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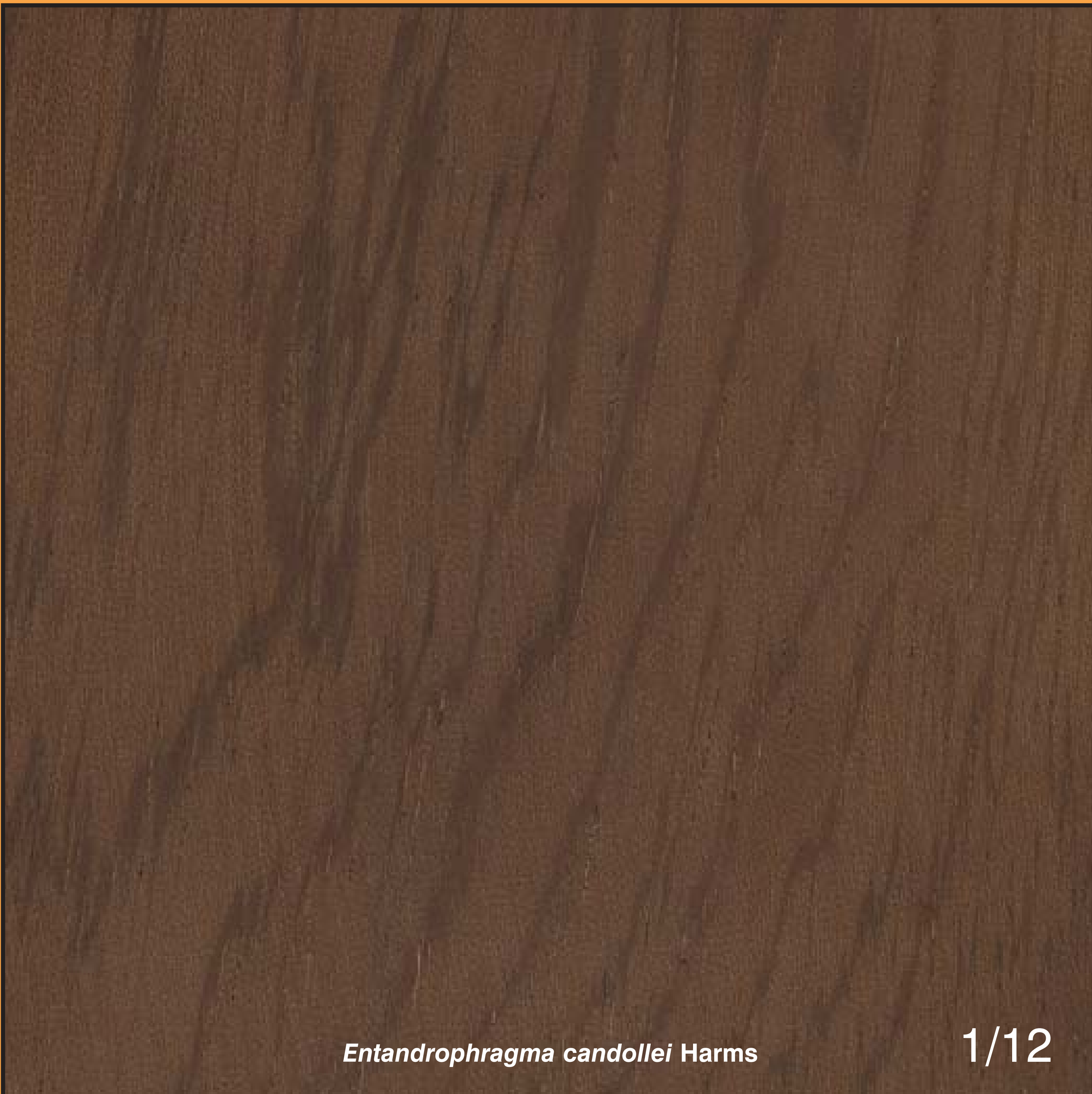

Entandrophragma candollei Harms

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Optimiziranje tehnološkog procesa uvijanja dvonavojnih matica

Optimization of Double Thread Nuts Screwing Process

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SAŽETAK • *U konstrukcijama namještaja ugaoni se sklopovi često izvode sastavljanjem uz pomoć dvonavojnih („trio“) matica i metalnih kutnika. Takvi su sklopovi posebice pogodni za konstrukcije koje je potrebno rastavljati ili se takvim sklopom ostvaruje ušteda pri transportu, kada se svi elementi konstrukcije prevoze u kutijama, a namještaj se sastavlja na mjestu upotrebe. Proces sastavljanja konstrukcije sastoji se od pritezanja veznih metalnih kutnika za drvene elemente vijcima metričkog navoja. Za postizanje optimalne kvalitete takvih sklopova proces proizvodnje mora biti usklađen sa zahtjevima različitih proizvoda, što podrazumijeva načine opterećivanja i čvrstoće pojedinih vrsta drva. U ovom su radu istraženi osnovni čimbenici koji utječu na kvalitetu te vrste sklopa. Posebna je pozornost pridana procesu uvijanja te sili izvlačenja dvonavojnih matica na trima različitim vrstama drva. Kao krajnji cilj postavljena je optimizacija tehnološkog procesa kojim se u proizvodnji može postići visoka razina kvalitete proizvoda.*
Ispitivanjima na jelovini, bukovini i hrastovini utvrđeni su optimalni provrti rupa i parametri uvijanja matica s obzirom na otpor uvijanja, silu izvlačenja i vremenski interval potreban za uvijanje.

Ključne riječi: *metalni kutnici, dvonavojne matice, moment uvijanja, utrošak vremena, sila izvlačenja*

ABSTRACT • *The construction of furniture corner joints is often carried out by assembling double thread (“Trio”) nuts and metal corners. Such connections are particularly suitable for disassemble bal structures and these connections are also used for savings in transport when all the structural elements are transported in boxes and furniture is prepared for in site assembly. The assembly process consists of fastening the binding metal corners to wooden elements with the metric thread screws. To achieve the optimal quality of these joints, the production process must comply with the requirements of various products including the loading applications and strength of individual wood species. This paper examines the fundamental factors affecting the quality of such joints. Special attention was paid to the process of screwing and loading capacity of double thread nuts in three different types of wood. Optimization of the technological process was set as the ultimate goal aimed at achieving a high level of product quality.*
Tests have been conducted on fir, beech and oak wood to determine optimal bore diameters and nut screwing parameters relative to the screwing resistance, extraction force and the time interval required for nut screwing.

Keywords: *metal angles, double thread nuts, screwing moment, time saving, extraction strength*

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1. UVOD
1 INTRODUCTION

U današnje vrijeme svoj životni prostor sve više prilagođujemo vlastitim željama i uređujemo ga prema raznovrsnim dizajnerskim rješenjima. Razvojem dizajna i načina razmišljanja ljudi se više ne žele prilagođivati onome što nameću proizvodnja namještaja i njezina ograničena ponuda (Grbac i Ivelić, 2005).

Stoga su fleksibilnost proizvodnje i sposobnost brze prilagodbe promjenama potražnje uvjeti koje treba ispuniti želimo li se održati na tržištu. Prilagodba proizvodnje namještaja tim uvjetima može se postići vrednovanjem rješenja dobivenih metodičkim pristupom (Tkalec, 1983) koji se, među ostalim, može ostvariti:
- uvođenjem nove tehnologije
- primjenom boljih konstrukcijskih rješenja uz postojeću tehnologiju.

Jedan od primjera prilagodbe proizvodnje primjenom boljih konstrukcijskih rješenja jest unifikacija veznog sastavljanja primjenom metalnih kutnika. Drveni se elementi pri tome međusobno povezuju metalnim kutnicima, bez obzira na oblike i namjenu krajnjeg proizvoda. Takav način vezanja omogućuje jednostavnu i brzu montažu, a metalnim se kutnicima ujedno osigurava čvrst i trajan sastav.

Dvonavojne matice, tzv. *trio* matice, uviju se u drvene elemente te se zatim za njih vijcima metričkog navoja učvrste metalni kutnici. Time je dobiven kvalitetan spoj koji ne nameće velike zahtjeve pri montaži.

Postoji više vrsta dvonavojnih matica za drvo koje se mogu svrstati u vezne elemente (Tkalec i Prekrat, 2000). Njihova se nosivost temelji na povećanom promjeru vanjskog navoja koji sam narezuje ležište u drvnim materijalima. Za sve matice karakteristična je izvedba unutarnjega metričkog navoja koja omogućuje upotrebu standardnih vijaka pri sastavljanju drvenih elemenata. Različitosti matica očituju se različito izvedenim vanjskim navojima. Oni bi trebali biti prilagođeni svojstvima materijala u koji se uvijaju. Tako neki proizvođači nude matice s klasičnim navojem za drvo koji su uvećana slika ravnih vijaka, dok drugi nude konusne matice čiji su navoji sličniji vijcima za drvo, koji barem u jednom svojem dijelu imaju konusni navoj za urezivanje navoja u drvu.

Slika 1. Dvonavojne matice ravnoga ureznog navoja
Figure 1 Flat double thread nuts

Osnova ugradnje takovih matica jest adekvatno izbušena rupa u drvu. Ako je promjer rupe premalen, uvijanje će biti otežano, a vanjski će navoj pri uvijanju uništiti površinu uz rupu te će time smanjiti nosivost sustava. Nasuprot tome, ako je promjer rupe prevelik, jasno je da će takav sastav biti slab jer vanjski navoj neće zadovoljavajuće zahvaćati drvni materijal i izvlačna će sila biti malena.

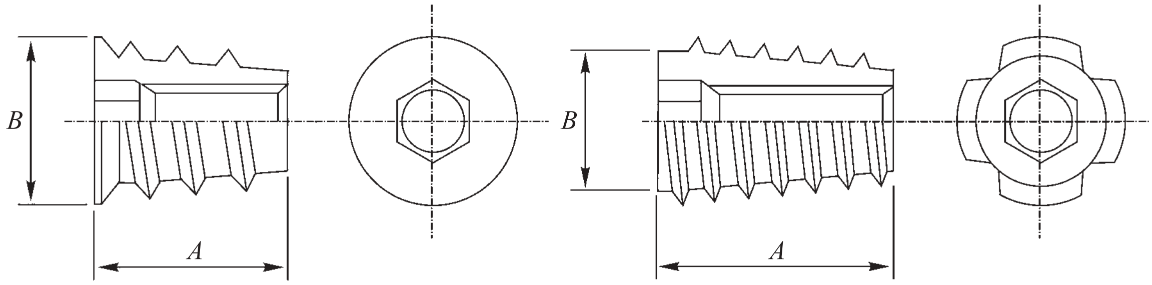
U radu Mihulje i suradnika (2008) rješavan je problem sastavljanja konstrukcije kreveta od bukovine pri čemu je mjestimično dolazilo do izvlačenja dvonavojne matice iz drva. Problem nedovoljne čvrstoće za promjere provrta od 11 mm upućivao je na potrebu smanjenja promjera provrta na 10 mm. Međutim, smanjenjem promjera provrta pojavili su se novi problemi. Naime, pri manjim promjerima provrta potrebna je veća sila za uvijanje matica, čime se opterećuje alat za uvijanje i produljuje vrijeme potrebno za njihovo uvijanje, što izravno utječe na tijek proizvodnje. Iskustva i rezultati tih istraživanja bili su temelj za nova istraživanja kojima bi se utvrdio optimalan promjer provrta za uvijanje matice s obzirom na specifična svojstva različitih vrsta drva, momente pri uvijanju, vremenske intervale potrebne za uvijanje te na sile izvlačenja matica.

Pretpostavlja se da će upotreba svrdla za bušenje provrta promjera 10,5 mm osigurati smanjenje momenta uvijanja i na drugim vrstama drva, a time i skraćivanje vremena tehnološkog procesa, pri čemu se sile izvlačenja neće statistički značajno smanjiti.

2. MATERIJALI I METODE
2 MATERIALS AND METHODS

Za ovo su istraživanje odabrane tri komercijalne vrste drva: bukovina, hrastovina i jelovina kako bi se raznovrsnošću mehaničkih svojstava drva adekvatno vrednovao utjecaj urezivanja navoja u drvo. Uzorkovanje materijala obavljeno je iz skupa elemenata koji su prošli kvalitetan proces predsušenja i sušenja standardnim postupkom, a kontrolom elemenata nisu primijećeni nikakvi nedostaci ili greške koje bi sušenjem nastale.

Odabrane su dvonavojne matice ravnoga ureznog navoja koraka 3,2 mm po navoju, promjera korijena 9,5 mm, ukupne duljine 14,5 mm.



Slika 2. Dvonavojne matice konusnoga ureznog navoja
Figure 2 Tapered double thread nuts

2.1. Priprema uzoraka za ispitivanje
2.1 Preparing test samples

Elementi bukovine, hrastovine i jelovine izdvojeni su iz složajeva slučajnim odabirom i osušeni su na vlažnost od 8 – 10 %, kondicionirani u laboratorijskim uvjetima 50 ± 5 % r.v.z. i 23 ± 2 °C, pravne žice, ujednačenih širina godova, bez vidljivih grešaka, obrađeni na četverostranoj blanjalici.

Na elementima dimenzija 300 x 42 x 30 mm bušene su rupe promjera provrta 10 mm, 10,5 mm i 11 mm. Rupe su bušene na međusobnom razmaku od 64 mm, tj. na svakom uzorku izbušena su po tri provrta (10 mm, 10,5 mm i 11 mm) u sredini elementa širine 42 mm.

Za potrebe ispitivanja sile izvlačenja dvonavojne su matice uvijane zračnom bušilicom tipa HAZET, pri tlaku zraka od 8 – 10 bara, kao u svakodnevnoj proizvodnji, pri čemu je uvijeno trideset matica po svakom provrtu i vrsti drva, tj. ukupno 270 matica, a za ispitivanje momenta uvijanja korišteno je još 270 provrta.

2.2. Ispitivanje sile izvlačenja matica
2.2 Testing the nut extraction force

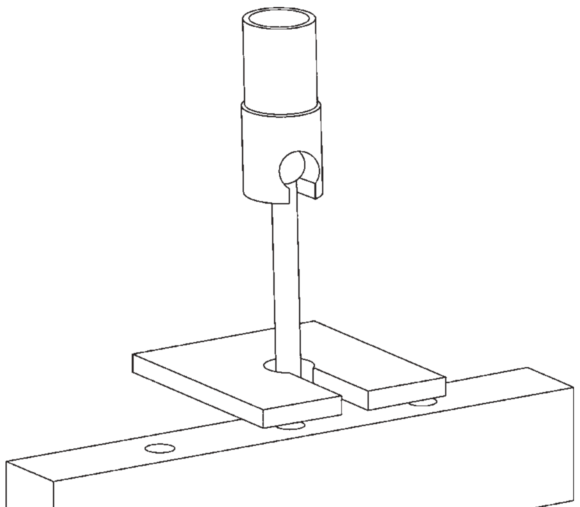
Uzorci su ispitivani u laboratoriju, na univerzalnoj hidrauličnoj kidalici opremljenoj dodatnom digitalnom mjernom opremom za mjerenje sile i pomaka.

Posebnim načinom učvršćivanja uzoraka u kidalicu simulirano je opterećivanje matica pri upotrebi (sl. 3).

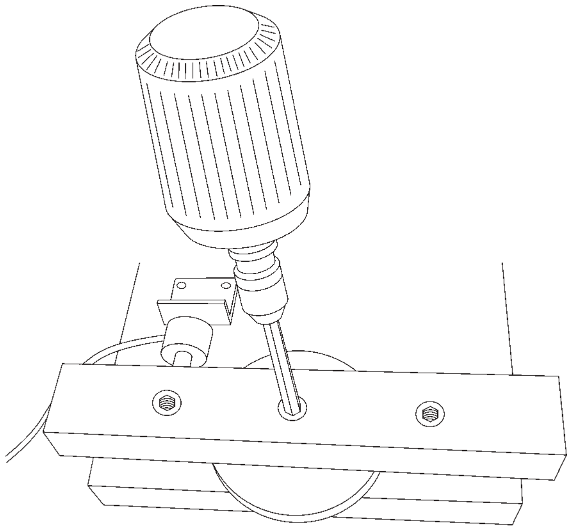
Brzina pomaka glave hidrauličnog cilindra od 5 mm/min odabrana je jer je to brzina kojom se u proizvodnji vijkom metričkog navoja metalni kutnici pričvršćuju za drvene elemente.

