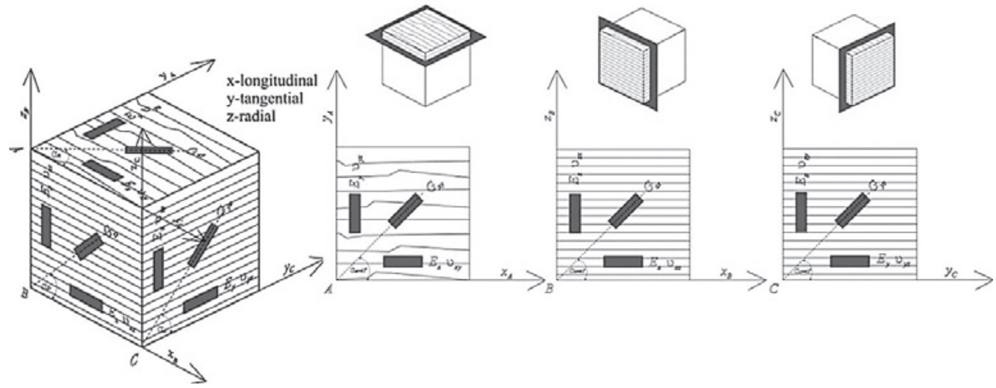

Figure 7 Test cube for determination of shear elasticity constants – scheme of cutting test specimens
Slika 7. Probna kocka za određivanje smičnih konstanti elastičnosti – shema izrezivanja testnih uzoraka

Figure 8 Cantilever chair from the doctoral thesis of B. Nestorović (left);free-form chair "Savannah Rocker III" made of uniform laminate by designer J. Yates, from http://www.fabulise.com/xodechair.com/ (middle and left)
Slika 8. Konzolni stolac iz doktorskog rada B. Nestorović (lijevo); slobodno oblikovani stolac *Savannah Rocker III* dizajnera J. Yatesa (preuzeto s http://www.fabulise.com/xodechair.com/) (sredina i desno)

while shear moduli are expressed as

$$G_{xy} = \frac{\sigma_Z}{2(\varepsilon_Z - \varepsilon_Y - \frac{\sqrt{3}}{2}\varepsilon_X)} \quad G_{xz} = \frac{\sigma_Y}{2(\varepsilon_Z - \varepsilon_Y)} \quad G_{yz} = \frac{\sigma_Z}{(\varepsilon_Y + \varepsilon_Z)} \tag{39}$$

Since expressions (37) and (39) give the same values, it is clear that only one test is necessary, while the other test can be used as control.

6. Based on the results obtained in experiments 5.1 and 5.2, material flexibility matrix S can be defined as well as constitutive matrix C, i.e.

$$S = \begin{bmatrix} \frac{1}{E_x} & -\frac{\nu_{yx}}{E_y} & -\frac{\nu_{zx}}{E_z} & 0 & 0 & 0 \\ -\frac{\nu_{xy}}{E_x} & \frac{1}{E_y} & -\frac{\nu_{zy}}{E_z} & 0 & 0 & 0 \\ -\frac{\nu_{xz}}{E_x} & -\frac{\nu_{yz}}{E_y} & \frac{1}{E_z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{yz}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{zx}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{xy}} \end{bmatrix} \Rightarrow C = S^{-1} \tag{40}$$

and dependencies between components of stress and strain tensors can be established in the form of

$$\sigma = C\varepsilon \tag{41}$$

where σ and ε represent the above defined vectors of stress and strain.

Relation (41) enables stress and strain analysis of the orthotropic and anisotropic composite structures that have a 3D character. In the static terms, they represent thick plates and shells, in which shear deformation in planes (x-z, y-z) perpendicular to the middle plane of plate/shell (x-y) could not be neglected.

Further to the above, Figure 8 presents models of chairs that illustrate the possibilities of application of developed apparatuses in the process of design and redesign, regardless of shape, type of material, thickness of layers, or fiber orientation.

