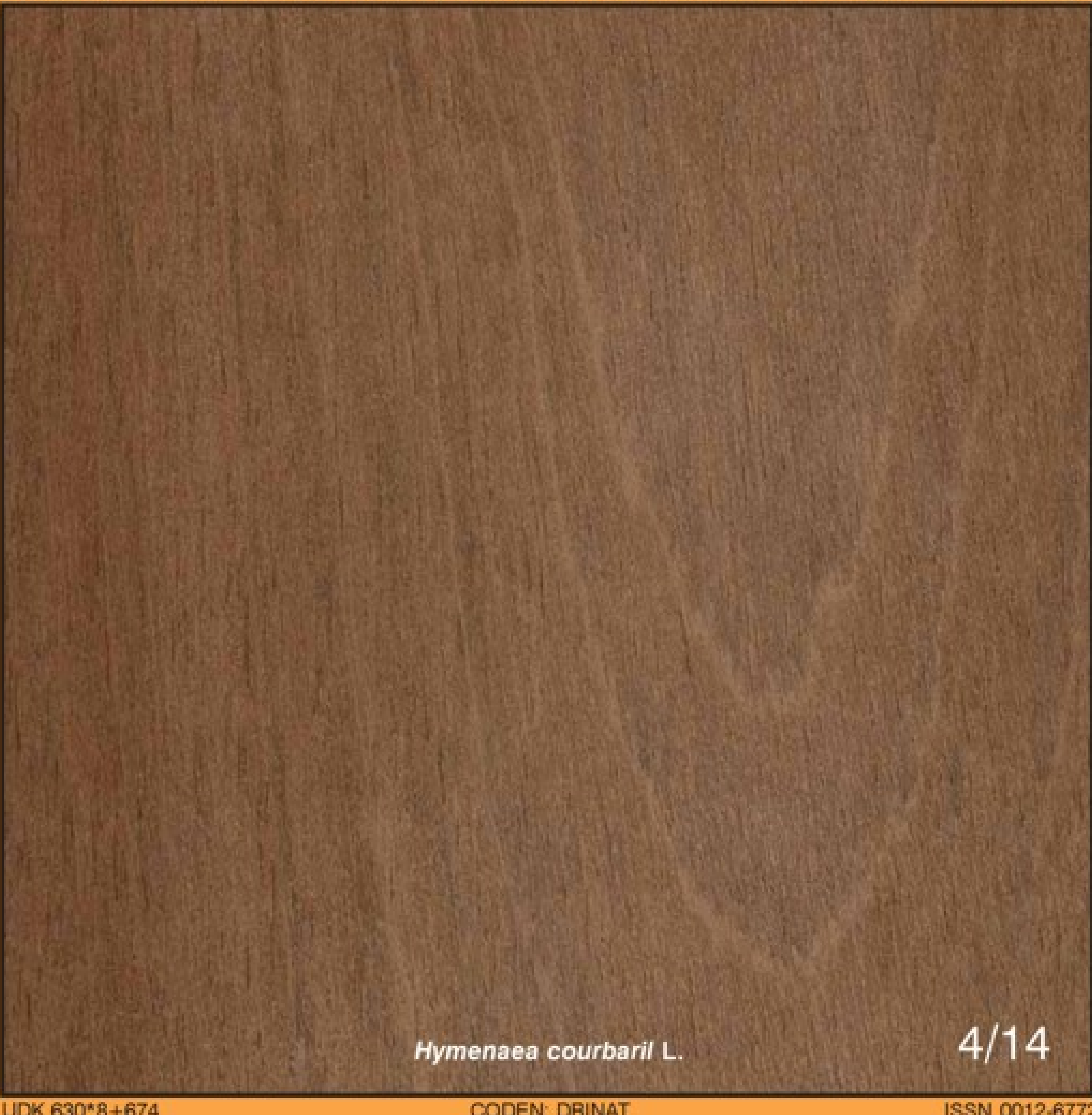
DRVNA INDUSTRIJA

ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE • ZAGREB • VOLUMEN 65 • BROJ 4
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY • ZAGREB • VOLUME 65 • NUMBER 4



Hymenaea courbaril L.

4/14

UDK 630*8+674 CODEN: DRINAT ISSN 0012-6772

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

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ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY

IZDAVAČ I UREDNIŠTVO
Publisher and Editor's Office
Šumarski fakultet Sveučilišta u Zagrebu
Faculty of Forestry, Zagreb University
10000 Zagreb, Svetošimunska 25
Hrvatska – Croatia
*Tel. (*385 1) 235 25 09*

SUIZDAVAČI
Co-Publishers
Exportdrvo d.d., Zagreb
Hrvatsko šumarsko društvo, Zagreb
Hrvatske šume d.o.o., Zagreb

OSNIVAČ
Founder
Institut za drvnoindustrijska istraživanja, Zagreb

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The journal is published quarterly.

OVAJ BROJ ČASOPISA POTPOMAŽE:

Sadržaj
Contents

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

DRVNA INDUSTRIJA · Vol. 65, 4 · str. 261-336 · zima 2014. · Zagreb
REDAKCIJA DOVRŠENA 2.12.2014.

Ján Kováč, Jozef Krilek, Marián Kučera, Štefan Barcík[1]

The Impact of Design Parameters of a Horizontal Wood Splitter on Splitting Force

Utjecaj projektnih parametara uređaja za horizontalno cijepanje drva na silu cijepanja

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 12. 6. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*823.11*
doi:10.5552/drind.2014.1335

ABSTRACT • *The article deals with the influence of the shape of the splitting wedge on the size and course of splitting force. Today maximum effort is made to search for and use of energy saving solutions in every industry. Such solutions can include a change of the form of the longitudinal splitting wedge for splitting logs. The core of this problem is the experimental detection of powers, followed by analysing the individual effects. For this purpose, an experimental device was designed. The base of equipment consists of a mobile horizontal splitter, which is well adapted to capture the process of splitting force in splitting logs.*
According to the results, the type of wood was the most influencal factor, followed by wood diameter and splitting wedge. When comparing the average values that were generated from repeated measurements, it is possible to follow the reduction of splitting force. The results showed that the splitting force was reduced by approximately 13 % when comparing splitting wedge No. 1 (simple) and No. 2 (refracted). When comparing splitting wedges No. 1 (simple) and No. 3 (concave), it can be observed that the splitting force was reduced by more than 50 %. The experiment also confirmed the effect of different anatomical structures of different species of wood on various physical and mechanical properties of such wood and hence also on the splitting force in splitting wood.

Key words*: *horizontal splitter, energy consumption, splitting force, splitting wedge

SAŽETAK • *U članku se govori o utjecaju oblika klina za cijepanje drva na veličinu i smjer sile cijepanja. U današnje vrijeme ulažu se veliki napori u pronalaženje i primjenu novih riješenja za uštedu energije u svim industrijama. Jedno od takvih rješenja može predviđati i promjenu oblika klina za uzdužno cijepanje trupaca. Za taj problem važno je eksperimentalno odrediti snagu te analizirati pojedinačne utjecajne parametre. Za tu svrhu izrađen je eksperimentalni uređaj za cijepanje drva. Baza opreme sastoji se od mobilnoga horizontalnog razdjelnika, koji je dobro prilagođen praćenju procesa cijepanja i sile za cijepanje trupaca.*
Rezultati su pokazali da najveći utjecaj na silu cijepanja ima vrsta drva, zatim promjer drva i, na kraju, oblik klina za cijepanje. Usporedbom prosječnih vrijednosti dobivenih ponovljenim mjerenjima može se pratiti smanjenje sile cijepanja. Rezultati su pokazali smanjenje sile cijepanja za oko 13 % ako usporedimo cijepanje uz pomoć klina

[1] Authors are assistants and associate professor at Technical University in Zvolen, Faculty of Environmental and Manufacturing Technology, Department of Forest and Mobile Technology, Zvolen, Slovak Republic.
[1] Autori su asistenti i izvanredni professor Tehničkog sveučilišta u Zvolenu, Fakultet zaštite okoliša i proizvodne tehnologije, Odjel za šumske i mobilne tehnologije, Zvolen, Slovačka.

1 (jednostavni) i klina 2 (slomljeni). Usporedimo li klinove za cijepanje broj 1 (jednostavni) i broj 3 (konkavni), može se uočiti smanjenje sile cijepanja za više od 50 %. Eksperiment je također potvrdio utjecaj anatomske građe različitih vrsta drva na fizikalna i mehanička svojstva drva, a time i na silu cijepanja pri obradi drva cijepanjem.

Ključne riječi: *uređaj za horizontalno cijepanje drva, potrošnja energije, sila cijepanja, klin za cijepanje*

1 INTRODUCTION
1. UVOD

Prices of energy have been rising and people are coming back to the oldest method of heating by burning of wood. Every year the number of households using wood mass to produce heat increases. The wood for heat production can be in various forms such as: chips, wood pellets or chopped wood. Chopped wood called fuel wood is obtained by shortening the tribe of the tree to the desired length with subsequent longitudinal splitting to the desired transverse dimension.

Also, production of logs is a necessary and important operation for every forest and wood-processing company (Krilek and Remper, 2012).

For preparing fuel wood, splitters are used working on the principle of chipping or pushing the wedge into the wood in the longitudinal direction. Thus they violate the consistency of wood fibres, which are separated by wedge pressure.

Splitters are mechanical machines designed for splitting wood logs faster and safer than ordinary axes (handle log splitter, wedges). They are safe and easy to operate by moving the splitting wedge controlled by pressure or by moving the lever. Wood is chipped by the action of a compressive force without a rapid kinetic movement of the cutting edge. This is the main reason why working with them is safer than with the classic manual splitting. Splitters are used by small households as well as large forest woodworking companies.

Wood splitters can be divided into groups by performance, position of logs during splitting, maximum strength that they can develop, size, weight, mobility, power, log size that can be chipped and ultimately the productivity. Further improvement of the machine will reduce energy consumption and costs required for preparing fuel wood.

Correct and reliable work of splitters is crucial especially in terms of power, strength, and splitting machine design. The examination of selected dependency and parameters of structure can eliminate necessary splitting force by its draft and thus ensure lower energy consumption while maintaining the same efficiency (Tajboš and Lukáč, 2005).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Theoretical analysis of the problem
2.1. Teorijska analiza problema

Splitting is a process of injection of the cutting tool between the wood fibres in order to pull them away from each other and thus create a divided area parallel to the fibres without violating their length (Kollmann and Côté, 1968). The nature of this process is to break the strength of wood perpendicular to the fibres, as a consequence of a perpendicular pressure action of the cutting wedge on the fibres. Splitting is one of chipless wood machining processes. The direction of injection of the cutting wedge may be parallel or perpendicular to the wood fibres (Blomberg, 2006). The splitting stress is the one in which the forces act normally like a wedge (Figure 1). The plane of cleavage is parallel to the grain, either radially or tangentially (Siklienka and Kminiak, 2013; Record, 2004).

When splitting, the splitting wedge usually pushes the wood fibres on the front of the logs in the parallel direction. In this direction, the wood fibres have the least resistance against being separated from each other. Splitting wedge initially compresses wood fibres and only then penetrates between the fibres and their flanks expand forming a rift, while it rips them from each other by the pressure of the wedge (Figure 1) (Remper and Krilek, 2012).

At the beginning of entering into the wood fibres, the splitting wedge increases the splitting force F_m proportionally to the depth of the wedge penetration. It reaches its maximum when the wedge enters to a depth of l_1, which is in the range from $(1/25 \cdot L)$ to $(1/20 \cdot L)$.

In another penetration of the wedge into the emerging cracks, the force required for F_s decreases to the length of penetration wedge l_2, this F_s being in the range from $(1/8 \cdot F_m)$ to $(1/10 \cdot F_m)$.

The force on the wedge at the average value of F_s is maintained to a depth of penetration wedge l_2, which is in the range from $(1/5 \cdot L)$ to $(1/6 \cdot L)$.

Then again, the force on the wedge significantly decreases and after tearing the log drops to zero. The depth of penetration wedge l_2 and maximum force F_m, in which the log breaks, are very dependent on the front angle of the wedge α, because its increasing power of the depth of penetration decreases. Also, species of trees and condition of wood, as well as the length of the splitting log, have a significant impact on splitting. Forces F_1 derive at the pressure of F acting on both sides of the wedge. When the wedge penetrates into the wood, it must overcome frictional force T, given by:

$$T = f \cdot F_1 \tag{1}$$

where:

f – the coefficient of friction between the tool and wood,

F_1 – the normal force acting on the front of the wedge, N.

The maximum compressive force on the wedge F_m is given by:

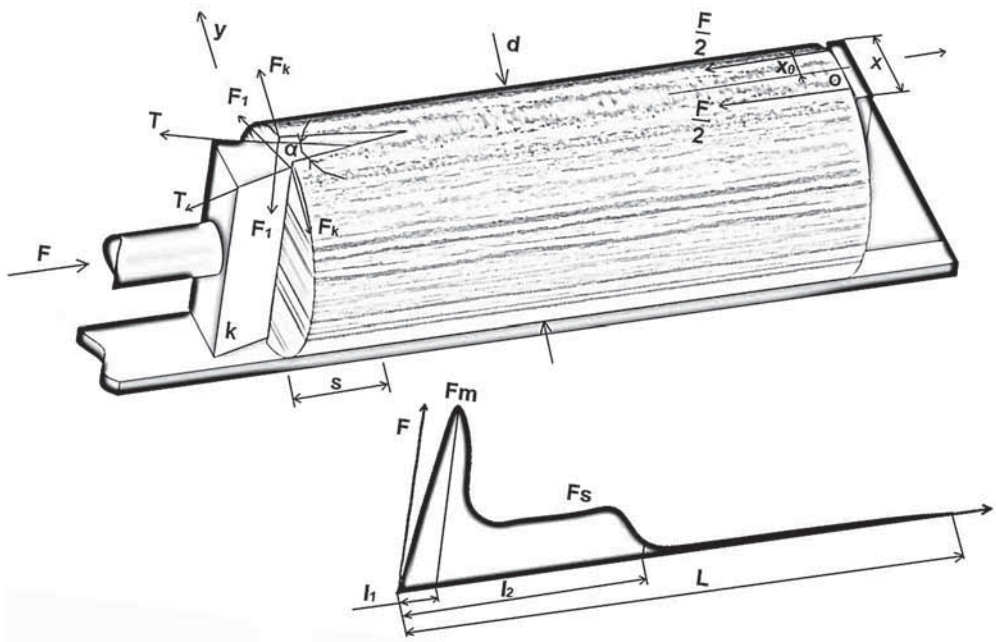

Figure 1 Scheme of forces acting by splitting wood (Remper and Krilek, 2012): *k* – splitting wedge, *o* – support, *d* – diameter of splitting log, *L* – length of splitting log, *F* – pushing force on the wedge, α - front angle of the wedge, F_m – maximum splitting force, F_1 – force perpendicular to the wedge front, F_k – force causing log splitting, *s* – trajectory of a wedge *x* – width of support, x_o – arm of the centre of the supporting reaction, l_1 – length of intrusion wedge with maximum pushing force, l_2 – length of intrusion wedge with the average pushing force, *F*s – average splitting force

Slika 1. Shema djelovanja sila tijekom cijepanja drva (Remper i Krilek, 2012.); *k* – klin za cijepanje, *o* – postolje, *d* – promjer trupca, *L* – duljina trupca, *F* – veličina sile na klinu, α – kut klina, F_m – maksimalna sila cijepanja, F_1 – sila okomita na klin, F_k – sila koja uzrokuje cijepanje trupca, *s* – putanja klina, *x* – širina postolja, x_o – krak središta potporne reakcije, l_1 – duljina prodora klina pri maksimalnoj sili na klinu, l_2 – duljina prodora klina pri prosječnoj sili na klinu, *F*s – prosječna sila cijepanja

$$F_m = 2 \cdot F_1 \cdot \left(f \cdot \cos\frac{\alpha}{2} + \sin\frac{\alpha}{2} \right) \qquad (2)$$

where:

α- the front angle of the wedge (°).

For splitting the log, the front of the wedge exerts force F_k, which is perpendicular to the longitudinal axis of the emerging cracks. This force is given by:

$$F_k = k \cdot d \cdot L \qquad (3)$$

where:

k – the specific splitting resistance of wood, kPa,
d – diameter of splitting log, m,
L – length of splitting log, m.

The specific splitting resistance depends on the type of tree species, condition of wood, diameter and length of the log, as well as on the front angle of the wedges:

$$k = k_z \cdot k_d \cdot k_s \cdot k_v \cdot k_k \qquad (4)$$

where:

k_z – the basic value of the splitting resistance, $N \cdot mm^{-2}$
k_d – wood factor (for example pine = 1, birch = 1.1 – 1.2)
k_s – wood factor status (dry = 1, crude = 1.1 – 1.2)
k_v – factor of the splitting log shape (logs = 1, prism = 1.25 – 1.3)
k_k – factor of the blunting wedge (normal = 1.1 – 1.2).

Apart from the need for a pull force of the wedge for splitting the log as much as possible, it is also necessary to provide low resistance wood of small diameter and length, as well as a small angle wedge with a flat front surface. The support of splitting machines must be wide (Remper and Krilek, 2012).

2.2 Experimental measuring equipment
2.2. Oprema za provedbu eksperimenta

Experimental measuring equipment (Figure 2) is designed to fluently record the process and the size of splitting force in the longitudinal splitting of wood. Its principle is based on the construction of horizontal splitter (1) with the pressure plate and fixed splitting wedge (2), which is removable. Linear hydraulic engine (3) creates compressive force on the plate which moves the log (5) against wedge (2). Pressure of hydraulic oil is produced by a hydraulic unit (6), and the control of the process is provided by a control panel (7).

In order to be able to determine the course of splitting force, an actuator was inserted between rods of the linear hydraulic engine and printing plates of the splitting machine. The use of a standard load cell was not appropriate because of its size, as the priority was to preserve the maximum length of splitting. For this reason, the idea of using a strain gauge applied to a selected part of the machine was carried out with the intention of monitoring the power of the splitting process. A ball bearing eye was chosen as the deformation member, and screwed into the internal thread rod. Cylindrical clamping part of the loop was sufficiently large and its shape was suitable for the application of strain gauges according to Figure 3, and it had several advantages.

The arrangement with two longitudinal and two transverse compensated strain gauges is the most popular to determine the axial load (Figure 2, 3).

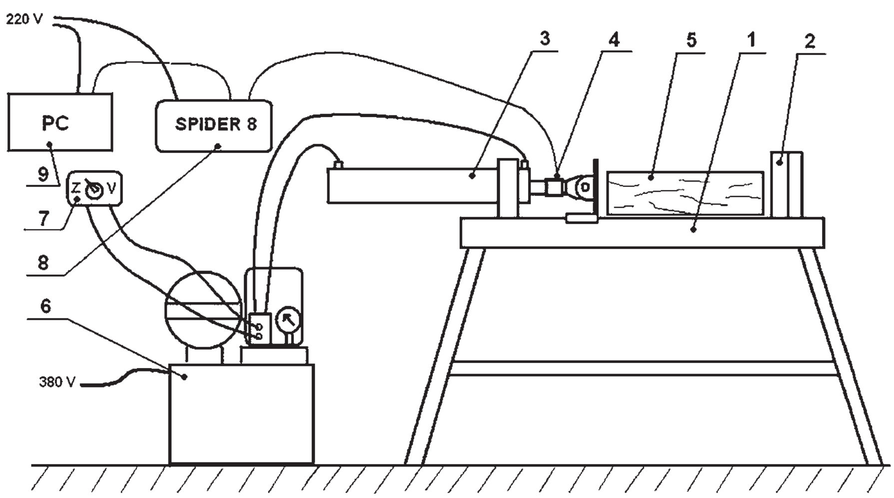

Figure 2 Horizontal splitter with measuring chain (1 – frame of horizontal splitter, 2 –splitting wedge, 3 – straightforward hydraulic engine, 4 – strain gauges, 5 – splitting log, 6 – hydraulic unit, 7 – control panel, 8 – logger, 9 – personal computer (pc)
Slika 2. Uređaj za horizontalno cijepanje drva s mjernim uređajima: 1 – okvir uređaja za cijepanje, 2 – klin za cijepanje, 3 – jednostavni hidraulički motor, 4 – mjerni instrumenti, 5 – trupac koji se cijepa, 6 – hidraulički uređaj, 7 – kontrolna ploča, 8 – kreiranje datoteka s podacima, 9 – računalo

Dependence is shown below:

$$\frac{U_v}{U_n} = \frac{K \cdot \varepsilon \cdot (1 + \mu)}{2 + K \cdot \varepsilon \cdot (1 - \mu)} \tag{5}$$

where:
U_v – output voltage, V
U_n – supply voltage, V
K – coefficient of deformation sensitivity of strain gauge,
ε – strain,
μ – Poisson's number.

This version provides very good temperature compensation, because the strain guages are in all adjacent arms of bridge. Both strain gauges are located in the adjacent arms of bridge. In comparison with the version of half Wheatstone bridge, involvement output is greater by a coefficient ($1 + \mu$) and characteristics of output are linear.

Calibration of strain gauges is performed using the universal testing machine Testometric M500-100 CT.

Complete calibration consists of loading in the longitudinal direction of the eye (removed from the piston rod) clamped in among the grips of the testing machine. The functionality and precision of strain gauge bridge applications were verified by calibration.

The output signal is transmitted to the measurement amplifier SPIDER 8, modified and subsequently deposited on the hard disk of a PC using the program Conmes Spider, in txt format. The measured values of splitting force were evaluated in Statistics 11.0 program by means of analysis of variance (Scheer, 2007). Estimates were made of the zero hypothesis H_0 that says that the mean squares of measured values of splitting power are equal, and alternative hypothesis H_1 that says that the mean squares are not equal. In order to determine the interaction of several factors affecting the change in the splitting process, ANOVA (multifactorial analysis of variance) was used. Reciprocal statistical dependency was found out among maximum splitting force (dependent variable) and wood, splitting wedges, diameter of splitting logs (independent variables).

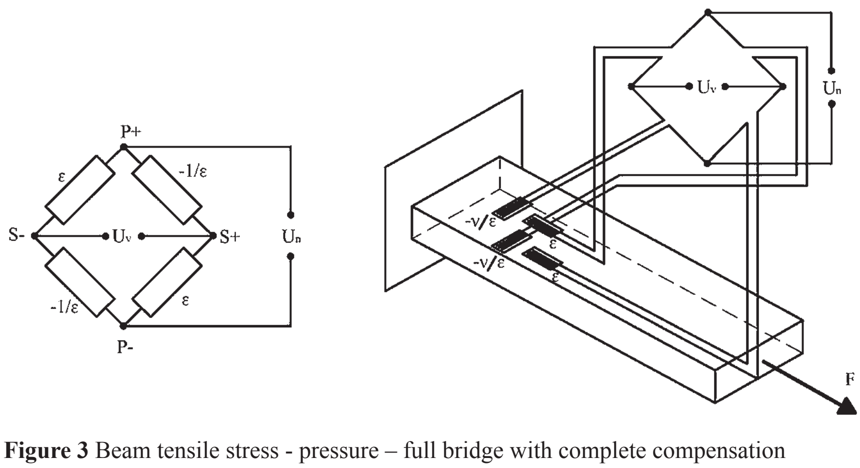

Figure 3 Beam tensile stress - pressure – full bridge with complete compensation (Hoffmann, 1989)
Slika 3. Vlačno i tlačno naprezanje u gredi – puni most s potpunom kompenzacijom (Hoffmann, 1989.)

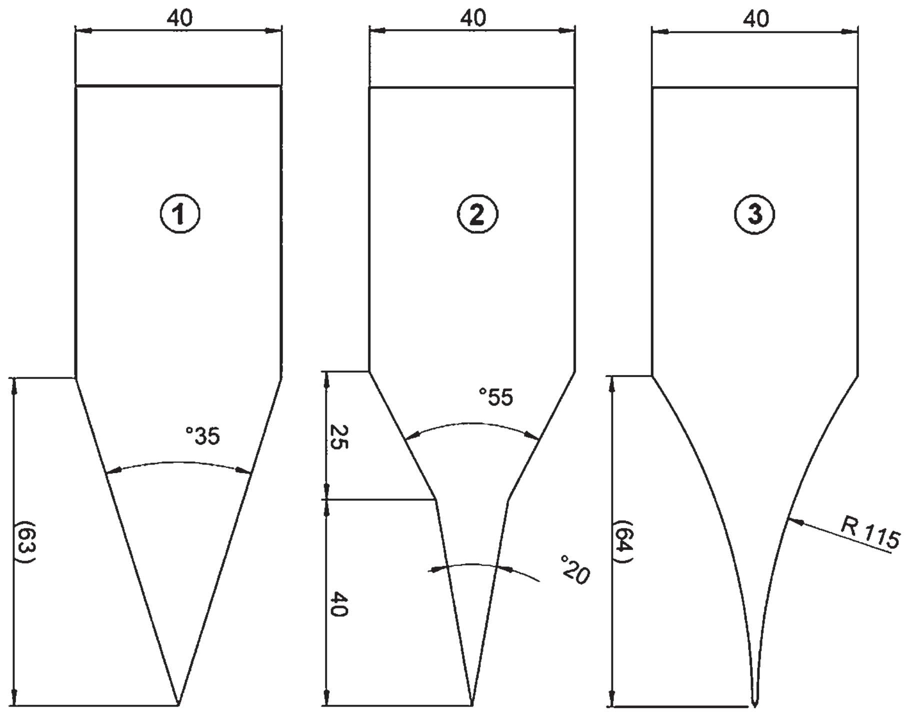

Figure 4 Various shapes of splitting wedges (1 – simple splitting wedge, 2 – refracted splitting wedge, 3 – concave splitting wedge)
Slika 4. Različiti oblici klina za cijepanje: 1 – jednostavni klin, 2 – slomljeni klin, 3 – konkavni klin

2.3 Methods of measurement
2.3. Mjerne metode

During the measurement, three types splitting wedges were used (Figure 4). Based on the survey, three types of splitting wedges were designed with different geometric shapes and sizes. The experiment samples were made of beech wood (*Fagus sylvatica* L.) and spruce wood (*Picea abies* L.). Cuts were sawn to length L = 85 cm, log diameter ranged between 27 and 36 cm and wood moisture content was ~ 34 %.

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

The criteria used for analysis are maximum splitting forces. As the criterion of statistical significance (p) F-test was used, although it is probable that the factor does not have statistical influence. It was assumed that individual parameters influence each other.

For each variation of three factors, there were two groups of diameters of splitting logs (27-31 cm and 32-36 cm) x two types of wood (BE – beech wood (*Fagus sylvatica* L.) and SP - spruce wood (*Picea abies* L.) x three different splitting wedges (simple, refracted and concave splitting wedge) = making a total of twelve variations. The representing of values of the tested item F - splitting force was filtered out. For each physical item, the results were statistically evaluated by three-factor analysis of variance.

The monitored factors show the following results: statistically the type of wood has the most significant influence, followed by diameters of wood and

Table 1 Univariate Tests of Significance for F_{max}
Tablica 1. Jednosmjerni testovi značajnosti za F_{max}

Effect	*SS*	*DF*	*MS*	*F*	*p*
Intercept / *Presjek*	3.615E+10	1	3.62E+10	1857.8	0.000
Group diameter of wood / *Skupina promjera drva*	3.983E+08	1	3.98E+08	20.5	0.000
Group types of woods / *Skupina vrste drva*	6.286E+08	1	6.29E+08	32.3	0.000
Group splitting wedge / *Skupina klina za cijepanje*	4.575E+08	2	2.29E+08	11.8	0.000
Group diameter of wood * types of wood *Skupina promjer drva * vrsta drva*	2.727E+06	1	2.73E+06	0.1	0.709
Group diameter of wood * splitting wedge *Skupina promjer drva * klin za cijepanje*	3.035E+08	2	1.52E+08	7.8	0.001
Group types of wood * splitting wedge *Skupina vrsta drva * klin za cijepanje*	7.674E+07	2	3.84E+07	2.0	0.147
Group diameter of wood * types of wood * splitting wedge *Skupina promjer drva * vrsta drva * klin za cijepanje*	1.215E+08	2	6.08E+07	3.1	0.050
Error / *Pogreška*	1.323E+09	68	1.95E+07		

Legend / *Legenda* (Scheer, 2007): *SS* – Summary of squares / *zbroj kvadrata*, *DF* – Degree of freedom / *stupanj slobode*, *MS* – Variance / *varijanca*, *F*– Critical value of Fischer Test / *kritična vrijednost Fišerova testa*, *p*– Level of significance / *razina značajnosti*

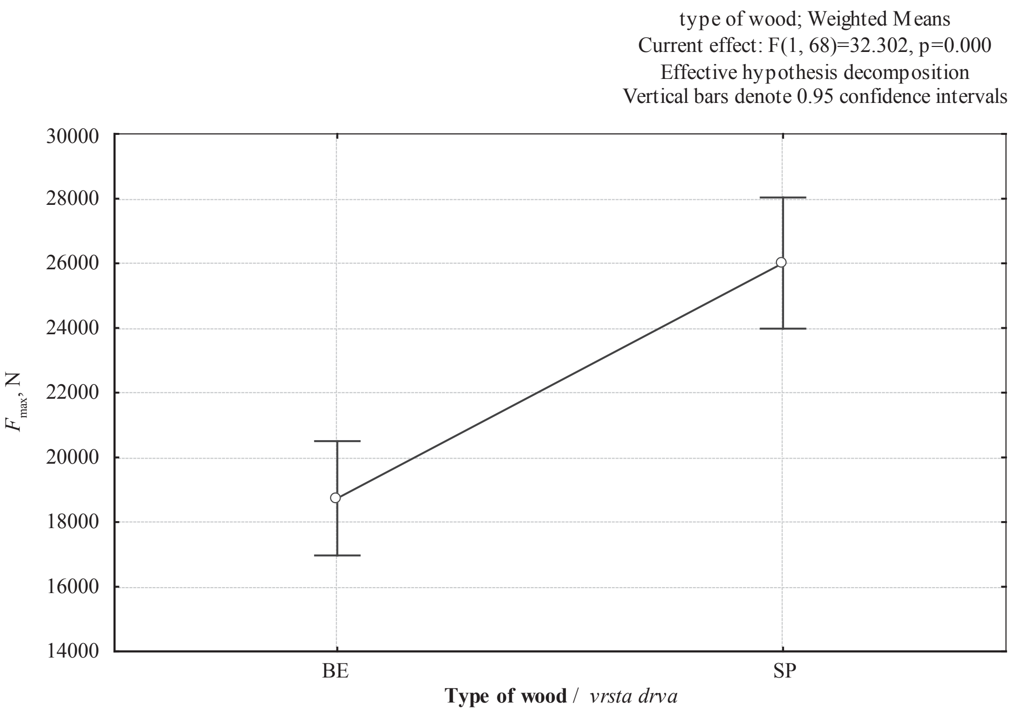

Figure 5 Graph of 95 % confidence interval for mean values of splitting force depending on wood species (beech wood and spruce wood)
Slika 5. Prikaz 95 %-tnog intervala pouzdanosti za srednjevrijednosti sile cijepanja u ovisnosti o vrsti drva (bukovina i smrekovina)

splitting wedge. The impact of splitting wedges is statistically significant, but among the monitored factors, its significance is the smallest.

The graph of splitting wedge - splitting strength in Figure 5 shows that the splitting force for sprucewood is significantly higher than for beechwood. This means that the sum of the averages of splitting forces measured are higher for sprucewood than for beech wood. The impact of the splitting wedge is included among random factors. Therefore, confidence intervals overlap (Figure 6), although the basic Table 1 analysis of variance shows that the effect of the splitting wedge

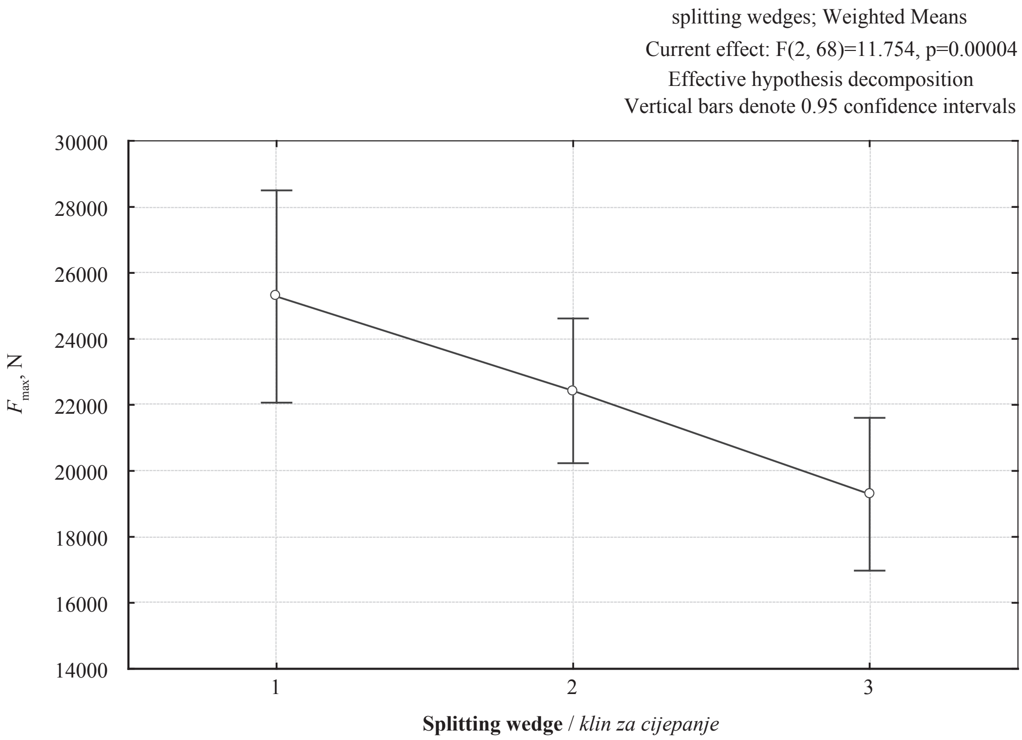

Figure 6 Graph of 95 % confidence interval for mean values of splitting force depending on the type of splitting wedges
Slika 6. Prikaz 95 %-tnog intervala pouzdanosti za srednje vrijednosti sile cijepanja u ovisnosti o obliku klina za cijepanje

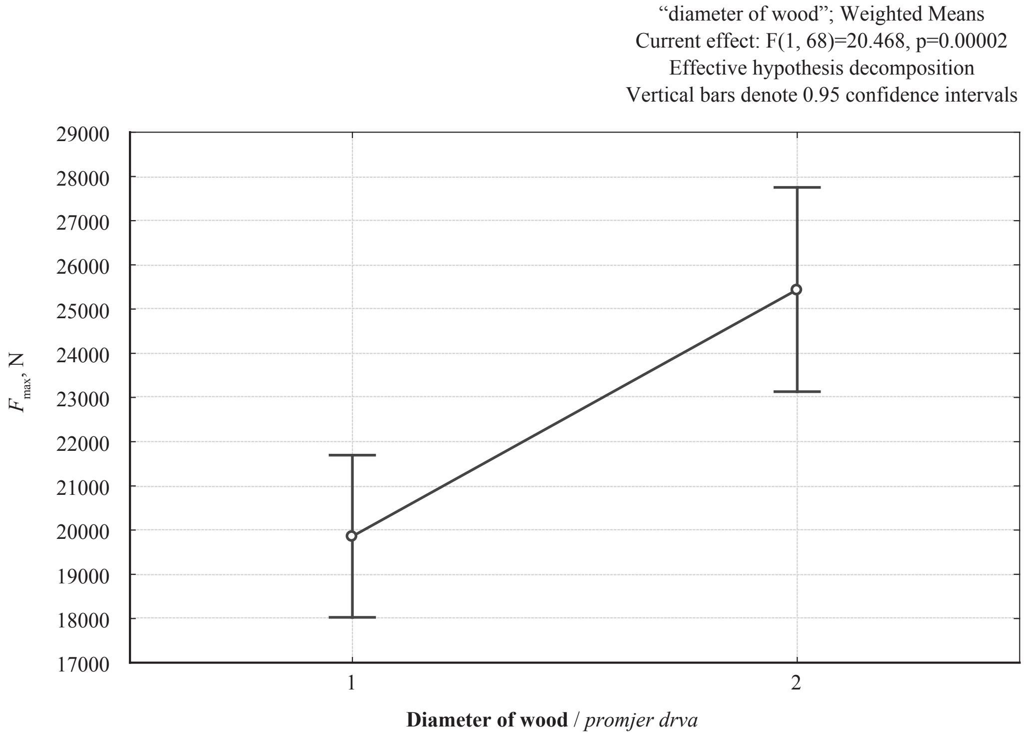

Figure 7 Graph of 95 % confidence intervals for mean values of splitting force depending on diameter of wood
Slika 7. Prikaz 95 %-tnog intervala pouzdanosti za srednje vrijednosti sile cijepanja u ovisnosti o promjeru drva

is statistically significant, i.e. the sum of the averages of splitting forces are the smallest for splitting wedge 3. Figure 7 shows clearly that the diameter of wood is statistically significant, i.e. the bigger diameter of the wood, the higher is the splitting force.

With the use of a simple splitting wedge (Figure 4), with maximum angle of 35°, maximum splitting force is produced compared to other wedges. With wedge No. 1, maximum force significantly increases linearly up to a value when the log tearing and cracking begins to grow faster than the splitting wedge. Subsequently F_{max} decreases to a value, which is needed for the distribution of fibres in the whole length of tribe. This force is many times less than the force F_{max}. When using refracted (degree) splitting wedge (Figure 4), with maximum angle of 20°, less splitting force is needed than with the simple wedge. Smaller maximum angle provides easier penetration of the wedge into tribe and its wider part provides the subsequent increase in the force required for splitting wood. The course of forces in the this splitting is more oscillating because splitting parts rub the edges of the wedge generating vibrations and causing the deformation of splitting force.