2.3. Ispitivanje sile uvijanja i vremena uvijanja
2.3. Testing the screwing force and elapsed time

Ispitivanje sile uvijanja provedeno je u industrijskom pogonu, na vertikalnoj glodalici snage 2,2 kW, koja je za potrebe istraživanja dograđena dodatnom digitalnom mjernom opremom (sl. 4). Postolje s dinamometrom spojenim na računalo postavljeno je na radni stol tako da je udaljenost mjerne točke od osi rotacije iznosila 7 cm.



Slika 3. Uzorak sa dodatnim elementima za kidalicu
Figure 3 Sample with additional elements for the tensile test



Slika 4. Uzorak pripremljen za ispitivanje momenta uvijanja
Figure 4 Sample prepared for torque testing

Mjerenje se obavljalo brzinama 160 i 260 min^{-1}. Brzina 260 min^{-1} brzina je uvijanja sukladna onoj u pogonu za proizvodnju, a brzinom od 160 min^{-1} ispitivane su razlike prouzročene smanjenjem brzine.

Vrijeme trajanja uvijanja dobiveno je naknadno, uvidom u mjerne rezultate, tako da je utvrđena vremenska razlika između početne točke, tj. minimalne sile (sila prije prve rastuće točke) uvijanja i maksimalne sile (prva točka prije pada vrijednosti) uvijanja.

2.4. Obrada i prikaz rezultata
2.4 Processing and display of results

Prilikom ispitivanja mjereni su iznosi sila i pomaka, a dobiveni su podaci analizirani programima Microsoft Excel i Statistica za Windows platforme.

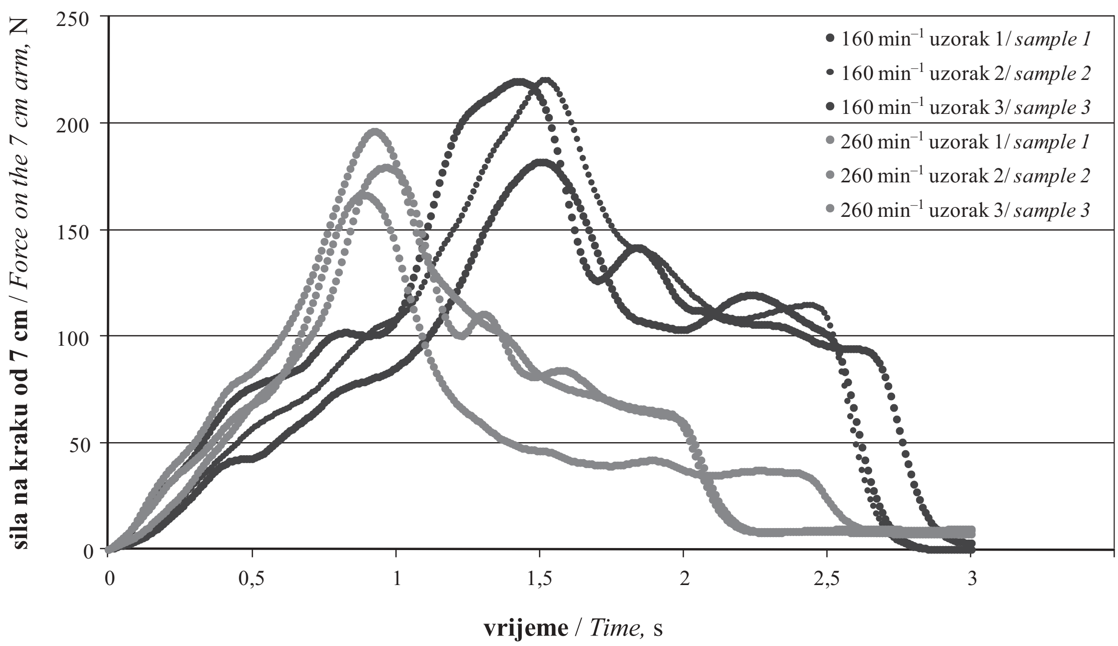
Za sve analizirane varijable napravljena je deskriptivna statistika (aritmetička sredina, minimum, medijan, maksimum, standardna devijacija), te je za pojedine testove izvršena postotna razlika. Pri svim statističkim analizama pogreška od 5 % smatra se statistički značajnom. U analizi varijance primijenjen je Scheffeov post hoc test, ili je u Kruskal-Wallisovu testu korištena višestruka usporedba rangova srednjih vrijednosti nakon Mann-Whitneyevih testova za analizirane parove grupa (Troendle, 1995; Sokal i Rohlf, 1995).

Grafički prikazi statističke analize rezultata mjerenja izvedeni su u obliku boxplot grafova, dok su ostali rezultati prikazani tabličnim statističkim proračunima. Pri tome je za grupe testirane parametrijskim testovima primijenjena aritmetička sredina i standardna devijacija, a za neparametrijske testove medijan i 25-i i 75-i percentil. Sve su analize rađene uz pomoć statističkog paketa Statistica 7.1 (StatSoft Inc., 2006).

3. REZULTATI I DISKUSIJA
3 RESULTS AND DISCUSSION

3.1. Vrijeme trajanja i otpori uvijanju dvonavojnih matica
3.1 Time consumption and resistance of nut screwing

Promatranjem dijagrama vremenskih promjena mjerenih sila uvijanja triju karakterističnih uzoraka u pro-

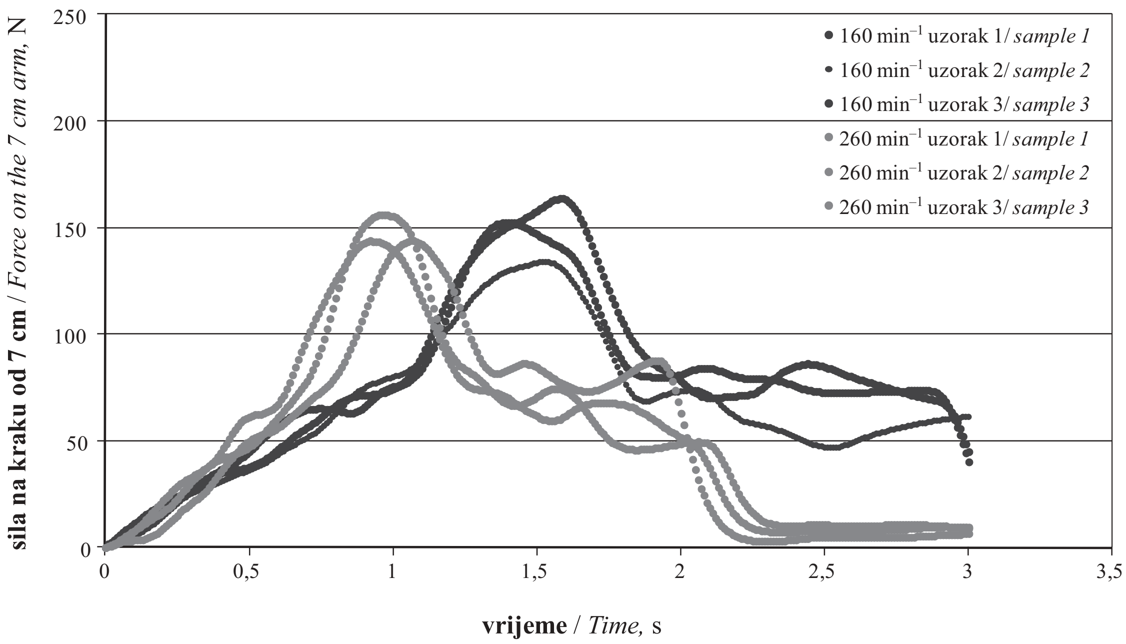


Slika 5. Tri karakteristična rezultata uvijanja matice u bukovinu za promjer provrta 10,5 mm
Figure 5 Tree characteristic results for screwing nuts in beech for 10.5 mm bore radius

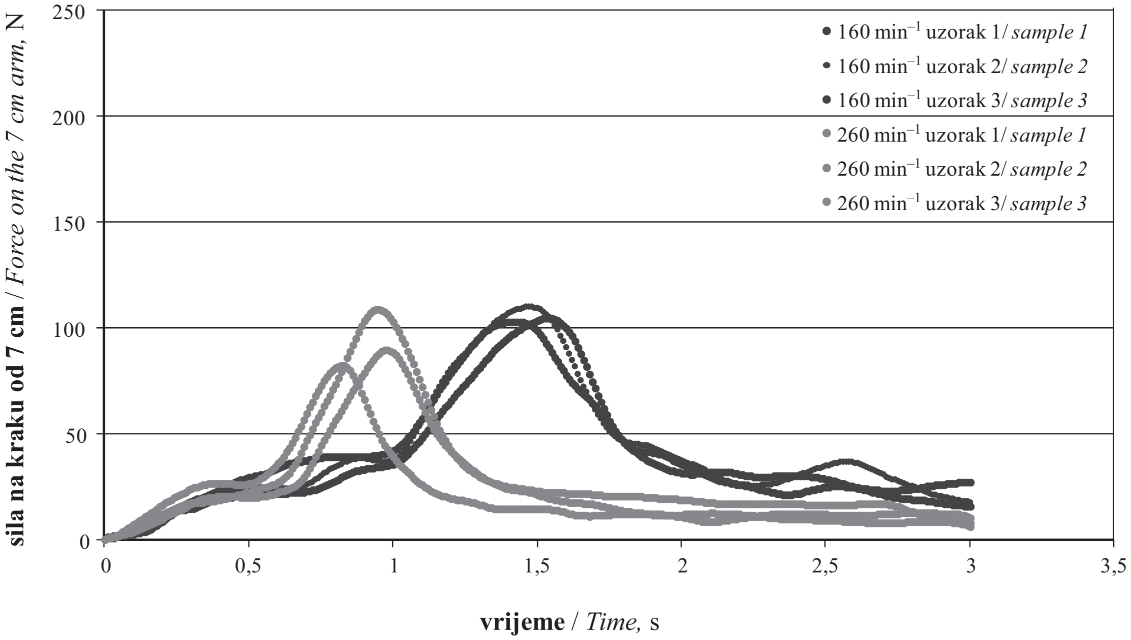
vrte promjera 10,5 mm jasno su se mogle uočiti razlike u otporu uvijanju koje pokazuju ponašanje matica pri različitim brzinama uvijanja i u različitim vrstama drva.

Iz dijagrama sila uvijanja dvonavojnih matica vidljivo je da mjerena sila pri uvijanju brzinom 260 min^{-1} ima ustaljeniji rast do maksimuma u odnosu prema dijagramima sila pri brzini uvijanja 160 min^{-1}. Iz oblika grafova (sl. 5 – 7) možemo pretpostaviti da pri uvijanju manjom brzinom zbog većeg variranja sile dolazi do nejednolikog narezivanja putanje navoja, što upućuje na nepravilno oštećenje staničja drva, a posljedica toga može biti slabije držanje dvonavojne matice. Prema tome, brzina od 260 min^{-1} bolja je brzina uvijanja unutar ovih istraživanja.

Jelovina je pokazala očekujuće male sile potrebne za uvijanje matica i rezultat koji nije usporediv s bukovinom i hrastovinom. Osim toga, pri njihovoj usporedbi može se uočiti da bukovina svojom jednoličnijom građom anatomske strukture postiže veće sile odnosno momente uvijanja od prstenasto porozne hrastovine. S obzirom na to da je gustoća obiju vrsta slična – gustoća standardno suhe bukovine je 490...680...880 kg/m^3 (Trajković i Despot, 1996), a hrastovine 390...650...930 kg/m^3 (Petrić i Trajković, 1995) – uz sličnosti nekih mehaničkih svojstava (čvrstoće na tlak, čvrstoće na vlak parelelno s vlakancima), može se zaključiti kako jednoličnija građa osigurava bolji dodir s navojem matice te time i veće trenje.



Slika 6. Tri karakteristična rezultata uvijanja matice u hrastovinu za promjer provrta 10,5 mm
Figure 6 Tree characteristic results for screwing nuts in oak for 10.5 mm bore radius



Slika 7. Tri karakteristična rezultata uvijanja matice u jelovinu za promjer provrta 10,5 mm
Figure 7 Tree characteristic results for screwing nuts in fir for 10.5 mm bore radius

3.2. Vrijeme uvijanja s obzirom na brzinu uvijanja
3.2 Screwing time consumption with respect to screwing rate

Pri svakome mjerenju otpora uvijanju dobiveno je i vrijeme uvijanja. Svako mjerenje trajalo je 5 sekundi. Kao početak mjerenja vremena uvijanja uzeto je vrijeme pri kojemu je sila uvijanja počela rasti, a kraj je označavao trenutak kada sila uvijanja počinje padati. Kraj mjerenja vremena ujedno je bio trenutak u kojemu je izmjerena maksimalna sila uvijanja upotrijebljena za izračunavanje maksimalnih momenata uvijanja.

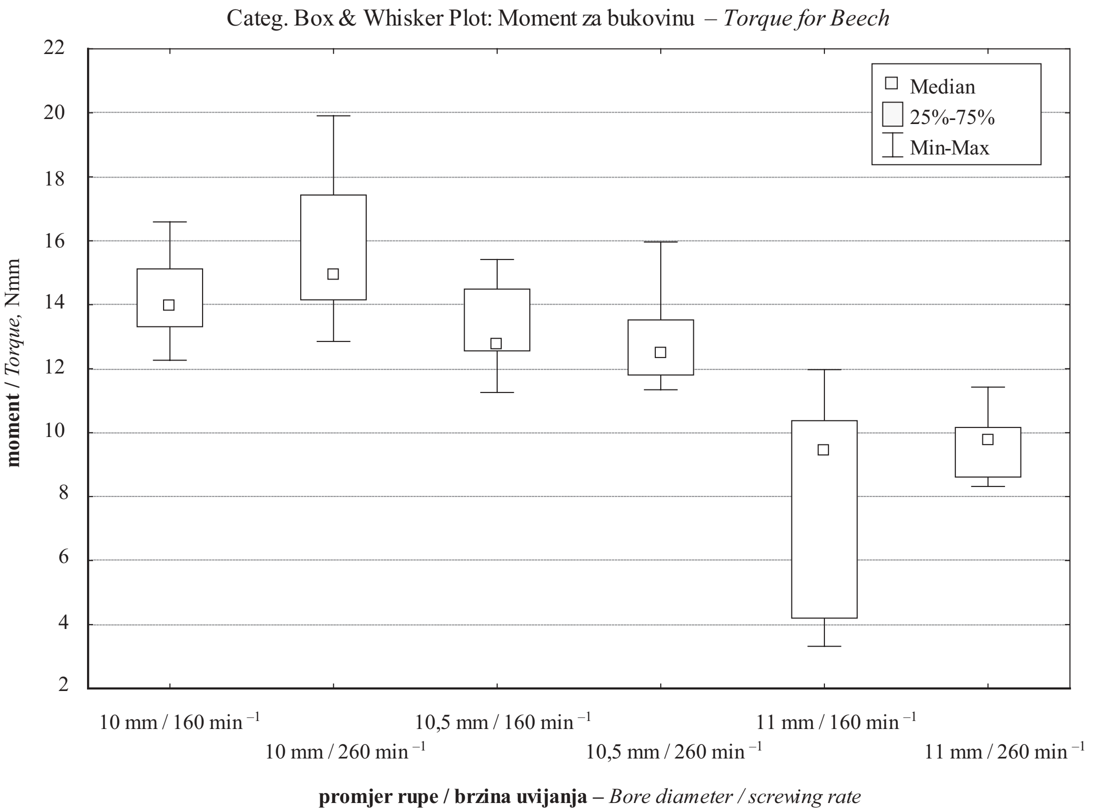
Prosječno izmjereno vrijeme jasno pokazuje da na svim ispitivanim vrstama drva povećanje provrta uzrokuje skraćenje vremena uvijanja. Razlika u rezultatima pri promjeni provrta od 10 na 11 mm pri brzini od 160 min^{-1} na bukovini iznosi 20,4 %, na hrastovini 20,9 % te na jelovini 19,9 %, a pri brzini od 260 min^{-1} na bukovini iznosi 22 %, na hrastovini 21,9 % te na jelovini 28 %. Trend produljenja vremena uvijanja jasno je uočljiv, međutim, statističkom analizom tih podataka nije utvrđeno postojanje značajnih razlika u vremenu trajanja uvijanja matica. Razlika bi nesumnjivo bila još veća i vjerojatno statistički značajno različita da je za uvijanje upotrijebljena oprema manje snage, na električni ili neki drugi pogon.