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7 REFERENCES
7. LITERATURA

1. Bathe, K. J., 1996: Finite Element Procedures. USA, Prentice - Hall, Inc.
2. Hughes, T. J. R., 1987: The Finite Element Method: Linear Staticand Dynamic Finite Element Analysis. New Jersey, Prentice-Hall.
3. Jones, R. M., 1975: Mechanics of Composite Materials. Washington, D. C., Script Book Co., pp. 31-54, 147-171.
4. Maneski, T., 1998: Computer modeling and calculation of structures. Belgrade, University of Belgrade, Faculty of Mechanical Engineering.
5. Nestorović, B.; Grbac, I., 2011: Validation numerical modelling with 3D optical measurement deformations. Ambienta, Proceedings of the 22th International Scientific Conference – Wood is Good, Faculty of Forestry, Zagreb University, pp. 141-148.
6. Nestorović, B.; Grbac, I.; Nestorović, P., 2012: Experimental Determination of Elastic Constants of Veener Composites. Ambienta, Proceedings of the 23th International Scientific Conference – Wood is Good, Faculty of Forestry, Zagreb University, pp. 127-138.
7. Nestorović, B., 2010: Research and Analysis of the Strength of Wood-Laminate Seating Furniture. Doctoral thesis. Belgrade, University of Belgrade Faculty of Forestry, pp. 80-100.
8. Nestorović, B.; Skakić, D.; Grbac, I., 2011: Determining the Characteristics of Composite Structure Laminae by Optical 3D Measurements of Deformation with Numerical Analysis. Drvna industrija, 62 (3): 193-200 http://dx.doi.org/10.5552/drind.2011.1103.
9. Nestorović, B.; Grbac, I.; Nestorović, P., 2013: Numerical Analysis of Laminated Wood Structures – Chairs by Application of FEA. Ambienta, Proceedings of the24th International Scientific Conference – Wood is Good , Faculty of Forestry, Zagreb University, pp. 101-109.
10. Vlaović, Z.; Grbac, I.; Domljan, D.; Bublić, A., 2010: Office Work Chairs – Research of Deformations and Comfort Index. Drvna industrija, 61(3): 159-168.

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Modeling of Compressive Strength Parallel to Grain of Heat Treated Scotch Pine (*Pinus sylvestris* L.) Wood by Using Artificial Neural Network

Modeliranje tlačne čvrstoće paralelno s vlakancima toplinski obrađenog drva škotskog bora (*Pinus sylvestris* L.) s pomoću umjetne neuronske mreže

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*In this study, the compressive strength of heat treated Scotch Pine was modeled using artificial neural network. The compressive strength (CS) value parallel to grain was determined after exposing the wood to heat treatment at temperature of 130, 145, 160, 175, 190 and 205ºC for 3, 6, 9, 12 hours. The experimental data was evaluated by using multiple variance analysis. Secondly, the effect of heat treatment on the CS of samples was modeled by using artificial neural network (ANN)***.**

Key words: *wood, heat treatment, Artificial Neural Network, compressive strength*

Rad prikazuje numeričku proceduru za analizu struktura izrađenih od kompleksnih laminata. PostuU radu se obrađuje modeliranje tlačne čvrstoće toplinski obrađenog drva škotskog bora uz pomoć umjetne neuronske mreže. Vrijednost tlačne čvrstoće (CS) paralelno s vlakancima određena je nakon toplinske obrade pri temperaturi 130, 145, 160, 175, 190 i 205 ºC tijekom 3, 6, 9 i 12 sati. Eksperimentalni podaci analizirani su primjenom višestruke analize varijance. Osim toga, učinak toplinske obrade na tlačnu čvrstoću uzoraka modeliran je uz pomoć umjetne neuronske mreže (ANN).

Ključne riječi: *drvo, toplinska obrada, umjetna neuronska mreža, tlačna čvrstoća*

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1 INTRODUCTION
1. UVOD

Heat treatment is a wood modification method used to improve some properties of the wood. Heat treatment also helps to diminish equilibrium moisture content of wood samples (Mazela *et al*., 2004). The temperature level and duration of heat treatment mostly change from 180 to 280 °C and from 15 min to 24 h depending on the heat treatment process, sample size, wood species, moisture content of the sample and the properties of the final product (Kandem *et al*., 2002; Militz *et al*., 2002).

The values of hardness and strength of wood decrease with the increase of heat treatment parameters (temperature and duration). These effects are achieved especially when heat treatment is carried out for a long time. The strength values of wood most affected by heat treatment are impact and static bending strengths, while the least affected property is the modulus of elasticity (Korkut *et al*., 2008).

Artificial neural network (ANN) is a computational model based on the information processing system of the human brain. ANN model is composed of three layers, which are called input layer, hidden layer and output layer. This network structure is also called MLP (Işeri and Karlık, 2009).

While the input layer receives the initial values of the variables, the output layer shows the results from the network for the input. The hidden layer carries out the operation design to achieve the output. The number of neurons in the input layer must correspond to the number of entry variables, and the output layer must have as many neurons as the number of outputs manufactured by the network. However, there is no rule to allow prior decisions to indicate the number of neurons contained in the hidden layer or sublayer. The only way to obtain the hidden layer is by a process of trial and error (Sha, 2007).