When using a concave splitting wedge (Figure 4), less splitting force is needed similarly as with refracted wedge. The maximum force is, relative to its force, almost 2/3 lower when using a simple wedge. Similarly as in the second case, forces are oscillating because splitting parts of the riven side rub the edges of the splitting wedge. In this case saving of splitting force is considerable, and in order to optimize it, the splitting force must be reduced as much as possible.

Three-factor analysis shows that splitting force of beech wood decreases with each splitting wedge and diameter of wood. With spruce wood, the mean values of splitting force are higher for the category wood diameter 1 (d = 27-31 cm).

For better evaluation of the measured data, categorized scatter plots were used (Figure 9). Figure 9 shows that when using beech wood of the increasing wood diameter, the mean splitting force increases, and with the splitting wedges 1 and 2, splitting force decreases. With spruce wood, the simple splitting wedge - 1 proved unsuitable for large diameter trees. For small diameter spruce wood, diameter factor proved to be opposite of splitting wedges 1, 2, 3, which explains the higher mean values of splitting force for wedge 2 and 3 for diameter of wood 1 (d = 27-31 cm) (Figure 8).

This is caused by physical and mechanical properties, and moisture of the spruce wood fibre saturation point (~ 34 %). The wedge is pushed deeper into the wood, thereby increasing contact zone of the splitting wedge, which results in a higher splitting force (Čadež *et al*., 2002). The weakest link is modullary rays that weaken wood and therefore splitting force is lower in beech wood (Antonović *et al*., 2007). Modullary rays consist exclusively of living parenchymatous cells with thin lignified walls, particularly at the point of connection to blood vessels or tracheids (Blomberg, 2006).

The results are similar to results of other authors (Stefanson, 1995; Tabarsa and Chui, 2000; Tabarsa and Chui, 2001), who say that the cleavability increases with the deformation in wood under compression. Siklienka and Kminiak (2013) say that in terms of

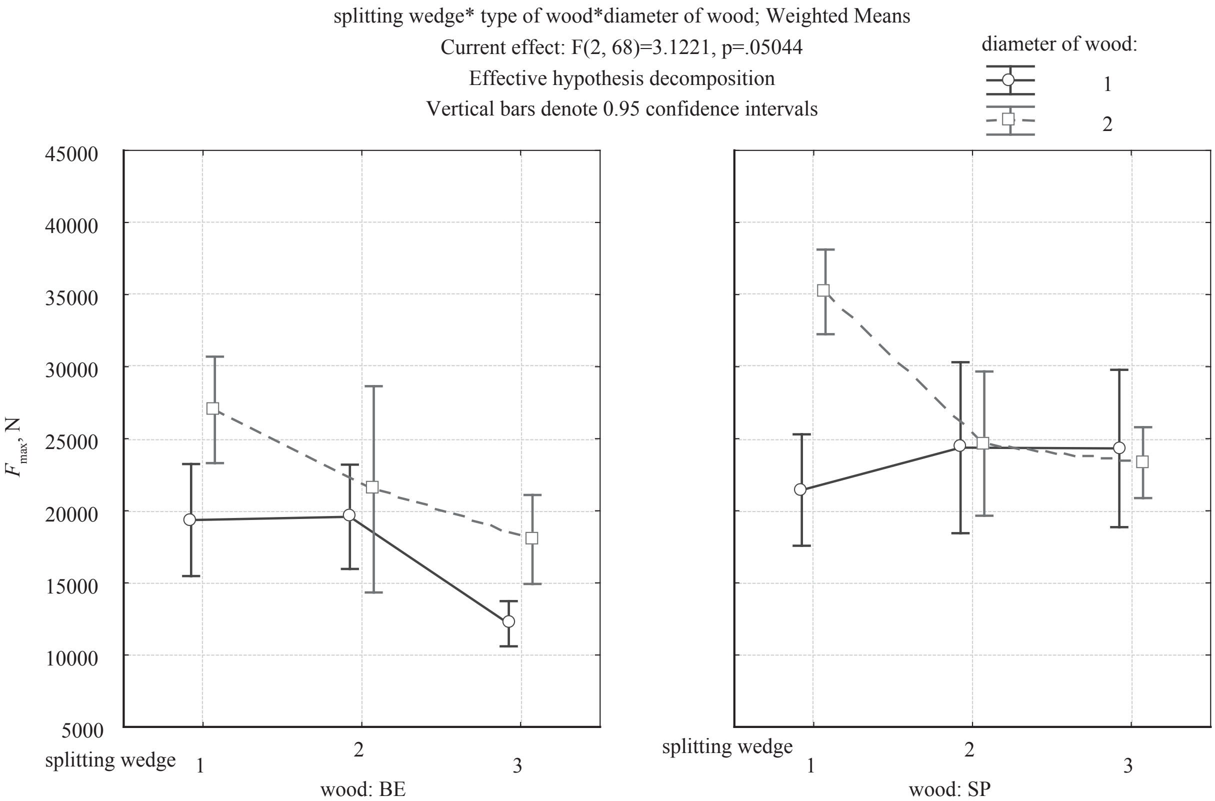

Figure 8 Graph of 95 % durability intervals for the mean values of splitting force for all input factors depending on wood diameter impact
Slika 8. Prikaz 95 %-tnog interval pouzdanosti srednjih vrijednosti sile cijepanja za sve ulazne parametre s obzirom na utjecaj promjera drva

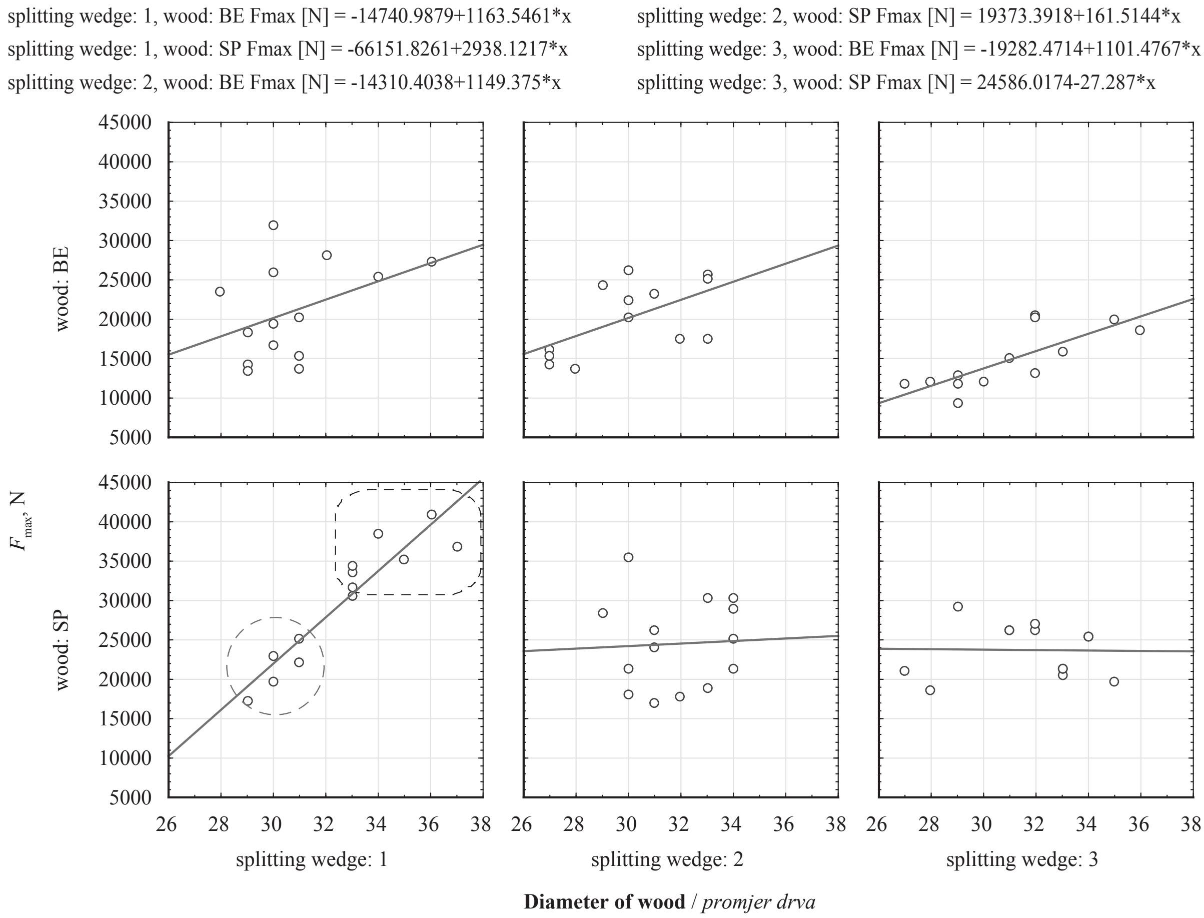

Figure 9 Dependence of splitting force by type of wood on diameter of wood and splitting wedges
Slika 9. Ovisnost sile cijepanja prema vrsti drva o promjeru drva i obliku klina

cleavability, an increase in water content in softwoods results in lower cleavability.

The above said is also shown by the monitorred length of wedge intrusion with the maximum splitting force l_1, in spruce wood higher by 30 % than in beechwood.

In the beech wood l_1 for splitting wedge 3, the length of intrusion is by 30 % shorter and for splitting wedge 2 by 56 % shorter.

In spruce wood, no influence has been demonstrated of splitting wedges 1, 2, and 3 on the length of wedge intrusion with the maximum splitting force l_1.

5 CONCLUSION
5. ZAKLJUČAK

The above theoretical analysis and the implementation of the experiment show that properly designed splitting wedge greatly influences the energy splitters.

When comparing the average values of the five repeated measurements, a decrease of splitting force can be observed. When comparing splitting wedges No. 1 and No. 2, splitting force ranges around 13 %, and when comparing splitting swedges No. 1 and No. 3, splitting force is over 50 %. However, it should be added that in terms of reducing the splitting force of the wedge, No. 3 is highly efficient.

Splitting wedges do not affect the splitting force in splitting spruce wood.

In terms of durability, it is less suitable because its thin and long blade is prone to dulling and bending and thereby requires the use of high strength steel. Increased complexity also requires re-sharpening of blunt wedge considering its concave shape. Further to the above, it can be concluded that the concave shape of the wedge is highly suitable for longitudinal splitting of logs, but its design and the need to use quality material have a negative impact on its economic aspect, and therefore nowadays it can only be seen on some splitters of reputable manufacturers.

It should be noted that it is necessary to take into consideration its life or durability.

Another option to reduce energy consumption is to reduce friction between the tool and logs, e.g. the method of surface coating, which can lead to further research of reducing adhesion and thus also the splitting forces.

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Corresponding address:

Ing. JOZEF KRILEK, Ph. D.

Faculty of Environmental and Manufacturing Technology
Department of Forest and Mobile Technology
Technical University in Zvolen
T.G. Masaryka 24
960 53 Zvolen, SLOVAKIA
e-mail: krilek@tuzvo.sk

Kazimierz A. Orlowski[1], Tomasz Ochrymiuk[2], Anthony Atkins[3]

An Innovative Approach to the Forecasting of Energetic Effects While Wood Sawing

Inovativni pristup predviđanju energijskih veličina tijekom piljenja drva

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 15. 7. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*822.02*
doi:10.5552/drind.2014.1341

ABSTRACT • *In the classical approach, energetic effects (cutting forces and cutting power) of wood sawing process are generally calculated on the basis of the specific cutting resistance, which is in the case of wood cutting the function of more or less important factors. On the other hand, the cutting forces (power) problem may be tackled with an innovative, up-to-date fundamental analysis of the mechanics of sawing based on modern fracture mechanics. This line of attack is an improvement on traditional approaches for cutting forces and power, many of which are empirical and based upon limited information. Such formulae do not permit generalisation to new conditions of operation of sawmills, such as e.g. the use of narrow-kerf blades. The presented algebraic model, for cutting power determination while sawing, in addition to timber 'strength' and friction between tool and workpiece, takes into account the property called 'fracture toughness' (resistance to cracking), which is a vital ingredient. Furthermore, forecasting of the shear plane angle with this model is achievable even for small values of uncut chips. Moreover, the mentioned model is a universal one, and useful for determination of energetic effects of sawing of every kinematics such as: frame sawing machines, bandsawing machines and circular sawing machines.*

Key words: *energetic effects, cutting power, wood sawing process, sawing machines, fracture mechanics, fracture toughness*

SAŽETAK • *U klasičnom pristupu energijske se veličine (sile rezanja i snaga rezanja) tijekom procesa piljenja drva obično izračunavaju na temelju specifičnog otpora rezanja, koji je pri rezanju drva funkcija više ili manje važnih čimbenika. Nasuprot tomu, problem određivanja sila rezanja i snage rezanja može se riješiti inovativnim pristupom uz primjenu temeljne analize mehanike piljenja koja se temelji na modernoj mehanici loma. Taj način pristupa određivanju sila rezanja i snage rezanja poboljšanje je s obzirom na tradicionalne metode, od kojih su mnoge empirijske i utemeljene na ograničenim podacima. Takve empirijske formule ne dopuštaju poopćenje prema novim uvjetima rada pilane, kao što je primjena tankih pila s malom širinom propiljka. Predstavljeni algebarski model za određivanje snage rezanja tijekom piljenja osim čvrstoće drva i trenja između alata i obratka uzima u obzir i svojstvo pod nazivom lomna žilavost (otpornost na pucanje), koje je ključni utjecajni čimbenik na snagu*

[1] Author is a professor at the Gdansk University of Technology, Faculty of Mechanical Engineering, Department of Manufacturing Engineering and Automation, Gdansk, Poland. [2]Author is a researcher at The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Department of Transonic Flows and Numerical Methods, Gdansk, Poland. [3]Author is an emeritus professor at the University of Reading, School of Construction Management and Engineering, Whiteknights, Reading, Berkshire, United Kingdom.
[1] Autor je profesor Fakulteta strojarstva Tehnološkog sveučilišta u Gdanjsku, Gdanjsk, Poljska. [2]Autor je znanstvenik Poljske akademije znanosti, Gdanjsk, Poljska. [3]Autor je profesor emeritus Sveučilišta u Readingu, Reading, Berkshire, Ujedinjeno Kraljevstvo.

rezanja. Nadalje, predviđanje kuta smicanja ravnine opisanim modelom ostvarivo je čak i za male vrijednosti debljine strugotine. Osim toga, model je univerzalan i primijenjiv za određivanje energijskih veličina pri različitim kinematikama rezanja kao što su piljenje pilom jarmačom, tračnom pilom i kružnom pilom.

Ključne riječi: *energijske veličine, snaga rezanja, proces piljenja drva, strojevi za piljenje, mehanika loma, lomna žilavost*

1 INTRODUCTION
1. UVOD

The mechanics of cutting wood has traditionally been interpreted in terms of the Ernst-Merchant model for cutting ductile metals in which, for given blade geometry and uncut chip thickness, the important parameters are mainly the strength of the material and friction between blade and workpiece (Manžos, 1974; Orlicz, 1988; Orlowski, 2007; Scholz *et al*., 2009; Naylor *et al*. 2011). Recent work in the mechanics of cutting (Atkins, 2009) shows that the resistance to cracking of the workpiece (the so-called fracture toughness) is just as significant as strength and friction in determining the forces and power to cut. Furthermore, incorporation of toughness in the new analysis predicts quantitatively many features that the Ernst-Merchant analysis fails to, such as values of the primary shear plane angle, the anomalous rise in specific cutting resistance at small uncut thicknesses, the transition to different types of chip, and so on. The new theory also gives physical meaning to terms in many empirical expressions for the forces and power to cut timber.

The present paper applies the new theory to the cutting of pine (*Pinus sylvestris* L.) by three different sorts of sawing machines, namely a sash gang saw, a circular saw and a bandsaw. Measured forces and power, as they change under different cutting conditions, are predicted by the theory. The capacity of the three sawing machines is discussed in terms of available power, feed rates and so on, leading to comments on the design of machines with different kinematic features.

2 THEORETICAL BACKGROUND
2. TEORIJSKA OSNOVA

Orlowski *et al*. (2013) have proved that cutting power models, which are based on modern fracture mechanics, are useful for estimation of energetic effects of sawing of every kinematics. According to Atkins (2009) and Orlowski (2010), moreover, taking into account that the chips have to be accelerated to the same velocity as the cutting tool velocity v_c (Atkins, 2009; Pantea, 1999), cutting power for one saw blade during the cutting stroke on a sash gang saw (for a whole cycle it means working and idling strokes $P_c = 0.5 \cdot \overline{P}_{cw}$ (Orlowski, 2010; Orlowski and Palubicki, 2009), and during cutting on a bandsaw machine, as their sawing kinematics are similar (Fig. 1a), has the following mathematical formula:

$$\overline{P}_{cw} = F_c \cdot v_c + P_{ac} = \left[z_a \cdot \frac{\tau_\gamma \cdot S_t \cdot \gamma}{Q_{shear}} \cdot v_c \cdot f_z + z_a \cdot \frac{R_\perp \cdot S_t}{Q_{shear}} \cdot v_c \right] + P_{ac} \tag{1}$$

where: $z_a = \left(\frac{H_P}{P}\right)$ is an average number of teeth being in contact with the kerf, P is tooth pitch, H_p is workpiece height (cutting depth), τ_γ is the shear yield stress, γ is the shear strain along the shear plane, which is given by:

$$\gamma = \frac{\cos\gamma_f}{\cos(\Phi_c - \gamma_f) \cdot \sin\Phi_c} \tag{2}$$

f_z is feed per tooth, h uncut chip thickness, S_t is a kerf width (the width of orthogonal cut), β_μ is friction angle which is given by $\tan^{-1}\mu = \beta_\mu$, with μ the coefficient of friction, γ_f is the rake angle, Φ_c is the shear angle which defines the orientation of the shear plane with respect to cut surface, $R_\perp$ is specific work of surface separation/formation (fracture toughness), and Q_{shear} is the friction correction:

$$Q_{shear} = [1 - (\sin\beta_\mu \cdot \sin\Phi_c / \cos(\beta_\mu - \gamma_f) \cdot \cos(\Phi_c - \gamma_f))] \tag{3}$$

For least force F_c the shear angle Φ_c satisfies (Atkins 2003):

$$\left[1 - \frac{\sin\beta_\mu \cdot \sin\Phi_c}{\cos(\beta_\mu - \gamma_f) \cdot \cos(\Phi_c - \gamma_f)}\right] \cdot \left[\frac{1}{\cos^2(\Phi_c - \gamma_f)} - \frac{1}{\sin^2\Phi_c}\right] = -\left[\cot\Phi_c + \tan(\Phi_c - \gamma_f) + Z\right] \cdot \left[\frac{\sin\beta_\mu}{\cos(\beta_\mu - \gamma_f)} \left\{\frac{\cos\Phi_c}{\cos(\Phi_c - \gamma_f)} + \frac{\sin\Phi_c \cdot \sin(\Phi_c - \gamma_f)}{\cos^2(\Phi_c - \gamma_f)}\right\}\right] \tag{4}$$

in which $Z = \frac{R}{\tau_\gamma \cdot f_z}$ is the parameter which makes Φ_c material dependent. Equation (4) is solved numerically.

Since, wood is an anisotropic material, its physical and mechanical properties differ in the three principal directions relative to the trunk of the tree (Fig. 2): longitudinal (L, axial), which is parallel to tree trunk and parallel to long axis of longitudinally oriented cells (tracheids and fiber tracheids); radial (R), which is perpendicular to longitudinal direction and parallel to the radius of the trunk and wood rays; and tangential (T), which is perpendicular to longitudinal direction and parallel to growth rings (FPL 1980). For that reason, values of R and τ_γ should be applied accordingly to the cutting speed direction in regard to the wood grain direction (Jeronimidis, 1980; Kretschmann, 2010), which is mainly a function of the sawing kinematics.

The chip acceleration power P_{ac} variation as a function of mass flow and tool velocity is given by:

$$P_{ac} = \dot{m} \cdot v_c^2 \tag{5}$$

where: $\dot{m}$ (kg·s^{-1}) represents the mass of wood (chips) evacuated in a certain period of time at the certain cut-

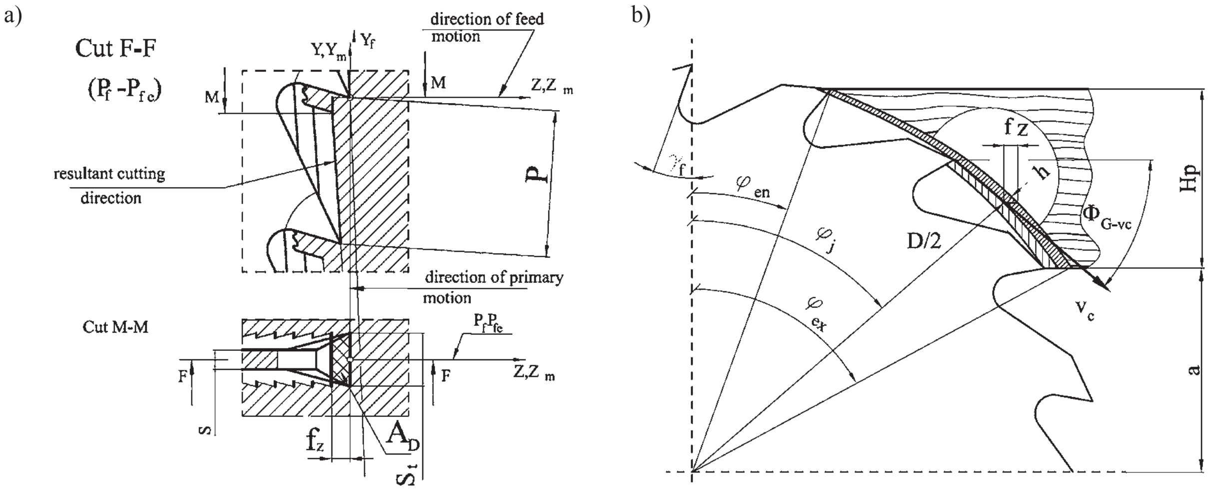

Figure 1 Sawing kinematics (a) on the sash gang saw and band sawing machine, along with kinematics on (b) circular sawing machine, where: f_z – feed per tooth, s – saw blade thickness, A_D – area of the cut, P – pitch, Y, Z and Y_M, Z_M – machine coordinate and setting axes, Y_f – f-set coordinate axis, P_{fe} – working plane, D – circular saw blade diameter, h – uncut chip thickness, H_p – workpiece height (depth of cut), a – position of the workpiece, φ – angular tooth position, $\Phi_{G\text{-}vc}$ – an angle between grains and the cutting speed direction (Orlowski *et al*., 2013)

Slika 1. Kinematika piljenja (a) na pili jarmači i tračnoj pili, (b) na kružnoj pili, gdje je: f_z – posmak po zubu, s – debljina lista pile, A_D – površina rezanja, P – korak zuba, Y, Z i Y_M, Z_M – koordinate stroja i postavljene osi, Y_f – f-set koordinatne osi, P_{fe} – radna ravnina, D – promjer kružne pile, h – debljina strugotine, H_p – visina obratka (debljina rezanja), a – pozicija obratka, φ – kutna pozicija zuba, $\Phi_{G\text{-}vc}$ – kut između vlakanaca i smjera brzine rezanja (Orlowski *et al*., 2013.)

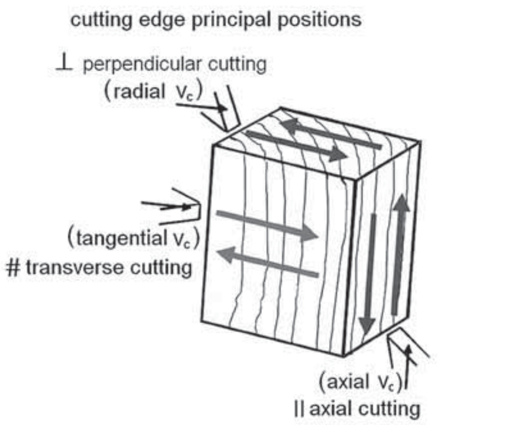

Figure 2 Tooth cutting edge principal positions and cutting speed directions (adapted by authors from Laternser *et al*., 2003; Orlowski *et al*., 2013)

Slika 2. Osnovne pozicije rezne oštrice i smjerovi brzine rezanja (prilagođeno prema Laternser *et al*., 2003.; Orlowski *et al*., 2013.)

ting tool velocity v_c (cutting speed), which can be calculated as follows:

$$\dot{m} = H_P \cdot S_t \cdot v_f \cdot \rho \qquad (6)$$

where: v_f is feed speed and ρ is the density of sawn wood. It should be emphasized, that in these analyses, it was assumed that the power P_{ac} is not a function of the number of working teeth. In case of both the circular sawing machine and the bandsawing machine, the chip acceleration power P_{ac} is several hundred times larger in comparison with the sash gang saw (Orlowski *et al*., 2013), thus, for the latter machine tool, the last term of Eq.(1) can be omitted.

Kinematics of sawing on circular sawing machines (Fig. 1b) differs from kinematics of cutting on sash gang saws and bandsawing machines (Fig. 1a). In case of cutting with circular saw blades, uncut chip thickness $\overline{h}$ (an average value e.g.) instead of feed per tooth f_z should be taken into account, hence, the cutting power may be expressed as:

$$\overline{P}_{cw} = F_c \cdot v_c + P_{ac} = \left[z_a \cdot \frac{\tau_\gamma \cdot S_t \cdot \gamma}{Q_{shear}} \cdot v_c \cdot \overline{h} + z_a \cdot \frac{R \cdot S_t}{Q_{shear}} \cdot v_c \right] + P_{ac} \qquad (7)$$

where: $z_a = \left(\frac{\varphi_2 - \varphi_1}{\varphi_t} \right)$ is a number of teeth being in contact with the kerf (average), φ_1 is an angle of teeth entrance which is given by $\varphi_1 = \arccos \frac{2 \cdot (H_p + a)}{D_{cs}}$, φ_2 is an exit angle which can be determined as $\varphi_2 = \arccos \frac{2 \cdot a}{D_{cs}}$, D_{cs} is a diameter of circular saw blade, an average uncut chip thickness is given by $\overline{h} = f_z \cdot \sin \overline{\varphi}$, and an average angle of tooth contact with a workpiece $\overline{\varphi}$ is calculated from $\overline{\varphi} = \frac{\varphi_1 + \varphi_2}{2}$.

Furthermore, it is difficult to presume that in this kind of sawing kinematics there is a case of perpendicular cutting, because the angle between the grains and the cutting speed direction differs from 90°, as it was assumed for the sash gang saw and the band sawing machines. Hence, taking into account the position of the cutting edge in relation to the grains, for indirect positions of the cutting edge fracture, toughness R and the shear yield stress τ_γ may be calculated from formulae known from the strength of materials (Orlicz, 1988). For example for cutting on circular sawing machines (a case of axial-perpendicular cutting), these material features are as follows:

$$R_{\parallel\perp} = R_{\parallel} \cdot \cos^2 \Phi_{G-vc} + R_{\perp} \cdot \sin^2 \Phi_{G-vc} \qquad (8)$$

Table 1 Tool and machine tool data
Tablica 1. Podaci o alatu i stroju

Parameter *Parametar*	**Sash gang saw** DTRB-63 (f. FOD) *Pila jarmača DTRB-63*	**Double shaft multi ripsaw** PRW 422 (f. TOS Svitavy) *Dvovretena višelisna kružna pila PRW 422*		**Bandsawing machine** ST-100R (f. Stenner) *Tračna pila ST-100R*
		Upper / *Gornja*	Lower / *Donja*	
H_p, mm	235.4	54.8	82.2	95
n_{sb}, mm	6	9	9	1
S_t, mm	3.9	3.9		2.2
P, mm	25	–		40
γ_f, º	18	22		25
z	38	18		138
v_c, m/s	5.2	69.6		35
v_f, m/min (m/s)	1.2 – 9 (0.02 – 0.15)	4 – 40 (0.07 – 0.67)		5 – 60 (0.083 – 1)
f_z, mm*	0.19 – 1.44	0.058–0.56		0.095 – 1.14
h, mm*	0.19 – 1.44	0.033 – 0.32	0.028 – 0.27	0.095 – 1.14
v_f, m/min (m/s) applied	3.9 (0.065)	16 (0.27)		45 (0.75)
f_z, mm, applied	0.625	0.233		0.86
h, mm, applied	0.625	0.131	0.111	0.86
P_{EM}, kW	45	110	110	15
P_i, kW	19	14	14	2.5
P_{cA}, kW (P^1_{cA})	20.8 (3.46)	76.8 (8.53)	76.8 (8.53)	10 (10)

Legend: *The values used in computation of predicted cutting powers, P_{EM} – electric motor power, P_i – idling power, P_{cA}, (P^1_{cA}) – available cutting power in the cutting zone (available cutting power per one saw blade), n_{sb} – number of saw blades
*Legenda: * vrijednosti korištene u računanju predviđene snage rezanja, P_{EM} – snaga elektromotora, P_i – snaga u praznom hodu, P_{cA}, (P^1_{cA}) – raspoloživa snaga u zoni rezanja (raspoloživa snaga rezanja za jednu pilu), n_{sb} – broj pila*

and

$$\tau_{\gamma\|\perp} = \tau_{\gamma\|} \cdot \cos^2 \Phi_{G-vc} + \tau_{\gamma\perp} \cdot \sin^2 \Phi_{G-vc} \quad (9)$$

where: $\Phi_{G\text{-}vc}$ is an angle between grains and the cutting speed direction (Fig. 1b).

3 MATERIAL AND METHODS
3. MATERIJAL I METODE

Predictions of cutting power have been made for the case of bona fide sawing processes on the sash gang saw DTRB-63 (f. FOD, PL, Fig. 3a), the double shaft multi ripsaw PWR422 (f. TOS Svitavy, CZ, Fig. 4) and the bandsawing machine ST100R (f. Stenner, UK, Fig. 5), which are installed in a Polish sawmill in the Cassubia Region in Poland. The basic sawing machines data and cutting parameters for which computations were done are shown in Table 1.

The raw material was pine wood (*Pinus sylvestris* L.) with the depth of cut equal to H_p. The raw material derived from the Baltic Natural Forest Region (A, Fig. 6), the Carpathian Natural Forest Region (B), the Little Poland Natural Forest Region (C) and the Great Poland-Pomeranian Natural Forest Region (D) in Poland. Moisture content was MC 8.5-12 % for bandsawing, and MC ~30 % for both the sash gang saw and the rip saw. For that reason, the latter cutting power results were additionally multiplied by 1.05 (Manžos,

a) b)

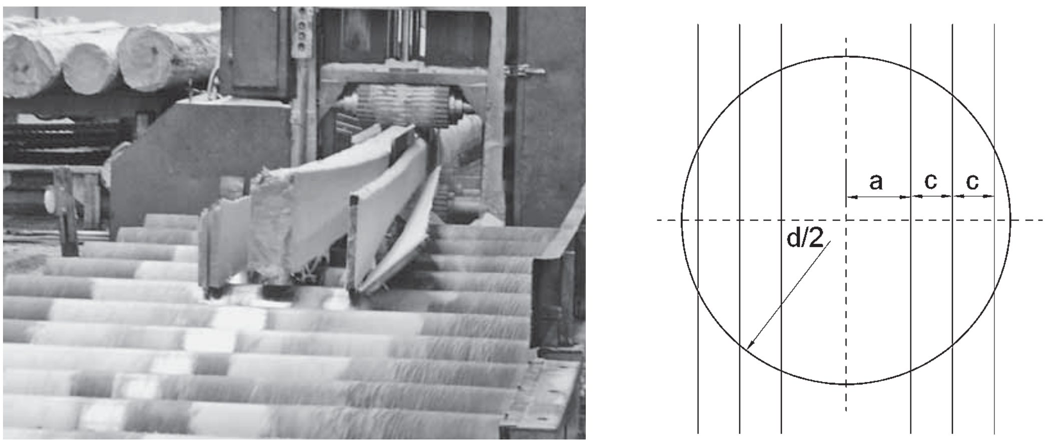

Figure 3 Sash gang saw DTRB-63 (a) and applied sawing pattern (b)
Slika 3. Pila jarmača DTRB-63 (a) i primijenjeni raspored pila (b)

a) b)

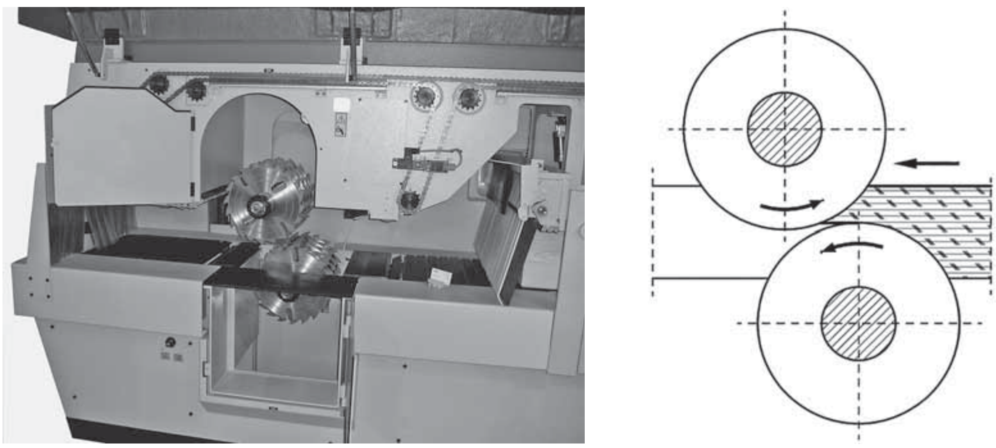

Figure 4 Double shaft multi ripsaw PWR422 (a, Web_source 1, 2013), along with kinematics and division of depth of cut (b)
Slika 4. Dvovretena višelisna kružna pila PWR422 (a), kinematika i podjela debljine rezanja (b)

1974). The value of kinetic friction coefficient μ = 0.6 for dry pine wood was taken according to Glass and Zelinka (2010), and Beer (2002).

In the case of circular sawing in which indirect positions of the cutting edge are present, R and τ_γ have to be calculated from formulae (8) and (9) (Orlowski *et al*., 2013). According to Aydin *et al*. (2007), it was assumed that fracture toughness of pine for longitudinal (axial) cutting $R_{||} = 0.05R_{\perp}$. Moreover, an assumption was made that in case of pine wood, for axial cutting, the shear yield stress $\tau_{\gamma||}$ is equal to 0.125×MOR (modulus of rupture in bending (Kretschmann, 2010; Krzysik, 1974)). The set of the raw material is presented in Tab. 2. Values of $R_{\perp}$ and $\tau_{\gamma\perp}$ were determined during sawing tests according to the methodology described in works by Orlowski and Atkins (2007) and Orlowski and Palubicki (2009). It should be emphasised that in the latter tests, the same samples were applied as in the experiments carried out by Krzosek (2009).

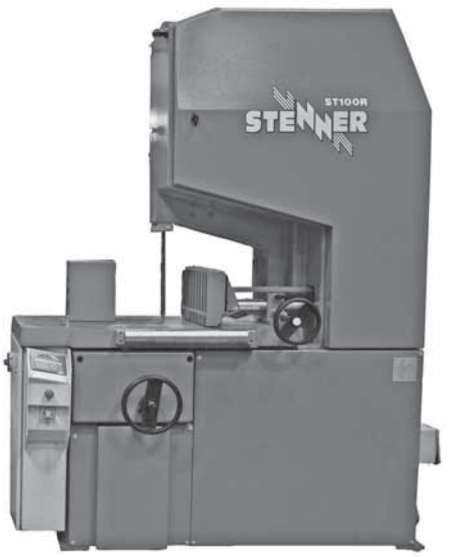

Figure 5 Bandsawing machine ST100R (Stenner, 2012)
Slika 5. Tračna pila ST100R (Stenner, 2012.)

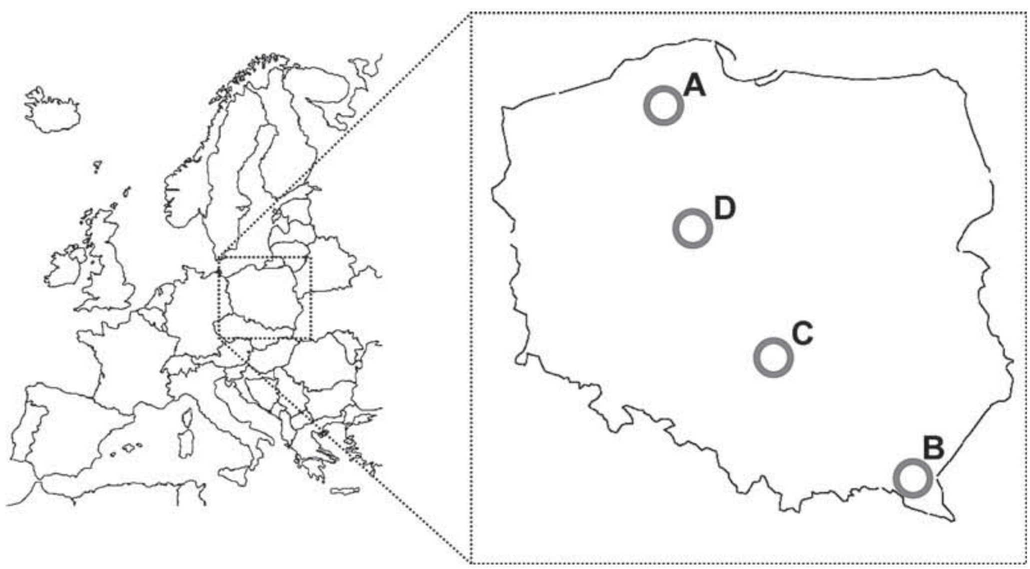

Figure 6 Locations of Polish Natural-Forest Regions of pine wood provenance
Slika 6. Lokacije prirodnih šuma bora u Poljskoj

Table 2 Raw material data (Orlowski *et al*., 2012)
Tablica 2. Podaci o materijalu (Orlowski *et al*., 2012.)