3.3. Usporedba momenta uvijanja pri različitim promjerima provrta i brzinama uvijanja
3.3 Comparison of torque for different bore diameter and screwing rate

Najuočljiviji rezultat svakako je trend smanjenja momenta uvijanja zbog povećanja promjera provrta. Dobiveni rezultati mjerenja tog momenta pokazuju da međusobne usporedbe na osnovi promjera provrta, bez obzira na vrstu drva i brzinu uvijanja, pokazuju međusobnu statistički značajnu razliku, osim između promjera provrta 10 i 10,5 mm u hrastovini, pri brzini uvijanja od 260 min^{-1}. Ta se pojava može objasniti samo slučajnim pojavljivanjem nekontroliranih veličina povezanih s procesom uvijanja matica u drvo, na što upućuje veliko rasipanje rezultata (sl. 9). Uz to se može uočiti da su razlike između provrta 10 i 10,5 mm na svim dijagramima manje nego razlike između momenata pri provrtu 10,5 i 11 mm, čime je dokazano da se idealan provrt nalazi bliže provrtu od 10 mm nego onome od

Tablica 1. Brzine uvijanja
Table 1 Screwing rate

Vrsta drva *Wood species*	**Promjer** *Diameter* mm	**Vrijeme uvijanja pri 160 min^{-1}** *Consumption time at rate of 160* min^{-1} s	**Vrijeme uvijanja pri 260 min^{-1}** *Consumption time at rate of 260* min^{-1} s
bukovina /*Beech-wood*	10	1,57	1,09
	10,5	1,48	0,96
	11	1,25	0,85
hrastovina / *Oak-wood*	10	1,58	1,05
	10,5	1,48	0,97
	11	1,25	0,82
jelovina / *Fir-wood*	10	1,61	1,00
	10,5	1,46	0,91
	11	1,29	0,72



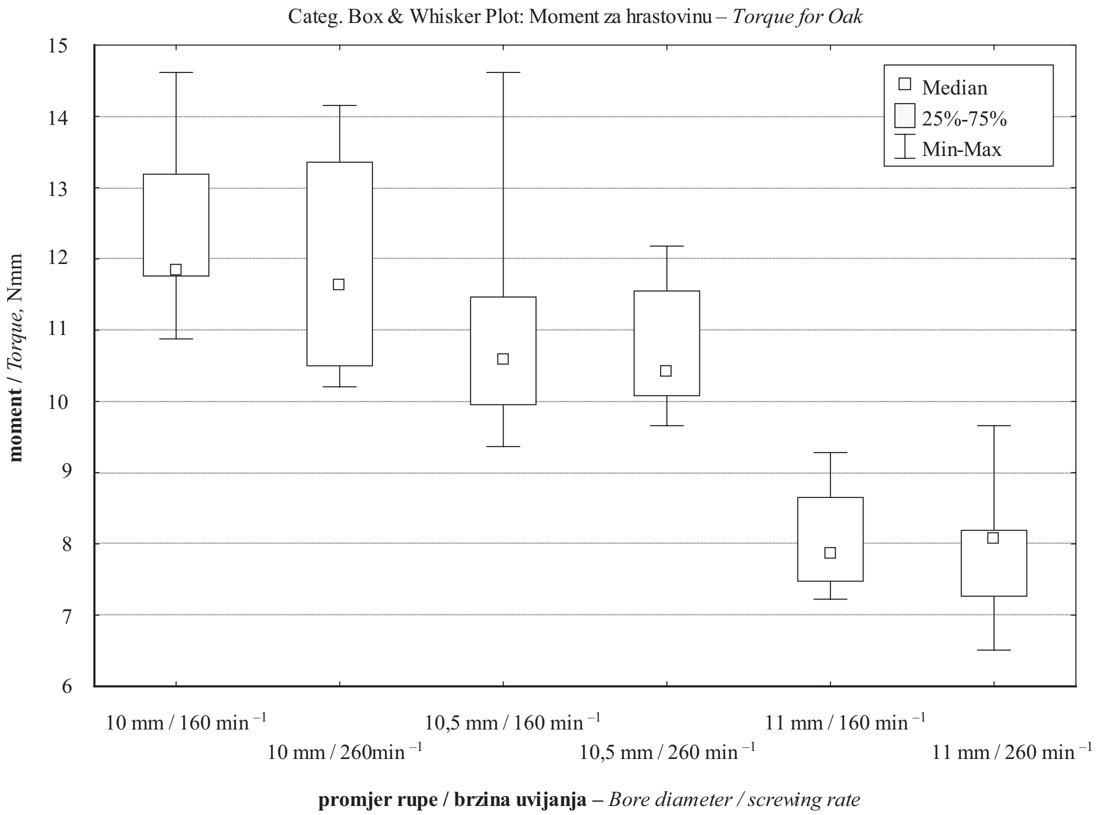
Slika 8. Statistička analiza rezultata izmjerenih momenata uvijanja dvonavojnih matica u bukovinu
Figure 8 Statistical analyzes of torque from screwing double thread nuts in beech-wood

Tablica 2. Utvrđivanje razlika za mjerenje momenata na bukovini
Table 2 Determination of differences between torque results on beech-wood

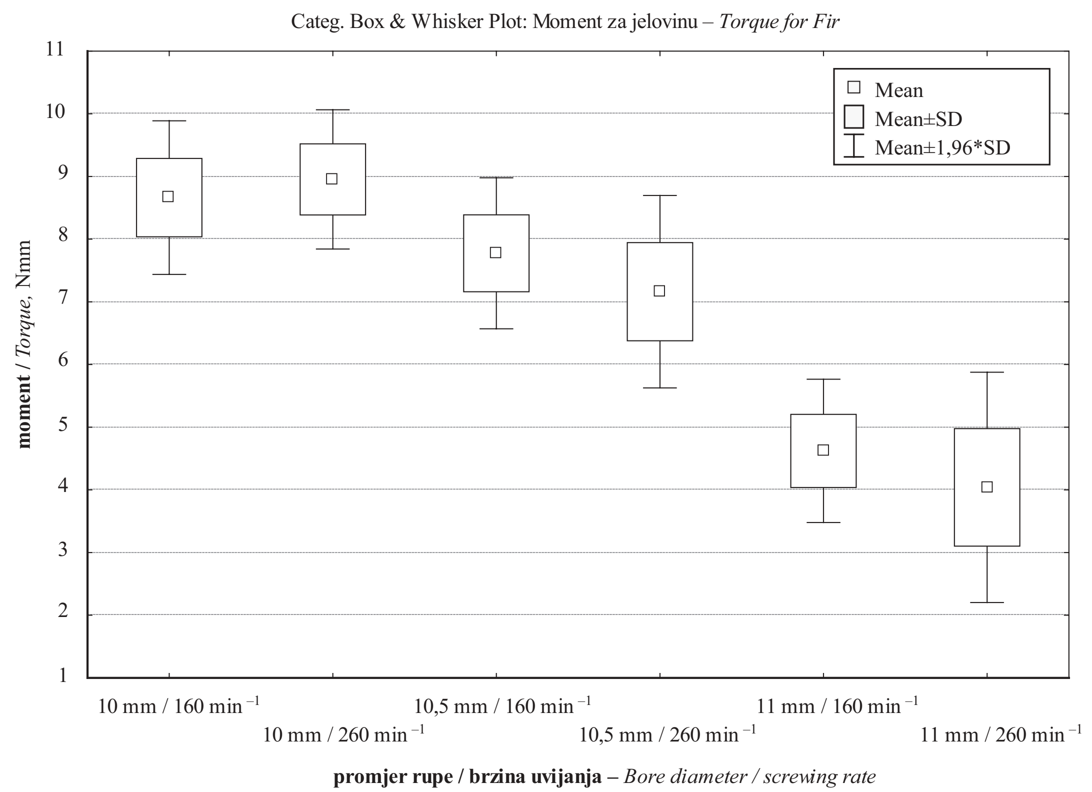
Scheffe test: bukva / *Beech* (**momenti** / *Torque*)			
Razlike značajne za $p < 0{,}05$ / *Marked differences are significant at p < 0.05*			
Promjer rupe / brzina uvijanja – *Hole diameter / Rotatiom speed*	10 mm / 160 min^{-1}	10,5 mm / 160 min^{-1}	11 mm / 160 min^{-1}
10 mm / 160 min^{-1}		0,039431	0,000000
10,5 mm / 160 min^{-1}	0,039431		0,000001
11 mm / 160 min^{-1}	0,000000	0,000001	
Kruskal-Wallis test: bukva / *Beech* (**momenti** / *Torque*)			
Razlike značajne za $p < 0{,}05$ / *Marked differences are significant at p < 0.05*			
Promjer rupe / brzina uvijanja – *Hole diameter / Rotation speed*	10 mm / 160 min^{-1}	10,5 mm / 160 min^{-1}	11 mm / 160 min^{-1}
10 mm / 260 min^{-1}		0,020143	0,000000
10,5 mm / 260 min^{-1}	0,020143		0,002746
11 mm / 260 min^{-1}	0,000000	0,002746	

Tablica 3. Utvrđivanje razlika za mjerenje momenata na hrastovini
Table 3 Determination of differences between torque results on oak-wood

Scheffe test: hrast / *Oak* (**momenti** / *Torque*)			
Razlike značajne za $p < 0{,}05$ / *Marked differences are signifikant at p < 0,05*			
Promjer rupe / brzina uvijanja – *Hole diameter / Rotatiom speed*	10 mm / 160 min^{-1}	10,5 mm / 160 min^{-1}	11 mm / 160 min^{-1}
10 mm / 160 min^{-1}		0,021910	0,000000
10,5 mm / 160 min^{-1}	0,021910		0,000000
11 mm / 160 min^{-1}	0,000000	0,000000	
Kruskal-Wallis test: hrast / *Oak* (**momenti** / *Torque*)			
Razlike značajne za $p < 0{,}05$ / *Marked differences are significant at p < 0.05*			
Promjer rupe / brzina uvijanja – *Hole diameter / Rotatiom speed*	10 mm / 160 min^{-1}	10,5 mm / 160 min^{-1}	11 mm / 160 min^{-1}
10 mm / 260 min^{-1}		0,167866	0,000000
10,5 mm / 260 min^{-1}	0,167866		0,000585
11 mm / 260 min^{-1}	0,000000	0,000585	



Slika 9. Statistička analiza rezultata izmjerenih momenata uvijanja dvonavojnih matica u hrastovinu
Figure 9 Statistical analyzes of torque from screwing double thread nuts in oak-wood



Slika 10. Statistička analiza rezultata izmjerenih momenata uvijanja dvonavojnih matica u jelovinu
Figure 10 Statistical analyzes of torque from screwing double thread nuts in fir-wood

Tablica 4. Utvrđivanje razlika za mjerenje momenata na jelovini
Table 4 Determination of differences between torque results on fir-wood

Scheffe test: jela / *Fir* (**momenti** / *Torque*)			
Razlike značajne za $p < 0,05$ / *Marked differences are significant at p < 0.05*			
Promjer rupe / brzina uvijanja – *Hole diameter / Rotatiom speed*	10 mm / 160 min^{-1}	10,5 mm / 160 min^{-1}	11 mm / 160 min^{-1}
10 mm / 160 min^{-1}		0,001142	0,000000
10,5 mm / 160 min^{-1}	0,001142		0,000000
11 mm / 160 min^{-1}	0,000000	0,000000	
Kruskal-Wallis test: jela / *Fir* (**momenti** / *Torque*)			
Razlike značajne za $p < 0,05$ / *Marked differences are significant at p < 0.05*			
Promjer rupe / brzina uvijanja – *Hole diameter / Rotatiom speed*	10 mm / 160 min^{-1}	10,5 mm / 160 min^{-1}	11 mm / 160 min^{-1}
10 mm / 260 min^{-1}		0,000001	0,000000
10,5 mm / 260 min^{-1}	0,000001		0,000000
11 mm / 260 min^{-1}	0,000000	0,000000	

11 mm, te da je provrt od 10,5 mm prihvatljivija supstitucija za provrt od 10 mm.

Osnovna usporedba momenata uvijanja na različitim vrstama drva pokazuje da je za bukovinu potreban najveći moment za uvijanje dvonavojnih matica, a za jelovinu najmanji. Taj se rezultat sam po sebi nameće zbog različitosti u gustoći i tvrdoći drva. Nasuprot tome, bukovina ima znatno veće iznose momenata uvijanja od hrastovine, što pokazuje da moment uvijanja ne raste isključivo s povećanjem volumne mase i tvrdoće drva. Veći iznosi u bukovine mogu se objasniti većom površinom drva koja je u dodiru s navojem matice zbog većeg udjela drvne tvari u području zone ranog drva nego u hrastovine.

Usporedno promatranje momenata pri različitim brzinama uvijanja pokazuju da povećanje brzine sa 160 na 260 min^{-1} uzrokuje smanjenje momenata, i to u prosjeku od 2 Nmm u bukovine do 1 Nmm u hrastovine i jelovine. Veća promjena u bukovine nego u hrastovine također se može objasniti njezinom ujednačenijom strukturom, zbog čega veća površina drva u dodiru s navojem matice uzrokuje veće trenje. Međutim, treba razmotriti i druga svojstva drva koja mogu utjecati na taj rezultat jer ta primjetna razlika ipak nije statistički značajna, osim za jelovinu na provrtu od 10,5 mm. Uzimajući u obzir iznose značajnosti razlika među rezultatima, može se zaključiti da se razlika momenata između primijenjenih brzina povećava sa smanjenjem mehaničkih svojstava drva.

3.3. Sile izvlačenja dvonavojnih matica
3.3 Results of testing the nut extraction force

Rezultati ponajprije nedvojbeno pokazuju trend smanjenja sile izvlačenja s povećanjem provrta. Povećanje provrta s 10 na 10,5 mm donosi 8,9 - postotno smanjenje prosječne sile izvlačenja za bukovinu, što je u odnosu na 53,8 % smanjenje pri provrtu od 11 mm zanemarivo. Statistička analiza pokazuje postojanje značajnih razlika između provrta od 10 i 11 mm, kao i između provrta od 10,5 i 11 mm, dok između provrta od 10 i 10,5 mm razlike nema. Taj rezultat neosporno opravdava primjenu provrta od 10,5 mm umjesto 10 mm jer se uz malo smanjenje sile izvlačenja znatno smanjuju momenati potrebni za uvijanje matica, što je dokazano prethodnim mjerenjima (tabl. 2 – 4) .