Artificial neural network has been widely used in many wood industries, such as in the wood identification system (Tou *et al*., 2007; Khalid *et al*., 2008; Estaben *et al*., 2009a; Junior *et al*., 2006) in the suggestion on the application of geodesy (Arslan *et al*., 2007), in the prediction of wood dielectric loss factor (Avramidis *et al*., 2006), in the calculation of wood thermal conductivity (Xu *et al*., 2007), in predicting fracture toughness of wood (Samarasinghe *et al*., 2007), in the evaluation of strength of wood timbers (Tanaka *et al*., 1996), in the prediction of bending strength and stiffness in western hemlock (Shawn *et al*., 2007), in the prediction of particleboard mechanical properties (Fernández *et al*., 2008), in the optimization of process parameter in a particleboard manufacturing process (Cook *et al*., 2000), in the detection of structural damage in medium density fiberboard panels (Long *et al*., 2008), in the prediction of modulus of rupture and modulus of elasticity of flake board (Yapıcı *et al*., 2009). It has also been applied to obtain the hygroscopic equilibrium points (Avramidis and Iliadis, 2005), to classify wood defects (Drake and Packianather, 1998), to determine the internal bond values of particleboard (Cook and Chiu, 1997; Fernandez *et al*., 2008), and in statistical process control in the manufacture of particleboard (Estaben *et al*., 2009b).

In this study, compression strength parallel to grain of heat treated Scotch pine wood samples was examined experimentally, and then artificial neural network (ANN) system was designed for predicting this value.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Scotch pine wood (*Pinus sylvestris* L.) was chosen randomly from timber merchants of Karabuk, Turkey. In the selection of wood material, special emphasis was on the properties of non-deficient, proper, knotless, normally grown wood (without zone line, reaction wood, decay, insect and mushroom damages). The selected specimens were cut to sizes of 20×20×300 mm and they were exposed to heat treatment at 130, 145, 160, 175, 190 and 205 ºC for 3, 6, 9, and 12 hours. Then, they were resized to 20×20×30 mm. The compressive strength values were determined from test samples according to TS 2595 standard (TS 2595).

2.1 Statistical analyses
2.1. Statističke analize

Data for each test were statistically analyzed. Analysis of variance was used to test the significance between factors and levels. When the analysis of variance pointed a significant difference among the factors and levels, a comparison of the means was conducted employing a Tukey test.

2.2 Design of artificial neural network for CS value
2.2. Dizajn umjetne neuronske mreže za tlačnu čvrstoću

In this study, the effects of heat treatment conditions on compressive strength parallel to grain of scotch pine wood were determined experimentally. Secondly, artificial neural network model was applied

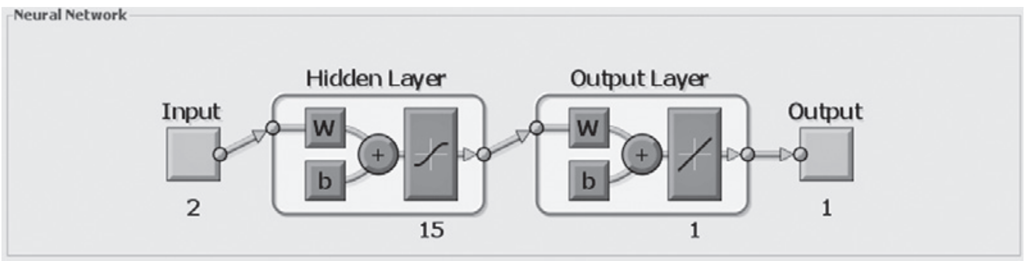

Figure 1 Design of ANN model
Slika 1. Dizajn modela umjetne neuronske mreže (ANN)

Table 1 The average values of CS
Tablica 1. Prosječne vrijednosti tlačne čvrstoće (CS)