Region *Regija*	ρ	$R_{\perp}$	$\tau_{\gamma\perp}$	MOR*
	kg·m^{-3}	J·m^{-2}	kPa	MPa
A	520	1295.33	20861	41,6
B	439	1496.32	16846	25,3
C	478	1267.17	17986	35,2
D	589	1141.29	29521	45,1

ρ – density, MOR – modulus of rupture in bending (* values were taken from Krzosek 2009)
ρ – gustoća, MOR – modul loma pri savijanju (vrijednosti preuzete od Krzosek, 2009.)*

The sawing pattern for the sash gang saw, in which thickness of the main material is $2a$ = 137 mm, with 2 boards of 27.5 mm in thickness additionally obtained on each side, is presented in Fig. 3b. Logs with diameter d_g in thinner end (top diameter) about 11″ (imperial units are still in use in sawmill practice, d_g ≈290 mm), and l = 4 m in length are sawn. The workpiece thickness H_P presented in Tab. 1 is in this case an average value of the kerf depth determined in the middle of the log length. In order to estimate a middle log diameter d, the taper coefficient TC (cm/m, the degree of taper) was calculated as follows (Leśnik, 2013):

$$TC = \frac{1}{10}\cdot\left[6.2 + 74\cdot l^{-3} + \left(\frac{0.48}{\sqrt{l}} - 0.12\right)\cdot\left(d_g - 22 + 0.3\cdot l\right)\right] \quad (10)$$

where: l is the log length in m, and d_g is the top diameter without bark in cm. Thus, in this case TC = 0.834 cm/m, and for this data middle log diameter is d = 30.66 cm. The latter value was applied in calculations of the total kerf height H_{Σ} as follows (Csanády and Magoss, 2013):

$$H_{\Sigma} = 4\sum_{i=1}^{i=k}\sqrt{\left(\frac{d}{2}\right)^2 - \left[a + (i-1)\cdot c\right]^2} \quad (11)$$

where: $\frac{d}{2} \geq a + (i-1)\cdot c$, and i is the number of cut right to the centre. Hence, for the sash gang saw, the average workpiece thickness H_P is a ratio of H_{Σ} to the number of saw blades n_{sb}.

Computations of cutting power were carried out in each case for one saw blade, and the obtained values were compared to P^1_{cA} available cutting power per one saw blade (Tab. 1). The latter was calculated as follows:

$$P^1_{cA} = \frac{\left(P_{EM} - P_i\right)\cdot\eta_m}{n_{sb}} \quad (12)$$

where: η_m is mechanical efficiency of the main driving system (for each machine tool η_m = 0.85 was assumed).

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

Predictions of the cutting model that includes work of separation in addition to plasticity and friction in the case of sawing dry pine wood of the Baltic Natural Forest Region (A) provenance on examined sawing machines are shown in Fig. 7. The reduction in Φ_c (Fig. 7a) and increase in γ (Fig. 7b) for all values of rake angle γ_f for small depths of cut (e.g. uncut chip thickness) according to Atkins (2003, 2009) are the reason for the increase in cutting pressure. Furthermore, an increase in shear plane angle Φ_c is observed when rake angle γ_f has a larger value.

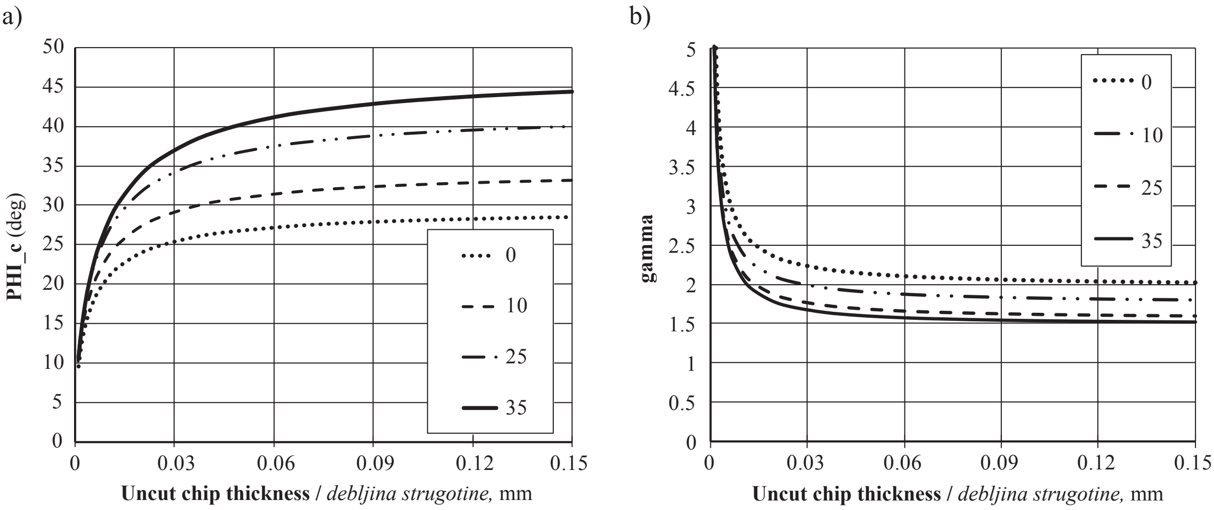

Figure 7 Predictions of cutting model that includes work of separation in addition to plasticity and friction in the case of sawing dry pine wood on examined sawing machines (a) shear plane angle Φ_c vs. f_z, (b) primary shear strain γ vs. f_z, in a function of uncut chip thickness h and rake angle γ_f
Slika 7. Predviđanja za model rezanja koji obuhvaća rad odvajanja uz plastičnost i trenje pri piljenju suhe borovine na ispitivanim strojevima: (a) kut ravnine smicanja Φ_c vs. f_z, (b) primarna čvrstoća smicanja γ vs. f_z, kao funkcija debljine strugotine h i prednjeg kuta γ_f

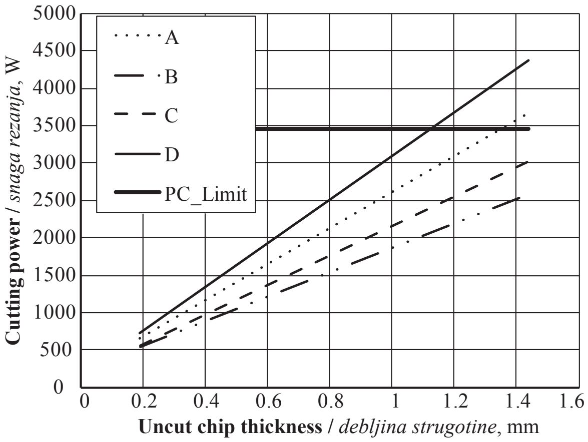

Figure 8 Predicted cutting power for one saw blade for the frame sawing machine DTRB 63
Slika 8. Predviđena snaga rezanja za jedan list pile jarmače DTRB 63

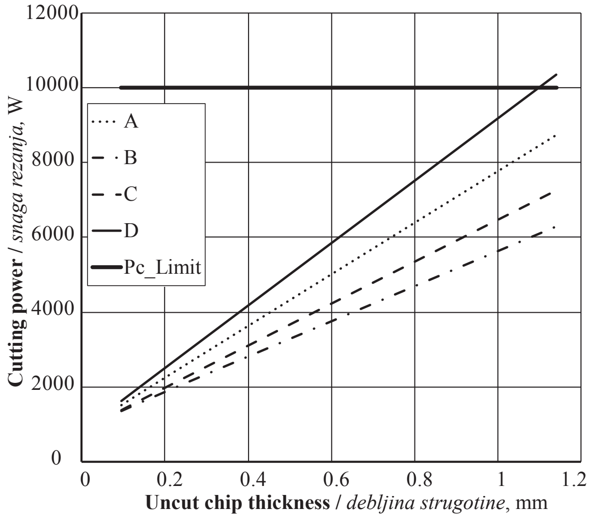

Figure 9 Predicted cutting power for the bandsawing machine ST100R
Slika 9. Predviđena snaga rezanja za tračnu pilu ST100R

Results of predictions of cutting powers obtained with the use of cutting models that include work of separation in addition to plasticity and friction, and chip acceleration power variation in the case of sawing of pine coming from different Polish regions with one saw blade are shown: in Fig. 8 for the frame sawing machine DTRB 63, in Fig. 9 when using the bandsawing machine ST100R, and in Fig. 10a (upper spindle) and Fig. 10b (lower spindle) for cutting on the rip saw PWR422. For both, the rip saw and the bandsawing machine, the results of the chip acceleration power P_{ac} have been taken into account.

For analysed sawing patterns of the actual Polish sawmill, the capacity of the three sawing machines could be discussed in terms of available power for pine wood of different provenance:

1. For the sash gang saw DTRB 63, it is impossible to apply maximum values of feed speed for every kind of pine wood (it concerns the raw material derived from the Baltic Natural Forest Region (A) and the Great Poland-Pomeranian Natural Forest Region (D)).
2. For bandsaw ST100R sawing pine wood from the Great Poland-Pomeranian Natural Forest Region (D), the cutting power could surpass the accessible cutting power in the cutting zone almost at maximum values of feed speed.
3. For the rip saw PWR422, the accessible cutting power in the cutting zone (per one saw blade) is not exceeded, because the workpiece height (cutting depth) is automatically divided among two spindles as a ⅔ ratio, and simultaneously the maximum value of feed speed is not so high compared to other machine tools currently present on the European market.

It ought to be emphasised that only the obtained cutting powers for pine wood of the Baltic Natural Forest Region (A) provenance (in each case of sawing the second line from the top in plots, Fig. 8–10) correspond to values calculated with empirical models presented e.g. by Manžos (1974) and Orlicz (1988). This piece of evidence could be stated, since, in the paper by Or-

a) b)

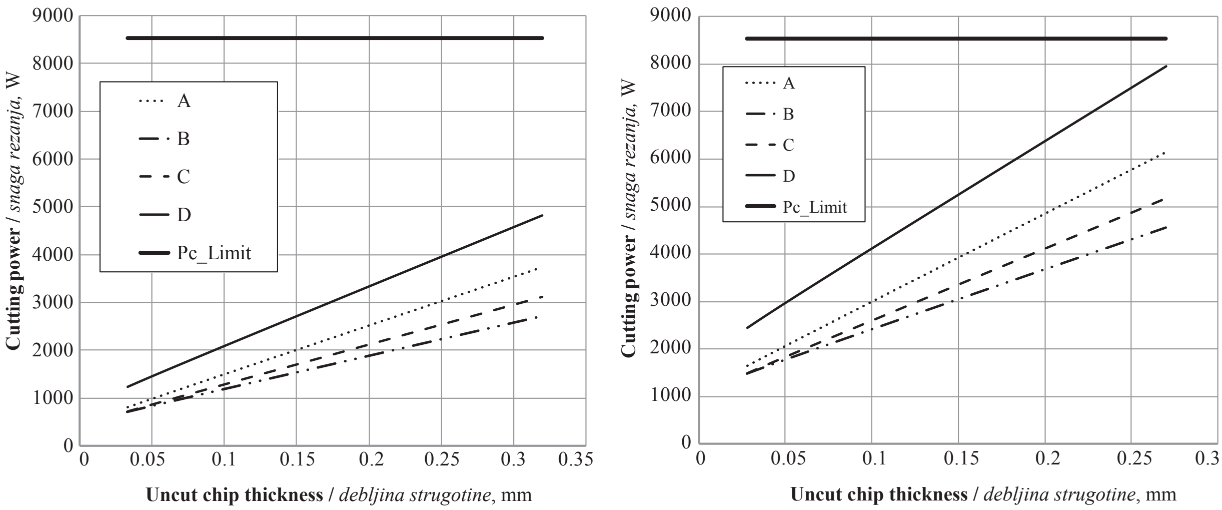

Figure 10 Predicted cutting power for one circular saw blade for the rip saw PWR422, where: a – upper spindle, b – lower spindle
Slika 10. Predviđena snaga rezanja za jedan list kružne pile PWR422: a) za gornje vreteno, b) za donje vreteno

lowski et al. (2013), it has been proved that the specific cutting resistance is in conformity with values calculated with the use of the mentioned empirical calculation models. Furthermore, the size effect was present for the cutting power prediction method, which is based on the fracture mechanics. For other locations (Regions B, C and D) of the raw material origin examined in this paper, cutting powers significantly differ from the cutting power values of pine wood originated from Region (A) because MOR, fracture toughness and simultaneously shear yield stresses significantly vary (shown in Table 2). Additionally, variability in properties is common to all materials. Since wood is a natural material and the tree is subject to many constantly changing influences (such as moisture, soil conditions, and growing space), wood properties vary considerably, even in clear material (Kretschmann, 2010; Krzosek, 2009). The same could be noticed in dispersion of the raw material data presented in Tab. 2.

Hence, it has been demonstrated that the approach to predictions of cutting powers obtained with the use of cutting models that include work of separation in addition to plasticity and friction, together with the chip acceleration power variation, is simultaneously an universal and useful tool for forecasting of energetic effects of sawing of every kinematics.

5 CONCLUSIONS
5. ZAKLJUČAK

The conducted forecasting of energetic effects with the use of cutting models that include work of separation in addition to plasticity and friction, together with the chip acceleration power variation, once more corroborated their versatility and revealed the efficacy for every known type of sawing kinematics (sash gang saw, bandsawing machine and circular sawing machine).

Furthermore, the conducted analyses revealed that the provenance of the raw material really affects an energetic demand of the cutting process.

This kind of approach to the forecasting of energetic effects while wood sawing allows the sawmill management to estimate the capacity of the rip sawing machines in terms of available power for pine wood of different provenance in advance before processing. It could also be an appropriate method for planning of the proper sawing pattern according to the available power of the sawing machine.

Acknowledgements – Zahvala

The authors would like to thank Dr. Sc. Krzosek S. (Faculty of Wood Technology, Warsaw University of Life Sciences–SGGW, PL) for the donation of the raw material used in the preliminary tests. A part of this paper was presented at the International Scientific Conference FORTECHENVI 2013 held in Brno (CZ) 26-30 May 2013. The financial assistance of the Ministry of Science and Higher Education, Poland, Grant N N 508 629840 is also kindly acknowledged. The authors would like to thank the firm PPH GASSTECH Sp. z o.o. for cutting tools data, and the COMPLEX Sawmill (Poland) for sawing process data.

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Corresponding address:

Professor KAZIMIERZ A. ORLOWSKI, Ph. D.

Gdansk University of Technology
Faculty of Mechanical Engineering
Department of Manufacturing Engineering and Automation
Narutowicza 11/12
80-233 Gdansk, POLAND
e-mail: korlowsk@pg.gda.pl

ZAGREB UNIVERSITY
FACULTY OF FORESTRY
WOOD SCIENCE AND TECHNOLOGY DEPARTMENT
Svetošimunska c. 25, p.p. 422
HR-10002 ZAGREB
CROATIA

385 1 235 2509 tel
385 1 235 2544 fax
hidralab@sumfak.hr
pervan@sumfak.hr
www.sumfak.hr

Jožica Gričar

Effect of Temperature on Radial Growth of Beech and Pine Saplings in the First and Second Year of the Experiment: a Comparison

Utjecaj temperature na radijalni rast mladica bukve i bora u prvoj i drugoj godini pokusa: usporedba

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 19. 8. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*811.4; 674.031.632.22; 674.032.475.4*
doi:10.5552/drind.2014.1344

ABSTRACT • *The aim of the study was to monitor the seasonal dynamics of radial growth in one to two-year old saplings of European beech (Fagus sylvatica L.) and Scots pine (Pinus sylvestris L.) under three different temperature regimes: greenhouse (G), cooling chamber (C) and outdoors (K). The research was conducted over two growing seasons, 2010 and 2011, in order to compare the effect of different environmental conditions on the radial growth of saplings in the first and second year of the treatment. The results showed that the patterns of the radial growth of beech saplings exposed to different temperature conditions were similar, especially in 2010. An increase in radial diameter was observed generally one month later in 2010 than in 2011, probably due to transplant shock in 2010. In pines, on the other hand, such delays were not recorded; however, the growth ring patterns of saplings exposed to different treatments differed in the studied growing seasons. In both years, the wood increment of beech was narrowest in G and widest in C. In 2010, xylem growth rings of pines were widest in Gand and narrowest in C, whereas in 2011 they were widest in K. Two-year xylem increments of beech saplings were lowest in G, but similar in C and K. In the case of pine, the two-year xylem increment was widest in K and narrowest in C. Comparison of xylem growth ring widths of pine and beech saplings in 2010 and 2011 under different regimes showed that widths in 2010 were wider in pines under all three regimes, whereas in 2011 increments of pines were narrower than those of beech only in C. Our findings indicate different phenotypic plasticity of pine and beech saplings under different temperature regimes, in terms of radial growth. It is also clear that a continuation of such experiments over many growing seasons is necessary to capture the short- and long-term growth response of trees in changing environmental conditions.*

Key words: *Fagus sylvatica, Pinus sylvestris, xylem increment, juvenile period, temperature*

[1] Author is scientist in Slovenian Forestry Institute, Department of Yield and Silviculture, Ljubljana, Slovenia.
[1] Autorica je znanstvenica Slovenskoga šumarskog instituta, Odjel za prirast i silvikulturu, Ljubljana, Slovenija.

SAŽETAK • *Cilj ovog istraživanja bio je praćenje sezonske dinamike radijalnog rasta jednogodišnjih mladica bukve (Fagus sylvatica L.) i bora (Pinus sylvestris L.) u tri različita temperaturna režima: stakleniku (G), rashladnoj komori (C) i na otvorenome (K). Istraživanje je provedeno tijekom vegetacije u 2010. i 2011. godini. Uspoređuje se dinamika radijalnog rasta u te dvije godine i raspravlja o utjecaju različitih ekoloških uvjeta na rast mladica u prvoj i drugoj godini eksperimenta. Rezultati su pokazali da su trendovi radijalnog rasta bukovih stabala izloženih različitim temperaturama međusobno slični, osobito u 2010. godini. Povećanje radijalnog promjera primijećeno je uglavnom mjesec dana kasnije u 2010. nego u 2011. godini, najvjerojatnije zbog transplantacijskog šoka u 2010. Za borove, nasuprot tome, takva kašnjenja nisu primijećena, ali postojale su razlike u dinamici radijalnog rasta mladica izloženih različitim tretmanima u dvije promatrane godine. U obje godine prirast drva bukve bio je najuži u G i najširi u C. Prirast drva bora bio je u 2010. najširi u G i najuži u C, a u 2011. godini prirast drva bora bio je najširi u K. Dvogodišnji prirast drva bukovih mladica bio je najuži u G, a međusobno sličan u C i K. Dvogodišnji prirast drva bora bio je najširi u K i najuži u C. Usporedba širina godova drva borovih i bukovih mladica u 2010. i 2011. godini pri različitim temperaturnim režimima pokazuje da su u 2010. u svim tretmanima godovi širi u bora, ali su u 2011. samo u C godovi bora bili uži nego u bukve. Rezultati upućuju na različitu fenotipsku plastičnost borovih i bukovih mladica u različitim temperaturnim režimima s obzirom na radijalni rast. Također se pokazalo da je potrebno nastaviti te eksperimente tijekom niza vegetacijskih razdoblja kako bi se otkrile kratkoročne i dugoročne reakcije rasta stabala u promjenjivim uvjetima okoliša.*

Ključne riječi: *Fagus sylvatica, Pinus sylvestris, prirast drva, juvenilno razdoblje, temperatura, svjetlosna mikroskopija*

1 INTRODUCTION
1. UVOD

With its 60 % forest cover, Slovenia is one of the most heavily wooded countries in Europe. The majority of Slovenian forests consist of beech, fir-beech and beech-oak stands (70 %), which are known for their relatively high productive capacity (Gozdnogospodarski *etc.*, 2006; Božič *et al*, 2010). Tree growth responds to short- and long-term environmental variations (e.g., Larcher, 2003). Due to global warming and climate change, growing conditions are expected to change in Slovenia in the coming decades and this will affect the biodiversity and production of its forest ecosystems (Kutnar *et al*, 2009). As a result of increasing climate extremes, which have a strong impact on forest stability and primary production, management risk is increasing due to lower prediction reliability, particularly in marginal and extreme forest ecosystems (e.g., Beniston and Diaz, 2004; Jump and Peñuelas, 2005; IPCC, 2007). At the moment, it is impossible to predict with certainty the long-term extent of the consequences, because the relationship of phenological events and tree productivity to climate is complex and not a simple matter of threshold values and monotonic responses (Jolly *et al*, 2005; Pichler and Oberhuber, 2007; Prislan *et al*, 2013). Changed climatic conditions will undoubtedly alter the onset, intensity and cessation of developmental processes in trees. However, species' response to climate change will be different, which will greatly affect their distribution and competition capacity in mixed stands and natural ecosystems, since tree migration will be influenced in the long-term. In the short-term, on the other hand, the physiological limits of tree growth at the warm and dry distribution limit are most important, since they determine species extirpation (i.e., local extinction) (Alpert and Simms, 2002; UNECE, 2008; Kramer *et al*, 2010). In order to adapt to the coming changes, it is necessary to understand the impact of climate change on forest ecosystems and to develop new approaches in forest and woodland management, based on the concept of sustainable management.

Empirical downscaling models developed to predict future climate change scenarios for Slovenia anticipate a 0.5-2.5 °C increase in temperatures in the period 2001-2030, 1-3.5 °C in the period 2031-2060 and 1.5-6.5 °C in the period 2061-2090. Model estimation in the case of precipitation is less reliable, although it is speculated that the amount of precipitation will decrease in summer (up to 12 %) and increase in winter (up to 20 %) (Bergant and Kajfež-Bogataj, 2004; Kajfež-Bogataj, 2007; De Luis *et al*, 2012). In Slovenia, plants are already responding to higher temperatures by their earlier flowering and leaf unfolding (Črepinšek *et al*, 2006; Čufar *et al*, 2012). Since the regional distribution of precipitation varies more than that of temperature, it is necessary to investigate independently the influence of the two climatic variables on the growth responses of trees. To do that, initial tests under stable environmental conditions are needed. Experimentally controlled tests on various tree species have shown that it is possible to influence cambial activity and cell differentiation, which is reflected in the anatomical structure of wood and phloem (e.g., Oribe *et al*, 2001; Gričar *et al*, 2006; Gričar *et al*, 2007; Begum *et al*, 2008; Begum *et al*, 2013; Gričar, 2013). Many such experiments have been performed on seedlings or saplings, allowing simulation of different growing conditions and evaluation of their impact on the growth and adaptivity of young trees (e.g., Rossi *et al*, 2009; De Luis *et al*, 2011). Determining how climate variability can modify both growth rates and the anatomical characteristics of formed tree-rings plays a decisive role in defining the hydraulic and mechanical properties of wood (De Luis *et al*, 2011; Froux *et al*, 2002; de Micco *et al*, 2008; Martinez-Meier *et al*, 2008; Hoffmann *et al*, 2011). The availability of this information may be critically important in evaluating the range of plasticity in species under different environmental conditions as a first step in predicting their response to future climatic scenarios (De Luis *et al*, 2011).

European beech (*Fagus sylvatica*) is the dominant deciduous tree species in Slovenia, so any changes in the quantity and quality of beech wood caused by climate change will have a major economic influence (Kutnar *et al*, 2009; Kutnar and Božič, 2011). Scots pine (*Pinus sylvestris*) is also an economically important species, representing about 4.3 % of the Slovenian timber stock (Westergren *et al*, 2010). Due to its moderate site demands, Scots pine is an ideal species for artificial regeneration and it is able to survive in an environment not optimal for its growth and development (Mátyás *et al*, 2009). The aim of the current study was to monitor the seasonal dynamics of radial growth in one to two-year old saplings of European beech and Scots pine under three different temperature regimes: greenhouse (G), cooling chamber (C) and outdoors (K). The research was conducted over two growing seasons, 2010 and 2011, in order to compare the effect of different environmental conditions on the radial growth of saplings in the first and second year of the treatment.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Tree material and growth conditions
2.1. Materijal mladica i uvjeti rasta

The tree material consisted of Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatic*a L.) saplings. For the experiment, 120 one- to two-year old pine and 90 one- to two-year old beech saplings were bought from Omorika tree nursery (Muta, Slovenia) in November 2010. The stem diameter and height of each sapling were measured immediately. The saplings were then planted in pots and 30 beech and 40 pine saplings were placed in each of the three different temperature regimes: greenhouse (G), cooling chamber (C) and outdoors (K) (Fig. 1).

Pine and beech saplings intended for controls (K) were placed outside; about 10 m from the greenhouse (G) and cooling chamber (C). Saplings were exposed to natural climatic conditions in Ljubljana in 2010 and 2011. A weather station, which recorded average, maximum and minimum daily air temperature (T) and precipitation, was installed in the immediate vicinity of the plants (Fig. 2a). Saplings in G were generally exposed to higher T than outdoors, although the oscillations in T were similar (Fig. 2b). However, minimum air T in G was much higher and always above 10 °C, while maximum T often exceeded 30 °C. Saplings in C were exposed to lower and more constant T than with G and K, with minimum air T of around 15 °C, maximum T around 20 °C and average T around 17 °C (Fig. 2c).

Water supply was not a limiting factor under any regime. Watering (frequency and amount) in G and C was performed according to the substrate humidity, which was automatically measured by Decagon EC-5 probes. The humidity of the substrate was maintained above 15 %. The relative air humidity was also constantly monitored and kept between 70 % and 90 %.

2.2 Monitoring radial growth of saplings and histometric analysis
2.2. Praćenje radijalnog rasta mladica i histometričke analize

We monitored the seasonal dynamics of the radial growth of beech and pine saplings in the growing seasons of 2010 and 2011. For this purpose, for better accuracy of data, we marked all sapling stems to ensure that the measurement was always taken at the same point of a stem base. Measurements were taken at two-week intervals with a vernier caliper providing a precision to 0.010 mm. At the end of the experiment, i.e., in winter 2011, 10 beech and 10 pine samplings from each regime were taken from the pots and prepared for further analysis.

For histometric analysis of wood increments at the stem base, about 2 cm long pieces of stems were extracted from each sapling and immediately placed in FEA fixative solution (a mixture of formalin, 50 % ethanol and acetic acid). After one week, the samples were dehydrated in an alcohol series (30 %, 50 % and 70 %) and permanently stored in 70 % ethanol. Using a G.S.L. 1 (© Gärtner and Schweingruber, design and production: Lucchinetti, Schenkung Dapples, Zurich, Switzerland) sliding microtome and disposable blades for universal knives, 20-25 μm thick stem cross-sections were prepared, stained in an aqueous mixture of safranin (Merck, Darmstadt, Germany) (0.04 %) and astra blue (Sigma-Aldrich, Steinheim, Germany) (0.15 %) dyes (Werfvan der *et al*, 2007) and finally mounted in Euparal (Waldeck, Münster, Germany) to produce permanent sections. All necessary observations and measurements of tissues were performed with an im-

Figure 1 Saplings of beech and pine in: a) greenhouse; b) cooling chamber and c) outdoors
Slika 1. Mladice bukve i bora: a) u stakleniku, b) u rashladnoj komori i c) na otvorenom prostoru

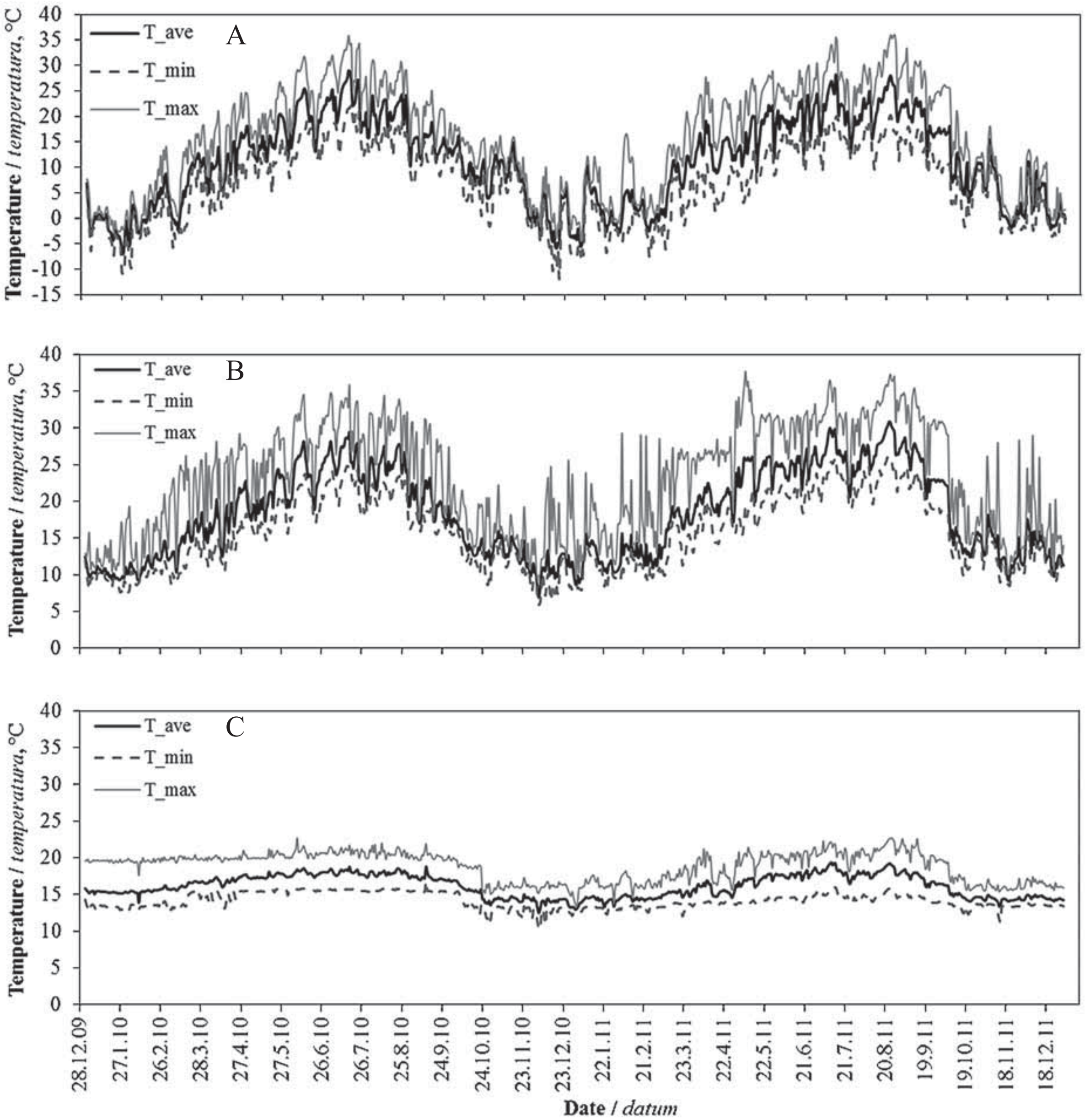

Figure 2 Average, maximum and minimum daily air temperatures during the experiments: outdoors (A), in the greenhouse (B) and in the cooling chamber (C)
Slika 2. Prosječne, maksimalne i minimalne dnevne temperature za vrijeme pokusa na otvorenom prostoru (A), u stakleniku (B) i u rashladnoj komori (C)

age analysis system consisting of an Olympus BX51 (Tokyo, Japan) light microscope, a PIXElink, PL-A66Z digital camera and NIS-Elements Basic Research V.2.3 image analysis program (Tokyo, Japan). We measured the widths of xylem increments for 2010 and 2011. Measurements were taken at four locations on the cross-sections and then averaged.

Data processing, graph preparation and statistical analysis were done in Microsoft Excel and Statgraphics programs. The one-way ANOVA test was used to compare growth characteristics of pine and beech saplings among regimes. In addition, Fisher's least significant difference (LSD) procedure was used for pairwise comparisons of treatment groups to discriminate among the means. Leven's test was used to assess the equality of variances in the samples. Student's t-test was used to compare the widths of xylem increments for 2010 and 2011 under a specific regime.

3 RESULTS
3. REZULTATI

The seasonal dynamics of radial growth of beech saplings were fairly similar in 2010 and 2011 under specific regimes, while they differed greatly with pine (Fig. 3, 4). In general, an increase in radial diameter was detected in beech at the beginning of May in 2010 under all regimes. Two weeks later, they had already reached maximum weekly growth, which slowly started to decline in mid-June (Fig. 3a). Beech saplings in C and G had a two-week radial diameter increase of more than 0.3 mm during this period, while K had an in-

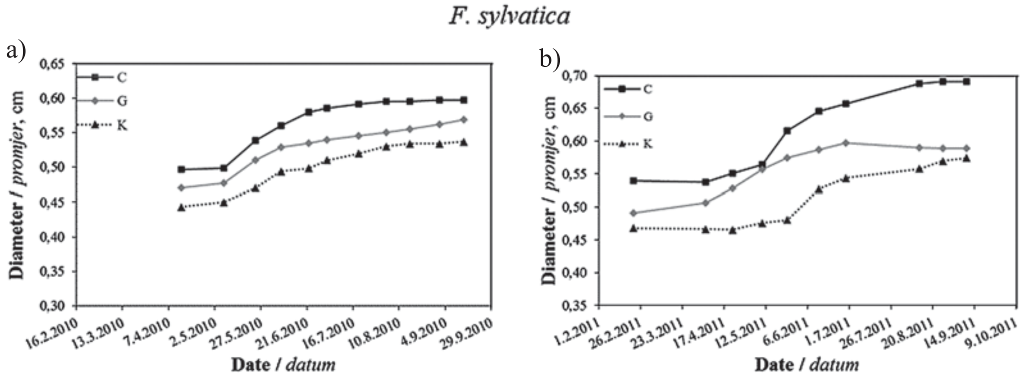

Figure 3 Seasonal dynamics of radial growth of beech saplings in 2010 (a) and 2011 (b) growing seasons. C = cooling chamber, G = greenhouse, K = outdoors

Slika 3. Sezonska dinamika radijalnog rasta bukovih mladica tijekom vegetacije u 2010. godini (a) i u 2011. godini (b), C – rashladna komora, G – staklenik, K – otvoreni prostor

crease of 0.25 mm. Radial growth stopped under all three regimes at the same time, at the end of August. In 2011, an increase in radial diameter of beech saplings was observed in mid-March in G, in the first half of April in C and in the second half of April in K (Fig. 3b). The most intense period of radial growth occurred in April in G, in the middle of May in C and at the end of May/beginning of June with the saplings exposed to natural conditions (K). In all three cases, the period of maximum radial growth occurred about one month after the onset of radial growth. During the most intense period of radial growth, the highest values were recorded in saplings in C (0.5 mm) and the lowest in those in G (0.28 mm). Radial growth of G saplings finished earliest (at the beginning of July), and at the end of August in C and K.

With pine saplings, radial growth started earliest in G (mid-April) in both years, followed by C saplings (end of April) and lastly those outdoors (K), at the beginning of May (Fig. 4). The peak of radial growth in 2010 was first reached in K (end of May/beginning of June) and only at the beginning of July in G and C. The two-week radial growth in 2010 was very low and did not exceed 0.4 mm. Radial growth stopped first in C at the end of July and a month later also in the other two regimes. In 2011, the seasonal dynamics of radial growth of pine saplings was different (Fig. 4b). The peak of radial growth occurred in all three regimes at the same time, at the end of June/beginning of July. However, the two-week increment was widest in K pines (up to 1 mm), whereas in G and C it was around 0.25 mm. Radial growth ceased at the end of August in C and K and in the middle of September in G.

With beech, wood increment was narrowest in both years in G (282.01 ± 94.52 µm in 2010; 371.40 ± 242.31 µm in 2011) and widest in C (380.89 ± 134.98 µm in 2010; 755.00 ± 182.93 µm in 2011) (Fig. 5). Xylem increments in 2010 were in general very narrow (less than 400 µm) under all three regimes. In 2011, the annual increments in C and K substantially increased (by about 100 %), while in G, increments increased by about a quarter (Fig. 7, Table 1).

In 2010, xylem growth rings of pines were widest in G (912.45 ± 206.69 µm) and narrowest in C (636.09 ± 136.21 µm) (Fig. 6). In 2011, the radial growth patterns of pine saplings exposed to given environmental conditions changed. With the exception of K pines, increments were smaller than in 2010 (Fig. 6b). Xylem widths in 2011 were double in K compared to the other two regimes (K =1242.63 ± 329.92 µm; G = 586.89 ± 329.92 µm; C = 572.74 ± 148.95 µm). The increment widths in G were significantly reduced in 2011, increased in K and only slightly decreased in C (Table 1). The xylem rings were thus narrowest in C in both years (Fig. 7).