Iako se sila izvlačenja dvonavojnih matica u hrastovine za promjer provrta od 10,5 mm statistički razlikuje

Tablica 5. Razlike sila izvlačenja iz bukovine
Table 5 Differences of extraction forces from beech-wood

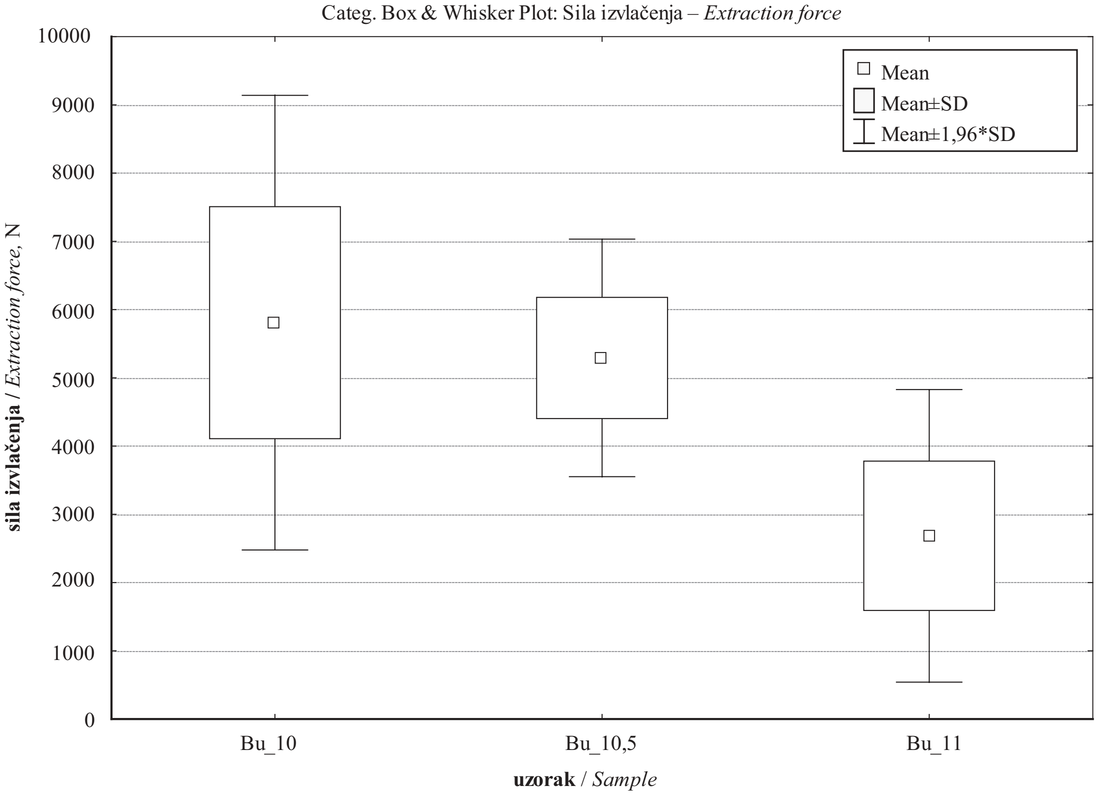
Scheffe test: bukva / *Beech* (**sila izvlačenja** *Extraction force*)			
Razlike značajne za $p < 0,05$ *Marked differences are significant at p < 0.05*			
Uzorak / *Sample* (Promjer rupe / *Hole diameter)*	Bu_10	Bu_10,5	Bu_11
Bu_10		0,293684	0,000000
Bu_10,5	0,293684		0,000000
Bu_11	0,000000	0,000000	

Tablica 6. Razlike sila izvlačenja iz hrastovine
Table 6 Differences of extraction forces from oak-wood

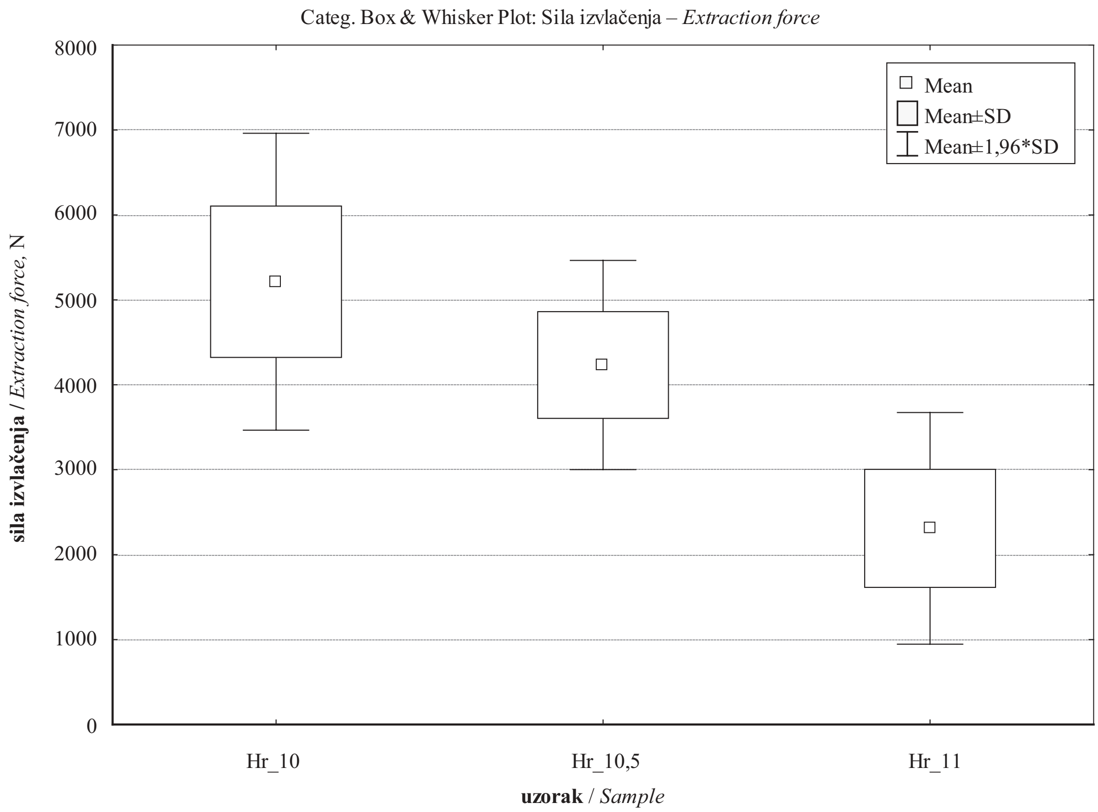
Scheffe test: hrast / *Oak* (**sila izvlačenja** / *Extraction force*)			
Razlike značajne za $p < 0,05$ / *Marked differences are significant at p < 0.05*			
Uzorak / *Sample* (Promjer rupe / *Hole diameter)*	Hr_10	Hr_10,5	Hr_11
Hr_10		0,000018	0,000000
Hr_10,5	0,000018		0,000000
Hr_11	0,000000	0,000000	

od sile pri provrtu promjera 10 mm, možemo primijetiti da je ta razlika od 18,8 % znatno manja u usporedbi sa smanjenjem od 56,3 % pri promjeru od 11 mm, pa je upotreba promjera rupe od 10,5 mm također opravdana. Može se pretpostaviti da je razlog nastanka statistički značajne promjene između promjera provrta 10 i 10,5 mm nejednolikost građe prstenasto porozne hrastovine. Naime, moguće je da staničje ranog drva mjestimično omogućuje veće elastične deformacije umjesto potrebnih trajnih deformacija uz navoj matice, zbog čega je njihova izvlačna sila manja nego u jednolično deformiranog staničja bukovine. Takav zaključak potkrepljuje i činjenica da je razlika pri usporedbi momenata pri uvijanju znatno veća između provrta od 10,5 i 11 mm nego između onih od 10 i 10,5 mm.

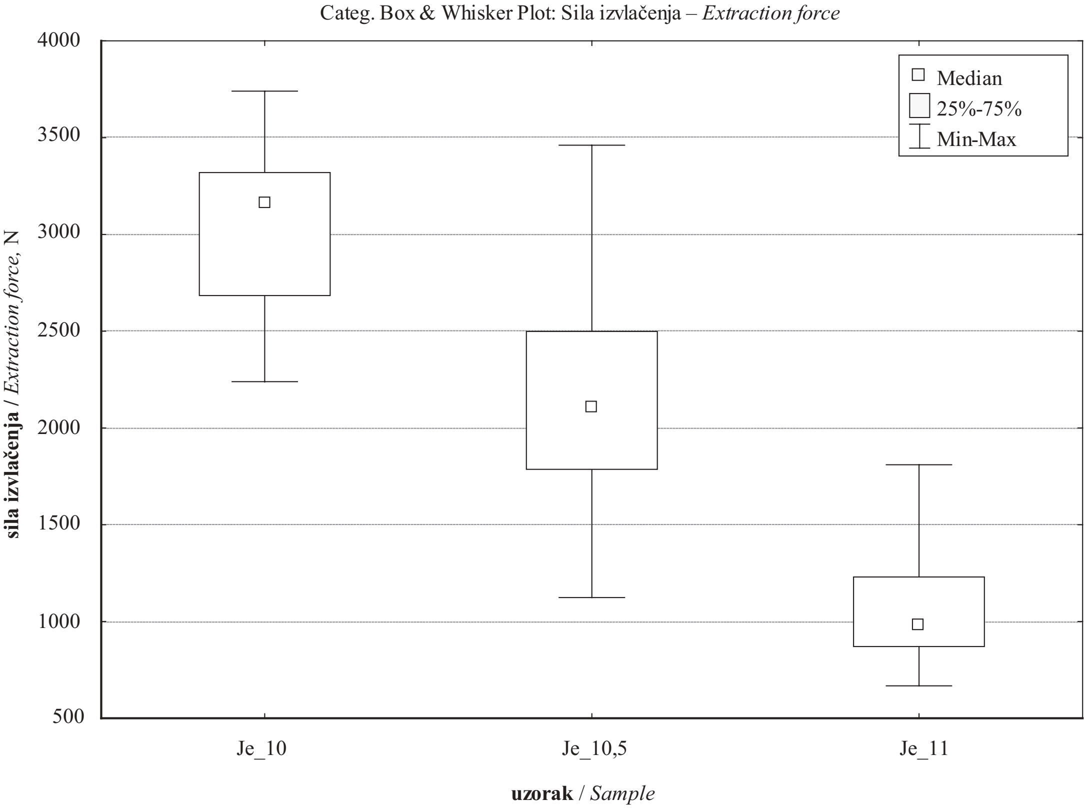
Na uzorcima jelovine sila izvlačenja značajno se razlikuje za sva tri provrta. Povećanje provrta s 10 na 10,5 mm donosi čak 32,3 – postotno smanjenje prosječne sile izvlačenja, što je u odnosu prema 65,6 %



Slika 11. Statistička analiza rezultata izmjerenih sila izvlačenja dvonvavojnih matica iz bukovine
Figure 11 Statistical analyzes of results of measured extraction forces of double thread nuts from beech-wood



Slika 12. Statistička analiza rezultata izmjerenih sila izvlačenja
Figure 12 Statistical analyzes of results of extraction forces of double thread nuts from oak-wood



Slika 13. Statistička analiza rezultata izmjerenih sila izvlačenja dvonvavojnih matica iz jelovine
Figure 13 Statistical analyzes of results of extraction forces of double thread nuts from fir-wood

Tablica 7. Razlike sila izvlačenja iz jelovine
Table 7 Differences of extraction forces from fir-wood

Scheffe test: jela - *Fir* (**sila izvlačenja** - *Extraction force*)			
Razlike značajne za $p < 0,05$; *Marked differences are significant at p < 0.05*			
Uzorak / *Sample* (Promjer rupe / *Hole diameter)*	Hr_10	Hr_10,5	Hr_11
Hr_10		0,000594	0,000000
Hr_10,5	0,000594		0,000018
Hr_11	0,000000	0,000018	

smanjenja pri provrtu od 11 mm upola manje. Sila izvlačenja dvonavojne matice iz jelovine značajno je manja u odnosu prema silama u bukovini i hrastovini zbog njezinih slabijih mehaničkih svojstava, pa se može zaključiti da za jelovinu nije potpuno opravdano u proizvodnju uvoditi nestandardni provrt od 10,5 mm. Tome pridonosi i činjenica da pri provrtu od 10 mm moment uvijanja, zbog male čvrstoće drva, ne uzrokuje veće probleme pri uvijanju.

4. ZAKLJUČAK
4 CONCLUSION

Prosječno vrijeme trajanja uvijanja jasno pokazuje da na svim ispitivanim vrstama drva povećanje provrta uzrokuje skraćenje vremena uvijanja iako statističkom analizom nije utvrđeno postojanje značajnih razlika u vremenu trajanja uvijanja matica.

Povećanjem provrta s 10 na 10,5 mm i povećanjem brzine postiže se skraćenje vremena izrade, a zbog manjih sila odnosno momenata uvijanja smanjuje se i mogućnost oštećenja alata i glave dvonavojne matice.

Smanjenje brzine uvijanja sa 260 na 160 min^{-1} uzrokuje povećanje momenata uvijanja u prosjeku od 2 Nmm u bukovine te 1 Nmm u hrastovine i jelovine jer jednoličnija građa bukovine osigurava veći dodir s navojem matice te time i veće trenje odnosno veći otpor uvijanju.

Vremenska promjena mjerene sile odnosno momenata upućuje na zaključak o nejednolikom narezivanju putanje navoja zbog nepostojanog otpora uzrokovanoga nejednolikim deformacijama staničja drva u dodiru s navojem. U ovim istraživanjima uočeno je da brzina od 260 min^{-1} osigurava kvalitetnije sidrenje matica u drvo odnosno bolju brzinu uvijanja.

Rezultati sila izvlačenja nedvojbeno pokazuju trend smanjenja s povećanjem provrta.

Analizirajući sile izvlačenja, možemo utvrditi da se hipoteza pokazala točnom za bukovinu i hrastovinu. Vidljivo je da ne postoje statistički signifikantne razlike za bukovinu između uzoraka s provrtom od 10 i 10,5 mm, dok se uzorci s provrtom od 11 mm značajno razlikuju od prva dva. U hrastovine postoji razlika između provrta od 10 i 10,5 mm, međutim smanjenje iznosa sile izvlačenja čini samo trećinu smanjenja zbog promjene provrta od 10 na 11 mm te se stoga može reći da je smanjenje provrta prihvatljivo i za hrastovinu.

Smanjenje provrta nije opravdano za jelovinu odnosno za vrste drva manje volumne mase jer se time samo smanjuje čvrstoća takvog sastava odnosno konstrukcije namještaja. Prema tome, optimizacija tehnološkog procesa za proizvodnju konstrukcija od vrsta drva veće volumne mase, poput bukovine i hrastovine, postiže se uvođenjem nestandardnog provrta od 10,5 mm, čime se veličina sile izvlačenja ne mijenja značajno u odnosu prema promjeru provrta od 10 mm, a postiže se smanjenje momenta uvijanja i skraćenje vremena uvijanja, odnosno procesa proizvodnje te potencijalno visoka razina kvalitete proizvoda.

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Lumber Recovery Efficiency among Selected Sawmills in Akure, Nigeria

Iskorištenje drvne sirovine u promatranim pilanama područja Akure u Nigeriji

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ABSTRACT • *This study was carried out to investigate the efficiency of lumber recovery among selected sawmills in Akure metropolis. Measurements were carried out before and after log conversion to estimate the volume of sawn timber and wood residues generated from the selected sawmills. The outcome of the research revealed that 56.08 % of the log input was recovered as sawn timber while 43.92 % was left as wood residues. From the 43.92 % of wood residue, 34.39 % was left as slab while 9.53 % was left as saw dust. This finding showed that the efficiency of these mills was comparably higher than the results from earlier studies. It is believed that the yield could still be improved by channeling the residues in the form of slabs to other valuable products.*

Keywords: *sawmills, lumber recovery, wood residue, logs*

SAŽETAK • *Istraživanje je provedeno s ciljem da se ustanovi iskorištenje drvne sirovine u odabranim pilanama u području Akure. Mjerenja su provedena prije i nakon obrade trupaca kako bi se utvrdio obujam proizvedenih piljenica i drvnih ostataka u promatranim pilanama. Rezultati istraživanja pokazali su da je iskorištenje trupaca u obliku piljenica 56,08 %, dok je udio drvnih ostataka bio 43,92 %. Od 43,92 % drvnih ostataka 34,39 % su okorci, a 9,53 % je piljevina. Istraživanja su pokazala da je učinkovitost istraživanih pilana veća od rezultata prethodnih studija. Pretpostavlja se da iskorištenje trupaca može biti i veće ako se drvni ostaci u obliku okoraka prerade u određene drvne proizvode koji imaju tržišnu vrijednost.*

Ključne riječi*: pilane, iskorištenje drvne sirovine, drvni ostaci, trupci*

1 INTRODUCTION
1. UVOD

The sawmilling industry in Nigeria is dominated by small scale and privately owned establishments. They are mostly concentrated in the city usually regarded as the centre of activity. Alviar (1993) reported that these sawmills have individual production capacities of about 500 cubic meters of lumber per year while they number well over 1500 across the country. A record by Ondo State Department of Forestry (2007) revealed that there are 311 registered sawmill complexes across the state with more than 50 % concentrated in the state capital. The first sawmill in the state was established in 1909 (Adewale, 1988) and since then the form and sizes of the available logs have reduced considerably (Lucas, 1990). While the form is poorer, the sizes are smaller and the population of merchantable timber in the country-owned forest has started declining in recent times (Malami, 2010). This is due to the growing demand for sawn timber in the furniture and building industries. To meet this demand, an appropriate sawmilling practice that encourages high lumber recovery rate is required. This situation demands con-

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stant review of the efficiency of conversion, which is the objective of this study.