Heat temperature conditions *Uvjeti toplinske obrade*		**Experimental value of CS** *Eksperimentalne vrijednosti tlačne čvrstoće* N/mm^2	**Prediction value of CS by using ANN** *Predviđene vrijednosti tlačne čvrstoće primjenom ANN* N/mm^2	
Time, hour *Vrijeme, sati*	Temperature, °C *Temperatura, °C*	Mean *Prosječno*	Mean *Prosječno*	Correct level, % *Razina točnosti, %*
0	0	45.46	44.80	98.54
3	130	50.40	48.40	96.03
	145	47.95	50.00	95.63
	160	49.20	50.80	96.75
	175	50.17	50.80	98.75
	190	50.80	51.20	99.21
	205	50.00	51.21	98.00
6	130	52.79	48.00	90.92
	145	51.14	50.00	97.77
	160	49.39	51.20	99.23
	175	50.96	51.20	99.52
	190	54.01	49.20	91.11
	205	51.08	51.21	99.98
9	130	54.53	51.60	95.97
	145	53.55	51.60	96.35
	160	51.14	52.00	98.42
	175	49.99	52.81	94.38
	190	50.70	52.60	97.26
	205	52.40	52.00	99.23
12	130	52.82	51.60	98.89
	145	49.77	52.40	97.66
	160	52.71	52.80	96.91
	175	53.52	50.80	98.45
	190	52.32	48.40	92.50
	205	49.60	48.40	97.58
Current level of the average value of CS, % *Trenutačna razina prosječne vrijednosti tlačne čvrstoće, %*				97.02

by using input values of heat treatment conditions and output values determined from the experimental results. Designed model is shown in Figure 1.

The aim of the network is to predict CS of test samples. The network is trained by using MATLAB neural network module (nftool). A total of 70 % of these data is used for training, 15 % is used for validation, 15 % is used for testing. The data for each class are chosen randomlly from the total data set.

In this study, the number of neurons in the hidden layer is 25. This number is obtained by trial and error. In the nftool nature hyperbolic tansig function $f(x)=1/(1+\exp(-x))$ is applied. Input data is applied after normalization process between -1 and +1.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The air dry density of Scots pine is 0.62 g/cm^3. The CS values of Scotch pine woods, obtained from experimental results, were compared with ANN model to determine the accuracy of the developed model. Our network was trained with designed data set to obtain the predicted result. Regression analysis of the training phase is given in Figure 2.

It is seen that regression coefficients obtained from training, validation and test phase of network are calculated close to 1. This result showed that the designed model is reliable.

Based on this comparison, the developed model agreed with average test results at the accuracy level of 97.02 % of CS value. Both experimental values and prediction values are given in Table 1.

The variance analysis of CS based on heat treatment circumstances was done by using variance analysis (Table 2.). The difference between the groups regarding the effect of variance sources on CS was significant (α =5 %).

It can be seen that the conditions of heat treatment has no effects on the CS values of Scotch pine wood according to variance analysis. So, the results of the Tukey test conducted to determine the importance of the differences between the groups are given in Table 3.

It can be seen that the CS values ranged between 45.46 N/mm^2 and 52.29 N/mm^2 according to Tukey's test (Table 3). It can be stated that when the temperature and time of the heat treatment increase, the value of CS increases. However, the ratio of increase is not statically significant. Thus, they are put into the same homogeneous group. The change of CS values, both experimental and prediction values, are given in Figure 3.