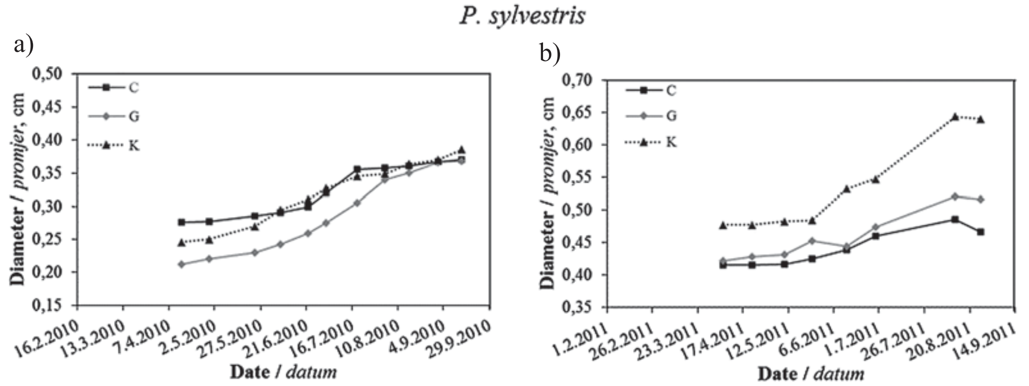

Figure 4 Seasonal dynamics of radial growth of pine saplings in 2010 (a) and 2011 (b) growing seasons. C = cooling chamber, G = greenhouse, K = outdoors

Slika 4. Sezonska dinamika radijalnog rasta borovih mladica tijekom vegetacije u 2010. godini (a) i 2011. godini (b); C – rashladna komora, G – staklenik, K – otvoreni prostor

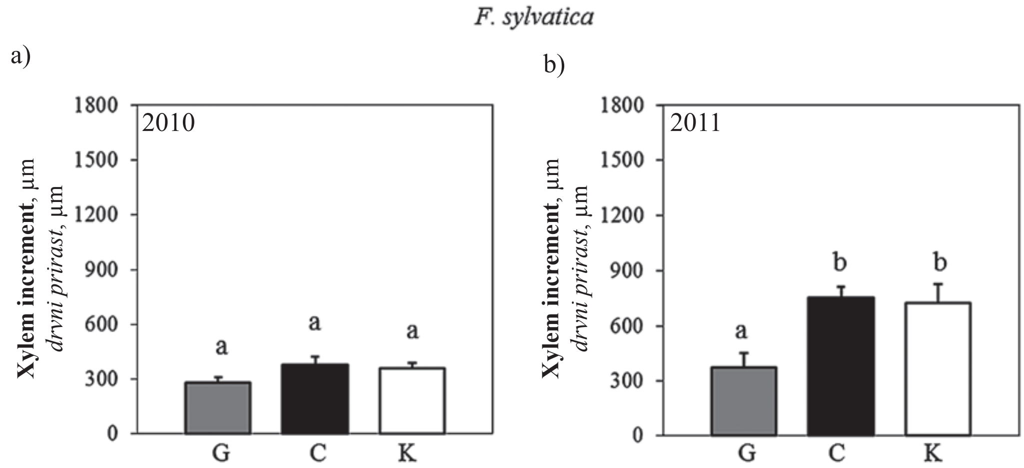

Figure 5 Xylem increment of beech saplings under different regimes during the growing seasons 2010 (F = 1.89, p = 0.1725) (a) and 2011(F = 7.86, p = 0.0025) (b) (mean ± SE, n = 10 independent saplings). Different letters indicate statistically significant differences between regimes (One-way ANOVA). C = cooling chamber, G = greenhouse, K = outdoors

Slika 5. Prirast drva bukovih mladica u različitim režimima tijekom vegetacije u 2010. godini. (F = 1,89, p = 0,1725) (a) i u 2011. godini (b) (F = 7,86, p = 0,0025) (srednja vrijednost ± SE, n = 10 neovisnih mladica); različita slova označavaju statistički značajne razlike među režimima (One-way ANOVA); C – rashladna komora, G – staklenik, K – otvoreni prostor

The two-year xylem increment of beech saplings was lowest in G (653.41 ± 274.10 µm), but similar in C (1102.73 ± 238.17 µm) and K (1081.12 ± 323.42 µm) (Fig. 8a). Xylem growth rings contributed almost equally to the two-year wood increment in G in 2010, whereas in C and K only about a third (Fig. 8b). In the case of pine, the two-year xylem increment was widest in K (1951.53 ± 414.04 µm) and narrowest in C (1208.83 ± 246.83 µm) (Fig. 9a). Xylem growth rings contributed 60 % to the two-year increment in G in 2010, 50 % in C and 34 % in K (Fig. 9b). Comparison of xylem growth ring widths of pine and beech saplings under different regimes in 2010 and 2011 showed that xylem ring widths of 2010 were wider in pines under all three regimes; even three times under the K regime, while in 2011 only increment widths of pines in C were narrower than those of beech (Fig. 4, 5, Table 1).

Table 1 Comparison of xylem ring widths in 2010 and 2011 in pine and beech saplings under different regimes (Student's t-test)

Tablica 1. Usporedba širina godova borovih i bukovih mladica u 2010. i 2011. godini u različitim režimima (Student›s t-test)

	P. sylvestris	*F. sylvatica*
Greenhouse /*Staklenik*	t = 3.78817 p = 0.00147	t = -1.03099 p = 0.317877
Cooling chamber *Rashladna komora*	t = 0.992511 p = 0.334101	t = -5.02165 p = 0.000105
Control / *Kontrola*	t = -4.45788 p = 0.000304	t = -4.03033 p = 0.00109

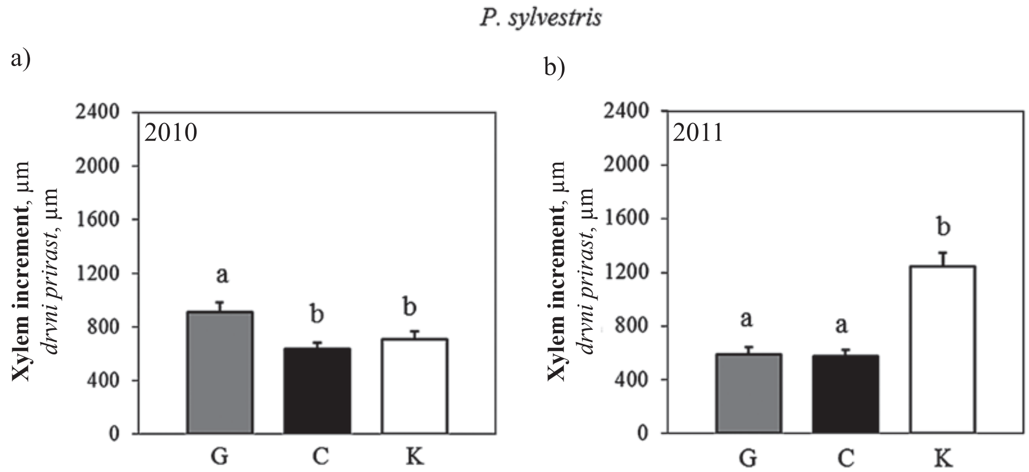

Figure 6 Xylem increment of pine saplings under different regimes during the growing seasons 2010 (F = 6.09, p = 0.0068) (a) and 2011 (F = 27.62, p = 0.0000) (b) (mean ± SE, n = 10 independent saplings). Different letters indicate statistically significant differences between regimes (One-way ANOVA). C = cooling chamber, G = greenhouse, K = outdoors

Slika 6. Prirast drva borovih mladica u različitim režimima tijekom vegetacije u 2010. godini (a) (F = 6,09, p = 0,0068) i u 2011. godini (b) (F = 27,62, p = 0,0000) (srednja vrijednost ± SE, n = 10 neovisne mladice); različita slova označavaju statistički značajne razlike među režimima (One-way ANOVA); C – rashladna komora, G – staklenik, K – otvoreni prostor

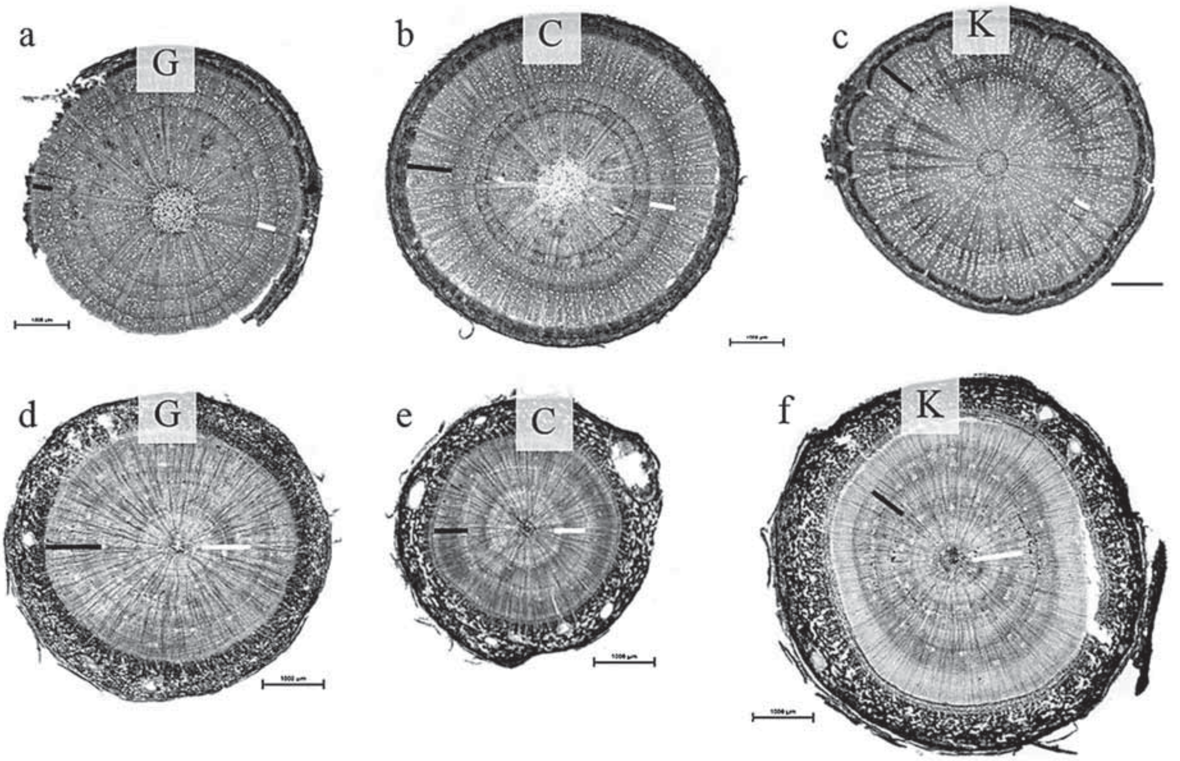

Figure 7 Transverse sections of typical beech (a-c) and pine (d-f) saplings in: greenhouse (a-beech, d-pine), cooling chamber (b-beech, e-pine) and outside (c-beech, f-pine). White line indicates xylem increment in 2010 and black line xylem increment in 2011. C = cooling chamber, G = greenhouse, K = outdoors. Bars – 1000 μm
Slika 7. Poprečni presjeci bukovih i borovih mladica u stakleniku (a – bukva, d – bor), rashladnoj komori (b – bukva, e – bor) i na otvorenom prostoru (c – bukva, f – bor); bijela crta pokazuje drvni prirast u 2010. godini, a crna u 2011. godini (C – rashladna komora, G – staklenik, K – otvoreni prostor); trake – 1000 μm

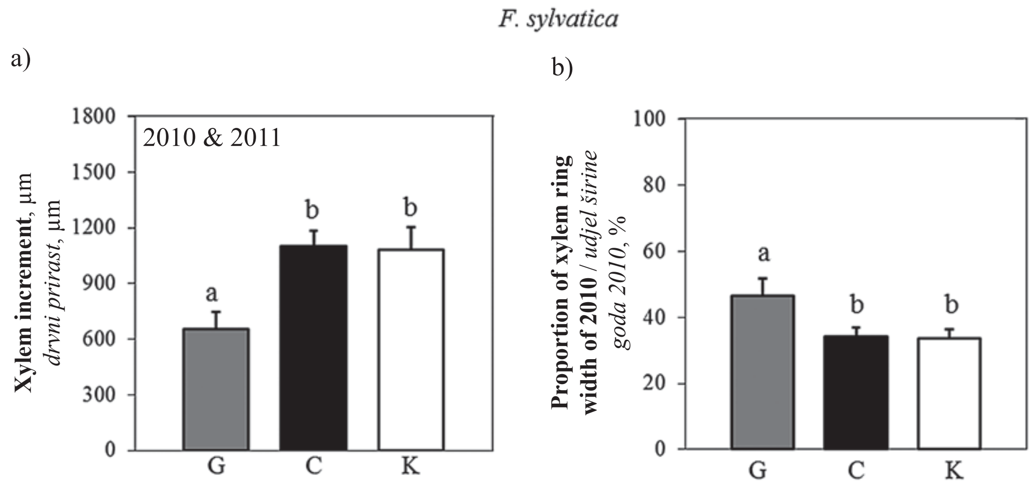

Figure 8 Two-year xylem increment of beech saplings under different regimes (F = 7.30, p = 0.0037) (a) and proportion of xylem ring width from 2010 (F = 3.52, p = 0.0472) (b) (mean ± SE, n = 10 independent saplings). Different letters indicate statistically significant differences between regimes (One-way ANOVA). C = cooling chamber, G = greenhouse, K = outdoors
Slika 8. Dvogodišnji prirast drva borovih mladica u različitim režimima (a) (F = 7,30, p = 0,0037) i udjel širine goda 2010. godine (b) (F = 3,52, p = 0,0472) (srednja vrijednost ± SE, n = 10 neovisnih mladica); različita slova označavaju statistički značajne razlike među režimima (One-way ANOVA); C – rashladna komora, G – staklenik, K – otvoreni prostor

4 DISCUSSION AND CONCLUSIONS
4. RASPRAVA I ZAKLJUČAK

The pattern of radial growth of beech saplings exposed to different temperature conditions was similar, especially in 2010. An increase in radial diameter was generally observed one month later in 2010 than in 2011, probably due to transplant shock in 2010. In pines, on the other hand, such delays were not recorded. However, the growth ring patterns of beech exposed to different treatments differed in the studied growing seasons. The wood increment of beech was narrowest in G and widest in C in both years. In 2010, xylem growth rings of pines were widest in G and narrowest in C, whereas in 2011 they were widest in K. Two-year xylem increments of beech saplings were lowest in G, but similar in C and K.

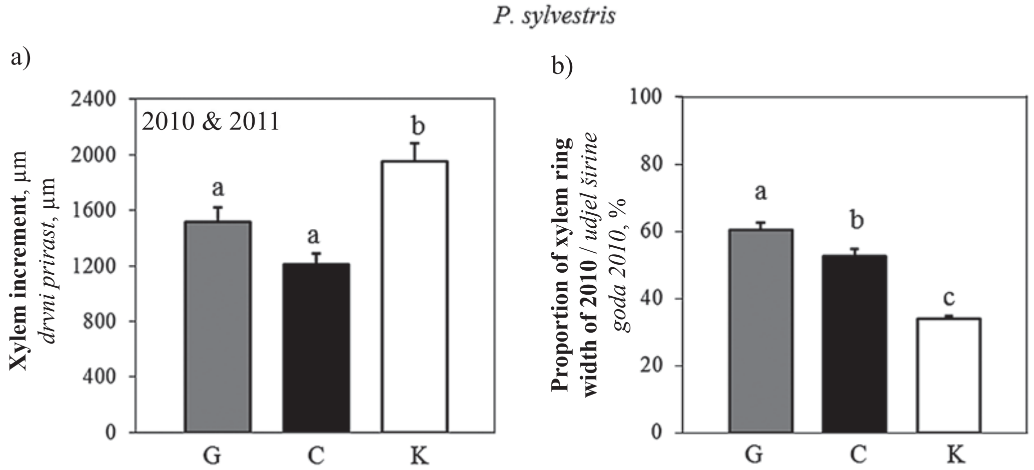

Figure 9 Two-year xylem increment of pine saplings under different regimes ($F = 12.63$, $p = 0.0001$) (a) and proportion of xylem ring width of 2010 ($F = 55.58$, $p = 0.0000$) (b) (mean ± SE, $n = 10$ independent saplings). Different letters indicate statistically significant differences between regimes (One-way ANOVA). C = cooling chamber, G = greenhouse, K = outdoors
Slika 9. Dvogodišnji prirast drva borovih mladica u različitim režimima (a) ($F = 12,63$, $p = 0,0001$) i udjel širine goda 2010. godini (b) ($F = 55,58$, $p = 0,0000$) (srednja vrijednost ± SE, $n = 10$ neovisnih mladica); različita slova označavaju statistički značajne razlike među režimima (One-way ANOVA); C – rashladna komora, G – staklenik, K – otvoreni prostor

In the case of pine, the two-year xylem increment was widest in K and narrowest in C. Comparison of xylem growth ring widths of pine and beech saplings in 2010 and 2011 under different regimes showed that widths in 2010 were wider in pines under all three regimes, whereas in 2011 increments of pines were narrower than those of beech only in C.

The influence of different environmental conditions on the radial growth of saplings was more distinct in pine than in beech. A cool environment thus limited the radial growth of pine, which is in line with its pioneer character. Lower temperatures limit the radial growth of pines, giving a shorter growing season, reflected in narrower xylem ring widths. Many pines respond to temperatures mainly by an alteration in radial growth dynamics, which emphasizes the importance of phenotypic plasticity. The functional phenological plasticity of wood formation has been commonly described as an important adaptation of trees to new, changed climatic conditions (De Luis *et al*, 2011). Tree species growing in different habitats are able to adapt to environmental conditions in terms of the beginning, end and dynamics of cambial activity, which reflect their flexibility and plasticity in terms of radial growth (De Luis *et al*, 2013). However, tree populations and species differ greatly in their phenotypic plasticity (Alpert and Simms, 2002).

Bioclimatic envelopes (i.e., conditions, under which species grow well) are expected to shift northwards and higher up in elevation. The range of Norway spruce and Scots pine might retreat from the south and west, while beech and other temperate broadleaved species might spread to the north. Conifer forests subjected to continuing disturbance show a more rapid shift to dominance of beech and other temperate broadleaves. Although beech adapts well to drought, the future dynamics of beech forest remains uncertain due to global warming. Beech is projected to face severe problems in regions in which temperatures are expected to rise and could be replaced by oaks due to the latter's lower sensitivity to water stress (European Forest Institute *et al*, 2008). Several dendroecological studies have emphasized the sensitivity of beech to increased temperature and drought, with growth declining with increasing temperature, but also indicating that this decline is not a direct response to temperature but to drought because of less rainfall (Cescatti and Piutti, 1998; Dittmar *et al*, 2003; Lebourgois *et al*, 2005). The relationship of phenological events and tree productivity to climate is complex and not a simple matter of threshold values and monotonic responses. Although phenology is related to some extent to temperature, phenological phases have been associated with different temperatures at different sites favourable for the growth of adult beech. The onset of cambial cell division has been associated not just with threshold temperature but with an extended period of preconditioning, which varied with site conditions (Prislan *et al*, 2013). Moreover, the difference in phenological patterns may be due to high intra-specific plasticity (Camarero *et al*, 2010). It is therefore impossible to assess the relative contribution of genetic determination, epigenetic regulation and somatic adaptation to growth and developmental processes.

However, it has been demonstrated that radial growth is an age-dependent process and that it differs in juvenile and adult trees in terms of dynamics and timing of wood production (Rossi *et al*, 2008; Rossi *et al*, 2011; Li *et al*, 2013). Cambial activity during spring and early summer may be critically important to the survival of saplings, especially in the first part of the growing season after planting, when the root system has not yet developed and newly formed wood is crucial for providing enough conductive tissue for water transport and storage of photosynthates (De Luis *et al*, 2011). The response of an individual tree species will thus also depend on tree age, among other things, and it will not therefore be the same for juvenile and mature trees, indicating that experimental results obtained on saplings cannot be simply transferred to adult trees and *vice versa*.

In terms of wood formation, any change in morphological characteristics of cells probably modifies the hydraulic and mechanical properties of wood and thus affects the survival and efficiency of the living tree (e.g., Rao *et al*, 1997). In this respect, saplings may be especially vulnerable to predicted climate changes, since their ability to survive may be restricted. This could affect both natural regeneration and the success of reforestation, leading to a change in the distribution of the species in the future (De Luis *et al*, 2011).

Studies of the seasonal dynamics of radial growth of trees and structure of xylem and phloem can be helpful in understanding the mechanism of these processes and their dependence on environmental conditions. Our findings imply different phenotypic plasticity of pine than of beech saplings in terms of radial growth. Nevertheless, the two-year experiment clearly demonstrates that a continuation of such observations over several growing seasons is necessary to capture the short- and long-term response of tree growth under changing environmental conditions.

Acknowledgements - Zahvale

Thanks to Špela Jagodic, Dr. Boštjan Mali, Melita Hrenko and Ines Štraus from the Slovenian Forestry Institute and graduate student Urška Mihoci at the Department for Forestry and Renewable Forest Resources at the Biotechnical Faculty, University of Ljubljana, for their invaluable help in the field and laboratory. The work was supported by the Slovenian Research Agency through projects Z4-9662, V4-0496, L7-2393, and P4-0107.

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Corresponding address:

Assist. Prof. JOŽICA GRIČAR, Ph. D.

Slovenian Forestry Institute
Department of Yield and Silviculture
Večna pot 2
SI-1000 Ljubljana, SLOVENIA
e-mail: jozica.gricar@gozdis.si

Pavlo Bekhta[1], *Galyna Ortynska*[1], *Jan Sedliacik*[2]

Properties of Modified Phenol-Formaldehyde Adhesive for Plywood Panels Manufactured from High Moisture Content Veneer

Svojstva modificiranoga fenol-formaldehidnog ljepila za furnirske ploče proizvedene od furnira s visokim sadržajem vode

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 16. 9. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*832.282.6; 630*824.325*
doi:10.5552/drind.2014.1350

ABSTRACT • *This paper presents the results of laboratory investigations of bonding high moisture content (15 %) birch veneers (Betula pubescens Ehrh.) with the use of modified phenol-formaldehyde (PF) resin. Wheat starch, rye flour, resorcinol and phenol-resorcinol-formaldehyde resin were chosen as modifying agents. Dynamic viscosity, hydrogen ions concentration, solid content, curing time, pot life of developed adhesive compositions and shear strength of plywood samples were evaluated. ANOVA analysis has shown that type, mixture and content of modifying agents affect significantly the mechanical performance of plywood panels. The obtained results of shear strength values were above the standard requirements (1 N/mm^2), and the properties of samples met the European standard EN 314-2 for gluing quality of class 3 and such plywood panels can be used in exterior conditions.*

Key words: *gluing, veneer, high moisture content, plywood, phenol-formaldehyde resin, modifying agents*

SAŽETAK • *U radu su prikazani rezultati laboratorijskih istraživanja furnirskih ploča proizvedenih od furnira od drva breze (Betula pubescens Ehrh.) s visokim sadržajem vode (15 %) i uz primjenu modificiranoga fenol-formaldehidnog (PF) ljepila. Pšenični škrob, raženo brašno, rezorcinol i fenol-rezorcinol-formaldehidna smola izabrani su kao sredstva za modificiranje. Analizirane su dinamička viskoznost, koncentracija vodikovih iona, sadržaj krute tvari, vrijeme otvrdnjavanja, otvoreno vrijeme smjese za lijepljenje i smicajna čvrstoća uzoraka furnirskih ploča. ANOVA analiza pokazala je da vrsta, smjesa i težinski udjel sredstava za modifikaciju ljepila značajno utječu na mehanička svojstva furnirskih ploča. Dobivene vrijednosti čvrstoće smicanja iznad su standardnih zahtjeva (1 N/*

[1] Authors are professor and assistant at Department of Wood-Based Composites, National University of Forestry & Wood Technology of Ukraine, Lviv, Ukraine. [2]Author is professor at Department of Furniture and Wood Products, Technical University in Zvolen, Zvolen, Slovakia.
[1] Autori su profesor i asistentica Odjela za drvne kompozite Nacionalnog sveučilišta šumarstva i drvne tehnologije Ukrajine, Lviv, Ukrajina. [2]Autor je profesor Odjela za namještaj i drvne proizvode Tehničkog sveučilišta u Zvolenu, Zvolen, Slovačka.

mm²), a svojstva uzoraka furnirskih ploča zadovoljavaju europsku normu EN 314-2 za kvalitetu lijepljenja klase 3 koja se odnosi na furnirske ploče koje se mogu rabiti u vanjskim uvjetima.

Ključne riječi: *lijepljenje, furnir, visok sadržaj vode, furnirska ploča, fenol-formaldehidno ljepilo, sredstva za modificiranje*

1 INTRODUCTION
1. UVOD

The process of gluing of veneer-based products, as plywood or laminated veneer lumber, is significantly affected by the moisture content in wood combined with water in an adhesive. This moisture directly influences the curing process and properties of the used adhesive, economic costs (consumption of glue, pressing time and costs for veneer drying) as well as physical and mechanical properties of veneer-based products. Nowadays in Ukraine, construction plywood is generally produced with adhesives based on phenol-formaldehyde resins and veneers that should be dried to 8 % moisture content. For such moisture content the conventional thermo-reactive adhesives provide high-quality bonding of plywood with physical and mechanical performances that meet European standard requirements. Gluing of veneers with lower moisture content (W < 8±2 %) involves the following disadvantages: high consumption of energy for drying, brittleness of veneers, rapid adhesive viscosity increase by diffusion of water into the cellular structure, worsened wetting and insufficient transfer of adhesive to another surface. Gluing of veneer with higher initial moisture content (W > 8±2 %) has the following disadvantages: increasing adhesive penetration by the flow inside the vessel network through the veneer thickness, high vapour pressure causing steam blisters or blows, decreasing the viscosity of the applied adhesive layer, and loss of wood mass as well as thickness due to compression. There is a risk of forming of discontinuous glue layer on veneer surface, retardation of glue curing or creation of insufficient joints. Furthermore, the process of plywood manufacture is characterized by significant energy costs for veneer drying (almost 60 %) and hot pressing (15 %), which significantly affects the cost of production. Therefore, using veneers with higher moisture would result in substantial savings of energy.

Recent developments and trends in the field of eco-efficient bonding technologies contribute to both ecological and economical aspects. Several new trends are in application of vegetable carbohydrates or proteins, namely as modifiers of existing adhesives. Addition of polysaccharides or soy proteins to traditional synthetic wood adhesives after partial hydrolysis and modifications has been reported (Pizzi, 2006). Some articles (Besinova *et al*., 1997; Elbez, 1997) were oriented on benefits of gluing high moisture veneers. More studies were performed on possibilities of bonding high moisture veneers using phenol-formaldehyde resin filled by hydrolysed soy protein, starch and tannin (Vijayendran *et al*., 2000). Other researchers prepared high solid PF adhesive mixtures with increased reactivity by grafting resorcinol (Clark *et al*., 1988) or they modified PF resin (Steiner *et al*., 1993) that consisted of an alkaline insoluble but swellable dispersed PF phase, an alkaline soluble continuous phase and propylene carbonate additive. Some systems of filling with pecan shell flour and two furfural-process residues were tested (Sellers *et al*., 1990). One of them involves mixing a high molecular weight resin with alkylene carbonates or phenol-resorcinol-formaldehyde resins (Clarke *et al*., 1990).

The wood porosity is one of the main physical indexes in wood science. Bonding of wood elements with higher moisture content is a difficult process; the details of the penetration of the hardening adhesives into the porous wood skeleton are rather complicated. It is strongly influenced by factors as wood species, grain orientation and surface roughness, adhesive factors as type of adhesive, solid content and viscosity, and process factors as applied pressure and temperature, which have the most significant influence on the bonding performance (Kamke and Lee, 2007; Varivodina *et al*., 2010). An analytical model to predict the penetration of adhesives into hardwood was proposed (Mendoza *et al*., 2012). The model considers a dimensional capillary fluid transport of a hardening adhesive through a single, straight vessel with diffusion of solvent through the walls of the vessel. Adhesive penetration follows the path of lowest resistance into the porous structure, either by gross penetration or by cell wall penetration. The bond line morphologies and the adhesive penetration into the wood structure were evaluated (Haas, 2012) after determining the hardening characteristics of adhesives.

The viscoelastic characteristics of wood play an important role in compression and densification. At high temperature and high moisture content, wood exhibits plastic behaviour that can be characterized as inconvenient. Temperature and conditions of pressing process affect the change of relative density and creep deformation, as well as properties of the resulting pressed plywood material. The dependence of inelastic behaviour of the gross wood on the elastic properties of the cell wall allows the time, temperature, and moisture dependence to be modelled with classical linear viscoelastic theory of amorphous polymers. Time-temperature-moisture relationship was shown (Wolcott *et al*., 1994) to be applicable to stress relaxation data collected for temperatures between 39 and 99 °C and moisture contents between 3 and 16 %.

The bond strength of thermosetting PF adhesives is developing during the hardening process carried out in a hot-press at stated pressure, temperature and for a defined period of time. Pressure parameters are influenced by several factors as thickness of the composite, thermal conductivity, or moisture content of the material. Pressure must be kept till strength of cured adhesive is higher than forces of internal vapour. Research has shown that the degree of cure is dependent on the pressing time and on the composition of the PF adhesive (Jost and Sernek, 2009). The temperature inside the bond line is firstly rapidly increasing slightly above 100 °C. The temperature stays around this level for the time of energy consumption for the evaporation of water from the veneer and adhesive. After that period the temperature is increasing up to the set pressing temperature. Significant mechanical strength in the adhesive bond was established in the last stage of the curing, when crosslinking of the PF adhesive occurred.

However, all of these above mentioned measures require the use of expensive adhesives, replacement of existing equipment, additional processing steps that can lead to significant investment and thus increase the cost of end products. These methods have not thereby found their use in the manufacture of plywood, so the question of bonding veneer of high moisture content is still important.

Therefore, the purpose of this study was to develop the adhesive compositions that allow gluing veneers with higher moisture content (up to 15 %) to provide the desired strength properties of plywood and veneer-based materials.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Rotary cut veneer sheets of birch wood (*Betula pubescens* Ehrh.) with dimensions of 300 × 300 mm and thickness of 1.5 mm without visible defects were prepared for the experiments. Commercial PF resin generally used for plywood with the following parameters: solid content 48.3 %, dynamic viscosity 790 mPa·s, was used in this research. Wheat starch (WS), rye flour (RF), technical resorcinol (R) and phenol-resorcinol-formaldehyde (PRF) resin were chosen as modifying agents.

High moisture content of veneer slows the curing of PF glue. Resorcinol and PRF resin are suggested to be added into PF resin to accelerate the adhesive curing process for improving its water resistance and increasing the adhesion of glue to the veneer with high moisture content. Resorcinol has a coherent orientation of –OH groups and its addition, or addition of PRF resin into PF resin will allow creating additional bonds with wood (phenyl-propane units). Adding of wheat starch and rye flour into PF resin allows taking excessive moisture from the glue, because they both absorb and swell in water very well. In addition, they prevent the penetration of glue into wood and through thin layers of veneer on the front surface of the plywood.

High moisture content level of 15 % was achieved by conditioning of dry veneer sheets inside a chamber at constant temperature over sulphuric acid solution with concentration of 30 %, till achieving the desired level of moisture content. The moisture content was controlled using electronic moisture-meter and exactly stated by weight method.

The adhesives compositions (Table 1) were proposed and the effect of modifying agents on their properties was investigated. The amount of added modifying agents was of 1, 3, and 5 weight parts per 100 weight parts of phenol-formaldehyde resin. Dynamic viscosity, hydrogen ions concentration (pH), solid content, curing time and pot life of adhesive compositions as well as shear strength of plywood panels were evaluated.

Solid content of prepared adhesive mixtures was determined by weight method. Curing time of adhesive mixtures was determined at the temperature of 150 °C. Dynamic viscosity was measured by the rotational viscometer at 20 °C and hydrogen ion concentration of the prepared adhesives was determined on pH-meter. Curing time of adhesive mixtures was determined on a steel disk at the temperature of 150 °C and pot life as the increase of the dynamic viscosity.

Table 1 Adhesive compositions
Tablica 1. Sastavi smjese za lijepljenje

Number of adhesive composition *Broj sastava ljepila*	Adhesive modifiers, weight parts *Sredstvo za modifikaciju, težinski udio*						
	PF	30 % R*	40 % R*	50 % R*	PRF	WS	RF
0	100	-	-	-	-	-	-
1	100	1	-	-	-	-	-
2	100	3	-	-	-	-	-
3	100	5	-	-	-	-	-
4	100	-	1	-	-	-	-
5	100	-	3	-	-	-	-
6	100	-	5	-	-	-	-
7	100	-	-	1	-	-	-
8	100	-	-	3	-	-	-
9	100	-	-	5	-	-	-
10	100	-	-	-	1	-	-
11	100	-	-	-	3	-	-
12	100	-	-	-	5	-	-
13	100	-	-	-	-	1	-
14	100	-	-	-	-	3	-
15	100	-	-	-	-	5	-
16	100	-	-	-	-	-	1
17	100	-	-	-	-	-	3
18	100	-	-	-	-	-	5
19	100	1	-	-	-	3	-
20	100	-	1	-	-	3	-
21	100	-	-	1	-	3	-
22	100	-	-	-	1	3	-
23	100	3	-	-	-	3	-
24	100	-	3	-	-	3	-
25	100	-	-	3	-	3	-
26	100	-	-	-	3	3	-
27	100	1	-	-	-	-	3
28	100	-	1	-	-	-	3
29	100	-	-	1	-	-	3
30	100	-	-	-	1	-	3
31	100	3	-	-	-	-	3
32	100	-	3	-	-	-	3
33	100	-	-	3	-	-	3
34	100	-	-	-	3	-	3

*The concentration of aqueous solutions of resorcinol was 30 % (30 % R), 40 % (40 % R) and 50 % (50 % R).
* Koncentracije vodene otopine rezorcinola bile su 30 % (30 % R), 40 % (40 % R) i 50 % (50 % R).

Three-layer plywood panels of 300 × 300 mm were made in the electrically heated hydraulic laboratory press. The specific pressing pressure of 1.8 MPa and temperature of 150 °C were used, and 6-min pressing time (during the last 30 s of press cycle the pressure was continually reduced to 0 MPa). The glue spread was 150 g/m^2 based on wet mass. PF adhesive mixture was applied onto one side of every uneven ply. The plies were assembled perpendicularly to each other (veneer sheets were laid up tight/loose) to form plywood of three plies. Glue was applied on the veneer surface with a hand roller spreader. Laboratory testing machine was used for the evaluation of the quality of gluing and the shear strength of plywood was determined according to EN 314-2 after pre-treatment for intended use in exterior conditions. Testing samples were immersed in boiling water for 4 h, dried in the ventilated drying oven at 60±3 °C for 16 h, immersed in boiling water for 4 h, followed by cooling in water at 20±3 °C for at least 1 h to decrease the temperature of test pieces to 20 °C. Ten samples were used for each variant shear strength mechanical testing. During experiment, all plywood samples were conditioned before testing for two weeks at 20±2 °C and 65±5 % relative humidity.

For each modifying agent, a one-way analysis of variance (ANOVA) was conducted to study the effect of type and content of modifying agents on the shear strength of plywood panels at the 0.95 confidence interval.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Homogeneous adhesives compositions were created when each of modifying agents was added into PF resin. Dynamic viscosity of prepared adhesive compositions increased 1.9-8.7 times, with increasing amount of resorcinol or PRF resin (Figure 1), compared with reference PF resin. Similar changes occur when adding wheat starch and rye flour (Figure 1) into PF resin. In particular, the dynamic viscosity of the adhesive increased 1.1-4.0 times, due to active adsorbing of water from the adhesive by the macromolecules of modifying extenders.

The favourable behaviour of the impact of modifying agents on curing time (Figure 2) was observed. In the case of increasing of resorcinol and PRF resin, the adhesive curing time is reduced by 20 % and with the increase of wheat starch and rye flour by 50 %. This pattern of changes in dynamic viscosity and curing time of adhesive compositions are appropriate and can be explained by the interaction of resorcinol or PRF resin with PF resin by forming cross-links (Urbanik *et al.*, 1997). Such cross-links increase the molecular weight of polymer, which respectively leads to the increasing of viscosity of the adhesive composition and to the fast curing (Waage *et al.*, 1991).

Increasing amount of modifying agents leads to a decrease in pot life of adhesive mixtures, obtained values range from 1 to 5 hours (Table 2). The solid content and concentration of hydrogen ions (pH) remain practically unchanged and are in the span from 50.1 to 57.6 % and from 11.3 to 12.0, respectively.