The efficiency rate of lumber recovery ranges between 40 and 50 % as reported by Alviar (1993). This implies that 50 – 60 % of the log volume ends up as waste usually in the form of slabs, sawdust, edges and shavings. Lumber recovery efficiency is widely used as a measure of assessing the performance of any sawmill. The mode of estimation is by dividing the total lumber product in cubic meters by total input volume. However, this does not take into account the size, quality or grade of the log in question. Log size, quality or grade and length are also important factors to be considered in lumber recovery efficiency. The lumber recovery factor is the percentage of sound lumber produced from a log. According to Badejo (1980) 75 small sized sawmills operating around Lagos State generate about 21,000 m^3 of residue every year. Further study by Alviar (1993) on 17 CD horizontal band saw headrigs sawing 84 m^3 in Lagos, Ibadan and Benin City found that 47 % of the product (sawn timber) was recovered while other residues such as slabs, sawdust and bark were 38.6 %, 8.1 % and 6.3 %, respectively. All these studies did not separate the quantity of saw dust from slabs. The present study has gone a step further to do the separation by taking into consideration the dimension of the saw kerf. The low product volume recovered in these sawmills was a result of adherence of mill operators to traditional practice, poor saw fitting and maintenance, lack of secondary processing machines to salvage the proportion of slab going to waste, poor sawing methods and inadequate training of sawyers. The sawmill practice has considerably improved in terms of equipment and personnel. This study has, therefore, been designed to investigate the lumber recovery efficiency of selected sawmills in Akure metropolis.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

This research was carried out in the metropolitan city of Akure, Ondo State, Nigeria, which is the administrative capital of Ondo State with its headquarters at Akure South Local Government. The town hosts more than 50 % of the saw mills in the whole state. Ten sawmills were randomly selected within Akure metropolis and each of these mills uses CD horizontal band saw with the following parameters; wheel diameter (1600 mm), blade width (200 mm), and power of 125 kW. Other operations such as ripping, crosscutting, edging and trimming are carried out on the circular sawing machine.

Data was collected based on production and working conditions of the selected sawmills. For primary conversion of logs, a sawing method was used called "sawing around". Ten wood species sawn predominantly and common to these sawmills were selected (see Table 1). The standard length of logs processed in these sawmills is 3.6 m (12 ft). The diameter at the top and bottom of each log varies with the taper levels. Before primary conversion in each of the mills, the top and bottom diameter of the logs were measured and the volume of each log was estimated using Smalian equation below:

$$V_{\log} = \frac{l \cdot \pi \cdot (D_b^2 + D_t^2)}{8} \qquad (1)$$

$V_{\log}$ – volume of the log before conversion, m^3
D_b – diameter at the base of the log, m
D_t – diameter at the top of the log, m
l – length of the log, m

The volume of sawdust from each log was estimated from equation 2:

$$V_{sd} = b \cdot l \int_1^n w \qquad (2)$$

V_{sd} – volume turned to dust, m^3
b – kerf of the saw blade
l – length of the log, m
w – width of each plank at the point of cut, m

The volume of sawn timber (plank) was estimated from the nominal sizes (1' x 12' x 12'') of individual planks from each of the logs, after calculating edging and trimming on the circular sawing machine, from equation 3:

$$V_{st} = \Sigma\, n \cdot (l \cdot b \cdot h) \qquad (3)$$

V_{st} – volume of sawn timber, m^3
l – length of the plank, m
b – breadth, m
h – thickness, m
n – number of planks from each sawn log

The volume of slab produced during the conversion process was then estimated using equation 4:

$$V_{slab} = V_{\log} - (V_{sd} + V_{st}) \qquad (4)$$

3 RESULTS
3. REZULTATI

The results in Table 1 show the log volume of wood species sampled from the selected sawmills and their recovery volumes of lumber and wood residues. Lumber recovery is low with most wood species as a result of higher volume of slabs generated from their wood logs.

The overall lumber recovery in the sampled sawmills was 56.08 % of the total log input. The remaining 43.92 % was the wood residue, out of which 34.39 % was the solid waste in the form of slabs and off-cuts, while 9.53 % was turned to saw dust during the conversion process. The volume of saw dust generated depends on saw parameters and the number of times the blade goes through the logs for sawing. The overall recovery rate in the selected sawmills is shown in Table 2. The result of the analysis of variance testing for the significance of the finished product (sawn timber) from the selected mills showed that there was no significant difference (p>0.05) in the recovery of the finished product (Table 3). Furthermore, the analysis of variance in Table 4 and 5 revealed that there was no significant difference (p>0.05) in the quantity of sawdust and slabs produced among the selected sawmills in Akure metropolis.

Table 1 Species names, trade names and mean volumes of round logs and lumber recovery after processing
Tablica 1. Vrste drva, trgovački nazivi, srednji obujam trupaca i količina piljenih proizvoda

Specie names *Vrsta drva*	**Trade name** *Trgovački naziv*	**Log** *Trupci* m^3	**Planks** *Piljenice* m^3	**Sawdust** *Piljevina* m^3	**Slabs** *Okorci* m^3
Khaya ivorensis	Mahogany	9.44	5.23	0.96	3.26
Mansonia altissima	Mansonia	2.32	1.14	0.16	1.07
Milicia excelsa	Iroko	11.07	7.05	1.24	2.78
Celtis zenkeri	Ita	10.94	6.24	1.25	3.48
Triplochyton scleroxylon	Obeche	5.99	3.32	0.43	2.25
Cordia milenii	Omo	8.12	4.59	0.71	2.79
Nelsogodonia papaverifera	Danta	7.68	4.34	0.62	2.72
Alstonia boonei	Ahun	8.28	4.28	0.77	3.34
Entandrophragma cylindricum	Ijebu	11.37	5.67	1.11	4.00
Terminalia superba	Afara	6.10	3.12	0.58	2.36

Table 2 Percentage of finished products and waste from selected sawmills
Tablica 2. Postotak gotovih proizvoda i drvnog ostatka u promatranim pilanama

Sawmills / *Pilane*	**Slabs, %** *Okorci, %*	**Sawdust, %** *Piljevina, %*	**Finished products, %** *Gotovi proizvodi, %*
YABSOL	33.77	9.79	56.44
GUANCO	33.55	9.56	56.89
OLUKAYODE	35.03	9.35	55.62
AYENI	34.55	9.78	55.67
EMINISA	34.29	9.50	56.21
ANIFOWOSE	34.91	9.45	55.64
AGBEDE	34.93	9.29	55.78
HOUSING	33.94	9.27	56.79
ISEOLUWA	36.19	9.57	54.24
ALAWIYE	32.74	9.73	57.53
Mean value / *srednja vrijednost*	34.39	9.53	56.08

Table 3 Analysis of variance (ANOVA) for finished products among the selected sawmills
Tablica 3. Analiza varijance (ANOVA) gotovih proizvoda u promatranim pilanama

SV	*SS*	*df*	*MS*	*F*-value	Sig.
Selected mills	23.444	9	2.605	0.425	0.918^{ns}
Error	555.035	90	6.123		
Total	574.479	99			

(ns = not significant at p>0.05 / *ns – nije signifikantno na razini p>0,05*)

Table 4 Analysis of variance (ANOVA) for waste (slabs) among the selected sawmills
Tablica 4. Analiza varijance (ANOVA) krupnoga pilanskog ostatka u promatranim pilanama

SV	*SS*	*df*	*MS*	*F*-value	Sig.
Selected mills	123.091	9	1.455	0.822	0.598^{ns}
Error	159.3115	90	1.770		
Total	172.406	99			

(ns = not significant at p>0.05 / *ns – nije signifikantno na razini p>0,05*)

Table 5 Analysis of variance (ANOVA) for waste (sawdust) among the selected sawmills
Tablica 5. Analiza varijance (ANOVA) količine piljevine u promatranim pilanama

SV	*SS*	*df*	*MS*	*F*-value	Sig.
Selected mills	0.760	9	0.084	0.202	0.993^{ns}
Error	37.630	90	0.418		
Total	38.390	99			

(ns = not significant at p>0.05 / *ns – nije signifikantno na razini p>0,05*)

4 DISCUSSION
4. RASPRAVA

The efficiency of any sawmill could be measured by the quantity of finished product recovered from a log compared to those resulting into residue. It could be observed that in all sawmills examined the recovery rate is almost the same. This is because there is no significant difference in the volume of sawn timber and residue produced from each of the selected sawmills. The efficiency of lumber recovery among these sawmills is a little higher than what was observed by Alviar (1993) among sawmills in Lagos, Ibadan and Benin City. He observed that in these cities, 47.0 % was recovered as sawn-timer (product), 44.9 % as slabs and 8.1 % as sawdust. Badejo (1980) asserted to the fact that the proportion of wood waste due to slab might be reduced with improved conversion methods. A review of level of wood conversion and utilization in Nigeria by Thorpe (1983) showed that 45 % of log input into the sawmill industry ended up as mill residues. Today this may be higher due to better training of personnel, newer equipment and higher consciousness for better performance. This assumption has been confirmed in the selected sawmills in Akure as it could be noted that the percentage of log input accounted as waste is about 43.91 %. As a result of variation in shape and form of logs, it is very important to position them properly for sawing so as to reduce waste and derive maximum volume of sawn timber (Fuwape and Sobanke, 1998). Optimum utilization of round logs is obtainable if the log is properly positioned during conversion and turned frequently for efficient recovery of sawn timber. Efficiency of wood conversion in sawmills implies that wood residue generated during conversion is reduced to the barest minimum. Efficiency of log conversion can be further improved in these mills by ensuring that logs are converted on time to reduce the harmful effect caused by bio-deteriorating agents. Sawmill equipments should be adequately maintained and the level of accuracy of sawyers would also improve the efficiency of wood conversion.

5 CONCLUSION
5. ZAKLJUČAK

There is some increase in the conversion efficiency. It was observed that the efficiency of different species is comparable among them. However, there are variations that are mainly due to different sizes and forms of individual production logs. As a result of variations in log forms, greater volumes of wastes in the form of slabs are generated. Higher efficiency in the utilization of wastes after sawmilling processes could, however, be enhanced through development of new production lines, whereby waste in the form of slab and sawdust can be re-processed to products such as wood parquets, tools handles, production of panel doors and briquettes for energy production.

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Janja Zule, Jožica Dolenc[1]

Distribution of Mineral Substances in Different Wood Tissues of European Larch (*Larix decidua* Mill.)

Raspodjela mineralnih tvari u različitim drvnim tkivima europskog ariša (*Larix decidua* Mill.)

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ABSTRACT • *Typical wood tissues, such as stemwood, bark, branches, twigs and needles, of two very old European larch trees (*Larix decidua *Mill.) were examined for the content of macro and micro mineral substances. Elemental analysis, atomic absorption spectrophotometry (AAS) and ultraviolet/visible (UV/VIS) techniques were applied for quantitative determination of individual elements. The results indicated that both trees had almost identical mineral content. The highest contents of macro elements N, P, S, K and Mg as well as micro elements Ni, Fe, Al and Co were measured in needles, while Ca, Mn and Zn prevailed in bark. Concentrations of substances were the lowest in stemwood. Comparison with similar studies of foliar mineral distribution proved that both trees had good nutrient status, which corresponded to their condition.*

Keywords: *European larch, micro and macro nutrients, AAS, elemental analysis, foliar mineral distribution*

SAŽETAK • *U radu se prikazuju rezultati istraživanja sadržaja mikromineralnih i makromineralnih elemenata u tipičnomu drvnom tkivu dvaju stabala vrlo starih europskih ariša (Larix decidua Mill.) kao što su stablo (deblo), kora, grane, grančice i iglice. Za kvantitativno određivanje pojedinačnih elemenata primijenjene su elementarne analize, atomska apsorpcijska spektrofotometrija (AAS) i ultraljubičasta/vidljiva (UV/VIS) analitička tehnika. Prema dobivenim rezultatima, svi su usporedivi uzorci oba drva imali praktički jednak mineralni sastav. Najveći sadržaj makroelemenata N, P, S, K i Mg, kao i mikroelemenata Ni, Fe, Al i Co, zastupljen je u iglicama, no Ca, Mn i Zn prevladavali su u kori. Najniže koncentracije mineralnih tvari izmjerene su u drvu stabla (debla). U usporedbi sa sličnim studijama raspodjele mineralnih tvari u iglicama, dokazano je da svi uzorci drva imaju primjeren sadržaj tih tvari, što odgovara njihovu zdravom stanju.*

Ključne riječi: *europski ariš (*Larix decidua *Mill.), sadržaj mikromineralnih i makromineralnih tvari, atomska apsorpcijska spektrofotometrija, elementarna analiza*

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1 INTRODUCTION
1. UVOD

Trees and other plants receive their nutritional elements from air, water and soil. The most basic building elements are carbon (C), oxygen (O) and hydrogen (H). Their sources are air and water. They combine to form higher structures such as carbohydrates, which compose plant tissues. Besides, there are at least 14 other mineral elements that are needed for the growth.

Minerals play an important role in plant metabolism. They are components of organic structures, such as proteins and nucleic acids, which are essential constituents of living organisms. They are charge carriers and osmotic regulators and serve as promoters of numerous enzymatic reactions. Their participation in the division and differentiation of cells as well as photosynthesis is also significant. In short, tree growth is in many ways dependent on mineral uptake and distribution (Fengel and Wegener, 1989; Leyton, 1957).

Most minerals are delivered to the tree from forest soil through its root system; however some can be absorbed through leaves. Total mineral contents and concentrations of individual elements vary within and between tree species and are also strongly dependent on ecological factors, i.e. the site where a tree is growing (Bujas, 1998; Antonović *et al*, 2007; Antonović *et al*, 2010). Typically, mineral contents of needles, leaves, bark, branches, twigs and roots are higher than those of stemwood. Younger trees are likely to contain higher concentrations of nutrients than mature ones and hardwoods are richer in them than softwoods. In most cases alkali and alkali earth elements such as potassium (K), calcium (Ca) and magnesium (Mg) make up to 80 % of the total inorganic constitution of softwoods and hardwoods. Among them Ca predominates constituting often up to about 50 % of the total inorganics. A variety of other elements can also be detected in wood tissues, altogether about seventy, however only 17 have been identified so far as essential, meaning that plant needs them to complete its reproductive stage of life cycle. These are the above mentioned carbon (C), oxygen (O), hydrogen (H), potassium (K), calcium (Ca) and magnesium (Mg) as well as nitrogen (N), phosphorus (P), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni) and chlorine (Cl). N, P, K, Ca, Mg and S are considered major or macro-nutrients, because they are required in large quantities that range between 1 to 150 g per kg of plant dry matter. Fe, Zn, Mn, Cu, B, Mo, Cl and Ni are minor or micro-nutrients that are required in amounts from 0.1 to 100 mg per kg of dry matter (Henry *et al*, 1992; Merilä and Derome, 2008; Ditmarova *et al*, 2007).

There is also a distinctive difference between nutrient minerals according to their mobility. Mobile nutrients are those able to move out of older plant parts to younger ones when supplies are not adequate. Mobile elements are N, P, K, Cl, Mg and Mo. In contrast, immobile nutrients are B, Ca, Cu, Fe, Mn, Ni, S and Zn. Typically they cannot move quickly or not at all from one plant part to another (Stenius, 1999; Raven *et al*, 2005; Rowell, 2005).

The role of individual elements can be fairly well explained but not always fully. N is contained in all enzymes essential for plant functions, P is a component of ATP, a compound that supplies the energy to grow and maintain the plant, K activates certain enzymes and balances the charge between ions, S is a part of certain amino acids and all proteins, Ca is contained in cell walls, regulates cell wall construction and balances charge, Mg is the central element within the chlorophyll molecule, B is important for sugar transport within plants and plays a role in cell division, Mo is needed for the reduction of absorbed nitrates into ammonia prior to incorporation into amino acids, Fe is a component of many enzymes and light energy transferring compounds, Zn is essential for plant hormone balance, Mn is a cofactor in many plant reactions, Cu is a component of enzymes involved in photosynthesis while Cl is a charge balancing ion (Raven *et al*, 2005).

Deficiency of individual macro and micro elements results in specific growth disturbances as well as overall plant health deterioration due to the fact that essential biochemical and physiological processes are interrupted. Proportions among elements should also be balanced in order for the plant to achieve optimal uptake of all the necessary minerals (Ericsson *et al*, 1993; Katzensteiner *et al*, 1992; Mandre and Kuznetsova, 2004; Cape *et al*, 1990; Ingestad, 1979). Nutritional condition of a living tree can be typically evaluated by chemical analysis of needles or leaves, respectively. Less common is the evaluation based on stemwood minerals characterization (Eriksson and Rosen, 1994; Komlenovič *et al*, 1995; Myre and Camiré, 1996)

Total inorganics in wood can be evaluated by determination of ash content after combustion of plant material. Woods typically contain from 0.1 to 1.5 % of ash, however in some tropical species these values may be exceeded. The ash is predominantly composed of different metal oxides, silicates, carbonates and other salts. Individual elements can be determined either from ash or after acidic digestion of plant material by various analytical techniques such as atomic absorption spectroscopy, colorimetry and elemental analyses (Stelzer *et al*, 1993).