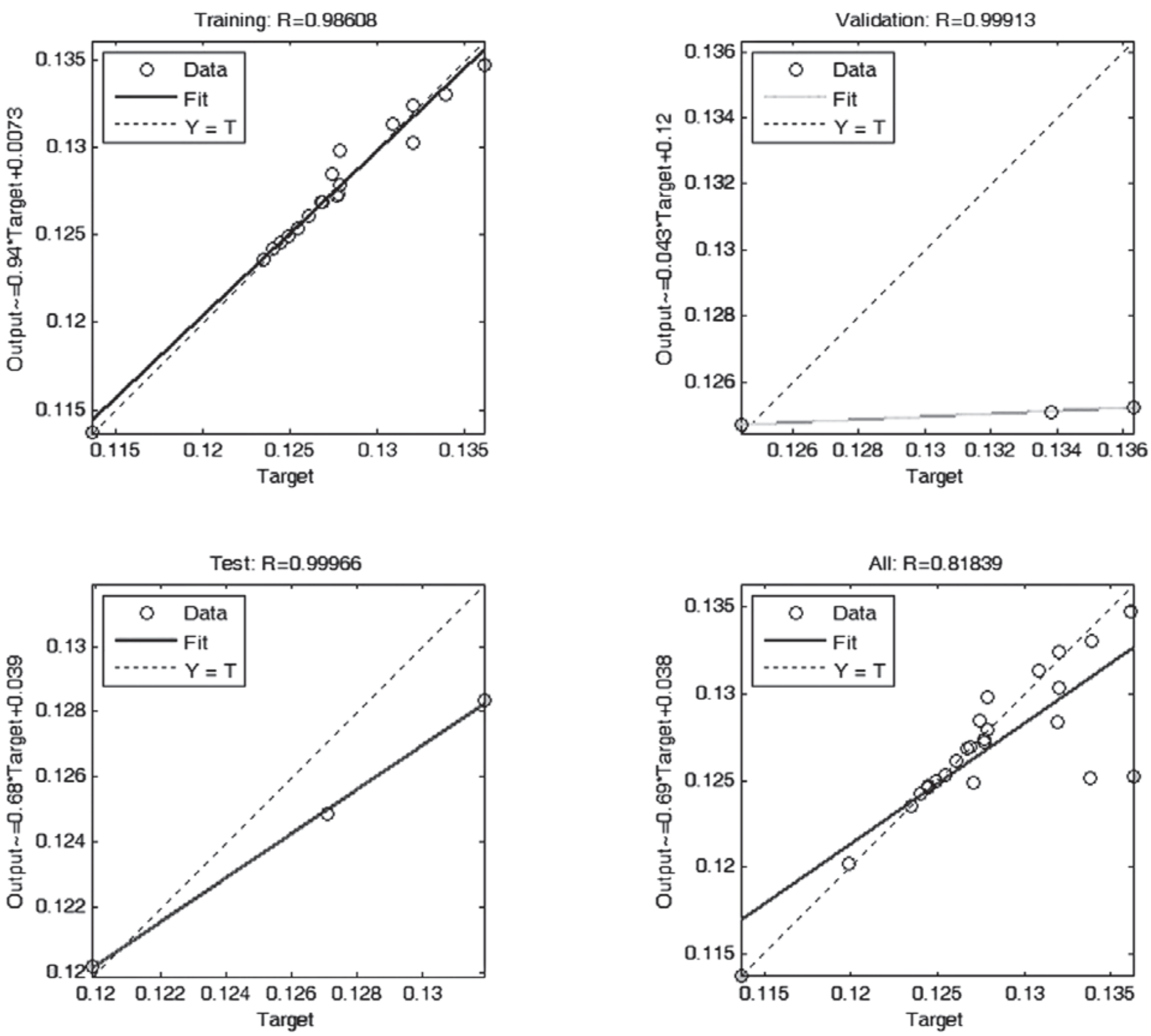

Figure 2 Network regression analyses of training
Slika 2. Regresijska analiza treniranja mreže

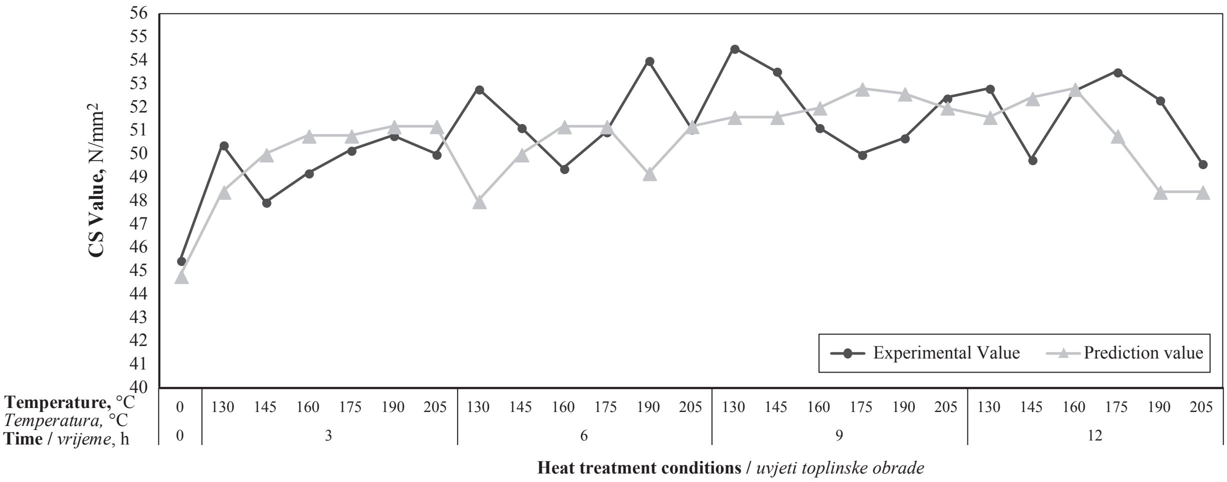

Figure 3 The change of experimental and prediction values of compressive strength
Slika 3. Promjena eksperimentalnih i predviđenih vrijednosti tlačne čvrstoće