An analysis of variance (ANOVA) was conducted to discern whether differences in shear strength using adhesives with various modifying agents are statistically significant. Table 3 presents ANOVA results for experimental data. This analysis found that type of modifying agents and their content in adhesive composition impacted shear strength. From the ANOVA analysis (Table 3), it is evident that the content of modifying agent is the most influencing factor on shear strength. The type of modifying agents is the next influencing factor on shear strength. In addition, the ANOVA showed that the interaction between the type

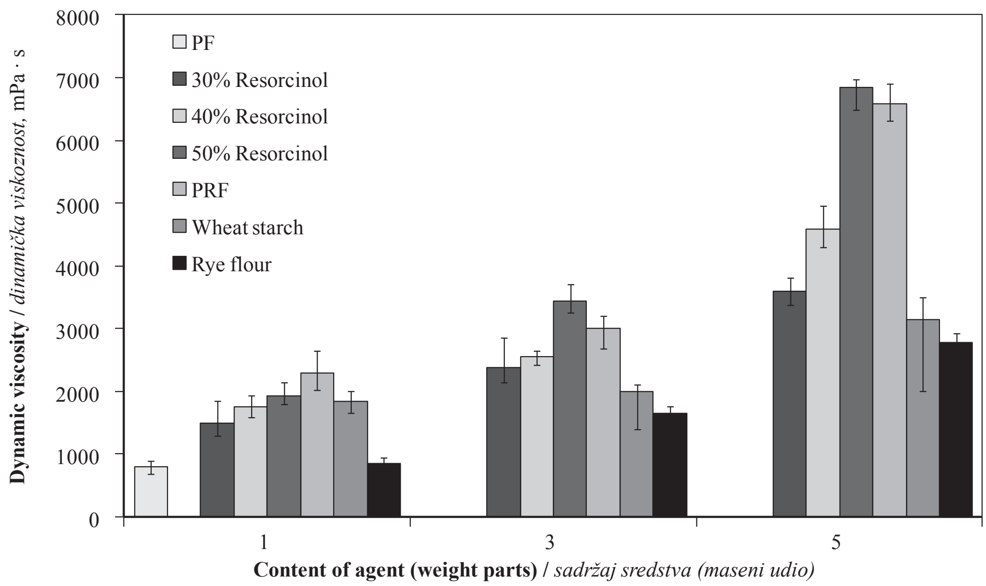


Figure 1 Dynamic viscosity of adhesive compositions
Slika 1. Dinamička viskoznost istraživanih smjesa za lijepljenje

Table 2 Pot life of adhesive compositions
Tablica 2. Otvoreno vrijeme smjese za lijepljenje

Number of adhesive composition *Broj smjese za lijepljenje*	**Pot life, hours** *Otvoreno vrijeme, sati*	**Number of adhesive composition** *Broj smjese za lijepljenje*	**Pot life, hours** *Otvoreno vrijeme, sati*	**Number of adhesive composition** *Broj smjese za lijepljenje*	**Pot life, hours** *Otvoreno vrijeme, sati*	**Number of adhesive composition** *Broj smjese za lijepljenje*	**Pot life, hours** *Otvoreno vrijeme, sati*
1	5	10	5	19	4	28	5
2	5	11	4	20	3	29	4
3	4	12	1	21	3	30	4
4	5	13	6	22	3	31	4
5	5	14	5	23	2	32	3
6	3	15	3	24	3	33	3
7	5	16	6	25	2		
8	4	17	6	26	2	34	3
9	3	18	6	27	5		

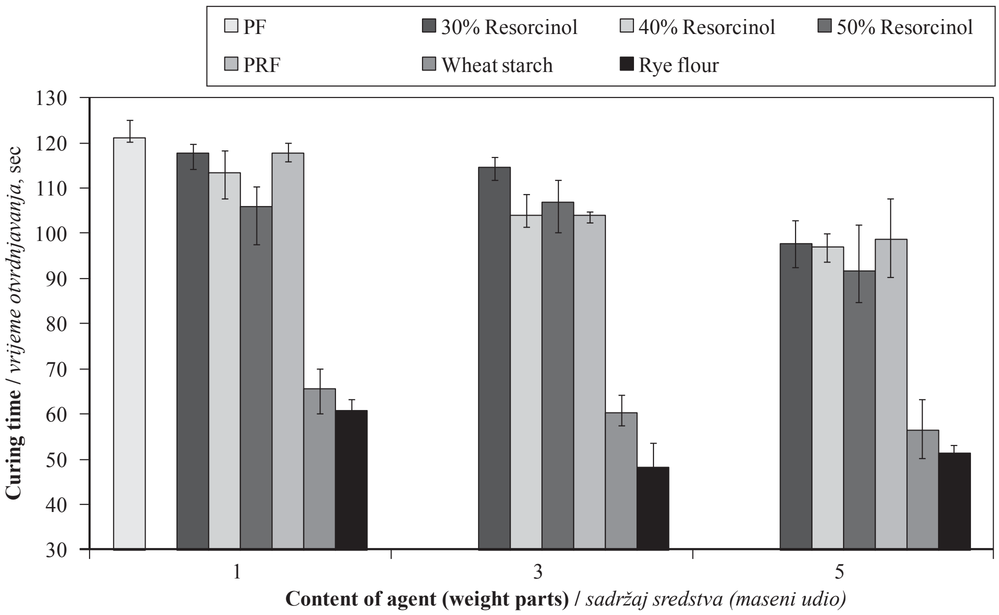


Figure 2 Curing time of adhesive compositions
Slika 2. Vrijeme otvrdnjavanja istraživanih smjesa za lijepljenje

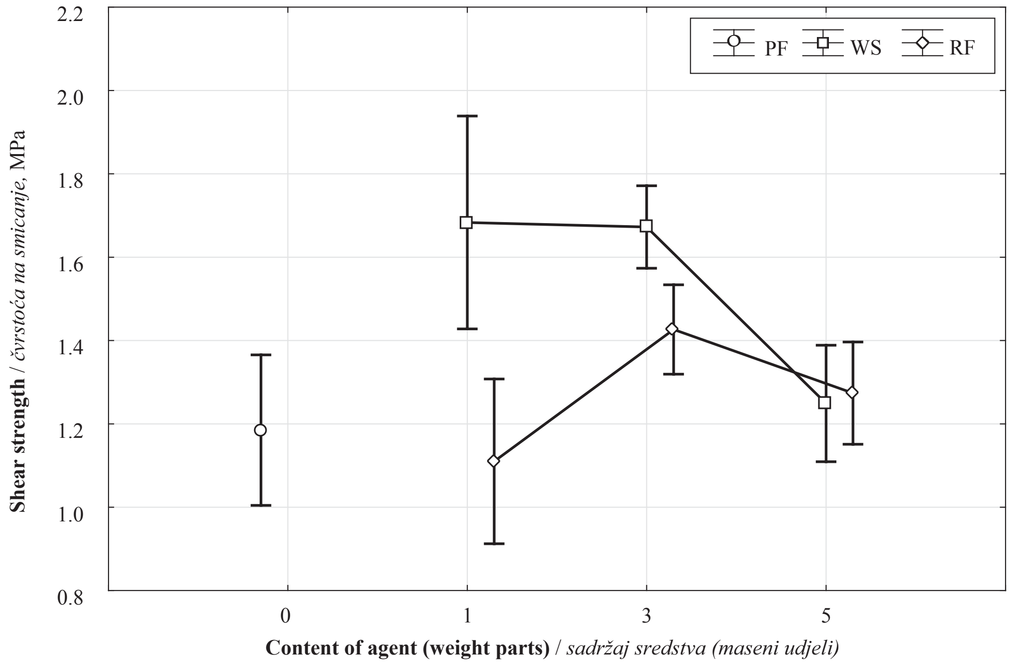
of modifying agents and their content in adhesion composition was also significant.

The effect of modifying agents on shear strength of plywood is shown in Figure 3. In the case, if resorcinol content is increasing from 1 to 5 weight parts for all concentrations, the course of shear strength of plywood is slightly decreasing, but still is over reference sample. The reason is that resorcinol very actively reacts with PF resin, viscosity is rapidly increasing and, thus, the adhesion of glue to the wood is reduced. However, the increase in shear strength is observed when the concentration of resorcinol solutions is increasing. This can be explained by the decrease of water amount in the adhesive composition, and hence the decrease of moisture content in the glued veneer lay-up. The increase of PRF resin content in the adhesives leads to an increase in shear strength due to the formation of three-dimensional polymer network and increasing number of methylene bonds (Skeist, 1977).

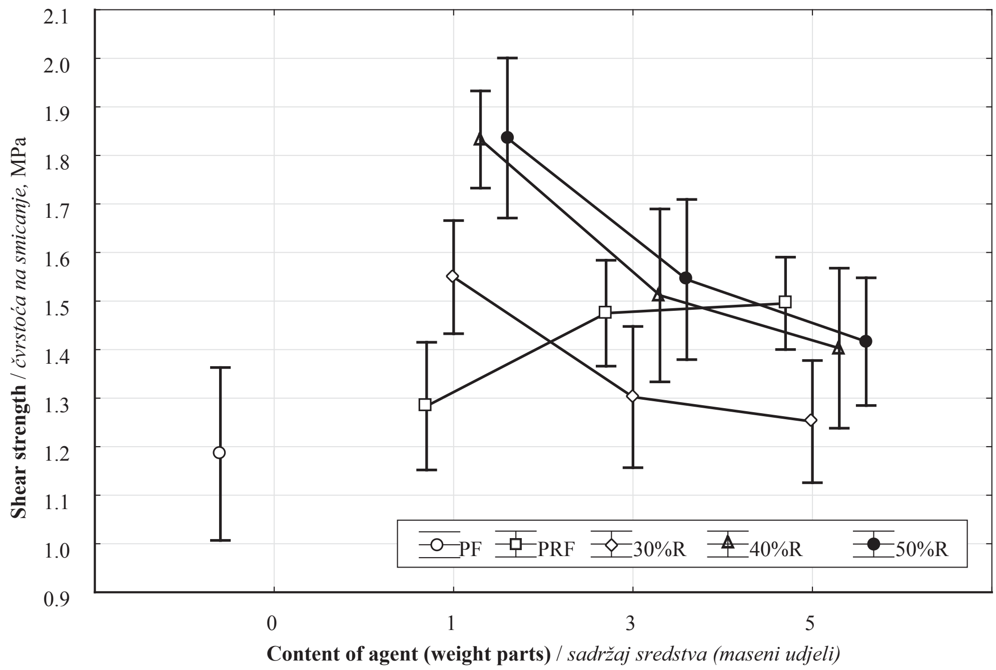
Table 3 ANOVA table for shear strength of plywood panels
Tablica 3. ANOVA tablica za čvrstoću furnirskih ploča na smicanje

Source / *Izvor*	***SS***	***df***	***MS***	***F*-ratio**	***p*-value**
Model /*Model*	7.968	18	0.443	9.030	0.000
Modifying agents / *Sredstva za modificiranje*	2.239	5	0.448	9.136	0.000
Content of modifying agent / *Udjel sredstva za modificiranje*	1.176	2	0.588	11.995	0.000
Interaction / *Međuodnos*	3.271	10	0.327	6.672	0.000
Error / *Pogreška*	9.560	195	0.049		
Total / *Ukupno*	481.078	214			

SS – Summary of squares / *zbroj kvadrata*, *df* – Degree of freedom / *stupanj slobode*, *MS* – Variance / *varijanca*, *F-ratio* – Critical value of Fischer Test / *kritična vrijednost Fišerova testa*, *p* – Level of significance/ *razina značajnosti*



(a)



(b)

Figure 3 Shear strength of plywood panels
Slika 3. Čvrstoća furnirskih ploča na smicanje

Further to the above, in order to improve the adhesive properties and to reduce costs of resin mixture, it should be more profitable to combine the organic extenders (wheat starch and rye flour) with PRF or resorcinol modifying agents.

It was found that the dynamic viscosity of adhesive mixtures with modifying agents significantly increases up 2.8-13.3 times (Figure 4) as well as solid content 1.02-1.16 times in comparison with PF resin and, therefore, the pot life of adhesive is reduced from 5 to 2 hours. The pH value (11.2-11.9) is not significantly changed.

The curing time of adhesive mixtures modified by various agents was shorter (30.1 to 55.2 s) than the curing time of adhesives only modified by one modifying agent. It was established that curing time decreases with the increase of resorcinol or PRF content in the adhesive composition (Figure 5).

Table 4 presents ANOVA results for plywood panels made using mixture of modifying agents. ANOVA tests showed that mixture of modifying agents, their content in adhesive composition and interaction between them also has statistically significant effect on the shear strength.

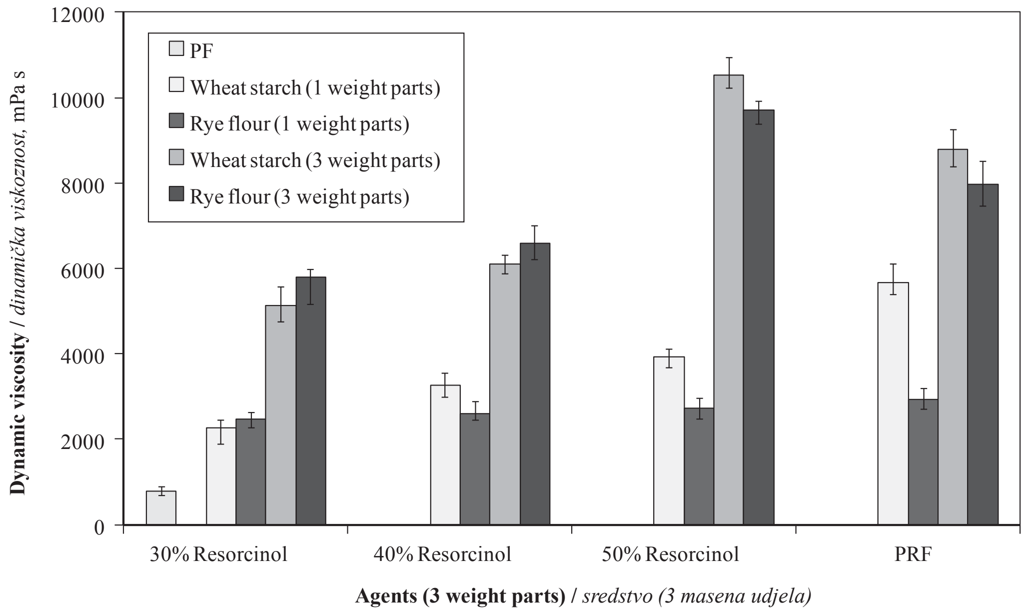


Figure 4 Dynamic viscosity of adhesive compositions with the different ratio of components
Slika 4. Dinamička viskoznost smjesa za lijepljenje pri različitim omjerima komponenata

Table 4 ANOVA table for shear strength of plywood panels
Tablica 4. ANOVA tablica za čvrstoću furnirskih ploča na smicanje

Source / *Izvor*	***SS***	***df***	***MS***	***F*-ratio**	***p*-value**
Model / *Model*	6.904	16	0.432	12.435	0.000
Mixture of modifying agents / *Smjesa sredstava za modificiranje*	5.527	7	0.790	22.754	0.000
Content of modifying agent / *Udjel sredstva za modificiranje*	.349	1	0.349	10.066	0.002
Interaction / *Međuodnos*	1.398	7	0.200	5.754	0.000
Error / *Pogreška*	6.316	182	0.035		
Total / *Ukupno*	382.352	199			

SS – Summary of squares / *zbroj kvadrata*, *df* – Degree of freedom / *stupanj slobode*, *MS* – Variance / *varijanca*, *F-ratio* – Critical value of Fischer Test / *kritična vrijednost Fišerova testa*, *p* – Level of significance/ *razina značajnosti*

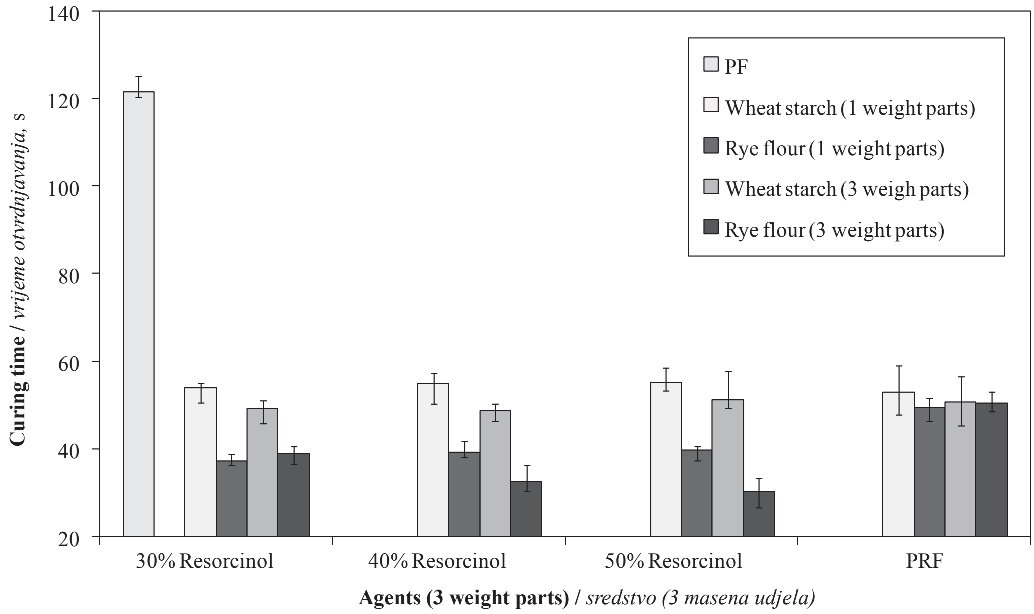
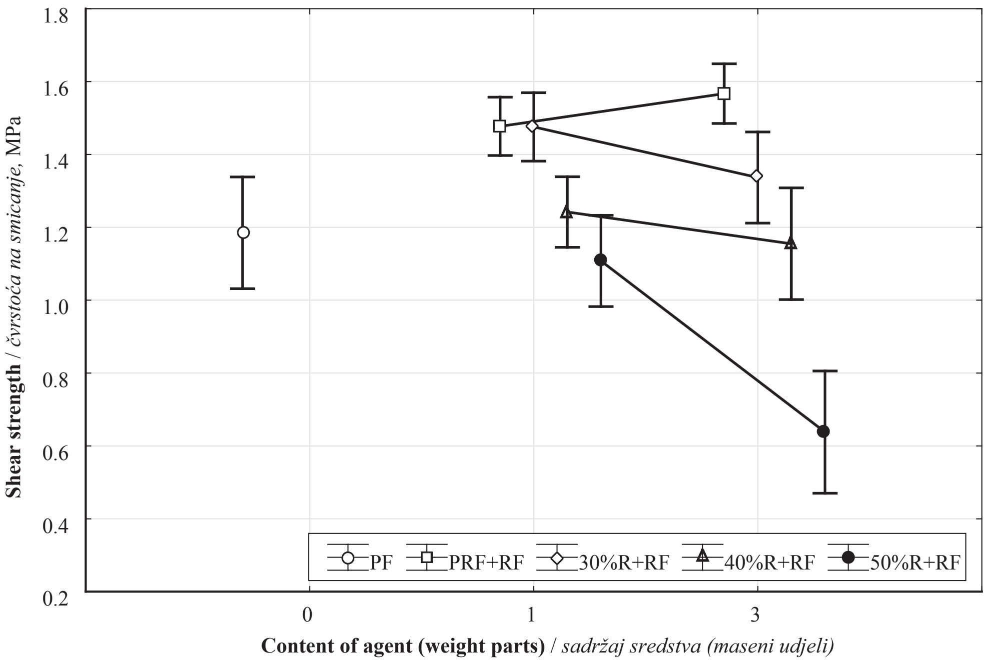
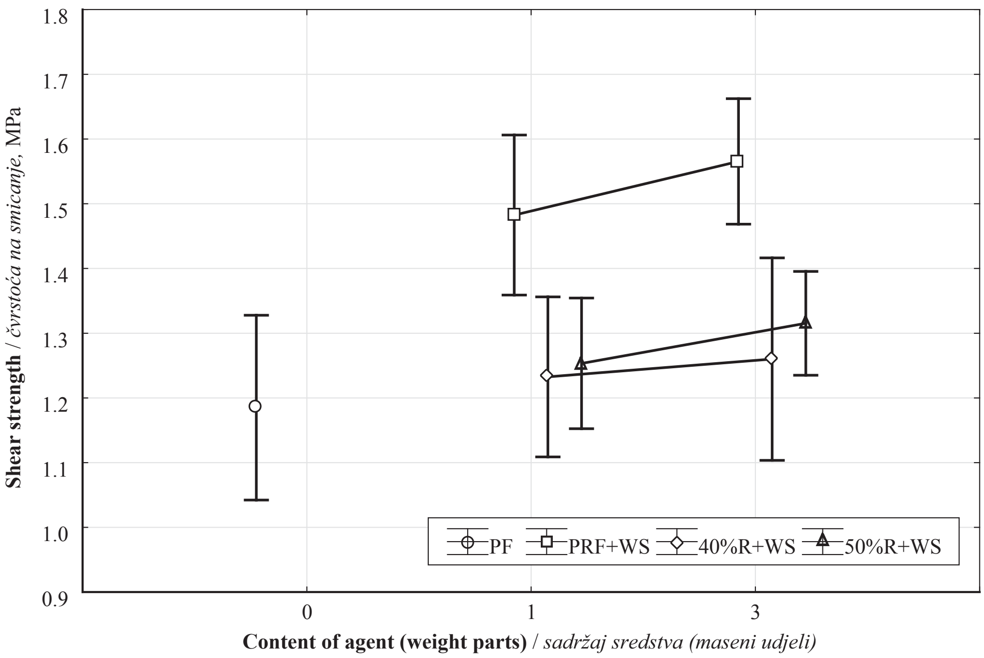


Figure 5 Curing times of adhesive compositions with different ratio of components
Slika 5. Vrijeme otvrdnjavanja smjesa za lijepljenje pri različitim omjerima komponenata



(a)



(b)

Figure 6 Shear strength of plywood panels made using a mixture of modifying agents
Slika 6. Čvrstoća na smicanje furnirskih ploča proizvedenih primjenom smjese sredstava za modificiranje ljepila

Increasing concentrations of resorcinol solution in a mixture with rye flour for any mass between ratios 1:3 or 3:3 lead to the decrease in shear strength of plywood because the dynamic viscosity of adhesive composition is significantly increased. In this case, worse glue wetting of the surface of veneer and thickening of the glue layer is observed. All of that leads to the reduction in shear strength. Similar behaviour of the dependence of shear strength of plywood is observed in the case of combining the resorcinol solutions with wheat starch by the ratio 1:3 (Figure 6a) or 3:3 (Figure 6b). Reactivity of resorcinol modified adhesives increases with increasing of resorcinol concentration in the solution. This leads to the rapid decrease of free reactive methylol groups, and reduction the adhesion strength of adhesive joint.

For adhesive compositions modified with PRF, regardless of its content in the mixture, the higher values of shear strength of plywood are provided in both cases in combination with rye flour and wheat starch.

4 CONCLUSIONS
4. ZAKLJUČAK

Modified PF resin with selected modifying agents allows using veneer with moisture content of 15 % for the manufacture of plywood in the laboratory scale, if their properties meet the standard requirements. Modifications of phenol-formaldehyde resin, in the way presented in this study, are possible with the use of wheat starch, rye flour, phenol-resorcinol-formaldehyde resin and 30 %, 40 %, 50 % concentrations of resorcinol. The results of tests of shear strength properties of plywood show that mainly PRF glue compositions are most appropriate for the gluing of veneer with higher moisture content. The improvement of technical parameters of adhesive compositions and glued products strongly depend on the composition of glue mixture, functionality of modifiers and the way of modification. With the aim to decrease the over penetration of glues through the veneer during hot pressing, organic extenders were applied in gluing mixtures. ANOVA analysis has shown that type, mixture and content of modifying agents affect significantly the mechanical performance of plywood panels. The positive results from the laboratory experiments gave the base to plan experiments in industrial conditions, and however the application of some of them is limited due to their higher viscosity, mainly from the view of glue spread control. These glues have the solid content higher in comparison with reference PF resin.

Acknowledgments - Zahvala

This work was supported by Slovak Grant Agency VEGA under the contract No. 1/0581/12.

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Corresponding address:

Prof. Ing. PAVLO BEKHTA, Dr. Sc.

Department of Wood-Based Composites
National University of Forestry & Wood Technology of Ukraine
Gen. Chuprynky 103
79057 Lviv, UKRAINE
e-mail: bekhta@ukr.net

Leon Oblak[1], Branko Glavonjić[2]

A Model for the Evaluation of Radio Advertisements for the Sale of Timber Products

Model za ocjenjivanje radijskih oglasa o prodaji drvnih proizvoda

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 29. 10. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*72; 339.1*
doi:10.5552/drind.2014.1357

ABSTRACT • *Timber companies must continually strive to improve or at least maintain their market share. There are several methods to achieve this, and advertising is one of them. When timber companies make decisions about advertising, many of them choose radio advertising instead of television advertising, because it is less expensive. Companies should prepare advertisements that consumers will find attractive and appealing. To achieve this, they must take into account a number of criteria, as well as the fact that some of them are more important than the others. In this paper, the AHP analysis was used to determine the opinion of market professionals about the importance of criteria in radio advertising of timber products. Based on the results, a model for evaluating radio advertisements was developed and tested with random respondents, who evaluated a sample radio advertisement of timber companies.*

Keywords: *timber company, timber products, radio advertisement, AHP analysis, survey*

SAŽETAK • *Tvrtke za preradu drva moraju stalno nastojati poboljšati ili barem zadržati svoj tržišni udio. Postoji nekoliko načina da se to postigne, među kojima je i oglašavanje. Kad tvrtke za preradu drva odlučuju o oglašavanju, više će se njih odlučiti za radijsko nego za televizijsko oglašavanje, jer su radijski oglasi jeftiniji. Tvrtke trebaju pripremiti oglase koji će potrošačima biti atraktivni i koji će im se svidjeti. Stoga moraju uzeti u obzir niz kriterija, kao i činjenicu da su neki kriteriji važniji od drugih. U radu je primijenjena AHP analiza kako bi se utvrdilo mišljenje tržišnih profesionalaca o važnosti kriterija u radijskom oglašavanju drvnih proizvoda. Na temelju rezultata razvijen je model vrednovanja radijskih oglasa te je ispitan na slučajnom uzorku ispitanika koji su ocijenili uzorak radijskih oglasa tvrtki za preradu drva.*

Ključne riječi: *tvrtka za preradu drva, drvni proizvodi, radijski oglas, AHP analiza, anketa*

[1] Author is associate professor at Biotechnical Faculty University of Ljubljana, Slovenia. [2]Author is professor at Faculty of Forestry, University of Belgrade, Serbia.
[1] Autor je izvanredni profesor Biotehničkog fakulteta Sveučilišta u Ljubljani, Slovenija. [2]Autor je profesor Šumarskog fakulteta Sveučilišta u Beogradu, Srbija.

1 INTRODUCTION
1. UVOD

Advertising is the most important and widely used tool of the promotion mix. It is done through mass media such as television, radio, newspapers, magazines, commercial billboards, brochures, catalogues, leaflets, direct mail, email and other media (Jelačić et al., 2012). A company provides information on its products to consumers by means of advertisement in the most attractive way possible. Due to the impersonal form of marketing communication, the persuasiveness of advertising messages is of significant importance for co nsumers to decide whether they will actually buy the product (Oblak, 2012).

Advertising messages have impact on consumers' purchase decisions. The primary functions of advertising are (Cravens and Piercy, 200s6):

- to present attractively the products offered by the company in the market,
- to direct hesitant buyers how to choose among a number of similar products,
- to influence and change established habits and customs in the use of products,
- to inform users about new products or technological achievements that improve current products,
- to create consumers positive attitude and confidence in a company and its products, and
- to indirectly influence the output growth and lowering costs due to increasing sales.

Advertising is used by companies to notify customers, convince them and form preferences for an individual product, trade mark or service and remind the customers where the product or service may be purchased.

Advertising expresses company's wish to maintain the current and acquire new consumers. Thus, its advertising activity is directed towards the current consumers, informing them about changes of the sales line, fashion news, prices, quality of the products or services, as well as to the potential new consumers, attempting to attract them not only for a one time purchase but to, instead, gain their lasting loyalty to the company.

A company has a number of options in choosing the advertising media. The biggest impact among all can be achieved with television, which combines pictures, sounds, colors and movement but this media is also very expensive. In addition, according to a survey by the Association of National Advertisers, 78 % of advertisers noted that TV advertising has become less effective during the past two years. Due to this, many timber companies choose radio advertising when they want to sell their products. When advertising on the radio, companies often choose local radio stations, especially small companies, because local radio stations provide much selectivity and elasticity of advertising at relatively low cost.

The objective of this paper was to define the importance of the individual evaluation criteria in radio advertising and to create a model for evaluating radio commercials of timber companies.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 AHP method
2.1. Metoda AHP

The AHP analysis is a widely used multi-criteria decision model for ranking alternatives or selecting the optimal alternative on the basis of a hierarchical tree structure of goal, criteria and sub-criteria. It has been used by many authors (Kitek Kuzman and Grošelj, 2012; Kitek Kuzman *et al*., 2013; Lipušček *et al*., 2010; Čančer and Mulej, 2010, 2013; Oblak *et al*., 2012; Paluš, 2005) as an aid in decision making.

The AHP (Analytic Hierarchy Process) analysis is one of the best known and most popular multiparameter decision-making methods. The components of multiparameter model are not included directly; the direct method of comparison by pairs is used instead. Weights in the AHP analysis are determined indirectly by comparing pairs of parameters, each to each.

The AHP analysis is based on pair-wise comparisons of the elements on the same level of the hierarchy in respect of the parent element on the higher level of hierarchy. Comparisons can combine measurable and non-measurable, tangible and intangible, quantitative and qualitative elements. The relative importance of pair-wise comparisons a_{ij}, $i, j = 1,...,n$ of elements i and j is evaluated on a scale from 1 to 9 (Table 1) and collected in the pair-wise comparison matrix $A = (a_{ij})_{n \times n}$. The inverse comparison is assigned a reciprocal value: $a_{ij} = 1/a_{ij}$.

The vector of weights $w = (w_1,..., w_n)$ belonging to the elements $i = 1,...,n$ can be derived from the pair-wise comparison matrix A by the eigenvector method (Saaty, 1980), where w is the eigenvector corresponding to the maximal eigenvalue of matrix A:

$$Aw = \lambda_{\max} w. \tag{1}$$

The inconsistency of matrix A can be measured by the consistency ratio $CR_A = CI_A / RI_n$, where consistency index $CI_A = \frac{\lambda_{A,\max} - n}{n-1}$ depends on the maximal eigenvalue of matrix A and the maximal eigenvalue of consistent $n \times n$ matrix, which is n, and the random index RI_n, which depends on the size of the matrix A.

Matrix A is acceptably consistent if $CR_A < 0.1$. If A is not acceptably consistent there are two possibilities: the decision maker can revise his judgment or we can improve the consistency of the matrix A by the consistency improving method (Zeshui and Ciuping, 1999):

$$a^*_{ij} = \left(a_{ij}\right)^{\lambda} \left(\frac{w_i}{w_j}\right)^{1-\lambda}, \tag{2}$$

where $0 < l < 1$. If the adopted matrix $A^* = (a^*_{ij})$ is still not acceptably consistent, we repeat the process of adoption.

The AHP analysis offers many suitable methods for the aggregation of individual results into a group result. In this research, the WGMDEA method was selected (Grošelj *et al*., 2011). The method is based on

Table 1 Scale of importance levels and preferences of the AHP method (Saaty, 2006)
Tablica 1. Ljestvica razine važnosti i preferencija metode AHP

Numerically expressed level / *Brojčano izražena razina*	**Verbally expressed level** / *Opisno izražena razina*
1	Both criteria are equally important, the alternatives are equally desirable. / *Oba su kriterija jednako važna, alternative su jednako poželjne.*
3	The criterion is moderately more important than the comparable criterion; we gave a moderate priority to the alternative. / *Kriterij je umjereno važniji od usporedivih kriterija; dali smo umjereni prioritet alternativi.*
5	The criterion is strongly more important than the comparable criterion; we gave a strong priority to the alternative. / *Kriterij je mnogo važniji od usporedivih kriterija; dali smo velik prioritet alternativi.*
7	The criterion is very strongly more important than the comparable criterion; we gave a very strong priority to the alternative. / *Kriterij ima znatno veću važnost od usporedivih kriterija; dali smo vrlo veliku prednost alternativi.*
9	The criterion is extremely more important than the comparable criterion; we gave an extreme priority to the alternative. / *Kriterij je izuzetno važniji od usporedivih kriterija; dali smo iznimnu prednost alternativi.*
2, 4, 6, 8	The middle values / *Srednje vrijednosti*

linear programming and has foundations in the Data Envelopment Analysis.

Let $a_{ij}^{(k)}$, $i,j=1,...,n$, $k=1,...,m$ be pair-wise comparisons of m decision makers. Let opinions of all decision makers be equally important. Solving linear programs for all w_i, $i=1,...,n$, provides n group priorities.

$$
\begin{aligned}
\max \quad & w_0 = \sum_{j=1}^{n} \sqrt[m]{\prod_{k=1}^{m} a_{0j}^{(k)}}\, x_j \\
\textit{subject to} \quad & \sum_{j=1}^{n} \left(\sum_{i=1}^{n} \sqrt[m]{\prod_{k=1}^{m} a_{ij}^{(k)}} \right) x_j = 1 \\
& \sum_{j=1}^{n} \sqrt[m]{\prod_{k=1}^{m} a_{ij}^{(k)}}\, x_j \geq n x_i, \; i = 1,...,n \\
& x_j \geq 0, \; j = 1,...,n.
\end{aligned}
\tag{3}
$$

The maximum values of linear programs w_i, i=1,…,n provide group vector of weights w=(w_1,…,w_n).

2.2 Survey
2.2. Anketa

A survey is a method of data collection, which enables to get data about the views and opinions of respondents. It is economically convenient since by means of a properly formatted survey a large number of information can be attained in a short time. Survey questions can be divided into two categories: open and closed questions. As regards open questions, respondents answer in their own words, and regarding closed questions, respondent are to choose one of the answers offered next to each question.

2.3. Model formulation and testing
2.3. Formuliranje i testiranje modela

Among the project criteria by which consumers memorize radio advertisements, the most important were determined. Several criteria were used and therefore it was necessary to determine the most important ones. The comparison had to be made in pairs, whereby the number of required comparisons was growing rapidly with the number of criteria. Based on the results of the expert group, which were obtained by means of the AHP method, the criteria were defined according to their importance. The expert group was made of five experts from different fields: wood science and technology, economics and advertising design. They assessed general advertising attributes. The results were used to formulate the model enabling evaluation of likeability of radio commercials. The model was tested; 15 respondents assessed a specific radio commercial of a timber company. To test the model, a sample size is large enough.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Results of the AHP method
3.1. Rezultati metode AHP

Advertising experts have defined four parameters, which in their opinion had the greatest impact on consumers' emotions in perception of radio advertisements. Using the AHP method for the evaluation, the parameters were compared to each other, each by each. Analysis provided identification of the importance of certain criteria for each assessor. After reviewing all the evaluated criteria, all their values were obtained, distributed proportionally. The resulting data, obtained with the help of the expert group, were analyzed using the computer program Expert ChoiceTM.

Experts evaluated the following parameters:
1. voice (easy to listen to, clarity, dynamics of narration),
2. background sound (music, effects…),
3. content of the advertisement,
4. duration of the advertisement.

The AHP method comprised the nine digit evaluation scale, i.e. one parameter on each side of the line, which is subject to a value assigned according to our impression. Pairs of advertising parameters were compared on a scale from 1 to 9, focusing on whether any of these parameters were more important than the others, and on the difference in the importance between them. The value was assigned to only one parameter.

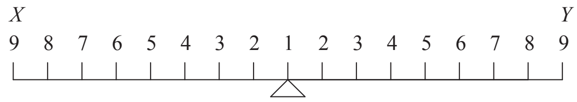

Figure 1 Comparative scale of the AHP method
Slika 1. Komparativna ljestvica metode AHP

The parameters were compared by the members of an expert group with the use of AHP method. Figure 2 shows a questionnaire, which was filled to compare the parameters of a radio advertisement.

After executing an inter-comparison of the parameters by means of a mathematical matrix or a computer program, for instance Expert ChoiceTM, the AHP method was carried out. The analysis indicates which evaluated parameter had the greatest weight in the evaluation of radio advertisements.

Table 2 shows the results of the AHP method for radio advertisements by experts.

Table 2 demonstrates that the content of the advertisement had considerably more weight than the other parameters. The voice, or how easy was to listen to something and how clear and dynamic the narration was, was the second in terms of importance, followed by the duration of the advertisement. The background sounds were, in the opinion of the experts, the least important criterion.

3.2 Survey results
3.2. Rezultati ankete

The objective of the survey was to evaluate a specific radio advertisement. Fifteen randomly chosen people, aged from 18 to 65, viewed a radio advertisement of furniture sale of a Slovenian timber company. The respondents were asked to evaluate individual cri-

voice (easy to listen to, clarity, dynamics of narration…)	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	background sound (music, effects…)
voice (easy to listen to, clarity, dynamics of narration…)	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	content of the advertisement
voice (easy to listen to, clarity, dynamics of narration…)	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	duration of the advertisement
background sound (music, effects…)	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	content of the advertisement
background sound (music, effects…)	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	duration of the advertisement
content of the advertisement	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	duration of the advertisement

Figure 2 Survey AHP questionnaire for a radio advertisement
Slika 2. Anketni AHP upitnik za radijsko oglašavanje

Table 2 Average of the results obtained with the AHP method for radio advertisements
Tablica 2. Prosječni rezultati dobiveni metodom AHP za radijsko oglašavanje

Parameter *Parametar*	**Person** / *Osoba*					**Sum** *Zbroj*	**Average** *Prosječno*
	A	B	C	D	E		
Content of the advertisement / *Sadržaj oglasa*	0.664	0.249	0.424	0.615	0.601	2.553	0.5106
Voice / *Glas*	0.208	0.592	0.231	0.208	0.251	1.49	0.2980
Duration of the advertisement / *Trajanje oglasa*	0.064	0.054	0.285	0.072	0.094	0.569	0.1138
Background sound / *Zvuk u pozadini*	0.064	0.105	0.06	0.105	0.054	0.388	0.0776

Table 3 Survey results
Tablica 3. Rezultati ankete

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	**Total** *Ukupno*	**Average** *Prosječno*
Content of the advertisement *Sadržaj oglasa*	5	5	4	4	5	5	4	2	3	2	5	2	2	4	5	57	3.800
Voice / *Glas*	5	2	4	4	4	4	5	3	4	4	5	3	3	4	5	59	3.933
Duration of the advertisement *Trajanje oglasa*	4	4	4	3	4	2	3	5	3	2	3	3	3	5	5	53	3.533
Background sound *Zvuk u pozadini*	4	1	3	3	2	4	4	4	2	2	4	2	2	5	5	47	3.133

Table 4 Evaluation of television advertisement with the model
Tablica 4. Ocjena televizijskog oglašavanja primjenom modela

Parameter *Parametar*	**Average rating** *Prosječna ocjena*		**Weight** *Važnost*		**Result** *Rezultat*
	3.800	x	0.5106	=	1.9403
Content of the advertisement / *Sadržaj oglasa*	3.933	x	0.2980	=	1.1720
Voice / *Glas*	3.533	x	0.1138	=	0.4021
Duration of the advertisement / *Trajanje oglasa*	3.133	x	0.0776	=	0.2431
			Σ = 1		3.7575

teria with values ranging from 1 to 5 (1 = lowest rating, 5 = highest rating). The results of the survey of radio advertisement are the values shown in Table 3.

The average value of individual evaluations was calculated and multiplied with the weight of the criteria.