The aim of our research was to evaluate concentrations of different essential elements as well as cobalt and aluminum in various anatomical parts of two healthy and very old European larches in order to define variations within individual tree as well as between trees growing in the same area. The data will be useful for further studies of relations between mineral constitution, growing conditions and plant health.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Samples
2.1. Uzorci

Two larch trees (*Larix decidua* Mill.) were felled at the end of June in the Alpine region of Slovenia at the altitude of 1000 m. They were growing in a mixed forest among beech and spruce trees. Both were 180 years old and about 30 m high. They were healthy as they had good living conditions provided by rich forest soil (brown, carbonate ground).

5 cm thick discs were cut from the trunks at the base (20 cm above ground) as well as at the heights of 8, 18 and 28 m. A living branch was taken from each tree at the height of 18 m. A part, up to 1.5 m from the trunk was used for analyses. Twigs (about 0.5 cm wide) and needles from the same branch were also collected (about 500 g of each).

Discs as well as branches were debarked and cut into smaller pieces. Samples, including stemwood, branchwood, bark, twigs and needles, were frozen at – 24 ºC till analysis. Stemwood bark was treated as only one bulk sample, so it was not divided according to the height levels. Samples were vacuum dried at 30 ºC, ground to wood meal and homogenized before combustion and digestion.

2.2 Analyses
2.2. Analize

Ash content

All samples were analyzed for the content of ash (550 ºC) according to the DIN EN 12879 standard method.

FTIR spectra

Spectra of ash samples were recorded on Biorad-Excalibur spectrophotometer as transmission spectra on KBr pellets in the range between 4000 and 400 cm^{-1}.

Elemental analyses

C, N and S were analyzed on CNS LECO 2000 instrument for elemental analysis, which was equipped with IR and thermoconductivity detectors.

Determination of phosphorus

P was determined spectrophotometrically after digestion of samples with conc. H_2SO_4 and HNO_3. Concentration of P was measured in diluted solution according to the ISO 6878 standard (ammonium molybdate method).

Determination of K, Ca, Mg, Cu, Ni, Co, Fe, Mn, Zn, and Al

Samples were digested by HNO_3 and H_2O_2. Concentrations of individual elements were measured by AAS technique on Varian SpectrAA 220 instrument using electrothermal atomization for Cu, Ni, Co, Al and flame ionization for K, Ca, Mg, Mn, Fe, Zn.

All analyses were performed in 3 parallels. The results are average values of individual measurements. They are expressed as % (*w/w*) for ash content and N, as g/kg for P, K, S, Mg and Ca and as mg/kg for Cu, Ni, Co, Fe, Mn, Zn and Al. All values are expressed per weight of dry sample.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Ash contents showed typical pattern of mineral distribution in the trees. Stemwood values increased

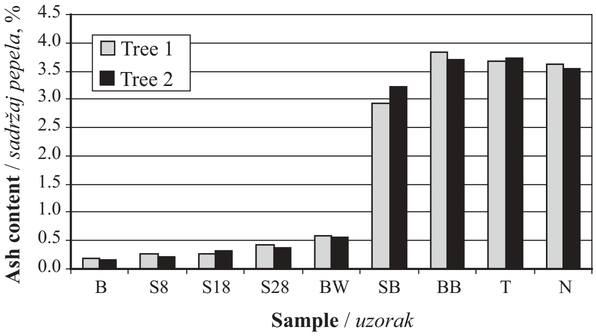

Figure 1 Ash content in larch samples of both trees
(B - stemwood at base (20 cm), S8 - stemwood at 8 m, S18 - stemwood at 18 m, S28 - stemwood at 28 m, BW - branch wood, SB - stemwood bark, BB - branch wood bark, T - twigs, N - needles)
Slika 1. Sadržaj pepela u uzorcima iz oba stabla ariša
(B - stablo u bazi, 20 cm, S8 - stablo na visini 8 m, S18 - stablo na visini 18 m, S28 - stablo na visini 28 m, BW - drvo grane, SB - kora stabla, BB - kora grane, T - sitne grane, N - iglice)

with increasing height of the trunks. Characteristic ash concentrations were between 0.15 and 0.43 % and there was little difference between both trees. Branch wood contained slightly more ash than the trunk parts. Typical values ranged from 0.5 to 0.6 %. In contrast to the wood samples, bark, twigs and needles contained much more inorganic material. They had similar ash concentrations, all of them approaching or exceeding 3 %.

The corresponding values are presented in Figure 1. FTIR spectra of wood and bark ashes showed practically no difference. There were intensive carbonate peaks with wave numbers of about 1440, 876 and 710 cm^{-1}. Silicate peak was also visible at 1050 cm^{-1}; however its intensity was poor. In contrast, twigs and needles gave spectra with much more abundant silicate peaks indicating that the concentrations of silicates increased from the trunk towards outer tree parts, such as bark, branches, twigs and needles.

FTIR spectra of ashes from stemwood, twigs and needles are presented in Figures 2, 3 and 4.

Distributions of N, P and S in different tree tissues showed similar pattern. Typically concentrations of N and P increased with tree heights, while the quantity of S remained more or less constant. Bark samples, twigs and needles proved to have relatively rich content of N and P, compared to the stemwood and branch wood. The highest average concentrations of all three elements were found in needles. They approached 2 % (*w/w*) for N, 3 g/kg for P and 1.7 g/kg for S, which is in good agreement with the results reported by Paques (1994) and Alriksson *et al*. (1998).

Distributions of N, P and S contents in different materials of both larch trees are presented in Figures 5, 6 and 7.

K and Mg exhibited practically the same concentration behavior as N and P, while Ca strongly predominated in bark samples, where the measured values ranged between 14 and 16 g/kg. The contents of Ca, Mg and K in needles were close to 8; 1.5 and 3 g/kg, which partly corresponded to the results published by

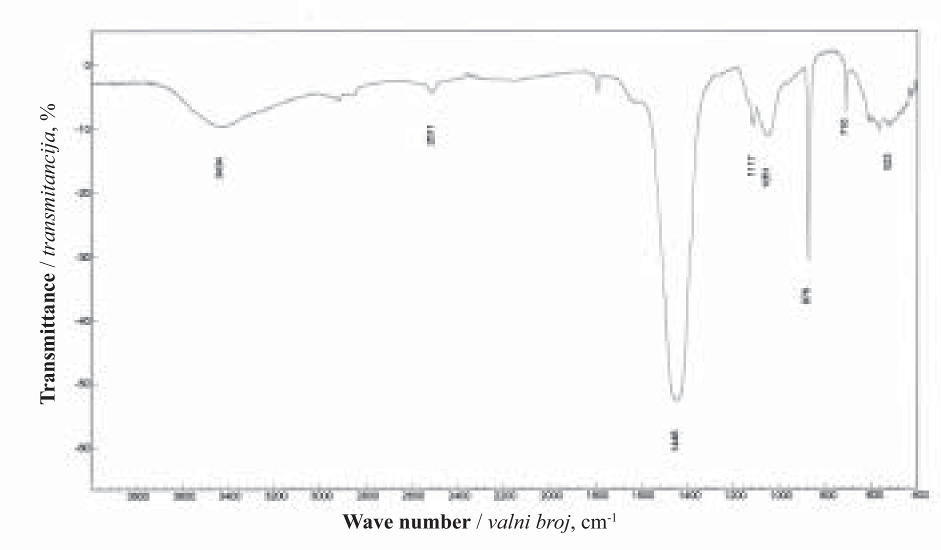

Figure 2 FTIR spectra of stemwood ash
Slika 2. FTIR spektar pepela od stabla

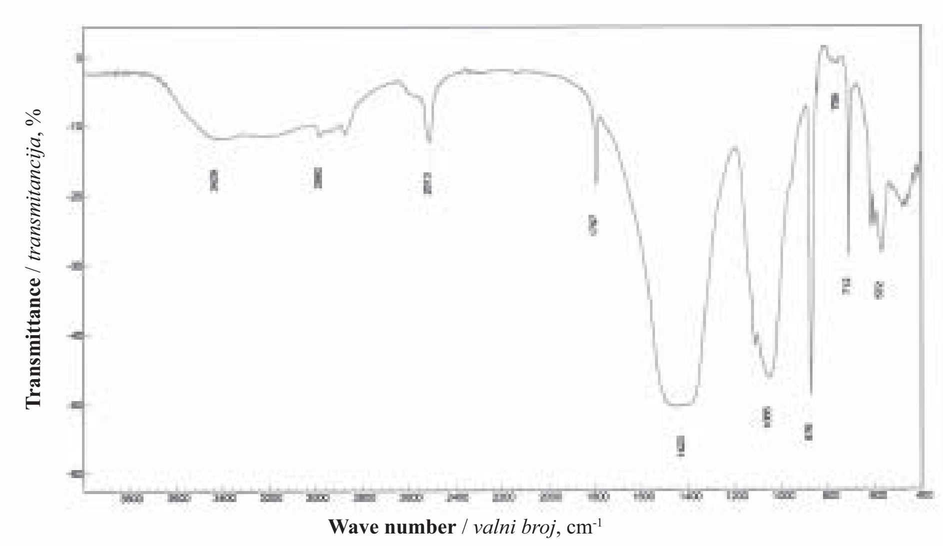

Figure 3 FTIR spectra of ash from twigs
Slika 3. FTIR spektar pepela od sitnih grana

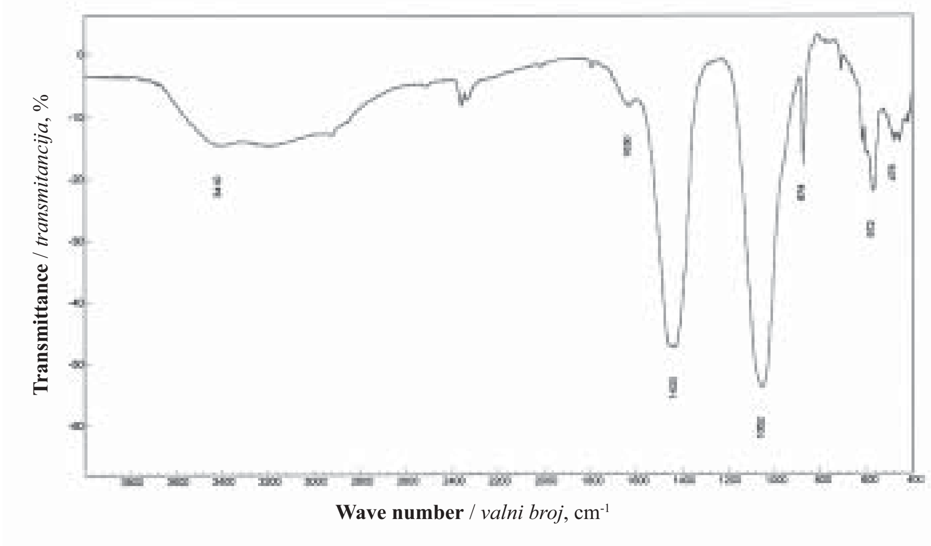

Figure 4 FT-IR spectra of ash from needles
Slika 4. FT-IR spektar pepela od iglica

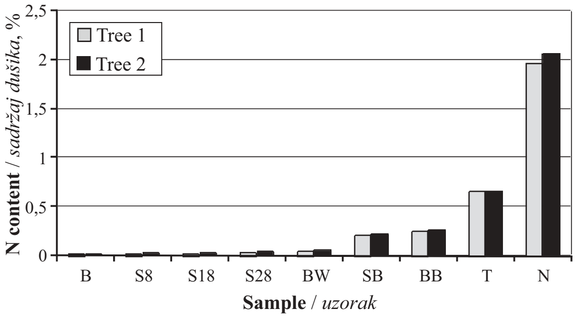

Figure 5 Nitrogen (N) content of larch wood tissues
Slika 5. Sadržaj dušika (N) u drvnim tkivima ariša

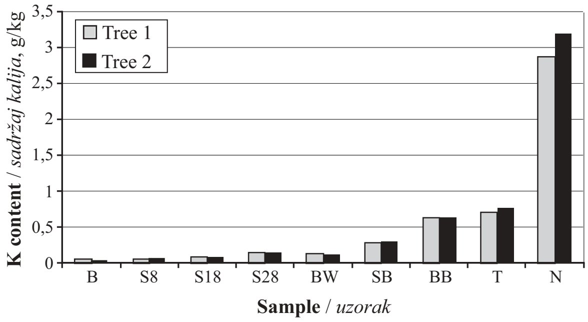

Figure 8 Potassium (K) content of larch wood tissues
Slika 8. Sadržaj kalija (K) u drvnim tkivima ariša

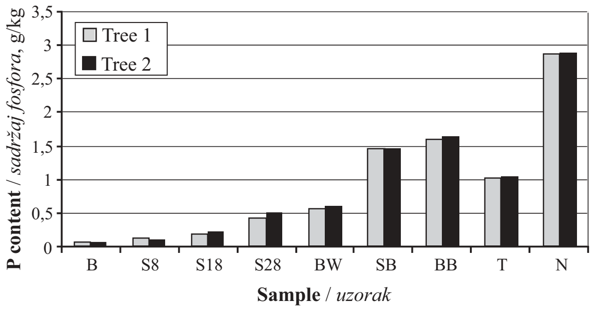

Figure 6 Phosphorus (P) content of larch wood tissues
Slika 6. Sadržaj fosfora (P) u drvnim tkivima ariša

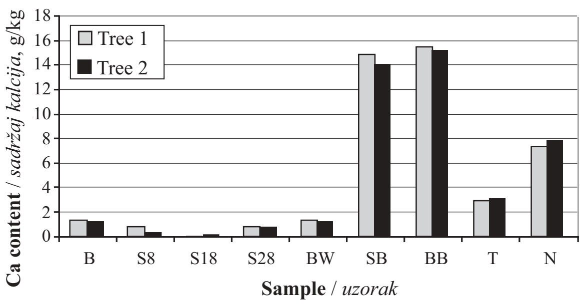

Figure 9 Calcium (Ca) content of larch wood tissues
Slika 9. Sadržaj kalcija (Ca) u drvnim tkivima ariša

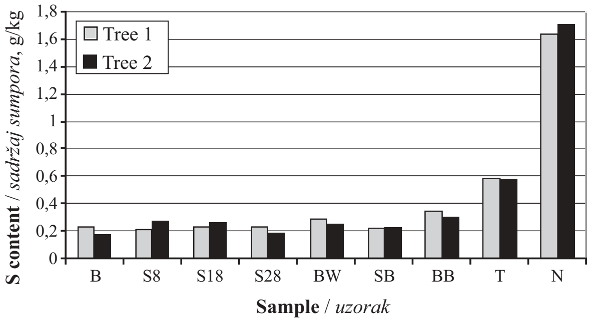

Figure 7 Sulphur (S) content of larch wood tissues
Slika 7. Sadržaj sumpora (S) u drvnim tkivima ariša

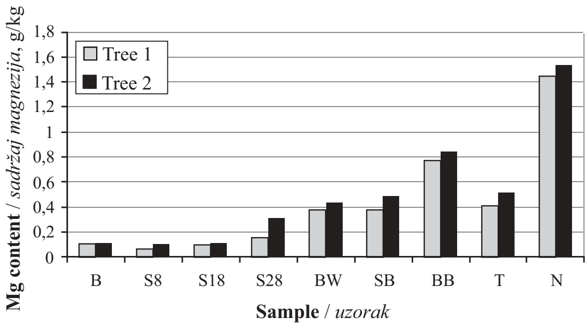

Figure 10 Magnesium (Mg) content of larch wood tissues
Slika 10. Sadržaj magnezija (Mg) u drvnim tkivima ariša

Paques (1994), Myre *et al.* (1996) and Alriksson *et al.* (1998), where the presented foliar concentrations of Ca and Mg in different larch species were similar, but those of K were typically somewhat higher.

According to our results, there was no significant difference between the two analyzed larch trees as far as the distributions of the six macro elements in various tree tissues are concerned.

K, Ca and Mg contents are shown in Figures 8, 9 and 10.