Table 2 Result of the variance test
Tablica 2. Rezultati testa varijance

Source / *Izvor*	**Type III Sum of Squares** *Tip III zbroj kvadrata*	***Df***	**Mean Square** *Kvadrat srednje vrijednosti*	***F*-value** *F-vrijednost*	**Sig.level** *Razina signifikantnosti*
Corrected Model / *Ispravljeni model*	1474.17	24	61.42	1.87	0.09
A: Time, h / *vrijeme, h*	159.72	3	53.24	1.62	0.18
B: Temperature, °C / *temperature, °C*	292.87	5	58.57	1.78	0.11
A * B	529.79	15	35.31	1.07	0.37
Error / *Pogreška*	11482.28	350	32.80		
Total / *Ukupno*	991349.46	375			

Table3 Results of Tukey's Test
Tablica 3. Rezultati Tukeyeva testa

Conditions of heat treatment *Uvjeti toplinske obrade*		**Mean** / *Prosječno*	**HG***
Time, h *Vrijeme, sati*	0	45.46	A
	12	50.31	B
	6	51.29	B
	3	51.44	B
	9	52.18	B
Temperature, °C *Temperatura, °C*	0	45.46	A
	130	49.53	B
	190	51.01	B
	145	51.45	B
	160	51.47	B
	205	52.09	B
	175	52.29	B

HG: Homogenous Group / *homogena skupina*

4 CONCLUSIONS
4. ZAKLJUČAK

Based on the results of tests, it can be said that the properties of compression strength parallel to grain were slightly affected by applying the heat treatment. It can be seen that the CS values decrease with the increase of the time and temperature of heat treatment. The values obtained from experimental work are used for artificial neural network system. CS values of test samples have been predicted by the designed model at 97.33 % accuracy level. So, ANN model can be used to predict many mechanical and physical properties of wood and wood composite materials.

5 REFERENCES
5. LITERATURE

1. Arslan, O.; Kurt, O.; Konak, H., 2007: Suggestions on applications of artificial neural networks in geodesy, TMMOB Harita ve Kadastro Mühendisleri Odası, II. Türkiye Harita Bilimsel ve Teknik Kurultayı, 2-6 April, Ankara.
2. Avramidis, S.; Iliadis, L., 2005: Wood-water sorption isotherm prediction with artificial neural networks: a preliminary study. Holzforschung, 59: 336-341 http://dx.doi.org/10.1515/HF.2005.055.
3. Avramidis, S.; Iliadis, L.; Shawn, D.; Mansfield, 2006: Wood dielectric loss factor prediction with artificial neural Networks, Wood Sci Techn., 40: 563-574 http://dx.doi.org/10.1007/s00226-006-0096-3.
4. Cook, D. F.; Ragsdale, C. T.; Major, R. L., 2000: Combining a neural network with a genetic algorithm for process parameter optimization. Eng Appl Artif Intell, 13: 391-396 http://dx.doi.org/10.1016/S0952-1976(00)00021-X.
5. Cook, D. F.; Chiu, C. C., 1997: Predicting the internal bond strength of particleboard, utilizing a radial basis function neural network. Eng Appl Artif Intell, 10 (2): 171-177 http://dx.doi.org/10.1016/S0952-1976(96)00068-1.
6. Drake, P. R.; Packianather, M. S., 1998: A decision tree of neural networks for classifying images of wood veneer. Int J Adv Manuf Technol., 14: 280-285 http://dx.doi.org/10.1007/BF01199883.
7. Esteban, L. G.; Fernandez, F. G.; Palacios, P. D.; Romer, R. M.; Cano, N. N., 2009a: Artificial Neural Networks in Wood Identification: The Case of Two Juniperus Species from The Canary Islands, IAWA JOURNAL, 30 (1): 87-94 http://dx.doi.org/10.1163/22941932-90000206.
8. Esteban, L. G.; Garcia Fernandez, F.; De Palacios, P.; Conde, M., 2009b: Artificial neural networks in variable process control: application in particleboard manufacture. Invest Agrar Sist Recur For, 18 (1): 92-100 http://dx.doi.org/10.5424/fs/2009181-01053.
9. Fernández, G. F.; Esteban, L. G.; De Palacios, P.; Navarro, N.; Conde, M., 2008: Prediction of standard particleboard mechanical properties utilizing an artificial neural network and subsequent comparison with a multivariate regression model. Invest Agrar Sist Recur For, 17 (2): 178-187 http://dx.doi.org/10.5424/srf/2008172-01033.
10. Işeri, A.; Karlık, B., 2009: An artificial neural networks approach on automobile pricing. Expert Systems with Applications, Part 1, 36, 2155-2160 http://dx.doi.org/10.1016/j.eswa.2007.12.059.
11. Junior, K. J. K.; Pinto, F.; Queiroz, D. M.; De Lucia, R. M. D.; Resende, R. C., 2006: Neural networks for recognition of eucalypts lumber defects in digital images, Scientia Forestalis, 70: 85-96.
12. Kamdem, D. P.; Pizzi, A.; Jermannaud, A., 2002: Durability of heattreated wood. Holz als Roh-und Werkstoff, 60: 1-6 http://dx.doi.org/10.1007/s00107-001-0261-1.
13. Khalid, M.; Yi, L. E.; Yusof, R.; Nadaraj, M., 2008: Design of an Intelligent Wood Species Recognition System, International Journal of Simulation: Systems, Science & Technology, 9 (3).
14. Korkut, S.; Kok, M. S.; Korkut, S. D.; Gurleyen, T., 2008: The effects of heat treatment on technological properties in Red-bud maple (Acer trautvetteri Medw.) wood. Bioresource Technology, 99: 1538-1543 http://dx.doi.org/10.1016/j.biortech.2007.04.021.
15. Long, W.; Rice R. W., 2008: Detection of Structural Damage in Medium Density Fiberboard Panels using Neural Network Method. Journal of Composite Materials, 42: 1133-1145 http://dx.doi.org/10.1177/0021998308090455.