The potential buyers assessed the radio advertisement with an average of 3.7575. The highest possible score was 5.

4 CONCLUSION
4. ZAKLJUČAK

Nowadays, consumers are very demanding and they require as much as possible information about the product to be sure about its quality. Television advertisements represent the most effective way to provide information about the product to a wide audience by combining pictures, sounds, colors and movement, but it is very expensive. An increasing number of timber companies, therefore, rather decided to use radio advertising. When creating an advertisement, experts' opinions, as well as the opinion of the consumers, should be taken into account.

In our project, the method called Analytic Hierarchy Process (AHP) was used. The method represents a strong and flexible decision making technique, which helps in setting priorities and reaching optimal decisions in situations when quantitative and qualitative aspects have already been taken into consideration. It is based on the comparison of pairs of alternative solutions, during which all alternatives are compared to one another, and the decision maker can express the intensity and level of preference towards one alternative in relation to the other according to the criteria he finds important. In the same way, criteria can be compared according to our own preferences and their intensity.

By means of the AHP method, the importance of individual weights was determined, as well as the criteria by which consumers assess radio advertisements. The content and the idea of an advertisement were found as the most important factors, followed by voice (easy to listen to, clarity, dynamics of narration), duration of the advertisement and background sound (music, effects…). A model enabling the evaluation of these types of advertisements was elaborated. The model was tested in a survey, whereby random potential buyers evaluated a radio advertisement of a Slovenian timber company.

Acknowledgements – Zahvala

The authors wish to thank the Slovenian Research Agency (ARRS) within the Programme Group P4-0015-0481.

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Corresponding address:

Assoc. prof. LEON OBLAK, Ph. D.

University of Ljubljana, Biotechnical Faculty
Department of wood science and technology
Rožna dolina C. VIII/34,
1000 Ljubljana, SLOVENIA
e-mail: leon.oblak@bf.uni-lj.si

Goran Milić[1], Branko Kolin[1], Nebojša Todorović[1], Željko Gorišek[2]

Energy Consumption of Beech Timber Drying in Oscillation Climates

Potrošnja energije tijekom oscilacijskog sušenja bukovih piljenica

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 17. 12. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*847.24; 630*847.7; 674.031.632.22*
doi:10.5552/drind.2014.1367

ABSTRACT • *The influence of applying the oscillations of air parameters during conventional drying of beech timber on energy consumption is discussed in the paper. A special drying software was created to enable the input of frequency (in hours) and amplitude (in percents) of oscillations. Altogether 12 drying runs were carried out: three conventional ones and nine by using the same schedule but with oscillations of equilibrium moisture content (EMC), temperature and the combination of these two. The combinations of two amplitudes (10 % or 20 %) and two frequencies (3 or 6 hours) were applied in different test runs. The results indicated that all test runs had energy consumptions proportional to drying time, with an important influence of the outside temperature. In runs with oscillations, often climate changes influenced to some extent the total energy consumption, especially in runs with short phases (3 hours) and high amplitudes (20 %). Despite frequent climate changes, it can be expected that the usage of oscillations would lead to the same or even lower energy consumption than in conventional beech timber drying, especially when shorter drying time is reached.*

Key words: *wood drying, energy consumption, conventional drying, oscillation climates, beech timber*

SAŽETAK • *Cilj istraživanja bio je ustanoviti utjecaj oscilacije parametara zraka tijekom konvencionalnog sušenja piljene bukove građe na potrošnju energije. Izrađen je poseban program koji je omogućivao regulaciju frekvencije (u satima) i amplitude oscilacija (u postocima). Provedeno je ukupno 12 ciklusa sušenja: tri konvencionalnim režimima i devet ciklusa istim režimom, ali s oscilacijom vlage ravnoteže, temperature ili kombinacijom oscilacije obaju parametara. Primijenjene su dvije amplitude (10 % i 20 %) te dvije frekvencije (3 i 6 sati) u različitim ciklusima sušenja. U svim postupcima sušenja potrošnja energije bila je razmjerna vremenu sušenja, uz značajan utjecaj vanjske temperature. U ciklusima sušenja s oscilacijom parametara sušenja česta promjena klime, posebno uz kraća vremena promjene (3 sata) i pri većim amplitudama (20 %) imala je značajan utjecaj na potrošnju energije. Usprkos čestim promjenama klime, može se očekivati da je potrošnja energije u režimima s oscilacijom klime jednaka ili čak niža u usporedbi s konvencionalnim režimom sušenja, posebno zbog očekivanoga kraćeg vremena sušenja.*

Ključne riječi: *sušenje drva, potrošnja energije, konvencionalno sušenje, oscilacija klime, bukova građa*

[1] Authors are assistant professor, professor and assistant professor at University of Belgrade, Faculty of Forestry, Department of Technology, Management and Design of Furniture and Wood Products, Belgrade, Serbia. [2]Author is associate professor at University of Ljubljana, Biotechnical faculty, Department of Wood Science and Technology, Ljubljana, Slovenia.

[1] Autori su docent, profesor i docent Sveučilišta u Beogradu, Šumarski fakultet, Odjel za tehnologiju, menadžment i dizajn namještaja i drvnih proizvoda, Beograd, Srbija. [2]Autor je izvanredni profesor Sveučilišta u Ljubljani, Biotehnički fakultet, Odjel za znanost o drvu i drvnu tehnologiju, Ljubljana, Slovenija.

1 INTRODUCTION
1. UVOD

Along with the continuous growth of prices of energy sources, the significance of energy consumption in industrial processes has also been growing from decade to decade. Energy consumption is critical for producers who deal with inexpensive products (such as majority of wooden products) as it affects running costs (Kudra, 2004). It is especially important in wood drying, because it is a process that consumes the most energy in the entire chain of timber industry. In the drying process, at least the latent heat of vaporization has to be supplied for removing water from wood. At the same time, conventional kilns, which prevail in the world, consume around 50 % more energy than required to evaporate the water (Elustondo and Oliveira, 2009). Potential improvements in conventional drying are focused on three parameters: drying quality, drying time and energy consumption. One of the possible strategies is the application of artificial variations of certain process parameters (such as temperature, relative air humidity, air velocity, etc.) during the conventional drying. This topic was researched by several authors (De La Cruz -Lefevre *et al.,* 2009; Haygreen, 1965**;** Langrish *et al.,* 1992; Milić and Kolin, 2008; Poskrobko and Vilchinski, 1983; Sackey *et al.,* 2004; Salin, 2003; Terziev *et al.,* 2002; Welling *et al.*, 2003). Previous researches on oscillating drying have already shown the potential advantages of such a schedule in the sense of shorter drying time and better drying quality of wood (Milić *et al*., 2013).

In addition to the drying quality and duration of the process, a very important aspect of oscillation changes in conventional drying is also energy consumption. The aim of this paper is to determine if frequent changes of drying conditions, i.e. the constant need for increasing and decreasing of temperature and EMC, increases the energy consumption compared to most used conventional kiln drying.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

The experiment was done in a laboratory kiln with the capacity of around 0.8 m^3 of timber (stack 2.1 m x 0.7 m x 0.9 m). The kiln consists of two reversible fans, cold water humidification system, electrical heating elements and computer control regulation with eight probes for measuring timber moisture content (MC), and two sensors for measuring temperature and equilibrium moisture content (EMC). The kiln manufacturer assumed that the average values of both temperature and EMC measuring points are always used, which can result in somewhat severe drying conditions, compared to the concept in which only the inlet measuring point is active.

To achieve the EMC and/or temperature oscillations in the previously set amplitudes and frequencies, it was necessary to upgrade the software whose simple activation engages oscillation drying. Additional software enables setting the duration of both phases (in hours), and the upward and downward deviation values of EMC and temperature (in percent) compared to the existing ones in the conventional schedule (Figure 1). Such amplitudes were chosen in order adapt their sizes to their respective drying phases. Such a definition of deviations was accepted because of technical possibilities of industrial kilns, and because of the influence and importance of oscillation on drying through the entire process (Salin, 2003). The phases are completely separated, which means that they can have different durations and amplitudes of both EMC and temperature. An important requirement for the new software was the easy implementation in industrial kilns, which was a drawback in most previous studies.

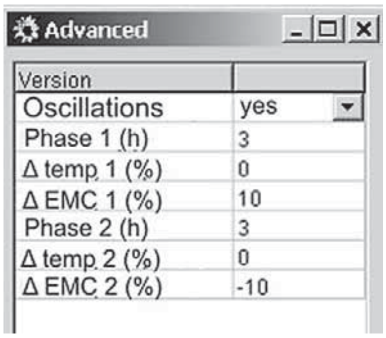

Figure 1 Setting the oscillations in a separate window
Slika 1. Odabir oscilacija u zasebnom prozoru programa

The research was done on 38-mm beech timber (*Fagus sylvatica* L.). The width of the boards was 12-18 cm and the length 2.1 m. The boards were sawn 2-3 days before each drying cycle from logs of similar diameters (30-39 cm) cut down on the same tree location in winter time. Twelve drying cycles were carried out in total. Out of these, three were conventional ones that used a moisture content based schedule commonly used in Serbia (Table 1), while nine others used the same schedules, but with oscillations, as shown in Table 2. The final, XII drying cycle was used for repeating the test run that showed the best results regarding time and quality. In each drying cycle (65-70 boards per run), 30 boards were selected and stacked in the central part of the stack to be used for the assessment of drying quality at the end of the process (Milić *et al.*, 2013). Timber was dried from green state to target 9 % moisture content, measured by the probes in the kiln.

Considering that an electric boiler was used for heating the kiln, the total energy consumption was recorded by an electricity meter. Energy consumptions of all 12 runs were compared. Comparison of energy consumption was done based on the values obtained prior to conditioning phase, because the drying was interrupted at that time. Specific energy consumptions (energy required for the removal of 1 kg of water from wood) were also calculated and compared because they eliminate the influence of different initial MC between runs. The mass of removed water (difference between stack weight before and after drying) was calculated based on the stack volume and initial and final MC. Energy consumption was followed during the en-

Table 1 Conventional drying schedule (beech, 38 mm)
Tablica 1. Konvencionalni režim sušenja (bukva, 38 mm)

MC, % / *Vlažnost drva*, %	60	55	50	45	40	35	30	25	20	15	10	5
Temperature, °C / *Temperatura,* °C	37	38	38	38	3 8	40	43	47	52	58	62	62
EMC. % / *Ravnotežna vlaga, %*	15	15	14.6	14.0	13.6	13.1	12.1	9.2	6.8	5.4	4.4	3.9

Table 2 Amplitudes and frequencies of oscillations (12 test runs)
Tablica 2. Amplitude i frekvencije oscilacija u 12 ciklusa sušenja

Test run *Ciklus*	**Description** *Opis*	**Amplitude**/*Amplituda,* % EMC *Ravnotežna vlaga*	**Amplitude**/*Amplituda,* % Temperature *Temperatura*	**Frequency** *Frekvencija* h
I	conventional/*konvencionalno*	-	-	-
II	conventional/*konvencionalno*	-	-	-
III	conventional/*konvencionalno*	-	-	-
IV	oscillations of EMC / *oscilacija ravnotežne vlage*	±10	-	3
V	oscillations of EMC / *oscilacija ravnotežne vlage*	±10	-	6
VI	oscillations of EMC / *oscilacija ravnotežne vlage*	±20	-	3
VII	oscillations of EMC / *oscilacija ravnotežne vlage*	±20	-	6
VIII	oscillations of temp. / *oscilacija temperature*	-	±10	3
IX	oscillations of temp. / *oscilacija temperature*	-	±10	6
X[a]	oscillations of temp. and EMC / *oscilacija ravnotežne vlage i temperature*	±10	±10	3
XI[a]	oscillations of temp. and EMC / *oscilacija ravnotežne vlage i temperature*	±10	±10	6
XII	repeated run IV / *ponovljeni ciklus IV*	±10	-	3

[a]Test runs X and XI: when temperature increases, EMC decreases and vice versa.
[a]*Ciklusi X i XI: kada se temperatura povećava, ravnotežna se vlaga smanjuje, i obrnuto.*

tire drying cycles, which enabled comparisons to be made between consumption above and below fiber saturation point (FSP), assumed to be at 30 % MC.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Energy consumption (Table 3) ranged from 791 kWh (run VIII) to 1104 kWh (run I). These values include all energy (heating, fans, valves, servomotors). Very low energy consumption in run VIII was the result of high average outside temperature (temperature, which resulted in smaller losses through heat transmission and air exchange). Energy consumption of the other runs was more or less proportional to drying time, with an always-present influence of the outside temperature (it varied between -7 °C and +15 °C among runs).

With the exception of run VIII, the lowest energy consumption was recorded in runs IV and XII in which drying time was short. On the contrary, run X had relatively high energy consumption, despite the short duration of drying. The reason is that frequent (3 h), oppositely directed oscillations of temperature and EMC that have been applied in this run, required frequent vent opening and thus caused higher heat losses. In addition, frequent EMC changes required more frequent humidification, and temperature changes required more heating, both of which increased energy consumption. A similar explanation applies for run XI with the same, but not so frequent (6 h), oscillations. Very high energy consumption was registered in run VI, as a result of 20 % and 3 h EMC oscillations, which, as for the above mentioned runs, required frequent and long vent opening. In all three conventional runs, relatively

Table 3 Initial and final moisture content (MC), drying time, energy consumption (EC) and specific energy consumption for each test run
Tablica 3. Početni i konačni sadržaj vode u drvu (MC), vrijeme sušenja, potrošnja energije (EC) i specifična potrošnja energije u svim ciklusima sušenja

Oscillating parameter(s) *Oscilirajući parametar*	**Conventional** *Konvencionalno sušenje*			***EMC* ±10%**		***EMC* ±20%**		***T* ± 10%**		***EMC, T* ± 10%**		***EMC* ±10%**
Oscillation time / *Oscilacija vrijemena*				3 h	6 h	3 h	6 h	3 h	6 h	3 h	6h	3h
Test run / *Ciklus sušenja*	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Initial MC, % / *Početni sadržaj vode,* %	89	87	81	85	99	85	80	81	79	91	80	81
Final MC, % / *Konačni sadržaj vode,* %	7.4	7.5	7.7	7.8	7.4	7.8	7.9	7.6	7.8	8.8	7.7	7.9
Drying time, h / *Vrijeme sušenja, h*	335	319	385	279	342	326	341	341	322	297	344	307
EC, kWh / *Potrošnja energije*, kWh	1104	934	954	917	996	1021	946	791	918	942	987	862
Specific EC, $kWh \cdot kg^{-1}$ *Specifična potrošnja energije,* $kWh \cdot kg^{-1}$	3.00	2.60	2.89	2.63	2.40	2.93	2.91	2.39	2.86	2.51	3.03	2.61

high energy consumption was recorded (particularly in run I when the average outside temperature was low).

Specific energy consumption was the highest in runs XI and I. Runs VI and VII with high amplitude (20 %) oscillations had higher specific energy consumption compared to runs with 10 % amplitude, despite the higher outside temperature during drying. The lowest energy consumption was recorded in runs VIII and V. The reason for the low total and specific energy consumption in run VIII was the high outside temperature. An important cause of low specific energy consumption in run V was a very high initial MC of timber (99 %), though the total energy consumption was relatively high. As the energy needed for evaporation of free water is significantly lower than for the bound water, the average specific energy consumption for the whole drying cycle was lower.

Run II, as the shortest conventional cycle, had specific energy consumption at the level of runs IV and XII, while the other two conventional runs had higher energy consumption. Generally, the average specific energy consumption obtained in this research (2.39-3.03 kWh·kg^{-1}) is higher than in industrial kilns, which was expected due to high air leakage (leading to heat and humidity losses), higher energy consumption for the fans, heating and humidification – in comparison with the volume of timber. Based on some data, heat losses account for 20-40 % of total energy in a kiln with the capacity of 11 m^3 (Elustondo and Oliveira, 2009) for more than 70 % in kilns of 0.3 m^3 or less (Rosen, 1980). In addition, Elustondo and Oliveira (2009) reported that the energy consumption to evaporate cold water used for humidification in small kilns accounts for more than 15 % of the total energy consumption, and if high both dry-bulb and wet-bulb temperatures (over 60 °C) are used, it can reach almost 50 %. Generally, in industrial conditions, the percentage of energy needed for heating of air and wood is relatively low (around 5 %, according to Denig *et al.*, 2000). When oscillations of drying parameters are used, the humidification system will be switched on more frequently than with conventional schedules, so it is expected that the energy consumption for heating of air and wood in those schedules will also be somewhat higher, but still low compared to the total energy consumption.

There are some differences in comparison of runs regarding total and specific energy consumption. The reason is higher energy consumption due to differential heat of sorption, which had to add drying below FSP. Therefore, drying below FSP had a greater influence on the total energy consumption (60 % of the total energy consumption in run V to 73 % in run VI – Fig. 2). On the other hand, the average specific energy consumption was dominantly influenced by the energy consumption above FSP, due to the higher amount of moisture removal in this range.

Specific energy consumption above FSP (Fig. 3) was between 1.02 kWh·kg^{-1} in run X and 1.49 kWh·kg^{-1} in run III. Below FSP, it ranged from 5.20 kWh·kg^{-1} (run VIII) to 8.07 kWh·kg^{-1} (run I). Guzenda and Olek (2000) reported values from the literature around 5000 kJ·kg^{-1} (1.4 kWh·kg^{-1}) for specific energy consumption above FSP, and more than 10000 kJ·kg^{-1} (2.8 kWh·kg^{-1}) below FSP. In this research, specific energy consumption below FSP was much higher because small kilns are less effective at this stage of drying (disadvantages of small kilns are more pronounced at higher temperatures). Above FSP, energy consumption is even lower than usual due to a very high initial MC in all runs. High initial MC means a longer and more efficient capillary flow, higher drying rate and lower specific energy consumption, which affected the average energy consumption above FSP.

The exactness of energy consumption analysis (both for total and specific energy consumption) is limited above and below FSP. There is no strict border between the periods of evaporation of free and bound water. At mean MC levels above FSP, surface MC quickly reaches the hygroscopic range where bound

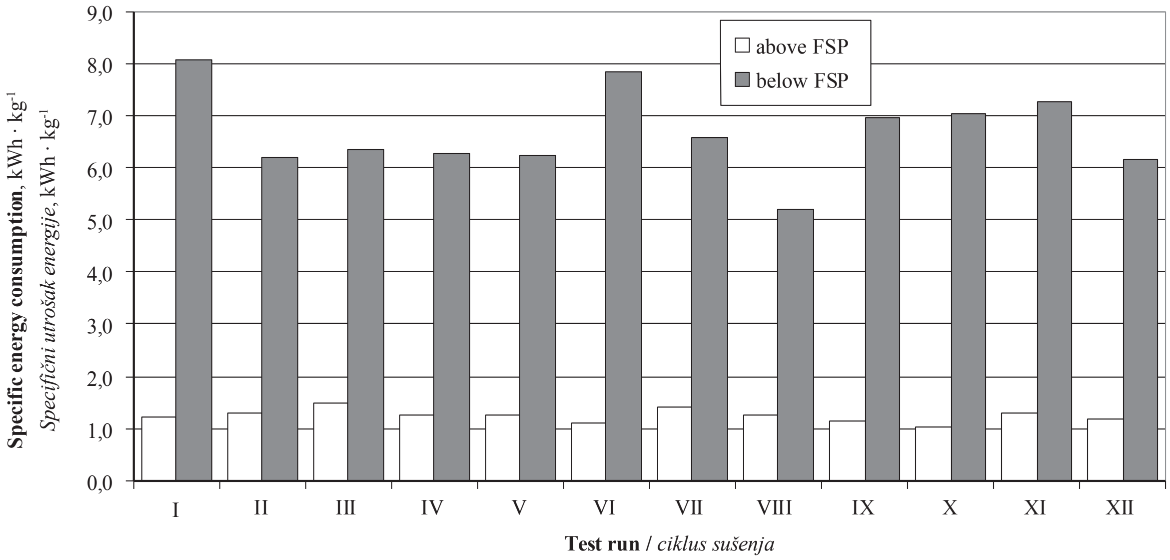

Figure 2 Energy consumption above and below FSP
Slika 2. Potrošnja energije iznad i ispod točke zasićenja vlakanaca

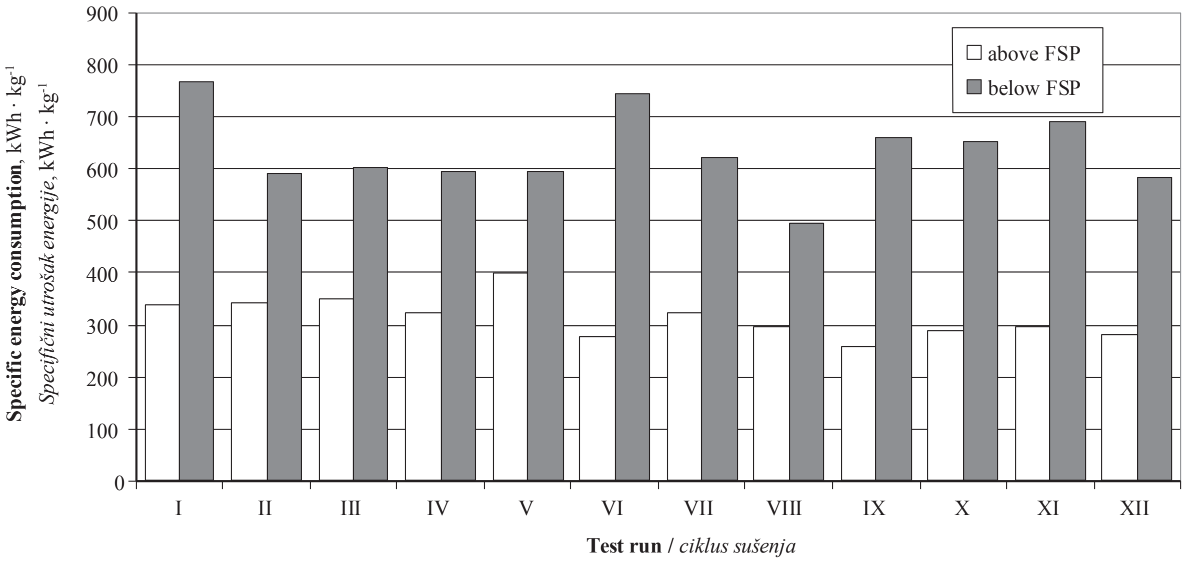

Figure 3 Specific energy consumption above and below FSP
Slika 3. Specifična potrošnja energije iznad i ispod točke zasićenja vlakanaca

water diffusion takes place. Similarly, when individual boards have a mean MC below FSP, liquid migration in inner layers still occurs.

4 CONCLUSIONS
4. ZAKLJUČAK

All test runs had energy consumptions proportional to drying time, with an ever present influence of outside temperature. All three conventional runs had relatively high energy consumption. In runs with oscillations, often climate changes influenced to some extent the total energy consumption, especially in runs with short phases (3 hours) and high amplitudes (20 %). This indicates that the amplitudes should not be over 20 %, otherwise they will increase energy consumption, but also reduce the drying quality. Also, in industrial conditions, the frequency should not be lower than 3 hours. Shorter duration would be insufficient to achieve the set values, the system could be overloaded and finally the energy consumption would be higher. Further work is needed to reveal all aspects of using oscillating climates in industrial conventional drying of beech timber. However, results from this study indicate that energy consumption for oscillation drying, even in industrial conditions, will not be higher than for the conventional runs and, depending on the eventual shortening of drying time, it can be lower. This means that the influence of oscillations of air parameters on the total energy consumption is relatively small, and it once again shows that shortening the duration of the process is the most significant possibility for energy saving in wood drying.

Acknowledgments - Zahvala

This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (TR 31041).

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Corresponding address:

Assistant Professor GORAN MILIĆ, Ph. D.

Department of Technology, Management and Design of Furniture and Wood Products
University of Belgrade - Faculty of Forestry
Kneza Višeslava 1
11030 Belgrade, SERBIA
e-mail: goran.milic@sfb.bg.ac.rs

Emilia Grzegorzewska[1]*, Renata Stasiak-Betlejewska*[2]

The Influence of Global Crisis on Financial Liquidity and Changes in Corporate Debt of the Furniture Sector in Poland

Utjecaj svjetske krize na financijsku likvidnost i promjene u dugovanjima korporacija u sektoru proizvodnje namještaja u Poljskoj

Review paper • Pregledni rad
Received – prispjelo: 17. 7. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*74*
doi:10.5552/drind.2014.1342

ABSTRACT • *This paper presents the analysis of one of the main objectives of flow and debt levels of furniture manufacturing companies in Poland. The analysis includes the average values of the selected financial ratios calculated for small, medium and large furniture manufacturing companies in 2007-2012, comparing them with the results for the entire manufacturing sector. The study results show that furniture manufacturing companies showed a higher ability to pay current liabilities with selected current assets and lower debt levels than industrial companies in general. In addition, the analytical results indicate that there are differences in the liquidity ratios of small, medium and large companies of the furniture industry. These companies also maintain different levels of debt. It should be emphasized that in 2009-2011 there was a negative trend - the liquidity decrease and the debt level increase. It mostly applied to companies of small and average level of employment.*

Key words: *financial liquidity, debt level, employment level, furniture industry, manufacturing*

SAŽETAK • *Jedan od glavnih ciljeva poduzeća u krizi jest da održe solventnost i osiguraju nastavak tržišnih aktivnosti. Stoga su u ovom radu analizirani trendovi u tijeku novca i dugovanjima u proizvodnji namještaja u Poljskoj. Analiza obuhvaća i prosječne vrijednosti odabranih financijskih indeksa izračunanih za male, srednje i velike kompanije za proizvodnju namještaja u razdoblju 2007. – 2012., pri čemu su oni uspoređeni s rezultatima cjelokupnoga proizvođačkog sektora. Rezultati istraživanja govore da industrija namještaja pokazuje veće mogućnosti podmirivanja trenutačnih financijskih obveza raspoloživim sredstvima i uz nižu razinu dugovanja nego što to mogu druga industrijska poduzeća u cjelini. Usto, rezultati analize pokazuju da postoji razlika između razine likvidnosti malih, srednjih i velikih poduzeća za proizvodnju namještaja. Ta poduzeća također održavaju različitu razinu dugovanja. Potrebno je naglasiti da se u razdoblju od 2009. do 2011. pojavio negativni trend – likvidnost se smanjila, a razina dugovanja porasla. To se ponajprije odnosi na mala i srednja poduzeća, gledano sa stajališta broja zaposlenih.*

Ključne riječi: *financijska likvidnost, razina dugovanja, razina zaposlenosti, proizvodnja namještaja, proizvodnja*

[1] Author is assistant at Faculty of Wood Technology, Warsaw University of Life Sciences, Warsaw, Poland. [2]Author is assistant at Faculty of Management, Czestochowa University of Technology, Czestochowa, Poland.
[1] Autorica je asistentica Fakulteta drvne tehnologije, Varšavsko sveučilište bioloških znanosti, Varšava, Poljska. [2]Autorica je asistentica Fakulteta menadžmenta, Tehnološko sveučilište u Czestochowi, Czestochowa, Poljska.

1 INTRODUCTION
1. UVOD

The financial crisis that had its origins in the subprime credit market in the United States turned into a global economic crisis. The negative effects of the crisis affected the entire world economy and contributed to the deterioration of the financial condition of most companies (Jelačić *et al*., 2010). A series of socio-economic difficulties have arisen as a result of these events, and the crisis has increased the interest in issues concerning the main causes of this situation on the world market (Goodhart, 2008; Mojon 2010; Eisenbeis, 2010; Prihod'ko, 2011; Lane, 2012).

The furniture industry is an important part of the Polish economy. Furniture is one of the major export products of the Polish economy. According to a study conducted by Eurostat, the Member States of the European Union, Poland recorded a significant increase in the production of furniture in 1997-2006 - an average of 11.5 % growth per year (Grzegorzewska *et al*., 2012). In 2001-2006, Lithuania and Spain also recorded double-digit annual growth in the mentioned industry (Furniture and other manufacturing activities in 2007). The important role of the furniture industry in the Polish economy is confirmed by the results of furniture exporter rankings. Poland ranks fourth in the world and third in Europe in terms of the furniture market export value. In 2012, the classification of European countries shows a higher position of only two countries - Italy and Germany, and according to the world ranking – China (Bičanić *et al*., 2010). In recent years, the value of Polish furniture market has decreased. Data from the Ministry of Economy shows that in 2007-2008 the production value of the furniture industry amounted to 26.5 (2007) and 27.5 billion PLN (2008). The peak was recorded in 2009, when the value of the furniture production amounted to 30.2 billion PLN. In the next two years, however, a decreasing trend was recorded. In 2010 the furniture market was worth 28 billion PLN, a year later - 27 billion PLN. This means that economic trends in global markets also affected the furniture industry condition and consequently also the financial situation of companies operating in this market. This is due to the fact that over 90 % of the domestic furniture production is devoted to exports. The importance of the non-financial factors that may contribute to minimizing its negative effects was highlighted in the crisis conditions (Sierpińska and Jachna, 2004; Śliwa and Wymysłowski, 2003). An important element in the company management, including furniture industry companies, among others, is to turn attention the factors motivating employees (Kropivšek *et al*., 2011; Drábek and Jelačić, 2007), and to give importance to image and brand recognition for building a competitive advantage (Motik *et al.,* 2010).

However, the financial aspect of the furniture business (Biernacka and Sedliačikova, 2012), which has a significant impact on its solvency forms as the basis of market survival, cannot be missed in the analysis. Creating an appropriate level of financial liquidity and corporate debt is one of the main factors determining the financial condition of the furniture companies. Therefore, in view of the economic situation on the international market in Poland, the issue of the financial liquidity of small, medium and large companies in the furniture industry was taken into consideration.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The aim of this study was to determine trends in terms of financial liquidity and corporate debt of the furniture industry. The average values of the resource liquidity and debt ratios were analyzed for businesses operating in the furniture market. The study covered the period 2007-2012. It was assumed that the period of research would be adequate to determine whether and to what extent industry liquidity and debt ratios have changed due to critical events that have taken place both in Poland and internationally. In the studied population, there were three groups of companies determined based on the criteria of employment level:

- Group 1 - companies employing 10 to 49 workers (small companies),
- Group 2 - companies employing between 50 and 249 workers (medium-sized companies),
- Group 3 - companies employing more than 249 workers (large companies).

The analysis presents a comparative study of average financial liquidity and debt ratios acquired by the furniture industry (Section 31.0 of the Polish Activities Classification – Furniture Manufacturing) in the case of companies with Section C - "Manufacturing", where the furniture industry is included. Companies in the manufacturing sector, including furniture, which were included in the study, are presented in Table 1.

Table 1 A number of manufacturing companies, including furniture industry surveyed in Polandin 2007-2012
Tablica 1. Broj proizvodnih tvrtki u Poljskoj anketiranih u razdobljuod 2007. do 2012., uključujući i poduzeća za proizvodnju namještaja

Year *Godina*	**Furniture production** / *Proizvodnja namještaja*			**Manufacturing** / *Proizvodnja*		
	Small *Mala pod.*	Medium *Srednja pod.*	Large *Velika pod.*	Small *Mala pod.*	Medium *Srednja pod.*	Large *Velika pod.*
2007	1910	320	116	6377	5767	1616
2008	1930	347	110	6539	6130	1569
2009	2390	350	109	6867	6298	1430
2010	2180	320	109	6631	5742	1475
2011	2240	312	102	6800	5722	1487
2012	2320	305	100	6994	5778	1485

Source / *Izvor*: own elaboration based on PONT INFO (2007-2012) / *vlastita istraživanja u PONT INFO*

Table 2 Financial liquidity and debt ratios applied in the analysis
Tablica 2. Financijska likvidnost i indeksi dugovanja korišteni u analizi

Kind of ratio *Vrsta indeksa*	**Definition of ratio** *Opis indeksa*	**Limited value** *Granična vrijednost*
Liquidity ratios / *Indeksi likvidnosti*		
Ratio of current liquidity *Indeks trenutačne likvidnosti*	Current assets / current liabilities *Trenutačnasredstva / trenutačneobveze*	1.2-2
Quick ratio *Indeks brze procjene*	(Current assets - inventories) / current liabilities *(Trenutačna sredstva – zalihe) / trenutačne obveze*	1
High liquidity ratio *Indeks visoke likvidnosti*	Cash and cash equivalents / current liabilities *Gotovina i ostala sredstva / trenutačne obveze*	0.2
Debt ratios / *Indeksi dugovanja*		
Debt ratio *Indeks dugovanja*	Total liabilities / total assets *Ukupne obveze / ukupna sredstva*	1:2-1:4
Equity debt ratio *Indeks uravnoteženih dugova*	Total debt / equity capital *Ukupna dugovanja / ukupni kapital*	2:1
Term debt ratio *Vremenski indeks dugovanja*	Long-term liabilities / equity capital *Dugoročne obveze / ravnotežni kapital*	1:2-1:1

Source / *Izvor*: based on Śliwa and Wymysłowski, 2003; Sierpińska and Jachna, 2004; Jerzemowska, 2006.

A primary source of research material was obtained from reports PONT INFO database (2007-2012), which contains data on the average annual value of financial ratios calculated for groups of companies awarded according to NACE.

Table 2 shows the resource financial liquidity and debt ratios, its definitions and values found as limiting or optimal in the finance literature.

In order to determine the relationship between the distinguished groups of furniture companies and the relation between the furniture industry entities and the entire industrial processing, the correlation analysis of selected financial ratios was done. The Pearson correlation coefficient was applied in the study. It is a relationship measurement of linear characteristics, which assumes values in the range [-1, 1]. The statistical analysis usually assumed that if the correlation coefficient is (Siedlecka,2001):

- below 0.2 - there is no relationship between the studied characteristics,
- 0.2 - 0.4 – the dependency is clear, but low,
- 0.4 - 0.7 – the dependency is moderate,
- 0.7 - 0.9 – the dependency is significant,
- above 0.9 - the dependency is strong.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Data presented in Figure 1 shows the average values of the current financial liquidity ratio for companies and entities in the furniture manufacturing industry.

The analysis of research results shows that the current liquidity ratio, indicating capabilities of current liabilities with current assets, increased in 2007-2009 in the case of furniture manufacturing companies regardless of the number of employees.

The highest value of this ratio was observed in companies employing 10 to 49 employees. Initially, the current ratio increased in this group from 1.48 to 1.58. In 2009-2011 there was a decrease of this ratio (1.45 in 2011), and in the last year of the analysis of the current liquidity, the situation improved again. However, it is worth noting that during the period of report, the ability to repay short-term liabilities with current assets remained above the limit value (1.2) in the case of small furniture companies. In the case of companies employing 50 to 249 employees, a similar trend was observed as in the group of small companies. The lowest level of current ratio (i.e. 1.29) was recorded in 2007. Another decrease of the analyzed value was observed in 2010, since then the ability of medium-sized companies to settle their current liabilities with current assets increased year on year.

In the group of companies with employment over 249 workers, in 2007-2008, lower current ratio values were recorded than the limit values set in the literature of finance (1.2). In 2009, the companies of the analyzed group reached the mentioned value.

Interesting information about financial liquidity of a furniture company can be obtained when comparing the results obtained for these companies to companies operating in NACE section "Manufacturing". It should be highlighted that in the period observed, current liquidity ratios calculated for furniture companies were higher than the same values calculated for the whole manufacturing. This relationship was observed in all three company groups regardless of their employment level. The exception was noted in 2007, when the ability of medium and large companies to pay current liabilities with current assets was generally higher for manufacturing.

Figure 2 shows the increasing changes in the liquidity ratio in the furniture industry companies in the context of industry processing. Results of data analysis indicate that the furniture companies that employ 10 to 49 workers have the highest ability to pay their current liabilities with the current assets excluding inventories. Exception was noted in 2008 and 2011, when small companies were characterized by a lower level of increased financial liquidity than the other groups of companies. It is worth noting that in this group of com-

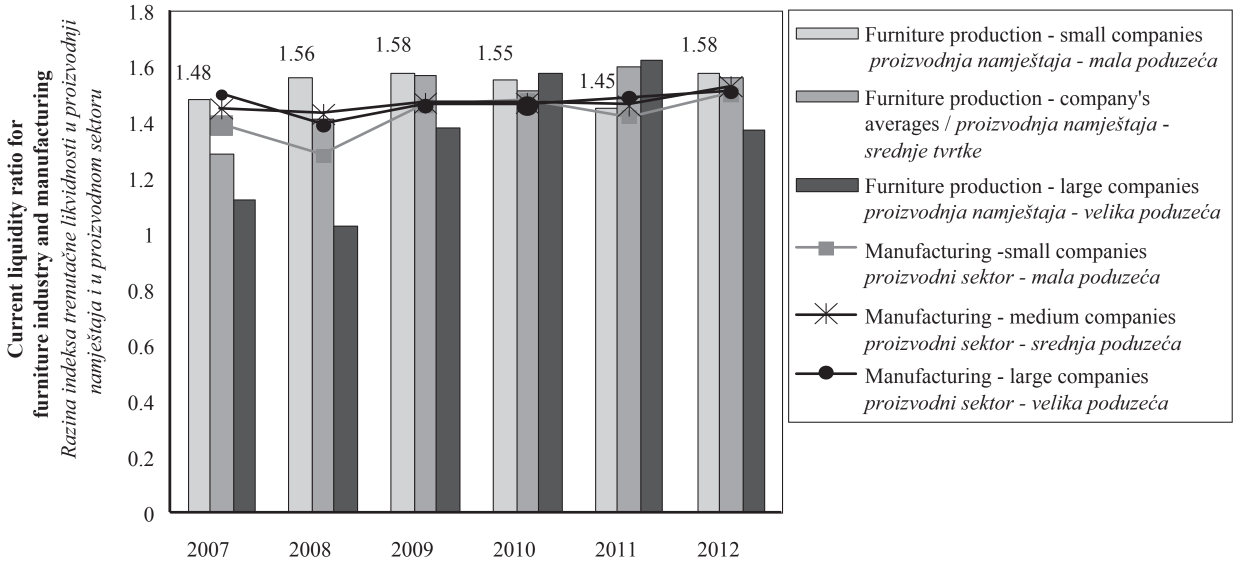

Figure 1 The level of the current liquidity ratio in furniture production and manufacturing in Poland in 2007-2012
Slika 1. Razina indeksa trenutačne likvidnosti u proizvodnji namještaja i u proizvodnom sektoru Poljske u razdoblju 2007. – 2012.

panies, the highest value of the presented relation (1.17) was noted in 2009. In the next two years, the level of this indicator decreased compared to the previous year. Only in the last year of the analyzed period, research results showed a significant increase. The smallest fluctuations of the increased liquidity ratio were observed in the case of furniture companies with a medium level of employment. In 2007-2008, 2010 and 2012, the present value of the analyzed relation was below the optimum level, which confirmed the insufficient ability of these companies to regulate short-term liabilities with the current assets excluding inventories. The highest increased current liquidity ratio (1.04) was noted in 2011, but it only slightly exceeded the level considered optimal (1.0).