Distribution patterns of measured microelements Ni, Zn, Mn, Fe, Cu, Al and Co within different anatomical parts of both larch trees were highly variable. Some similarity was observed in case of Zn and Mn, as both elements prevailed in bark samples where their concentrations amounted to about 45 and 270 mg/kg, while needles contained surprisingly lower quantities and namely about 25 mg/kg of Zn and between 25 and 50 mg/kg of Mn. The concentrations of Mn were substantially lower, compared to the results of a similar study published by Myre *et al.* while values for Zn were quite comparable. The distribution of Zn and Mn concentrations in different larch tissues are presented in Figures 11 and 12.

Ni, Fe, Al and Co predominated in needles where average concentrations amounted to about 1; 135; 200 and 0.6 mg/kg. Surprisingly high contents of Ni, Cu and Fe were determined in stemwood base samples (about 0.6; 12.5 and 30 mg/kg), which was not the case with other elements. Significant is also the fact that the lowest overall concentrations were measured for Ni, Cu and Co.

The results for Cu and Fe are in good agreement with the values obtained by Bending and Moffat (1999) in their systematic studies of foliar nutrients in Japanese larch. Average values of Ni, Fe, Cu, Al and Co analyses of larch wood tissues are presented in Figures 13 to 17.

It has to be emphasized that the repeatability of all macro and micro element determinations was very high due to efficient homogenization of samples before the analyses. Parallel measurements never differed more than 11 % from each other, even in case of low concentration elements, such as Co, Cu and Ni. The

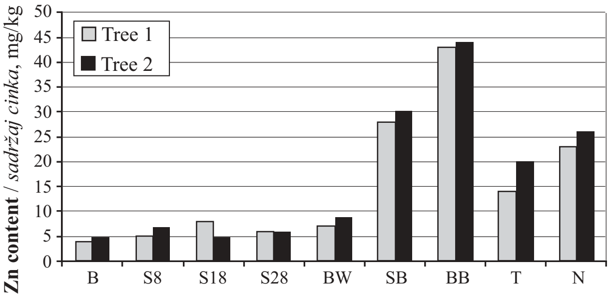

Figure 11 Zinc (Zn) content of larch wood tissues
Slika 11. Sadržaj cinka (Zn) u drvnim tkivima ariša

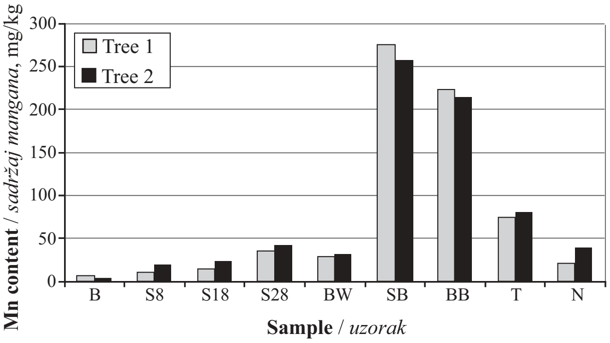

Figure 12 Manganese (Mn) content of larch wood tissues
Slika 12. Sadržaj mangana (Mn) u drvnim tkivima ariša

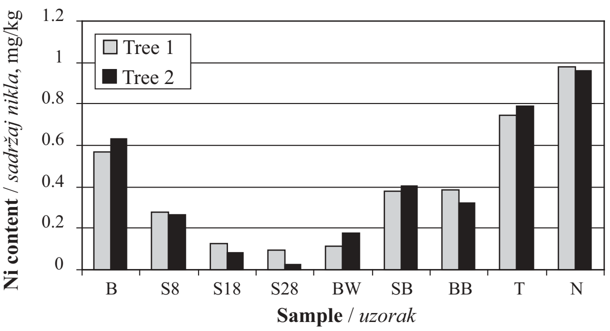

Figure 13 Nickel (Ni) content of larch wood tissues
Slika 13. Sadržaj nikla (Ni) u drvnim tkivima ariša

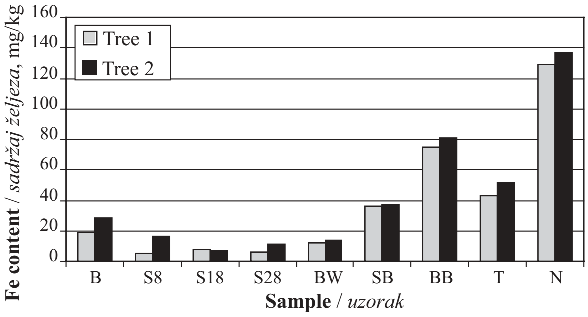

Figure 14 Iron (Fe) content of larch wood tissues
Slika 14. Sadržaj željeza (Fe) u drvnim tkivima ariša

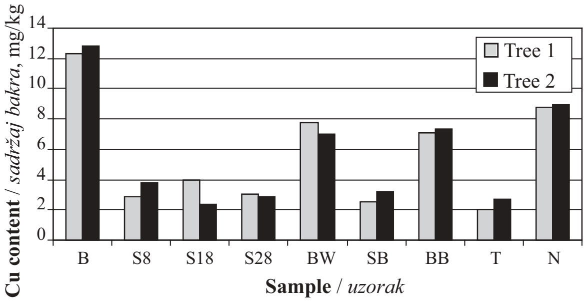

Figure 15 Copper (Cu) content of larch wood tissues
Slika 15. Sadržaj bakra (Cu) u drvnim tkivima ariša

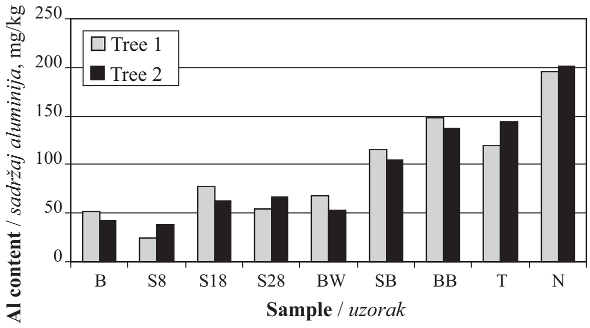

Figure 16 Aluminium (Al) content of larch wood tissues
Slika 16. Sadržaj aluminija (Al) u drvnim tkivima ariša

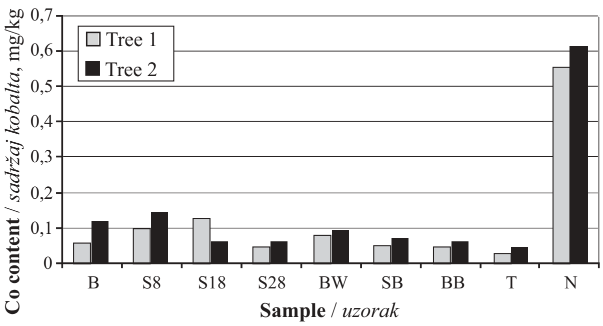

Figure 17 Cobalt (Co) content of larch wood tissues
Slika 17. Sadržaj kobalta (Co) u drvnim tkivima ariša

results indicated that the two examined larch trees exhibited surprisingly high similarity in their mineral structure and showed no pronounced deficiency in the content of most analyzed elements, which corresponded to their healthy condition.

4 CONCLUSIONS
4. ZAKLJUČCI

By determination of macro and micro nutrients in different larch tissues, a typical distribution pattern was obtained for each element. Most elements such as N, P, S, K, Mg, Ni, Fe, Al and Co predominated in needles, while Ca, Zn and Mn were most abundant in bark. External tree parts as for example bark, branches, twigs and needles had much higher inorganic contents than stemwood where the concentrations of individual elements increased with height.

According to FTIR spectra many elements in stemwood and bark were bound as carbonates in contrast to twigs and needles where silicates prevailed.

It was established by foliar analyses that nutrient status of both trees was good as most of the measured elements exhibited optimal or close to optimal values.

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Economical Wood Sawing with Circular Saw Blades of a New Design

Ekonomično piljenje drva kružnom pilom novog dizajna

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ABSTRACT • *Material-saving and energy-saving belong to the basic requirements imposed on contemporary manufacturing processes. The realization of these processes gives measurable profits, not only economical but also ecological. In the case of wood sawing with circular saw blades, material- and energy-savings are dependent on total overall set of teeth (theoretical kerf) and teeth position accuracy in relation to the workpiece. Hence, it is necessary to achieve a decrease of both raw material and energy losses by the use of narrow-kerf saw blades, an increase of sawing accuracy, as well as a reduction of spacing in case of sawing with a gang of circular saws. However, meeting these requirements in the case of rip sawing with circular saw blades is a quite difficult issue and depends on many factors. The detailed analyses concerning ways of chip transportation in the kerf slot, saw blade stiffness, saw blade movement and workpiece feeding accuracy are the proof of these inconvenient technical problems in sawmills. Hence, the realization of economical wood sawing with circular saw blades seems not to be viable until the whole system of sawing fulfils the defined requirements. Thanks to the application of the pro-ecological technology (circular saw blades of a new design), in the examined industrial case, the following results have been achieved: an increase of about 18 % in the amount of side lumber, roughly 16 % less sawdust (as an effect of kerf reduction) and about 16 % lower values of the cutting power consumption.*

Keywords: *rip sawing, circular saw blade, increased yield of raw material*

SAŽETAK • *Ušteda materijala i energije pripadaju temeljnim zahtjevima koji se nameću proizvodnim procesima. Realizacija ušteda donosi mjerljive profite, ali ne samo ekonomske, već i ekološke. Kad je riječ o piljenju drva kružnim pilama, uštede materijala i energije ovise o širini reznog brida (teorijskoj širini propiljka) i točnosti položaja reznih bridova prema obratku. Dakle, nužno je osigurati smanjenje gubitaka materijala i energije uporabom tankih listova pila s malom širinom propiljka, povećati točnost piljenja te smanjiti razmak između listova pila pri piljenja slogom kružnih pila. Međutim, ispunjavanje tih zahtjeva pri piljenju kružnim pilama za uzdužno propiljivanje vrlo je teško i ovisi o brojnim činiteljima. Ozbiljne tehničke probleme s kojima se susreću pilanari potvrđuju i brojne provedene detaljne analize vezane za uklanjanje piljevine iz propiljka, napetost listova pila, gibanje lista pile i točnost posmaka obratka. Prema tomu, realizacija ekonomičnog piljenja kružnim pilama neće biti ostvariva dok cijeli sustav piljenja ne bude ispunjavao zadane zahtjeve. Zahvaljujući primjeni ekološki prihvatljive tehnologije (kružnih pila novog dizajna), u industrijskim su uvjetima postignuti ovi rezultati: oko 18 %*

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povećanja količina krajnjih piljenica, oko 16 % manje piljevine (što je rezultat smanjenja širine propiljka) i oko 16 % manje potrošnje energije za piljenje.

Ključne riječi: *uzdužno piljenje, list kružne pile, povećano iskorištenje sirovine*

1 INTRODUCTION
1. UVOD

The ecological friendliness is a basic demand of contemporary manufacturing processes. In the field of wood sawing with circular saw blades, which is one of the basic cutting methods in the wood industry, the ecological friendliness is primarily connected with material- and energy-saving of the process. The application of the technologies in sawmills, which allow the users to reduce raw material losses and energy consumption, gives measurable advantages, not only economical but also ecological (Steele *et al.*, 1992; Steele and Araman, 1996; Orlowski, 2003a, 2010; Orlowski *et al.*, 2007). Environmental restrictions and increasing log costs have caused many sawmills to look at new ways to extract more value from their raw material. A more traditional way to accomplish this aim is to increase volume recovery. Firstly, a saw kerf can be reduced through improvements in saw design that reduce either the saw blade thickness or the side set of the saw (Manes and Lin, 1995; Wasielewski *et al.*, 2007). However, it has been shown that changes in these two saw design factors can lead to increased within-board sawing variation, or deviation through the cut (Steele *et al.*, 1992; Manes and Lin, 1995). These phenomena may be caused by decreasing either the saw blade specific stiffness or the saw blade operating stiffness due to the loss of saw blade stability (Stakhiev, 2000; Orlowski, 2003a, 2003b, 2010). The latter may also be the effect of the temperature increase caused by the passage of chips between the saw blade and kerf walls (Wasielewski, 2009).

Twin shaft multi-rip saws provide very efficient sawing of wood even in the case of large cutting depths. With regard to this advantage, these circular sawing machines are willingly and often used in sawmills of large productivity. Collar clamped circular saw blades of the "Multix" type (Figure 1a) are frequently applied on these machine tools. They are designed for ripping of hard and soft green wood. Except for traditional carbide teeth on the rim, the saw is additionally equipped with four scraper carbide edges (cleaning knives). Manufacturers of these tools advertise that the "Multix" circular saws provide fast removal of shavings from the cutting space. Nevertheless, some cases have been recorded of catastrophic damages of saw blades due to the passage of chips between the saw blade and kerf walls (Wasielewski, 2009). For this reason, a new circular saw design has been developed (Figure 1b). The new circular saw has larger static and dynamic stiffness, and thus protects a saw blade against deviations in the cut. Furthermore, special scrapers, placed just below each tooth, prevent the saw blade from heating by the uncontrolled chip flow on both sides of the saw blade (Wasielewski *et al*. 2007, 2008).

a)

b)

Figure 1 Circular saw blades for rip sawing of (a) a traditional type "Multix" and (b) a new design "Ekomultiks"
Slika 1. Listovi kružne pile za uzdužno piljenje a) tradicionalni tip "Multix" b) novodizajnirani list "Ekomultiks"

Each sawmill decides where its strong points are and how best to choose the most economical way to improve its own productivity. While one sawmill may prefer to improve its efficiency, another might concentrate its efforts on better utilization of raw materials. Operational reliability, however, is by far the most important factor (Sandvik, 1999). At the preliminary assessment stage, the effect of the kerf size upon raw material savings may be done by calculation of relative kerf losses Q_m, which are estimated in the case of sawing machines, for a gang of saws, as a ratio of the

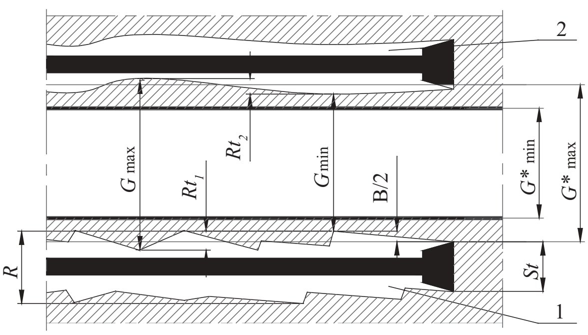

Figure 2 Kerf and board thickness changes, where G^*_{min} and G^*_{max} are acceptable board thickness values, G_{min}, G_{max} are minimum and maximum values of the actual thickness
Slika 2. Promjene širine propiljka i debljine piljenica, pri čemu su G^*_{min} and G^*_{max} prihvatljive vrijednosti debljine piljenica, a G_{min}, G_{max} stvarne vrijednosti minimalne i maksimalne debljine piljenica

total loss volume and the stock volume (Orlowski 2003a, 2010; Wasielewski, 2010), provided that each board has the same thickness:

$$Q_m = \frac{(n+1)R + \sum_{j=1}^{j=2} G_{bj}}{(n+1)R + \sum_{j=1}^{j=2} G_{bj} + n \cdot G_{\min}} \quad (1)$$

where: n – number of produced boards, R – maximum value of the real kerf calculated as $R = S_t + B$, and S_t is a sum of theoretical kerf (overall set), B is an axial run out in relation to the workpiece (equal to roughness of sawn surface R_t, Figure 2), G_{min} is the minimal board thickness, and G_{bj} is the thickness of side boards (slabs or offcuts). If in the sawn pattern, elements have different thickness instead of $n \cdot G_{min}$, $\sum_{j=1}^{j=n} G_{\min j}$ ought to be put into Eq. (1). Figure 2 shows two cases of real kerfs observed on board surface, the kerf #1 when changes of the sawn profile could depend on circular saw blade rotational frequency, and the kerf #2 when changes of the circular saw blade position are slow (observed snaking or wandering of the circular saw blade in the workpiece).

In some sawmills, determination of raw material yield is used more frequently. This concept illustrates which part of the raw material is utilized as ready-made product. The raw material yield W_m for the analyzed sawing pattern can be determined as follows:

$$W_m = 1 - Q_m = \frac{n \cdot G_{\min}}{(n+1) \cdot R + \sum_{j=1}^{j=2} G_{bj} + n \cdot G_{\min}} \quad (2)$$

In case of raw material with the same width G and height H, on its whole length L, the assessment task seems to be very easy. However, in industrial reality, ready-made elements are often obtained from raw material of whose width and height change along its length (Figure 3).