16. Mazela, B.; Zakrzewski, R.; Grzes'kowiak, W.; Cofta, G.; Bartkowiak, M., 2004: Resistance of thermally modified wood to basidiomycetes. Wood Technology, 7 (1): 253-262.
17. Militz, H., 2002: Thermal treatment of wood: European processes and their background. IRG/WP 02-40241, 33rd Annual Meeting, 12-17 May, Cardiff-Wales 4, pp. 1-17.
18. Samarasinghe, S.; Kulasiri, D.; Jamieson, T., 2007: Neural Networks for predicting fracture toughness of individual wood samples. Silva Fennica, 41 (1): 105-122 http://dx.doi.org/10.14214/sf.309.
19. Sha, W., 2007: Comment on the issues of statistical modelling with particular reference to the use of artificial neural networks. Appl Catal A-Gen, 324: 87-89 http://dx.doi.org/10.1016/j.apcata.2007.02.053.
20. Shawn, D.; Mansfield; Iliadis, L.; Avramidis, S., 2007: Neural network prediction of bending strength and stiffness in western hemlock (*Tsuga heterophylla* Raf.). Holzforschung, 61 (6): 707-716.
21. Tanaka, T.; Nagao, H.; Ve Kato, H., 1996: A preliminary investigation on evaluation of strength of soft wood timbers by neural network, 10th international symposium on nondestructive testing of wood, August 26-28, pp. 323-329.
22. ***TS 2595, Wood-determination of ultimate stress in compression parallel to grain, 2005, TSE, Ankara.
23. Tou, J. Y.; Lau, P. Y.; Tay, Y. H., 2007: Computer Vision-based Wood Recognition System, Proceedings of International Workshop on Advanced Image Technology (IWAIT), January, Bangkok, Thailand, pp.197-202.
24. Xu, Xu.; Yu, Zi-Tao.; Hu, Ya-Cai.; Fan, Li-Wu.; Tian, Tian.; Cen, Ke-Fa., 2007: Nonlinear fitting calculation of wood thermal conductivity using neural Networks. Zhejiang University Press, 41 (7): 1201-1204.
25. Yapıcı, F.; Ozcifci, A.; Akbulut, T.; Bayir, R., 2009: Determination of modulus of rupture and modulus of elasticity on flakeboard with fuzzy logic classifier. Materials and Design, 30: 2269-2273 http://dx.doi.org/10.1016/j.matdes.2008.09.002.

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RICINODENDRON AFRICANUM MUELL. ARG.

UDK: 674.031.757.291.2

NAZIVI

Ricinodendron africanum Muell. Arg. naziv je drva botaničke vrste iz porodice *Euphorbiaceae.*

Trgovački je naziv te vrste essessang (Francuska, Gabon); erimado (Angola, Belgija, Njemačka, Velika Britanija); musuku, mulela, sanga (Angola); ehi, itani, katotou, popossi (Obala Bjelokosti); issanguila (Gabon); wama, epuwi, sosali (Gana); esango, njansang, timboa (Kamerun); mulela, sanga sanga; koor (Liberija); ekku, okwen (Nigerija); gbolei, ekok (Sierra Leone); Kisongo (Uganda).

NALAZIŠTE

Stabla *Ricinodendron africanum* Muell. Arg. nalazimo u zapadnoj, južnoj i istočnoj Africi. Areal im se proteže od Sierra Leonea gvinejskom obalom sve do Angole i dalje preko Rodezije i Botswane do Istočne obale. Raste na područjima do 1300 metara nadmorske visine.