Figure 3 shows the average values of high liquidity ratio for furniture companies and entities acting in industry processing. The lowest values of the current ratio, total increased liquidity, were again recorded for furniture companies with the highest number of employees. In 2007, the ratio of current assets, excluding inventories, was created in this group of companies at the level of 0.71 (an increase of 30 % below the optimum value).

A year later, the rate dropped to 0.68. In 2009-2011 there was an increase of liquidity results close to the optimum value. However, the last year covered by the analysis indicated again a significantly lower ability to pay current liabilities with current assets excluding inventories. Then, the quick liquidity ratio was 0.85.

Comparative analysis of the furniture industry and manufacturing shows that the level of high liquidity ratio in small and medium-sized furniture companies was on average higher than in manufacturing companies. A different situation was observed in the case of companies employing more than 249 employees. In general, the level of the analyzed relationship was lower in the furniture factories.

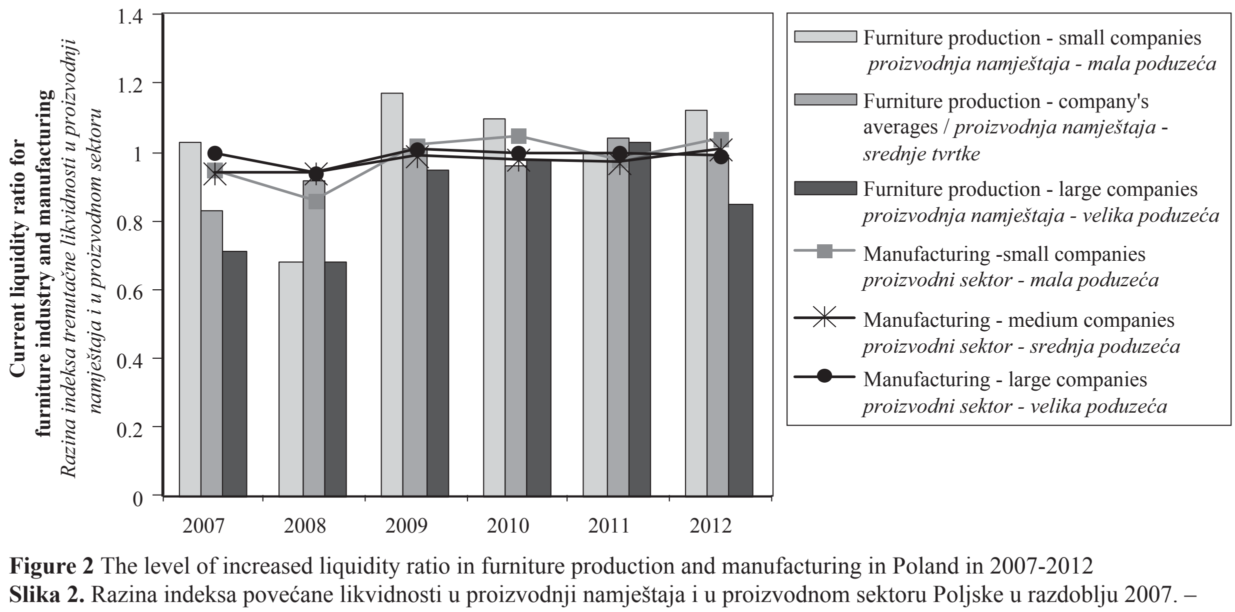

Figure 2 The level of increased liquidity ratio in furniture production and manufacturing in Poland in 2007-2012
Slika 2. Razina indeksa povećane likvidnosti u proizvodnji namještaja i u proizvodnom sektoru Poljske u razdoblju 2007. – 2012.

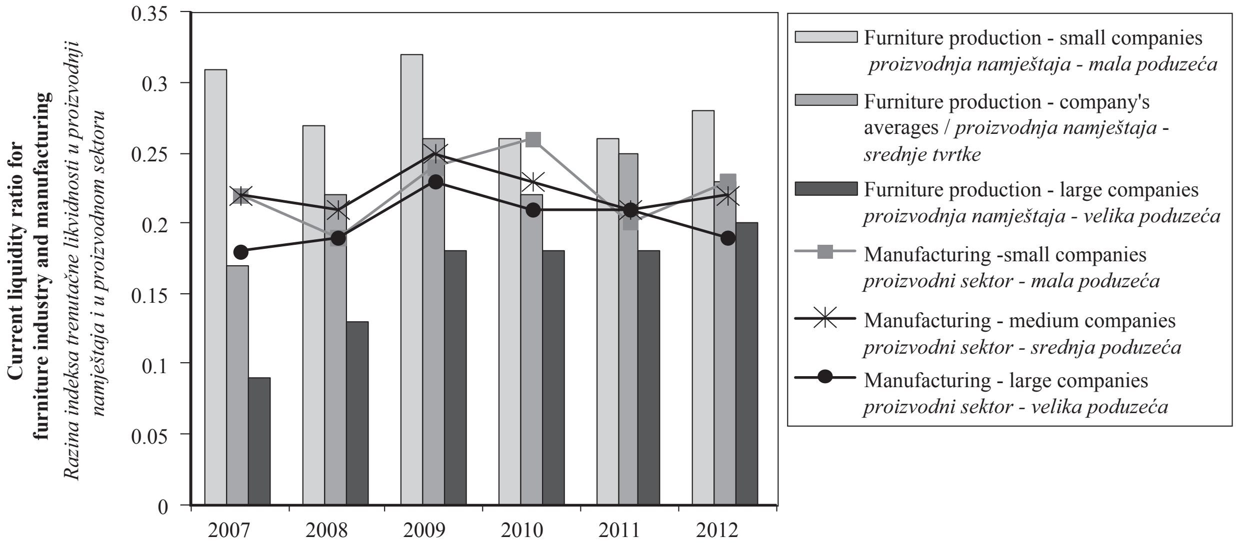

Figure 3 The level of high liquidity ratio in furniture production and manufacturing in Poland in 2007-2012.
Slika 3. Razina indeksa visoke likvidnosti u proizvodnji namještaja i u proizvodnom sektoru Poljske u razdoblju 2007. – 2012.

A high liquidity ratio (the so-called quick ratio) is considered the most reliable indicator of resource liquidity ratio as it indicates the possibility of controlling short-term liabilities with cash, which is the most liquid financial asset. Figure 3 shows average values of the ratio obtained by furniture industry and industry processing in general. The highest values of high liquidity ratio were recorded again in the furniture companies with the number of employees ranging between 10 and 49. The analyzed relation exceeded the level considered as a safe level (i.e. 0.2) in the entire research period. It should be noted that in 2010-2011, the speed indicator was significantly lower than in 2009.

In the analyzed period, the lowest ability to pay short-term liabilities with cash was significant for the furniture companies employing more than 249 workers, although it should be noted that the level of this index for the analyzed period 2007-2012 increased more than doubled (from 0.09 to 2.0). In 2010-2011, this group of companies reported the index at the level of 0.18 and it has not changed compared to 2009, as it did in the case of small and medium-sized furniture companies.

Similar trends in the changes were rapidly observed in companies of industry processing. The lowest capacity for timely payment of short-term liabilities with cash was characteristic for companies employing more than 249 employees. In addition, in 2007-2009 the value of this ratio increased from 0.18 to 0.23 and since this time it has gradually decreased, and at the end of the period reached the level of 0.19.

The ability of small and medium-sized companies included in the section „Manufacturing“ was generally higher. In the case of companies employing between 10 and 49 employees, the best period was the year 2010, when the high ratio was at the level of 0.26. However, for industrial companies with an average employment, the level of the highest value of this ratio (0.25) was reached in 2009.

In addition to maintaining a safe level of financial liquidity, an important aspect of financial management is to determine the debt level and structure, considering the distinction between the short obligations and long repayment period (Drábek and Jelačić, 2007). This subject has particular importance because of the negative effects of the global economic crisis. In fact, excessive debt can result in the loss of solvency and therefore lead to the company bankruptcy.

One of the key indicators to assess the level of debt is the total debt ratio, calculated as the ratio of total liabilities to total assets. Figure 4 presents the average values of this ratio in furniture companies compared with manufacturing.

In 2007, in medium and large furniture companies, this relation was recorded at the level of 0.56 and 0.55, which means that it exceeded the level considered as safe. The following year, in companies employing more than 249 workers, an increase of the analyzed ratio (0.61) was recorded. It can be stated that on average 60 % of assets of the surveyed companies was financed from external sources. In this group of furniture companies, every year since 2008, a slight decrease was recorded in the present value of the analyzed relationship. The year 2011 was an exception, and however since 2010, the furniture manufacturing companies with the highest level of employment maintained a relatively safe level of debt.

In the analyzed period, changes in the value of the total debt ratio were observed in the furniture companies employing 10 to 49 workers. Its highest level in this group of companies was observed in 2008 and amounted to 0.54. However, it is worth noting that in 2009 only in small companies the ratio of total liabilities to total assets stood at less than 0.5. Conversely, in the furniture industry employing 50 to 249 employees, a safe level of total debt has been recorded since 2008.

Analysis of the total debt ratio in Section C „Manufacturing“ (Polish Activity Classification) shows that the highest values of total debt ratio were observed in companies employing 10 to 49 workers. In 2009-2011 the level of analyzed relation increased

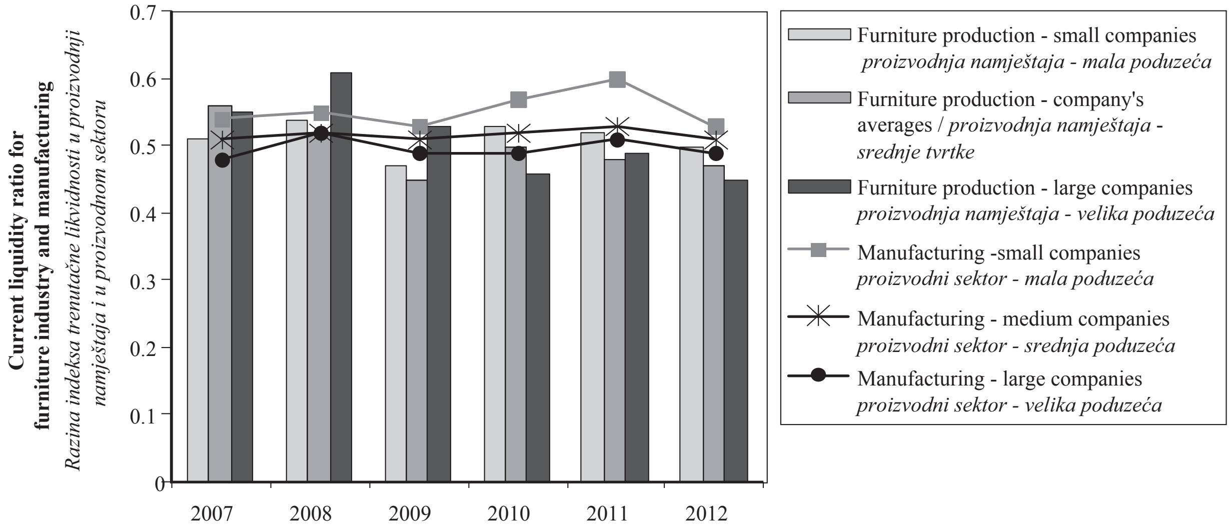

Figure 4 Total debt ratio in furniture production and manufacturing in Poland in 2007-2012
Slika 4. Ukupni indeks dugovanja u proizvodnji namještaja i u proizvodnom sektoru Poljske u razdoblju 2007. – 2012.

from 0.53 to 0.60. Only in 2012 there was a decrease to the level of 0.53. However, it is worth noting that throughout the period under consideration, the values of companies exceeded the level considered as safe. A lower level of total liabilities in relation to total assets was observed in manufacturing companies employing more than 249 workers. Only in the years 2008 and 2011, the total debt ratio slightly exceeded the limit value of 0.5 and was 0.52 and 0.51, respectively.

In assessing the level of corporate debt, the debt to equity ratio is also calculated as the ratio of total liabilities to shareholders‘ equity. The values of debt to equity in furniture companies and manufacturing are presented in Figure 5.

Research findings concerning the furniture market show that, at the beginning of the analyzed period, the lowest level of the debt to equity ratio (1.05) was observed in small companies. However, in the medium and large companies, in terms of employment, a slightly higher level of the analyzed relation was recorded, amounting to 1.25 and 1.23, respectively. In small furniture companies, the lowest debt to equity ratio (0.89) was noted in 2009. In the next two years, the result of the analyzed relation of total liabilities to equity ratio was higher, while at the end of the period it showed a decrease in the value of 0.99. Similar trends were observed in the medium-size furniture companies. It should be noted that, in the research period, the average of all the furniture companies did not exceed the limit value, which has been set to 2.0 in the literature of finance.

A comparative study of the furniture industry in the processing industry shows that, in the period observed, small companies in manufacturing sector reported a higher average level of debt to equity. Since 2010, these trends were also observed in the case of medium and large companies. In the section „Manufacturing“, as well as in the “Furniture manufacturing“, during the analyzed period the level of debt to equity did not exceed the limit value, which means that the manufacturing companies maintain a safe level of equity in relation to total assets.

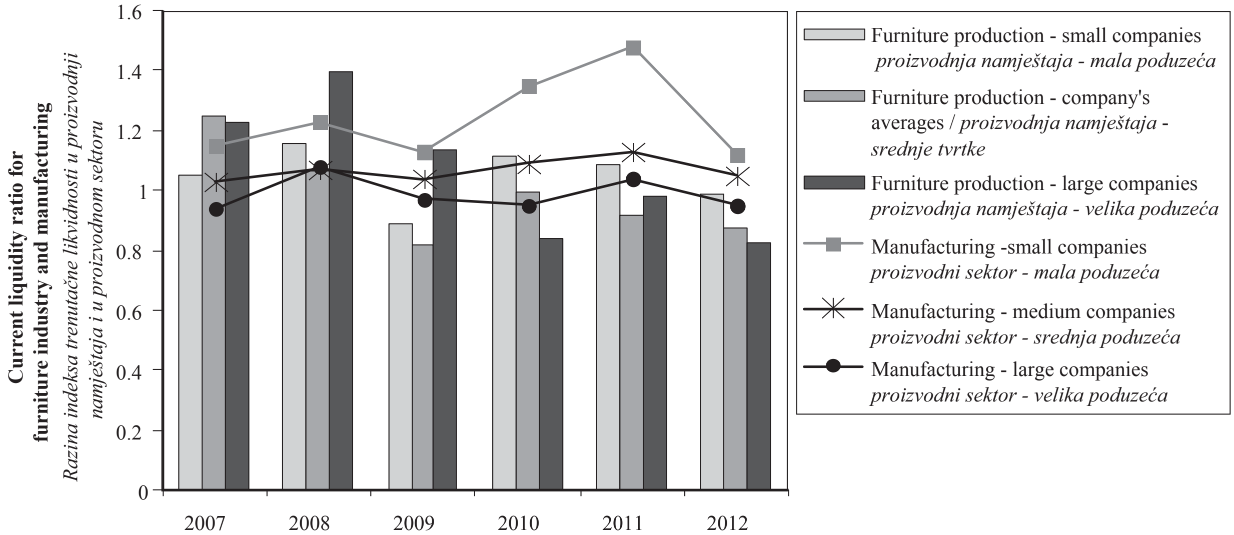

Figure 5 The level of debt to equity ratio in furniture production and manufacturing in Poland in 2007-2012
Slika 5. Razina uravnoteženog dugovanja u proizvodnji namještaja i u proizvodnom sektoru Poljske u razdoblju 2007. – 2012.

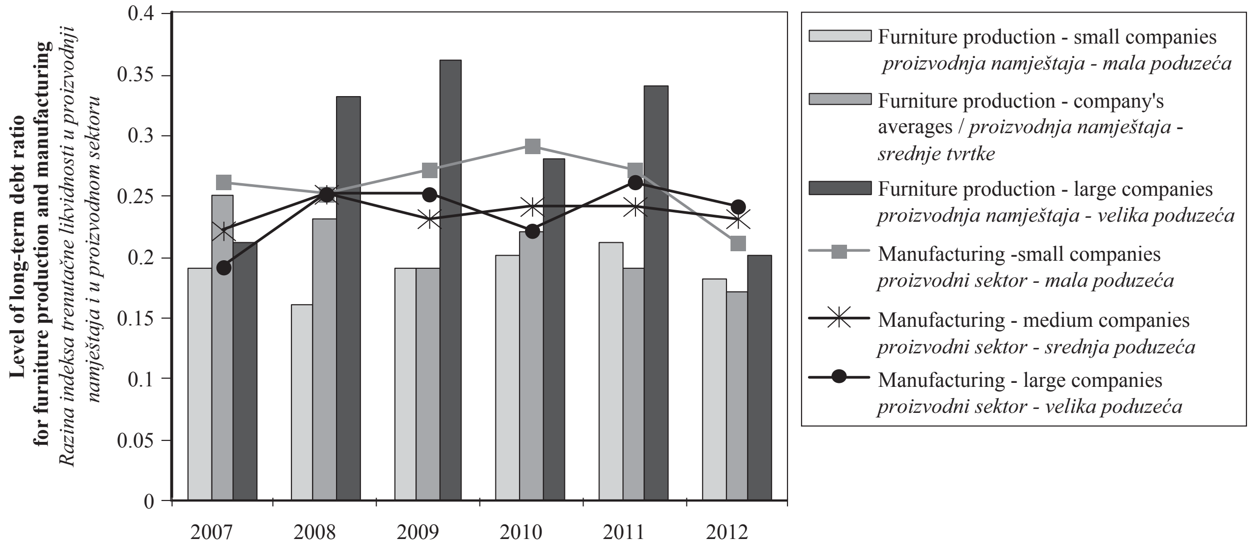

Figure 6 The level of long-term debt ratio in furniture production and manufacturing in Poland in 2007-2012
Slika 6. Razina indeksa dugoročnih dugovanja u proizvodnji namještaja i u proizvodnom sektoru Poljske u razdoblju 2007. – 2012.

The evaluation of the debt level for surveyed companies was also made on the basis of long-term debt ratio. The level of this index for furniture production and manufacturing in Poland in the years 2007-2012 is presented in Figure 6.

At the beginning of the period observed, the highest level of long-term debt ratio was recorded in the furniture industry in companies with an average level of employment amounting to 0.24, and the lowest in small companies.

Analysis of long-term debt ratio calculated for Section C „Manufacturing" shows that the highest values were observed in small companies. An exception is the year 2012, in which the companies in this group have the lowest level of the analyzed relation. It should also be noted that during the period observed large furniture companies were characterized by higher levels of long-term debt than companies of the manufacturing sector as a whole. Different trends were observed in the case of small and medium-sized furniture companies. They reached values that were on average lower than the analyzed relations in „Manufacturing".

It should be emphasized that the average values of long-term debt exceeded the level considered as safe in the analyzed period. This case concerns both companies belonging to the sector of manufacturing and furniture production. In the literature of finance, the view is presented that the optimum value of this ratio is at the level of 0.5. Companies, whose relation exceeds the level of 1, are considered substantially in debt.

The study analysis of various liquidity and debt ratios was also supplemented by an analysis of the correlation between the furniture industry companies and the entire manufacturing sector.

In the case of small industrial and furniture companies, a strong positive correlation (0.93) was observed in the case of the increased liquidity ratio. In turn, the debt ratios of equity and long-term debt show a moderate positive correlation formed at the level of 0.58 and 0.55. This means that highlighted financial ratios obtained for small companies of the furniture industry increased with the increase quoted for the entire industrial sector. In the group of medium-sized and large companies, a moderate correlation was reported within liquidity ratios. In addition, in the companies employing more than 249 people, a strong positive correlation (0.96) was observed in the case of long-term debt ratio.

The interdependence between financial indicators in the furniture business groups is also specified on the basis of the number of employees. In the group of small furniture companies, significant negative correlations were noted between increased and high liquidity indicators and indicators of total debt and equity. This means that the growth of specific liquidity ratios was accompanied by the ratio of liabilities to total liabilities and the debt is highly correlated to total equity.

In the case of furniture companies employing from 50 to 249 people, it was observed that all the analyzed indicators of liquidity are strongly positively correlated with each other (Pearson's correlation coefficient above 0.9), and they are strongly negatively correlated with the analyzed debt indicators. This means that with an increase in the ability of this group of companies to settle their current liabilities by selected categories of liabilities decreases their level of debt in relation to the liability and equity.

In companies employing more than 249 people, similar trends were reported as in the case of entities with an average level of employment. However, it should be noted that the relationships between the discussed financial ratios were lower than in the previous group.

4 CONCLUSION
4. ZAKLJUČAK

The economic crisis that began in the U.S. financial market, as a result of advancing globalization, transformed into a global crisis. The economic and social consequences of the crisis, more or less, affected all countries. These events have not only affected the economic situation of the world economy, but also the situation on the Polish market and the position of industries that are highly dependent on trade exchange. Due to the fact that 90 % of furniture production sale is exported, the analysis concerns the furniture market results.

Research findings presented in this paper show that the highest level of financial liquidity was generally observed in small furniture companies. In the case of small and medium-sized companies in the analyzed industry, liquidity ratios were reduced in 2009-2011. However, companies with the highest level of employment had the lowest ability to regulate their current liabilities with current assets selected. In the research period, high liquidity ratio was recorded above the limit value. In addition, it should be emphasized that small and medium-sized furniture companies generally characterized by a higher level of liquidity than companies in the "Manufacturing". A different situation was observed in large-size furniture companies.

The highest level of the total debt was observed in 2007-2009 in the furniture companies employing more than 249 workers, and the lowest in small companies. An opposite trend was observed in 2010-2012. Large companies were characterized by the lowest level of debt to total assets, which could be considered as safe, because it does not clearly exceed the value of 0.5. Similar results can be observed in the case of the level of the debt to equity ratio. It should also be emphasized that, in the furniture industry companies, debt ratios were lower than in the case of companies included in the section "Manufacturing". This means that furniture companies were less indebted than manufacturing companies.

The studies highlighted that there are differences in the ability of small, medium and large companies of the furniture industry to regulate their current liabilities with different current assets. These companies also maintain different levels of debt. The analysis of research findings also shows that in 2009-2011 there was a deterioration of liquidity and debt ratios in the furniture companies. As a rule, it was related to the small and medium-sized companies. This may mean that the effects of the global crisis affected less adversely the financial liquidity position and debt of companies with the highest level of employment. However, it should be pointed out that the present research findings have some limitations as the average values are given for each group of companies.

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Corresponding address:

EMILIA GRZEGORZEWSKA, Ph. D.

Department of Technology and Entrepreneurship in Wood Industry
Faculty of Wood Technology
Warsaw University of Life Sciences-SGGW
Nowoursynowska str. 159; 02-776 Warsaw, POLAND
e-mail: emilia_grzegorzewska@sggw.pl

Agron Bajraktari[1], Alexander Petutschnigg[3], Muhamet Ymeri[1], Zeki Candan[4], Suleyman Korkut[5], Lina Nunes [6,7], Helena Pereira[2]

Forest Resources and Sawmill Structure of Kosovo: State of the Art and Perspectives

Šumski resursi i struktura pilana u Republici Kosovo: stanje i perspektiva

Professional paper • Stručni rad
Received – prispjelo: 31. 7. 2013.
Accepted – prihvaćeno: 13. 10. 2014.
*UDK: 630*62; 630*79; 630.832.1*
doi:10.5552/drind.2014.1343

ABSTRACT • *Kosovo, located in the heart of the Balkans, was formerly a part of Yugoslavia. The breakup of Yugoslavia led not only to the creation of new countries and borders; it also had a huge impact on the transportation and availability of raw materials and goods. Kosovo's forest products industry has been greatly affected by the country's current political and legal environment. The creation of new boundaries, combined with trade constraints between Kosovo and some neighboring countries, has changed the amount and type of available wood raw material. Although the forest products industry is a very important part of Kosovo's economy, this change in distribution has had a negative impact on the sawmill structure of the country. To better understand the current state of Kosovo's forest products sector, data was collected through a survey of all sawmills in Kosovo and through information gathered from the Ministry of Agriculture, Forestry and Rural Development of Kosovo. In this paper, the forest resources and sawmill structure of Kosovo are analyzed and the availability of different species of wood in different regions of the country is presented. Based on these findings, recommendations are provided for further development of the forest and sawmill industry.*

Keywords: *forest resources, sawmills, Kosovo*

SAŽETAK • *Kosovo, koje se nalazi u srcu Balkana, nekad je bilo dio Jugoslavije. Raspad Jugoslavije nije doveo samo do stvaranja novih država i granica; to je također imalo velik utjecaj na transport i dostupnost sirovina i roba. Kosovska industrija drvnih proizvoda uvelike je pod utjecajem trenutačnoga političkog i pravnog okruženja*

[1] Author is professor at University of Prishtina, Faculty of Applied Sciences, Department of Design and Wood Technology, Republic of Kosovo. [2]Author is professor at Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Lisboa, Portugal. [3]Author is professor at University of Applied Sciences Salzburg, Department of Forest Products Technology and Timber Construction, Kuchl, Austria. [4]Author is assistant at Department of Forest Products Engineering, Faculty of Forestry, Istanbul University, Istanbul, Turkey. [5]Author is associate professor at Department of Forest Products Engineering, Faculty of Forestry, Duzce University, Duzce, Turkey. [6]Author is researcher at National Laboratory for Civil Engineering, Lisbon, Portugal. [7]Author is researcher at Azorean Biodiversity Group (CITA-A) and Platform for Enhancing Ecological Research & Sustainability (PEERS), Universidade dos Açores, Angra do Heroísmo, Terceira, Açores, Portugal.

[1] Autor je profesor Sveučilišta u Prištini, Fakultet primijenjenih znanosti, Odjel za dizajn i drvnu tehnologiju, Priština, Republika Kosovo. [2]Autor i autorica profesori su Tehničkog sveučilišta u Lisabonu, Lisabon, Portugal. [3]Autor je profesor Sveučilišta primijenjenih znanosti u Salzburgu, Kuchl, Austrija. [4]Autor je asistent Šumarskog fakulteta Sveučilišta u Istanbulu, Istanbul, Turska. [5]Autor je izvanredni profesor Šumarskog fakulteta Sveučilišta u Duzceu, Duzce, Turska. [6,7]Autorica je znanstvenica Nacionalnog laboratorija za građevinarstvo, Lisabon, Portugal i znanstvenica Sveučilišta u Açoresu, Açores, Portugal.

u zemlji. Nastajanje novih granica, u kombinaciji s trgovinskim ograničenjima između Kosova i nekih susjednih zemalja, promijenilo je količinu i vrstu dostupne drvne sirovine. Iako je industrija drvnih proizvoda vrlo važan dio gospodarstva Kosova, ta promjena u distribuciji negativno je utjecala na strukturu pilana u zemlji. Radi boljeg razumijevanja trenutačnog stanja drvnog sektora Kosova, prikupljeni su podaci od svih pilana na Kosovu, i to anketiranjem i dobivanjem informacija od Ministarstva poljoprivrede, šumarstva i ruralnog razvoja Kosova. U radu su analizirani šumski resursi i struktura pilana Kosova te opisana dostupnost različitih vrsta drva u različitim dijelovima zemlje. Na temelju tih nalaza, dane su preporuke za daljnji razvoj drvne industrije i pilanarstva Kosova.

Ključne riječi: *šumski resursi, pilane, Kosovo*

1 INTRODUCTION
1. UVOD

Kosovo, a former part of Yugoslavia and a newly formed independent country, is a landlocked country located in the heart of the Balkan Peninsula. Of the country's total surface area of 10 887 km², approximately 42 % is covered by forests (Luma and Bajraktari, 2008). Therefore, forestry and forest products industry are important components of the country's economy.

However, the recent political changes regarding new countries and borders have significantly influenced transport and availability of goods and raw materials. Companies formerly conveniently located near abundant raw material sources (e.g. forests) may now be burdened with transport costs and challenging complications due to the need of crossing borders.

Today the wood processing industry in Kosovo only uses roundwood for producing lumber in sawmills and for firewood. The export of logs is negligible (Bajraktari, 2009) and there are no other primary wood working industries (e.g., pulp & paper or wood based panel industry) located in the country. However, the development of a wood products industry is recognized as an important component for enhancing the economic development of Kosovo. The sawmill structure of Kosovo has not been investigated in detail. This is essential to enable future developments and to support an effective and efficient use of wood resources in Kosovo.

This paper presents the results of a research analysis conducted to understand the situation and structure of forest resources and sawmill industry in Kosovo. The following objectives were defined: 1) to determine the annual roundwood volume felled in the forests of Kosovo in relation to the amounts of timber available in the forests; 2) to describe the sawmill structure in Kosovo; and 3) to analyze the balance between potential supply and processing demand. The understanding of such questions provides the basis for future targets and activities of the Ministry of Agriculture, Forestry and Rural Development of Kosovo (MAFRD), and will encourage efforts to strengthen the country's sawmill industry.

2 METHODS AND MATERIALS
2. METODE I MATERIJALI

2.1 Wood resources from Kosovo forests
2.1. Drvna sirovina iz kosovskih šuma

Data related to Kosovo's current wood resources and use of roundwood were collected using the 2003 data of a forest inventory compiled by the Food and Agriculture Organization of the United Nations (FAO, 2003). This report indicates that Kosovo's total forest area is approximately 460 800 ha. Of the total forest area, approximately 353 400 ha (77 % of the total) are broadleaf forests, 19 200 ha (4 %) are dominated by softwoods, and 88 200 ha (19 %) were not investigated due to risks associated with military mines. Additional information obtained from a 2008 project conducted by the United States Agency for International Development (USAID), which also addressed forest resources in Kosovo, was used and annual roundwood fellings were estimated (Kaciu *et al*., 2008).

The annual felling allowance for each wood species in Kosovo is currently set by the Ministry of Agriculture, Forestry and Rural Development (MAFRD). The felling allowance for 2008 was divided by three main groups of wood species: beech (*Fagus sylvatica* subsp. *moesiaca*) with 436 000 m³; oaks (*Quercus spp.*) with 341 000 m³; and softwoods (*Abies alba*, *Picea abies*, *Pinus heldreichii*, etc.,) with 123 000 m³ (MAFRD, 2008). The total allowance for each species is divided between all the districts of Kosovo.

The potential log resource is defined as the amount of logs with a small end diameter above 7 cm and was calculated according to the felling allowance and the MAFRD data (Bajraktari *et al*., 2009). The quality of the logs was not considered in this analysis.

2.2 The structure of Kosovo sawmill industries
2.2. Struktura pilanske industrije Kosova

According to a study conducted by the Ministry of Trade and Industry of Kosovo (MTI, 2008), the amount of lumber imported into Kosovo is much higher than the amount exported. In 2006, the difference amounted to 223 797 m³. The study also indicated that Kosovo's forests were capable of supplying a log volume of 693 000 m, which is much higher than currently felled and cut in sawmills. However, specific information about the sawmill structure was not given.

To gather additional data about the structure of sawmill industries, the following information for all the 143 registered sawmills (Ukaj and Abazi, 2009) in Kosovo was collected via telephone interviews:

- the cutting technology used (in Kosovo only frame saws and band saws are in use)
- the annual log breakdown divided into the above mentioned groups of wood species.

The results were analyzed separately for 30 districts of Kosovo.

2.3 Comparing wood resources and sawmill demand
2.3. Usporedba resursa drvne sirovine i zahtjeva pilana

The amount of available roundwood resources and the amount of wood demanded by various sawmills were compared for each district. The difference between total log supply and demand was calculated for the three groups of wood species. This calculation was used to determine the regions with oversupply and undersupply and a map highlighting this balance was created.

The information obtained will be used to describe the current state of the sawmill industry in Kosovo and to determine future opportunities for establishing or reorienting manufacturing enterprises to optimally utilize the available roundwood resources.

3 RESULTS
3. REZULTATI

3.1 Wood resources per district and wood species
3.1. Resursi drvne sirovine prema distriktu i vrsti drva

Figure 1 shows the geographical distribution of availability of wood resources per district and by groups of species in Kosovo, as given by the felling allowances (MAFRD, 2008).

Overall, there is a low quantity of wood available for felling in the central region of Kosovo (mainly in the districts of Obiliq, Fushe Kosove and Gllogovc).

Beech wood resources are widely available in all the remaining districts of Kosovo, except for the ones located in the southern region where there is a smaller amount available for felling.

Although oaks are common wood species in the country, the data show that the southern and western regions have a significantly lower quantity than the northern and eastern regions.

As regards the softwoods available for felling, they are only abundant in high quantities in the western part of the country (the districts of Gjakove, Peje and Istogu), while in the east and especially in the southeast of Kosovo there are almost no softwoods allowed for felling (Figure 1).

3.2 Sawmill structure
3.2. Struktura pilana

Out of a total of 143 sawmills in Kosovo, 106 sawmills work with a frame saw and 37 with a band saw (74 % and 26 %, respectively). Figure 2 shows the breakdown per district for the two technologies in relation to the amount of processed wood. It can be seen that operations using frame saws are concentrated in the western districts (Deqan, Peje and Istogu), while those using

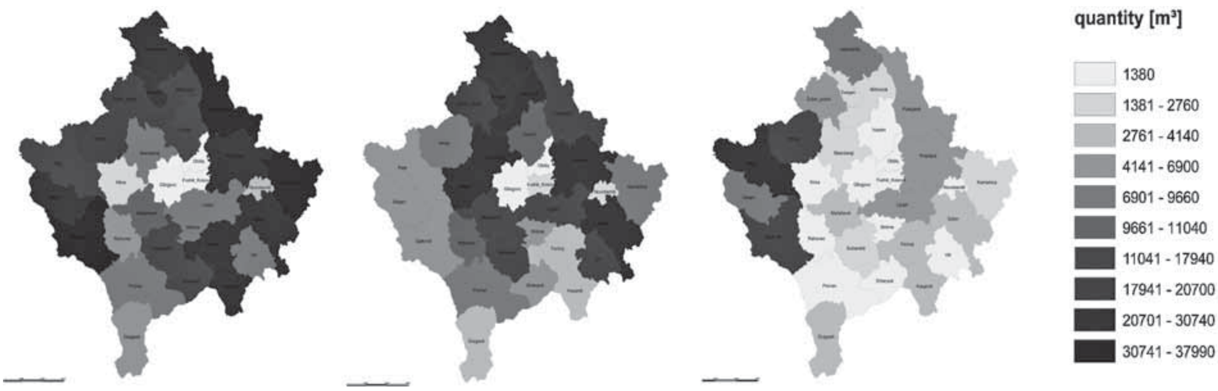

Figure 1 Allocation of beech (left), oak (middle) and softwood (right) in Kosovo (light green – low quantity, dark green – high quantity)
Slika 1. Alokacija bukve (lijevo), hrasta (sredina) i mekih vrsta drva (desno) na Kosovu (svjetlozeleno – mala količina, tamnozeleno – velika količina)

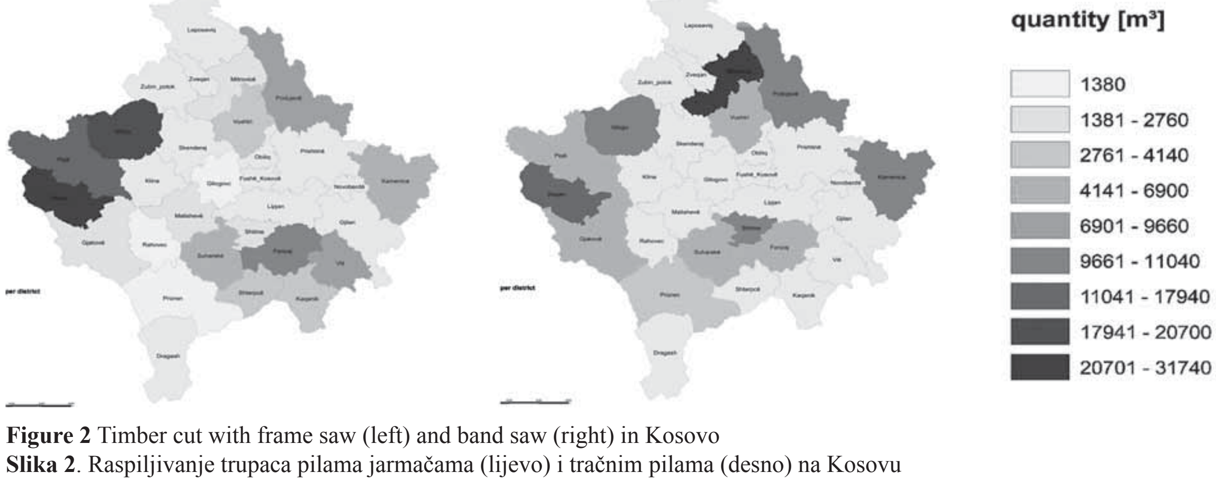

Figure 2 Timber cut with frame saw (left) and band saw (right) in Kosovo
Slika 2. Raspiljivanje trupaca pilama jarmačama (lijevo) i tračnim pilama (desno) na Kosovu

Figure 3 Breakdown of beech (left), oak (middle) and softwood (right) in sawmills in Kosovo
Slika 3. Raspodjela bukovih trupaca (lijevo), hrastovih trupaca (sredina) i trupaca mekih vrsta drva (desno) u pilanama na Kosovu

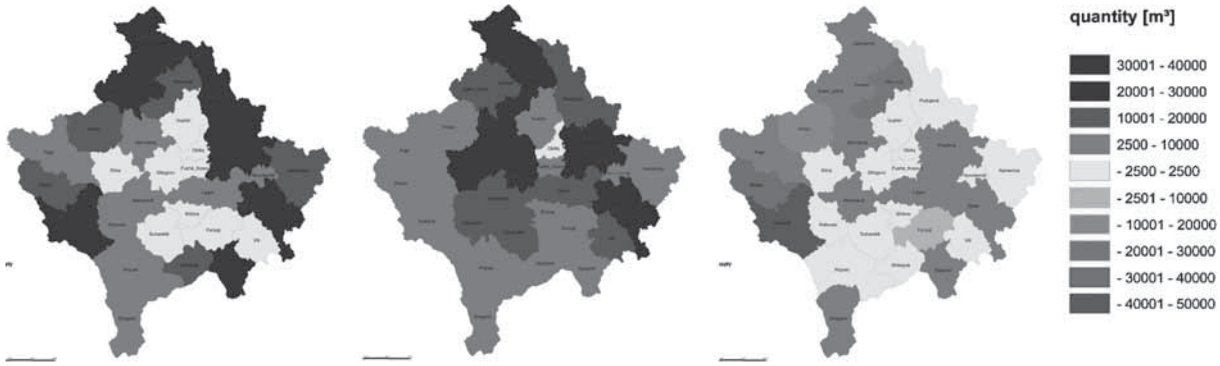

Figure 4 Oversupply and undersupply of beech (left), oak (middle) and softwood (right) in Kosovo (blue oversupply, red undersupply)
Slika 4. Prevelika i premala ponuda bukovih trupaca (lijevo), hrastovih trupaca (desno) i trupaca mekih vrsta drva (desno) na Kosovu (plavo – prevelika ponuda, crveno – premala ponuda)

band saws are concentrated in the eastern districts with a very high concentration in Mitrovice. Most log processing takes place in the regions located in the east and west of Kosovo, with significant amounts being processed in the districts of Ferizaj, Shtime and Suhareke (amounting to more than 21 000 m³).

As regards the breakdown of processed timber by species, the data is shown in Figure 3. It can be seen that for beech and oaks, processing is distributed throughout the country without a high concentration in one specific region. This is different for softwood sawmilling and it seems that the sawmills in the western region, including the districts of Peje, Istogu, Deqan and Mitrovice, have a focus on cutting softwoods. The frame saw mills are also mainly concentrated in the western region in the districts of Peje, Istogu and Deqan. This indicates that these frame saw mills have specialized in cutting softwoods, while the sawmills in Mitrovice mainly use band saws to cut softwoods.

3.3 Comparison of supply and demand
3.3. Usporedba ponude i potražnje

The balance between the potential wood supply (allowable cuts, Figure 1) and the industrial wood demand (sawmill processed wood, Figure 3) was calculated and the undersupply and oversupply of wood resources was determined for each district and species (Figure 4).

The supply of beech and oak sawlogs sufficiently meets the demands of sawmills in all of Kosovo's districts. However, the situation is different for softwoods. There is a need for additional softwood supply especially in the districts of Deqan, Mitrovice and Istogu. In total, there is a softwood undersupply of approximately 15 000 m³ in Kosovo. This negative balance is met by imports, and currently softwoods are predominately imported from Montenegro.

In former times, softwood was also imported from Serbia with a large quantity going to the district of Mitrovice. However, softwood imports from Serbia have not been available since 1999 due to the border closing for log imports. Log imports are possible from Montenegro and Albania, and therefore the districts near these countries (Deqan and Istogu) have a higher share in the softwood supply.

4 DISCUSSION AND CONCLUSIONS
4. RASPRAVA I ZAKLJUČAK

It is evident from the results that one of the country's major forest management tasks should be the efficient management of softwood resources to meet the continuous demand of the sawmill industry.

The softwood sawmill industry of Kosovo has drastically changed due to the breakup of Yugoslavia. Sawmills located in districts like Mitrovice, that were near large supplies of softwoods, are no longer optimally located. On the contrary, numerous sawmills were established in the last 10 years in the districts of Deqan and Istogu, showing that the sawmill industry is reacting to the new resource location. The efficient management of this resource may, therefore, support the development of a thriving wood products industry and enhance the economy of Kosovo. At the forest level, and given the deficit of national softwoods for the processing industry, attention should be focused on development plans and silvicultural management options for an increased softwood production.

This study also shows that sawmills processing beech and oaks are located over the country and that there is a potential supply surplus allowing the increase of production of sawn products from beech and oaks. However such a production increase only makes sense if two factors converge: i) a market need for the sawn wood; and ii) an effective supply of quality logs. The present study did not investigate the quality of the potential available logs and further research is needed in this area. In fact developing log grading rules and increasing the availability of high quality logs are two of the main objectives of MAFRD that has already started to increase thinning in Kosovo's forests in order to accomplish these objectives. A careful and cooperative approach between the wood products market, wood industry and forest services is certainly a key issue for a balanced forest-to-consumer chain.

The lack of wood-fiber based industries (e.g., wood-based panel production or pulp industries) is also an important topic for the value optimization of the wood chain that requires the cooperation of the forest raw-material supplier (MAFRD) and the forest products industry. Currently, by-products like wood shavings or sawdust do not have a market and their use as an energy resource is virtually non-existent. The creation of markets for by-products could further enhance the economic development of the country and a full resource valorization. Awareness of emerging uses, such as those based on biorefinery approaches to value residual biomass, should also be scrutinized. A recent example is the potential valorization of *Quercus cerris* bark (an oak species of Kosovo) through its cork component to be used as insulation material in the form of expanded cork agglomerates in the construction industry (Sen *et al*., 2012).

An important topic not covered in this research is the impact of the use of firewood in Kosovo. This paper only focused on sawmills because of the complexity of obtaining information on firewood (e.g. illegal firewood cutting or missing census). However, understanding the amount of the use of firewood in Kosovo is also an important element for improving the whole forest sector and will be a focus of this research group in the future.

In conclusion, this paper discusses the current state of wood supply and demand of Kosovo's sawmill industry and represents a basis for implementation of policies and activities in this field. Numerous research and policy questions remain to be answered, but our belief is that solving them stepwise and with an integrated sectorial approach will be crucial for successfully reconstructing and developing Kosovo's economy.

Acknowledgements - Zahvala

This research was supported by the Agency of European Integration and Economic Development.

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Corresponding address:

Prof. Agron BAJRAKTARI, Ph. D.

University of Prishtina
Faculty of Applied Sciences
Department of Design and Wood Technology
Deshmorete Kombit, Ferizaj,
REPUBLIC OF KOSOVO
e-mail: agron.bajraktari@uni-pr.edu

Matija Jug obranio doktorski rad

Matija Jug, mag. ing. techn. lign., obranio je 12. svibnja 2014. na Šumarskom fakultetu Sveučilišta u Zagrebu doktorski rad pod naslovom *Primjena infracrvene termografije i termogravimetrijske metode u istraživanju činitelja zapaljenja drvnih čestica*, pred povjerenstvom u sastavu: prof. dr. sc. Vlado Goglia (Šumarski fakultet Sveučilišta u Zagrebu), prof. ing. Štefan Barcik, CSc. (Fakultet šumarstva i znanosti o drvu, Sveučilište bioloških znanosti u Pragu, Češka) i doc. dr. sc. Igor Đukić (Šumarski fakultet Sveučilišta u Zagrebu), i time stekao akademski stupanj doktora znanosti s područja biotehničkih znanosti, znanstvenog polja drvna tehnologija. Mentorice rada bile su prof. dr. sc. Ružica Beljo Lučić (Šumarski fakultet Sveučilišta u Zagrebu) i prof. dr. sc. Ivanka Boras (Fakultet strojarstva i brodogradnje Sveučilišta u Zagrebu).

PODACI IZ ŽIVOTOPISA

Matija Jug rođen je u Virovitici 11. svibnja 1984. godine. Osnovnu školu pohađao je u Virovitici, a zatim i srednju Drvodjeljsku školu, u kojoj je 7. lipnja 2002. maturirao i stekao zvanje drvodjeljskog tehničara. Iste se godine upisao na Šumarski fakultet Sveučilišta u Zagrebu, a 13. srpnja 2007. obranom diplomskog rada *Utjecaj modifikacije drva obične bukve (Fagus sylvatica) limunskom kiselinom na biološku otpornost* stekao je zvanje diplomiranog inženjera drvne tehnologije, što je izjednačeno sa zvanjem magistra inženjera drvne tehnologije. Nakon studija zaposlio se u drvnoj industriji TVIN d.o.o., gdje je radio kao konstruktor tehnolog, a potom se zaposlio na Šumarskom fakultetu u Zagrebu, na kojemu od 1. siječnja 2008. radi kao znanstveni novak na Zavodu za procesne tehnike. Iste, 2008. godine, upisao se na poslijediplomski doktorski studij Drvna tehnologija.

Nastavni rad započinje kao asistent za kolegij Transport u drvnoj industriji (stari program), a prelaskom na bolonjski sustav obrazovanja postaje asistent za kolegije Transportna tehnika u drvnoj industriji i Primijenjena tehnička grafika na preddiplomskom sveučilišnom studiju Drvna tehnologija, za kolegij Rukovanje materijalom na diplomskom sveučilišnom studiju Drvnotehnološki procesi te za kolegij Informatika (AutoCAD) na stručnom studiju Drvna tehnologija u Virovitici. Pri tome je kao neposredni voditelj sudjelovao u izradi dvaju završnih radova s temom usko povezanom sa sustavom odsisavanja drvnih čestica u pogonima za preradu drva. Od 2008. kao istraživač sudjeluje u znanstvenom projektu Ministarstva znanosti, obrazovanja i sporta broj 068-0682094-2095 pod nazivom *Optimiranje energijskih i ergonomskih čimbenika mehaničke obrade drva* voditeljice prof. dr. sc. Ružice Beljo Lučić. Ukupno je kao autor ili suautor objavio 17 znanstvenih radova. Sudjelovao je na dvanaest međunarodnih znanstvenih skupova i jednom hrvatskome. Član je Hrvatskog udruženja za zaštitu zraka.

PRIKAZ DOKTORSKOG RADA

Doktorski rad Matije Juga, mag. ing. techn. lign., *Primjena infracrvene termografije i termogravimetrijske metode u istraživanju činitelja zapaljenja drvnih čestica* sastoji se od 135 stranica (I-IV + 131) teksta, u koje je uključeno 80 slika, 33 tablice i 111 navoda citirane literature. Doktorski rad podijeljen je na sedam osnovnih dijelova. To su:

1. *Uvod*, 5 stranica,
2. *Problematika*, 38 stranica,
3. *Cilj istraživanja*, 1 stranica,
4. *Mjerne metode i pribor*, 21 stranica,
5. *Rezultati istraživanja s diskusijom*, 45 stranica,
6. *Zaključci*, 4 stranice,
7. *Literatura*, 8 stranica.

Eksperimentalni dio rada vezan za infracrvenu termografiju i analizu zatupljenosti oštrice proveden je na Šumarskom fakultetu, u Laboratoriju za mehaničku obradu drva Zavoda za procesne tehnike, uz primjenu mjerne opreme Fakulteta strojarstva i brodogradnje Sveučilišta u Zagrebu. Termogravimetrijska mjerenja provedena su u laboratoriju Tekstilno-tehnološkog fakulteta Sveučilišta u Zagrebu.

1. Uvod

U uvodnom dijelu rada navode se brojne opasnosti pri mehaničkoj obradi drva, među koje se ubraja zapaljenje usitnjenih drvnih čestica i pojava požara pri radu, ali autor naglašava i to da izlaganje radnika drvnoj prašini hrastovine i bukovine tijekom duljega vremenskog razdoblja povećava opasnost od pojave adenokarcinoma nosne šupljine. Nadalje, u radu je istaknuto da se pri mehaničkoj obradi drva mora voditi briga o odabiru brzine rezanja, posmičnoj brzini, vrsti alata i broju njegovih oštrica kako bi se osigurala optimalna mehanička obrada drva, uz postizanje potrebne kvalitete obrade i zaštite radnika. Pritom se navodi da se tijekom mehaničke obrade drva pojavljuje temperaturno opterećenje oštrice alata, obrađivane plohe i odvojenih čestica, što može dovesti do zapaljenja drvnih čestica koje nastaju tijekom obrade te do nagorenosti obrađene površine. Valja spomenuti da se smanjuje čvrstoća termički modificiranog drva na cijepanje, kao i tvrdoća u smjeru vlakanaca. Pri izlaganju drva visokim temperaturama smanjuju se njegova mehanička svojstva, a povećava se krtost drva u smjeru vlakanaca i okomito na njih, što je uzrok povećanja udjela sitnijih lebdećih čestica pri mehaničkoj obradi termički modificiranog drva. Čestice termički modificiranog drva opasnije su za čovjekov respiracijski sustav nego čestice nemodificiranog drva, i to zbog niza kemijskih reakcija koje se događaju u drvu tijekom termičke modifikacije. Zato je bitno optimizirati debljinu odvojene čestice kako bi se smanjio njezin utjecaj na čovjekovo zdravlje. Današnji visokoproduktivni strojevi primjenjuju alate s postojanijom oštricom, zbog čega se smanjuje njezino zagrijavanje. S obzirom na moguće štetne posljedice razvijanja visokih temperatura pri mehaničkoj obradi drva te na mogućnost zapaljenja usitnjenih drvih čestica, izuzetno je važno istražiti i analizirati činitelje koji utječu na zagrijavanje mjesta reza. Zbog velike opasnosti, mjerenja zagrijavanja lista pile, drvnih čestica i obrađene površine temperatura obavljala su se beskontaktnom metodom, uz primjenu infracrvene (IC) termografije. Primjena IC termografije pokazala se korisnom na mnogim područjima ljudskog djelovanja, iako još nije našla primjenu u drvnoj industriji, osim pri određivanju toplinskih gubitaka u sušionicama drva. Dugi se niz godina IC termografija upotrebljava u graditeljstvu, pri kontroli toplinske izolacije objekata, odnosno pri mjerenju toplinskih gubitaka na stambenim objektima ili u proizvodnim pogonima.

Nadalje, u radu je analizirana temperatura zapaljenja drvnih čestica. Svaka vrsta drva ima neku kritičnu temperaturu pri kojoj dolazi do zapaljenja ili samozapaljenja. Većina vrsta drva ima sličnu temperaturu zapaljenja, a najčešće je to temperatura od približno 200 °C. Temperatura zapaljenja tvari određuje se termogravimetrijskom (TG) analizom u strogo kontroliranim uvjetima rada s mogućnošću podešavanja režima zagrijavanja. Metoda se temelji na analizi promjene mase uzorka u ovisnosti o temperaturi.

2. Problematika

U poglavlju *Problematika*, podijeljenome na sedam potpoglavlja, opisane su metode određivanja koncentracije drvne prašine i mjerenje temperature tijekom mehaničke obrade drva. Naglasak je i na svojstvima zapaljive i eksplozivne prašine. U poglavlju se najprije upozorava na opasnost zapaljive i eksplozivne smjese drvne prašine te se objašnjavaju opasnosti od drvne prašine u radnom okruženju za zdravlje poslužitelja radnih strojeva. Pritom su citirani i komentirani rezultati dosadašnjih dostupnih istraživanja. Navedeni su postupci i potrebna oprema za mjerenje koncentracije prašine u zraku. Potom se problematika usmjerava na neposredni zahvat alata i obratka pri mehaničkim obradama drva, analiziraju se tokovi mehaničke energije te posljedice njezine pretvorbe u toplinsku energiju. Dalje su u radu detaljno opisani načini mjerenja temperature primjenom infracrvene termografije. Spominju se mogući mjerni sustavi za određivanje temperature alata i obrađene plohe te temperature odvojenih čestica. Razmatra se i mogućnost mjerenja temperature primjenom infracrvene termografije. Pozornost se pridaje mogućnostima određivanja temperature zapaljenja drva te se autor pri tome osvrće na primjenu termogravimetrijske metode za određivanje te temperature. Analizirana su fizikalna svojstava drva i tehnološki parametri obrade koji utječu na proces zatupljenja oštrice te, posljedično, na temperaturu u prostoru neposrednog zahvata alata i obratka. Na kraju poglavlja navedene su mjere sprečavanja požara, i to preventivne ili zaštitne mjere, te optimalni parametri pri mehaničkoj obradi drva.

3. Cilj istraživanja

Cilj rada bio je istražiti mogućnost primjene IC termografije za mjerenje temperature zagrijavanja oštrice alata, temperature odvojenih drvnih čestica i temperature obrađivane plohe. IC termografijom i TG metodom utvrđene su temperature nastale tijekom piljenja kružnom pilom odnosno temperature zapaljenja drvnih čestica nastalih pri piljenju kružnom pilom uz odabrane parametre obrade. Ciljevi istraživanja bili su:

- TG analizom odrediti temperaturu zapaljenja drvnih čestica hrastovine i bukovine nastalih pri piljenju kružnom pilom
- usporediti temperature zapaljenja drvnih čestica hrastovine i bukovine različitog sadržaja vode i različitih veličina
- IC kamerom izmjeriti te analizirati temperature na oštrici alata, odvojenoj čestici i obrađivanoj površini tijekom mehaničke obrade drva piljenjem
- utvrditi utjecaj zatupljenosti alata i posmične brzine na vrijednosti temperature razvijene na alatu, odvojenim česticama i površini obrade.

Osnovna je hipoteza planiranih istraživanja bila da jedinični otpor pri mehaničkoj obradi drva ima važan utjecaj na temperaturu alata, odvojenih čestica i obrađivane površine. Pretpostavka je također bila da postoji granična posmična brzina, odnosno srednja debljina strugotine pri kojoj se znatno povećava temperatura oštrice alata i odvojene drvne čestice. Pretpostavljeno je da povećanje zatupljenosti alata utječe na razvijanje većih temperatura, a da povećani sadržaj vode u drvu ima suprotan učinak. Usto, pretpostavljeno je da temperatura zapaljenja drvnih čestica ovisi o vrsti drva, sadržaju vode u njemu i o veličini drvnih čestica.

4. Mjerne metode i pribor

Poglavlje donosi detaljan opis metoda mjerenja, mjerne opreme te potrebnog pribora. Obrazloženi su razlozi izbora hrastovine i bukovine za izradu uzoraka na kojima je provedeno istraživanje. Detaljno su opisana svojstva izabranih vrsta drva. Iznesen je plan istraživanja te su definirane pripremne aktivnosti nužne za provođenje plana istraživanja. Uzorci na kojima su obavljena istraživanja podijeljeni su na četiri osnovne skupine: po dvije skupine za svaku vrstu drva te još po dvije skupine unutar toga, prema sadržaju vode u drvu. Za određeni sadržaj vode u drvu uzorci su dodatno podijeljeni na još četiri podskupine kako bi se istraživanja, sukladno planu, obavila pri četiri razine posmičnih brzina. Iz toga proizlazi da su istraživanja pojava pri neposrednom zahvatu oštrice i obratka obavljena na 672 uzorka. Tijekom rezanja svakoga pojedinog uzorka termovizijskom je kamerom snimljen veći broj termograma. U konačnici, uz potporu odgovarajućeg softvera analizirano je više tisuća termograma. Usporedno sa snimanjima temperature neposrednog prostora zahvata oštrice alata i obratka periodički su mjereni geometrijski parametri vrha oštrice koji su omogućili uvid u dinamiku zatupljenja. Usto je termogravimefrijskom metodom određivana i zapaljivost drvnih čestica.

5. Rezultati istraživanja s diskusijom

Rezultati mjerenja izneseni su u skladu s postavljenim ciljevima te provedenim planom istraživanja te su stoga grupirani u tri skupine: rezultati mjerenja temperature, rezultati terngravimetrijske metode i rezultati mjerenja zatupljenosti oštrice. Na kraju poglavlja analizirani su odnosi temperature na bočnoj obrađenoj plohi u ovisnosti o stanju glavnoga reznog brida. Kroz cijeli rad provlači se kritički osvrt na dostupne radove sličnih istraživanja, uspoređuju se rezultati te izvode pravilni zaključci. U potpoglavlju *Rezultati mjerenja temperature infracrvenom termografijom* pokazalo se da smanjenje posmične brzine utječe na povećanje temperature na svim mjernim mjestima. S obzirom na to da su veće posmične brzine u skladu s ciljem postizanja većeg učinka, istraživanja su pokazala da povećanje posmične brzine nema ograničenja u smislu razvijanja temperature na mjestu reza. No istraživanja upućuju na moguće posljedice malih posmičnih brzina, što može biti problem pri ručnom pomaku obratka. S druge strane, autor je upozorio na praktične mogućnosti smanjenja temperature promjenama u konstrukciji stroja kružne pile. U potpoglavlju *Rezultati termogravimetrijske analize drva* pokazano je da je temperatura zapaljenja za sve uzorke gotovo jednaka, a da su temperature konačne degradacije za uzorke hrastovine nešto veće. Temperatura konačne degradacije za uzorke bukovine bila je nešto niža nego za uzorke hrastovine. U posljednjem potpoglavlju – *Rezultati mjerenja zatupljenosti oštrice*, ustanovljeno je da se oštrica lista pile više zatupi pri piljenju drva s manjim sadržajem vode, kao i pri piljenju bukovine nego pri piljenju hrastovine. Navedena potpoglavlja prate predviđeni slijed eksperimentalnog dijela istraživanja, pa su i rezultati analizirani istim slijedom, uz statističku obradu dobivenih podataka.

6. Zaključci

Poglavlje *Zaključci* posljednje je poglavlje doktorskog rada u kojemu se navode dostignuća rada izvedena iz rezultata istraživanja i rasprave o njihovu značenju. Iz zaključaka proizlaze novostečena znanja koja su dobra osnova za daljnji znanstvenoistraživački rad na području mehaničke obrade drva, a odnose se na zagrijavanje alata, drvnih čestica i obrađene površine. Prema ciljevima postavljenima u ovom istraživanju, dobivene su važne spoznaje o problematici zagrijavanja alata i usitnjenih drvnih čestica tijekom piljenja na kružnoj pili, kao i o zatupljivanju alata u različitim uvjetima obrade. Na osnovi rezultata i spomenutih činjenica doneseni su sljedeći zaključci.

- Rezultati upućuju na to da je pri piljenju drva poželjno odabirati veće posmične brzine uzimajući pritom u obzir sva ograničenja koja se pojavljuju u sustavu stroj – alat – obradak. Valja imati na umu i činjenicu da takav izbor posmičnih brzina vodi razmjernom povećanju učinka stroja.
- Smanjeni sadržaj vode u drvu utječe na jače zagrijavanje oštrice alata, pa stoga veći sadržaj vode u drvu uvelike smanjuje mogućnost zapaljenja. Nadalje, važno je navesti i činjenicu da piljenje drva iznad točke zasićenosti vlakanaca rezultira nižim vrijednostima jedinične energije rezanja. Stoga su i sile, kao i zagrijavanje oštrice, mnogo manje.
- Preporuka je da se prije izbora parametara mehaničke obrade za pojedinu vrstu drva uzimaju u obzir i osnovna fizikalna svojstva drva koje se obrađuje.
- Istraživanja su nedvojbeno pokazala da infracrvena termografija može imati važnu ulogu u nadzoru mjesta na kojima se unutar tehnoloških procesa pojavljuju visoke temperature.
- Termogravimetrijskom analizom nije moguće sasvim točno odrediti početnu temperaturu razgradnje svakoga drvnog sastojka pa se navode približne početne i konačne temperature, odnosno temperaturni rasponi razgradnje. Pretpostavka je da bi se detaljniji podaci dobili analizom plinova odnosno hlapljivih komponenata koje se oslobađaju tijekom pirolize drva.
- Temperatura zapaljenja gotovo je jednaka za obje skupine uzoraka s jednakim sadržajem vode. Razumljivo, potrebno je više vremena za isparavanje vode i početak pirolize u uzorcima sa sadržajem vode većim od 30 %.

U posljednjem dijelu istraživanja analiziran je proces zatupljivanja oštrica lista kružne pile.

- Pri piljenju uzoraka bukovine s manjim sadržajem vode oštrica alata brže se zatupljuje nego pri piljenju uzoraka hrastovine. Isto je uočeno pri piljenju uzoraka bukovine sa sadržajem vode većim od 30 %.
- Povećanje sadržaja vode u drvu pri jednakim radnim uvjetima pridonosi smanjenju radne temperature oštrice, zbog čega se usporava proces njezina zatupljivanja. Osim toga, povećan sadržaj vode pridonosi smanjenju temperature drvnih čestica i propiljka. Stoga je logična preporuka da se što više tehnoloških operacija izvede dok drvo ima visok sadržaj vode.
- Istraživanje je pokazalo da se oštrica alata brže i više zatupljuje pri manjim nego pri većim posmičnim brzinama piljenja.
- Povećanje radijusa oštrice pridonosi većim vrijednostima jediničnih energijskih normativa, a time i povećanju temperature vrha oštrice, porastu temperature odvojenih drvnih čestica, kao i višim temperaturama u propiljku. Stoga je važno list kružne pile nakon određenog broja efektivnih sati rada zamijeniti novopripremljenim, tj. iznova naoštrenim listom.

OCJENA DOKTORSKOG RADA

Doktorski rad Matije Juga, mag. ing. techn. lign., pod naslovom *Primjena infracrvene termografije i termogravimetrijske metode u istraživanju činitelja zapaljenja drvnih čestica* obrađuje dosad neistražene metode i njihovu primjenu kako u drvnoj industriji, tako i u znanstvenoistraživačkom radu u polju drvne tehnologije. Istraživanje je specifično po tome što je napravljena sinteza mjerenja temperature tijekom mehaničke obrade drva piljenjem, temperature zapaljenja drvnih čestica i zatupljenosti alata kao posljedice njegova zagrijavanja. Tijekom istraživanja velika je pozornost pridana sintezi rezultata pojedinih faza eksperimenta, pri čemu su rezultati jasno i nedvosmisleno objašnjeni.

Ovim su radom stečene nove, znanstveno utemeljene spoznaje i postavljeni dobri temelji za buduća istraživanja na području zagrijavanja alata, drvnih čestica i zatupljenosti oštrice. Vrijedni rezultati istraživanja podrazumijevaju autorov angažman na tom zanimljivom i slabo istraženom interdisciplinarnom području. Provedena istraživanja kojih su rezultati izneseni u radu dala su odgovore na neka zanimljiva, otprije nerazjašnjena pitanja, zbog čega je rad vrijedan doprinos drvnotehnološkoj znanosti na području mehaničke obrade drva.

prof. dr. sc. Vlado Goglia

COST Training School Surface Characterization of Wood Using Microtensile Testing at Faculty of Forestry, University of Zagreb

From July 2 to July 4 2014 the Faculty of Forestry hosted 20 young researchers, mainly PhD students from 11 European countries on a three day scientific training entitled *Surface characterization of wood using microtensile testing.* The training was organized and led by dr Vjekoslav Živković, within the frame of COST Action FP 1006 - *Bringing new functions into wood through surface modification*.

After the Vice Dean *Marijan Šušnjar* and Vice Dean *Alan Antonović* presented the specifics of the Faculty of Forestry and its study programs, professor *Hrvoje Turkulin* gave a series of lectures on the basics of microtensile testing, possibilities of applying the method in wood research and the experiences gained over many years of his scientific work with thin strips and microtensile testing. Faculty of Forestry has a complete infrastructure for the implementation of the microtensile testing method. In combination with the microscopic and other analytical techniques, the method is used for studying the chemical changes caused by modification or (photo) degradation of the wood material.

Tests are carried out either on Pulmac paper testing machine or on a universal mechanical testing machine, which has a possibility to detect very fine changes in the mechanical properties of wood.

Second and the third day of training were devoted to a series of short lectures and practical work in small groups. This enabled detailed presentation of the method and discussions about the specifics of testing the thin wood strips.

Professor Vlatka Jirouš Rajković presented the testing of wood surface protective systems using the packs of thin wood strips, dr *Vjekoslav Živković* gave a lecture on the impact of narrower wavelengths of ultraviolet and visible light (activation spectra) on photodegradation of wood, whereas dr *Christian Lehringer* presented the applicability of thin strip method to analyze biodeteriorated wood. *Dr Josip Miklečić* gave a lecture about the specifics of accelerated artificial aging of wood surface and the correlations of these results with those in natural exposure, and *professor Boguslav Šefc* about the modification of thin wood strips with citric acid.

Practical work in laboratories of the Faculty of Forestry covered all the steps of preparation and testing of thin wood strips. Participants showed particular interest for the practical part of the training where they microtomed thin wood strips, performed color and microtensile strength measurements, analyzed results and observed anatomical changes using optical microscope.

Numerous discussions during lectures, and especially during the practical part of the training, showed not only the interest in this method, but its applicability and efficiency in various aspects of wood research.

Figure 1 Vice Dean Alan Antonović presenting the Faculty of Forestry

Figure 2 Professor Hrvoje Turkulin lectures about the basics of microtensile testing

Figure 3 Microtoming the thin wood strips

Figure 4 Preparation of thin wood strips for accelerated exposure in QUV device

Figure 5 Microtensile strength testing on Pulmac testing device

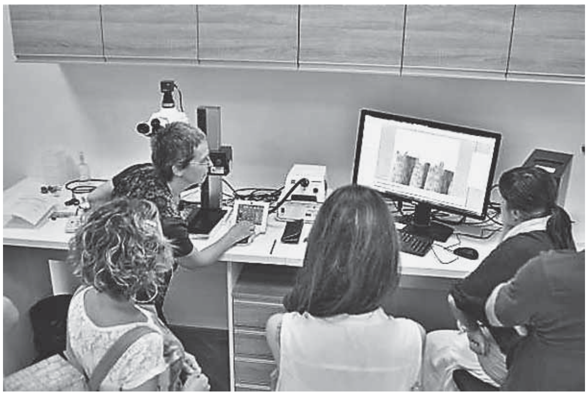

Figure 6 Observation of thin wood strips using research light microscope

Before the end of the training, trainees visited other laboratories of the Faculty of Forestry with the aim to get insight into the research capacities and possible collaboration on ongoing and future projects.

The success of the training school is shown by very positive comments and high grades given by trainees. On a scale from 1 to 5, the general grade/mark is 4.9.

Communication with trainers is rated 4.7, and gained knowledge and working materials are rated 4.8. Trainees expressed their opinion that the topics were well selected and interest in further education in this field.

The presented knowledge, experience and research capacities are an excellent promotion of the Faculty of Forestry, laboratories, researchers and their research capacities.

Last but not least, I wish to express my sincere gratitude to everyone who made this training school possible: COST action FP 1006, Faculty of Forestry; my coworkers who took part in the organization and/or implementation of the training school, preparation of the working materials, samples, or equipment; to lecturers and practical session leaders and to colleagues who organized and lead the informal part of the training and guided the tour through Zagreb historical city centre. Many thanks to everyone!

Vjekoslav Živković, Ph.D.

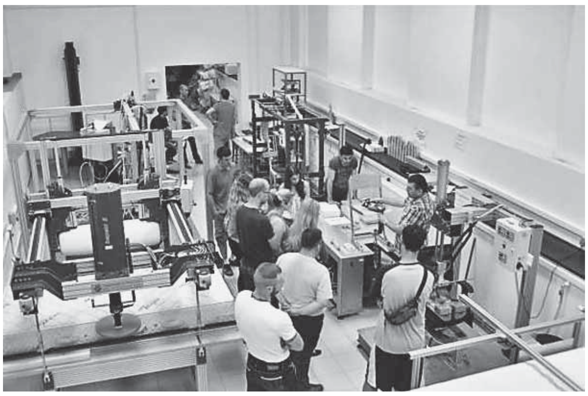

Figure 7 Presentation of furniture testing laboratory of the Faculty of Forestry to trainees

Figure 8 Trainees in Zagreb downtown

JATOBA

UDK: 674.031.738.722

NAZIVI

Jatoba je naziv drva botaničke vrste *Hymenaea courbaril* L. iz porodice Leguminosae – *Caesalpinioideae*.

Trgovački naziv te vrste je jatoba, algarobo, jutabi (Brazil); courbaril (Francuska, Velika Britanija); locust (Velika Britanija, Nizozemska). Lokalni trgovački nazivi su kawanari, itaiba locust (Gvajana); algarroba, coapinol, nere (Meksiko); avati (Panama); copalier (Gvajana, Venezuela).

NALAZIŠTE

Stabla jatobe rastu u tropskim šumama Srednje i Južne Amerike. Glavno područje rasprostranjenosti jatobe jest bazen područja rijeke Amazone u Brazilu, a moguće ju je pronaći i sjevernije – u Gvajani, Venezueli, Kolumbiji, državama Srednje Amerike, sve do Meksika, te na nekim otocima Karipskog mora, osobito uz Trinidad. Raste na pjeskovitim, dobro dreniranim tlima tropskih kišnih šuma i na svježim tlima listopadnih kišnih šuma do 500 metara nadmorske visine.

STABLO

U svojoj domovini jatoba naraste od 30 do 40 metara, a dužina njezina debla iznosi od 20 do 25 metara, prsnog promjera 1 – 2 metra. Deblo je pravilnoga, cilindričnog oblika. Kora drveta je glatka, čvrsta i žilava, vanjska je svjetlosmeđa, a unutarnja crvena. Debljina kore je do 3 centimetra. Kora starijih stabala izlučuje žućkastu do narančastu smolu od koje se dobiva kopal.

DRVO

Makroskopska obilježja

Drvo jatobe je jedričavo. Srž je u svježem stanju narančasta do crvenosmeđa, često s tamnim prugama, a bjeljika je široka, sivosmeđa. Drvo je rastresito porozno. Granica goda jasno je vidljiva. Pore, drvni traci i aksijalni parehnim dobro su vidljivi pod povećalom.

Mikroskopska obilježja

Traheje su raspoređene pojedinačno, rjeđe u parovima i u malim skupinama, malobrojne su. Promjer traheja iznosi 90...180...280 mikrometara, gustoće 1...3...6 na 1 mm^2 poprečnog presjeka. Volumni je udio traheja oko 8 %. Traheje srži često su ispunjene crvenosmeđim sržnim tvarima.

Aksijalni parenhim je paratrahealno aliforman, konfluentan i vrpčast. Vrpce su široke do deset stanica. Volumni udio aksijalnog parenhima kreće se oko 13 %. Stanice aksijalnog parenhima često sadržavaju veće kristale kalcijeva oksalata.

Drvni su traci heterogeni, visine 140...420...720 mikrometara, odnosno 6 do 45 stanica, a širina im je 20...50...70 mikrometara, odnosno 1...4...5 stanica. Gustoća drvnih trakova je 6 do 9 na 1 mm, a njihov volumni udio iznosi oko 17 %. Drvna su vlakanca libriformska, odnosno vlaknaste traheide. Dugačka su 730...1370...1860 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 2,1...3,3...5,5 mikrometara, a promjer lumena 4,6...12,1...15,2 mikrometara. Lumen vlakanaca često je ispunjen crvenkastosmeđim sadržajem. Volumni je udio vlakanaca oko 62 %.

Fizikalna svojstva

Gustoća standardno suhog drva, ρ_o	710...900 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	800...950...980 kg/m^3
Gustoća sirovog drva, ρ_s	oko 1100 kg/m^3
Poroznost	40...53 %
Radijalno utezanje, β_r	3,2...4,5 %
Tangentno utezanje, β_t	7,6...8,6 %
Volumno utezanje, β_v	11,0...13,4 %

Mehanička svojstva

Čvrstoća na tlak	57...89 MPa
Čvrstoća na vlak, paralelno s vlakancima	150...180 MPa
Čvrstoća na savijanje	95...136 MPa
Čvrstoća na smik	13...16...18 MPa
Tvrdoća (prema Janki), paralelno s vlakancima	oko 11,4 MPa
Tvrdoća (prema Janki), okomito na vlakanca	oko 10,6 MPa
Modul elastičnosti	oko 15,8 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se strojno i ručno dobro obrađuje, uz veći utrošak energije. Dobro se blanja i tokari, a izblanjane su površine vrlo glatke. Drvo se dobro kala i drži čavle. Lako se lijepi i odlično polira. Bruševina nastala preradom može uzrokovati dermatitis u ljudi.

Sušenje

Građa se suši sporo, ali bez teškoća.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva jatobe srednje je otporna do otporna na gljive truležnice (razred otpornosti 2 i 3) te srednje otporna na termite (razred otpornosti M). Otpornost srži na tercijarne kukce klasificirana je kao srednje trajna (razred otpornosti 3). Srž je vrlo slabo permeabilna (razred 4).

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

Uporaba

Od drva jatobe mogu se izrađivati rezani furniri, namještaj, drvena stubišta i parketi. Upotrebljava se i kao konstrukcijsko drvo za unutarnje i vanjske teške konstrukcije, u brodogradnji, za izradu vagona, tokarenih proizvoda, intarzija i pragova.

Sirovina

Drvo jatobe isporučuje se u obliku trupaca i piljenica različitih dimenzija. U Americi je odlična zamjena za bagremovinu.

Napomena

Napomena: Slične su vrste cocobolo (*Dalbergia retusa* Hemsl.) i oko sedam vrsta *Hymenaea* spp.

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

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

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

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

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

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

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Primjeri navođenja literature

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

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

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

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