STABLO

U svojoj domovini drvo naraste 30 – 40 metara visoko, duljina debla mu je 20 – 25 metara, a prsni promjer 0,5 – 1,0 metar. Kora drva je glatka i svjetlosiva, često gotovo bijela, ili je pak hrapava i smećkasta. U starijih stabala kora se ljušti u debelim ljuskama. Debljina kore iznosi 1,0 – 2,0 centimetra. Stablo je brzorastuće.

DRVO

Makroskopska obilježja

Bjeljika i srževina ne mogu se međusobno razlikovati. Drvo je rastresito porozno, bljedožute do slamnato žute boje. Godovi se teško raspoznaju. Drvni su traci vidljivi samo povećalom, na radijalnoj površini sjaje. Tekstura drva je jednolična, prugasta, nije dekorativna.

Mikroskopska obilježja

Traheje su raspoređene pojedinačno, u parovima i kratkim radijalnim nizovima (do pet pora). Promjer traheja iznosi 100...210...280 mikrometara, gustoća im je 1...3...6 na 1 mm^2 poprečnog presjeka. Volumni je udio traheja 4,4...5,0...5,4 %. Pore su često ispunjene tilama.

Aksijalni je parenhim apotrahealno marginalan, paratrahealno vazicentričan. Volumni udio aksijalnog parenhima beznačajno je malen.

Drvni su traci heterogeni, katnog rasporeda, visine 240...560...950 mikrometara, a širine 14...25...37 mikrometara, odnosno jednu stanicu. Gustoća drvnih trakova je 7...10...12 na 1 mm poprečnog presjeka. Volumni udio drvnih trakova iznosi 17,2...17,6...18,1 %. U drvnim tracima i aksijalnom parenhimu ima kristala.

Drvna su vlakanca libriformska. Dugačka su 1450...1650...1850 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 1,65...2,95...3,75 mikrometara, a promjer lumena 13,2...32,8...48,2 mikrometara. Volumni je udio vlakanaca 76,5...77,4...78,3 %.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	oko 250 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	oko 300 kg/m^3
Gustoća sirovog drva, ρ_s	700...800 kg/m^3
Poroznost	oko 83 %
Radijalno utezanje, β_r	oko 4,8 %
Tangentno utezanje, β_t	oko 5,0 %
Volumno utezanje, β_v	oko 9,6 %

Mehanička svojstva

Čvrstoća na tlak	oko 21,0 MPa
Čvrstoća na savijanje	oko 44,0 MPa
Modul elastičnosti	5200 MPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro i bez poteškoća ručno i strojno obrađuje. Čavla se i dobro drži vijke. Pri blanjanju se zbog čupanja vlakanaca teško postižu glatke površine. Teško se lijepi i politira.

Sušenje

Drvo se vrlo brzo suši, no sklono je vitoperenju.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva srednje je slabo otporna na gljive uzročnice truleži (razred otpornosti 5) i slabo otporna na termite (razred otpornosti S). Srž je permeabilna (razred 1).

Uporaba

Drvo *Ricinodendron africanum* Muell. upotrebljava se za izradu dijelova namještaja, furnira i drvenih plovila, a služi i kao drvo za rezbarenje i tokarenje.

Sirovina

Drvo *Ricinodendron africanum* Muell. Arg. na tržištu se pojavljuje u obliku trupaca promjera 60 – 90 cm i duljine od 5 metara naviše.

Napomena

Drvo nije na popisu ugroženih vrsta međunarodne organizacije CITES ni na popisu međunarodne organizacije IUCN Red list. Može se rabiti kao zamjena za balzu.

Slične vrste

Ricinodendron rautaneii Schinz
Alstonia congensis Engl.
Hura crepitans L.
Triplochiton scleroxylon K. Schum.

Literatura

1. Richter, H. G.; Dallwitz, M. J. (2000 onwards): „Commercial timbers: descriptions, illustrations, identification, and information retrieval“. In English, French, German, and Spanish. Version: 4th May 2000. http://biodiversity.uno.edu/delta/
2. Wagenführ, R.; Scheiber, C., 1974: HOLZATLAS, VEB Fachbuchverlag, Leipzig, 327-328.
3. ***1964: Wood dictionary, Elsevier publishing company, Amsterdam.
4. ***http://tropix.cirad.fr/FichiersComplementaires/EN/Africa/ESSESSANG.pdf (preuzeto 7. prosinca 2015.).

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časopisa Drvna industrija

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