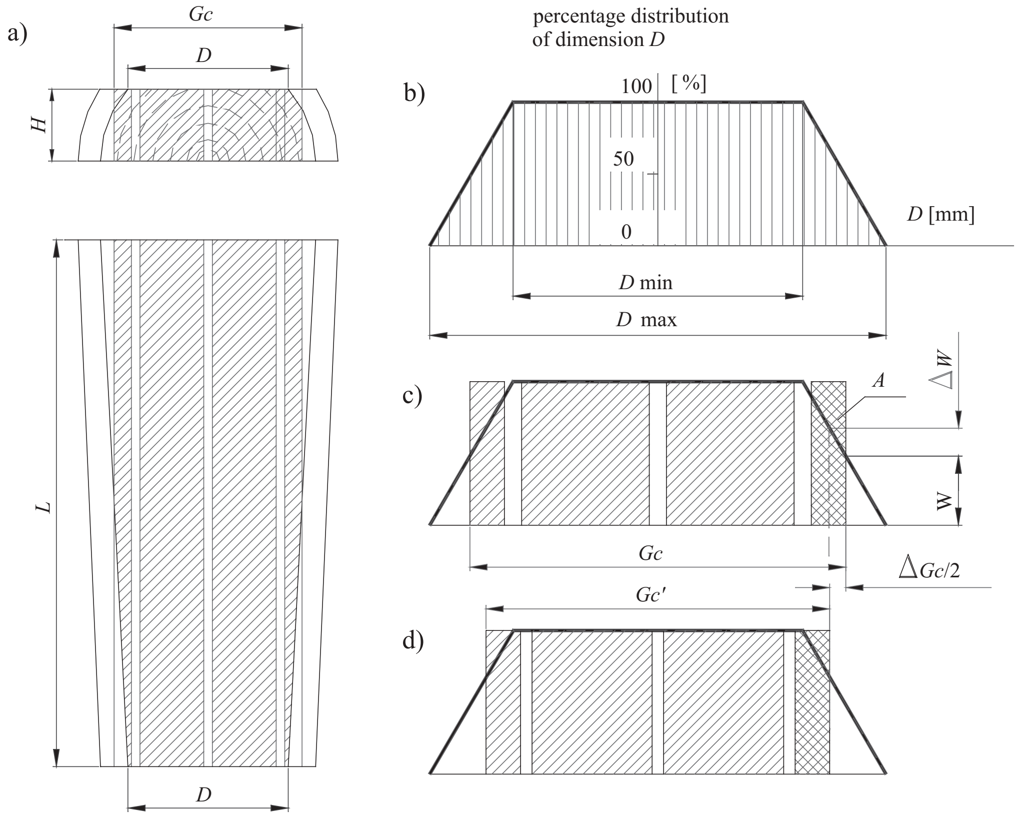

Figure 3 (a) Changes of width and height of side offcuts along the plank length, (b) percentage change distribution of the smallest width D, (c) determination of material yield for the defined total width of the circular saw blade span G_c and (d) the effect of the total width reduction on the material yield
Slika 3. a) Promjene širine i visine bočnih okrajaka uzduž piljenice; b) raspodjela postotne promjene najmanje širine D; c) određivanje iskorištenja sirovine za definiranu ukupnu širinu rasporeda listova kružnih pila G_c; d) učinak smanjenja ukupne širine na iskorištenje materijala

The dimension D is the smallest width of the individual plank with the height H on both sides (Figure 3a). However, in the batch of the raw material that comes to the rip saw, the smallest dimensions D can change in the range of $<D_{min}, D_{max}>$. It can be assumed that during cutting of a quite large batch, the probability of rip sawing of planks with size D in the range of $<D_{min}, D_{max}>$ has a linear distribution (Figure 3b). Thus, in case of the specific plank batch, when boards with the total width of the circular saw blade span Gc should be obtained, only W% of elements A can achieve height H along the whole plank length L. The use of the sawing technology, in which the total width of the circular saw blade span is reduced to the dimension Gc', the quantity of elements A with dimension H along the whole plank length L will increase in value of ΔW % (Figure 3d). That increase of element A efficiency is the increment of raw material yield ΔW and for the range of changes of the total width of the circular saw blade span $D_{min} < Gc < D_{max}$ it can be determined as:

$$\Delta W = \frac{\Delta Gc}{D_{max} - D_{min}} \cdot 100 = \frac{Gc - Gc'}{D_{max} - D_{min}} \cdot 100, \% \qquad (3)$$

Hence, it can be noticed that during rip sawing operations of the plank in the shape as shown in Figure 3 the increment of raw material yield ΔW depends on both the necessary total width of the circular saw blade span G_c of sawn boards and on the spread of the dimension range D in the whole batch. In consequence, a reduction of material losses of the sawing process with circular saw blades demands for a reduction of the tooth overall set of the circular saw (application of thinner saw blades), an increase of sawing accuracy (reduction of circular saw blades axial run-out) and a reduction of the saw blade spacing. An evident proof of the application of a new design of circular saws is especially perceptible if lamellae are an effect of rip-sawing (Wasielewski and Orlowski, 2010). In this case the raw material yield W_m increased by about 10 %, and there were about 16 % less chips. Hence, there was more wood from side boards, which could be raw material for the production of chips for paper mills for instance. What is more, a reduction of power consumption could be expected by roughly 16 %. Since cutting power is a function of the specific cutting resistance k_c, cutting speed v_c and a total area of cut (Manžos 1974):

$$A_{DTot} = z_c \cdot h \cdot S_t \qquad (4)$$

where: z_c is an average number of teeth being in the contact with the kerf, h is an average uncut chip thickness and S_t is a kerf (the width of cut), which is reduced.

The goal of this paper is to make the comparative assessment of both the traditional collar clamped circular saw blades of the "Multix" type and the new design of the circular saw "Ekomultiks" in industrial (plant) conditions.

2 MATERIAL AND METHODS
2. MATERIJALI I METODE

Circular saw blades of the new design ("Ekomultiks", Figure 1b) and the traditional issue ("Multix" type, Figure 1a), both types with carbide tipped teeth, have been examined in industrial (plant) conditions on the twin shaft multi-rip saw Heavy Duty PRW422 (f. TOS Svitavy, CZ). The experiment design variants corresponded to circular saw blade specifications as follows:

1. Variant 1, the traditional issue "Multix": diameter Ø300 mm, overall set (kerf) S_t = 3.7 mm, saw blade thickness s = 2.5 mm separated with distance pieces of Ø110 mm (nominal control board thickness 25.3 mm);
2. Variant 2, the new design "Ekomultiks": diameter Ø300 mm, overall set (kerf) S_t = 3.4 mm, saw blade thickness s = 2.5 mm separated with distance pieces of Ø110 mm (nominal thickness of 25.6 mm for control boards);
3. Variant 3, the new design "Ekomultiks": diameter Ø300 mm, overall set (kerf) S_t = 3.1 mm, saw blade thickness s = 2.2 mm separated with distance pieces of Ø130 mm (nominal thickness of 25.1 mm for control boards).

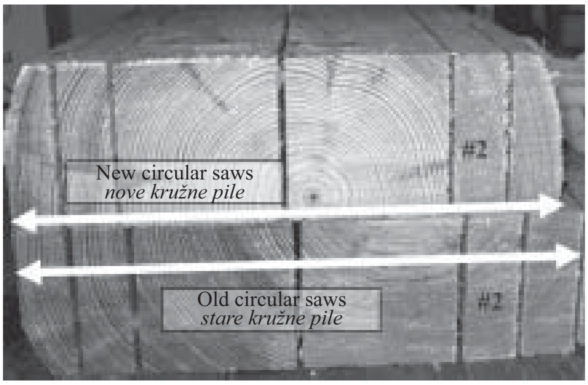

Figure 4 Comparison of pine planks slotted with gangs of circular saws in case of sawing with traditional circular saws "Multix" (lower plank) and new circular saws "Ekomultiks" (upper plank); where: #2 are control boards
Slika 4. Usporedba borove prizme prorezane slogom kružnih pila pri piljenju tradicionalnom pilom "Multix" (niža piljenica) i novom kružnom pilom "Ekomultiks" (gornja piljenica); kontrolna piljenica označena je sa #2

Pine planks (*Pinus sylvestris* L.) were sawn of the height H = 105 mm, and moisture content MC of 25–32 % (Figure 4). During one 8-hour shift, sawn lumber at the controlled position in the gang (boards #2, nominal thickness in the range of 25.1–25.6 mm according to the experiment design variants, Figure 4), was measured with the digital caliper (f. Gedore). Measurements were carried out on the upper (Gg) and lower measurement line (Gd), respectively. Both measurement lines were positioned about 10 mm from the board edge, and at each line three measurements of thickness were done (at points 100 mm away from the board ends and additionally one in the middle of the board).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Comparison of two pine planks slotted during industrial experiments with gangs of circular saw blades in case of sawing with traditional circular saws "Multix" (the lower plank) and new circular saws "Ekomultiks" (the upper plank) is presented in Figure 4. In this picture the position of the measured board is shown as #2.

The measurement results of board thickness determined on the lower and upper measurement line for rip-sawing with "Multix" circular saw blades and "Ekomultiks" circular saw blades are presented in Figure 5. While the "Multix" circular saw blades were used, the range of lumber thickness distribution was 0.5 mm. In the next step "Multix" circular saw blades were replaced with "Ekomultiks" circular saw blades (saw blade thickness of 2.5 mm) and separated with old distance pieces in the gang. In such changed conditions, the lumber thickness distribution of 0.3 mm was obtained both on the upper and lower line. Eventually, we have decided to reduce both circular saw blade thickness (s = 2.2 mm) and distance pieces thickness, and the effects of sawing with "Ekomultiks" circular saw blades separated with new distance pieces, with an outside diameter enlarged to Ø130 mm, are presented in Figure 5c. In this case, the lumber thickness distribution was 0.3 mm both on the upper and lower line. However, it should be emphasized that a reduction of saw blade thickness and a simultaneous increase of the distance piece diameter (from Ø110 mm to Ø130 mm) has guaranteed the same value of the circular saw blade stiffness.

Additionally, comparison of effects of material-saving technology and the traditional sawing technology may be done analytically on the basis of distribution of the input workpiece width changes in percents D (Figure 6). In the examined sawing conditions, from 100 sawn pine planks the following pieces have been

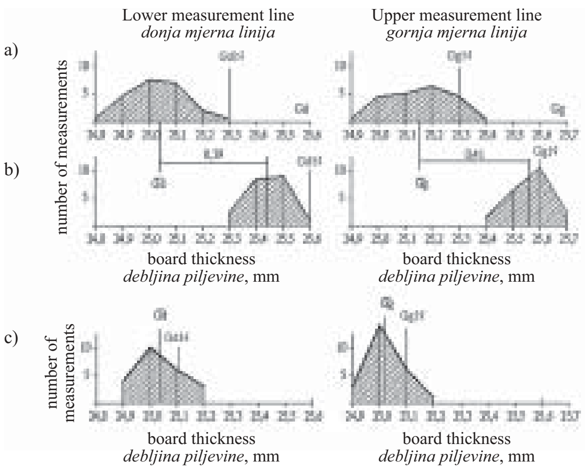

Figure 5 Board thickness determined on the lower and upper measurement line for (a) sawing with "Multix" circular saw blades (S_t = 3.7 mm), (b) "Ekomultiks" circular saw blades (S_t = 3.4 mm) with the use of old distance pieces and (c) "Ekomultiks" circular saw blades (S_t = 3.1 mm) with the use of a new type of distance pieces, where: G_{dN}, G_{gN} – board nominal thickness, G_d, G_g – board average thickness
Slika 5. a) Debljina piljenice određena na donjoj i gornjoj liniji mjerenja pri piljenju kružnom pilom "Multix" (S_t = 3,7 mm), b) kružnom pilom "Ekomultiks" (S_t = 3,4 mm), uz uporabu starih distantnih prstenova; c) kružnom pilom "Ekomultiks" (S_t = 3,1 mm), uz uporabu novog tipa distantnih prstenova, pri čemu su G_{dN}, G_{gN} – nominalne debljine piljenica, G_d, G_g – srednje debljine piljenica

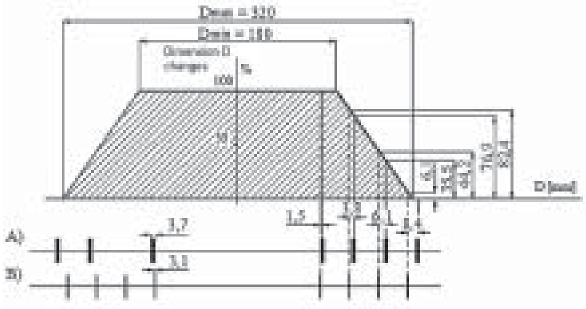

Figure 6 Distribution of changes of the input workpiece width and circular saw blade spacing for sawing with "Multix" circular saw blades (A), and "Ekomultiks" circular saw blades (B)
Slika 6. Raspodjela promjena ulaznih širina obradaka i razmaka između listova pila pri piljenju (A) kružnom pilom "Multix" i (B) kružnom pilom "Ekomultiks"

obtained: 2×(76.9 pcs + 35.5 pcs) = 224.8 pieces of side lumber in the case A, and in the case B 2×(82.4 pcs + 44.2 pcs + 6.1 pcs) = 265.4 items of the side lumber. Thanks to the application of the pro-ecological technology, the following results have also been achieved: an increase of about 18 % in the amount of side lumber, roughly 16 % less sawdust (as an effect of kerf reduction) and about 16 % lower values of the cutting power consumption (see explanation in Chapter 1).

4 CONCLUSION
4. ZAKLJUČAK

On the basis of the conducted experiments and analyses, it can be stated that the use of narrow-kerf saw blades and an increase of the sawing accuracy reduces both the cutting losses and cutting energy consumption in wood sawing. The better use of the input raw material in the presence of the lower cutting energy consumption is the basis of the pro-ecological technologies of wood sawing. The application of such a technology allows the reduction of raw material consumption and furthermore brings measurable economical profits.

However, the actual profits arising out of raw material and energy savings in the case of application of the new sawing technologies (unconventional ones) depends on specific sawmill conditions, i.e.: the sawing pattern, the state of the rip sawing machine and its maintenance, and the staff attitude, as a really important issue. Eventually, the realization of economical wood sawing with circular saw blades seems not to be viable until the whole system of sawing fulfils the defined requirements.

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Investigations of the Compressive Behaviour of Veneer in Thickness Direction

Istraživanje kompresijskih svojstava furnira u smjeru debljine

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ABSTRACT • *Compression tests were conducted with veneers in the thickness direction. Thereby differences between the stress-strain curves of veneers and other known stress-strain curves were observed. Based on microscopic studies during the compression, it was possible to describe the deformation behaviour of the veneer, and deviations from known, typical stress-strain curves were substantiated and explained. It was found that a considerable part of the strain occurs by straightening the veneer at a relatively low stress level due to the waved form of veneer sheets and specimens. A distinctive stress plateau has not been established.*

Keywords: *compression test, deformation, light microscope, stress-strain curve, veneer*

SAŽETAK • *Na furnirima su provedeni kompresijski testovi u smjeru njihove debljine. Uspoređene su dobivene krivulje naprezanja-deformacije furnira s drugim poznatim krivuljama naprezanja-deformacija. Na osnovi mikroskopske studije tijekom kompresije furnira moguće je opisati deformacije furnira i objasniti odstupanje od dosad poznatih, tipičnih krivulja naprezanja-deformacija. Istraživanja su pokazala da se zbog valovitosti listova furnira i uzoraka velik dio deformacija pojavljuje pri ispravljanju furnira već uz relativno nisku razinu naprezanja.*

Ključne riječi*: kompresijski test, svjetlosni mikroskop, krivulja naprezanja-deformacija, furnir*

1 INTRODUCTION
1. UVOD

During veneer coating of boards, veneers are exposed to compressive stress perpendicular to fibre direction. Thereby, the amount of compression depends on the used adhesive, i.e. the compression is determined by the producer of adhesives. In order to estimate the behaviour of veneers under pressure, compressive tests in thickness direction of veneers were conducted. Thereby, differences were observed of the stress-strain curves of veneers from other known stress-strain curves. Gibson and Ashby (1997) have described the compressive stress-strain curve for a number of wood species perpendicular to the fibre. They have described linear-elastic behaviour for very small strains, less than about 2 %. Beyond this area, the curve shows a stress plateau extending to strains between 10 % and 80 % depending on the density of the wood. For beech

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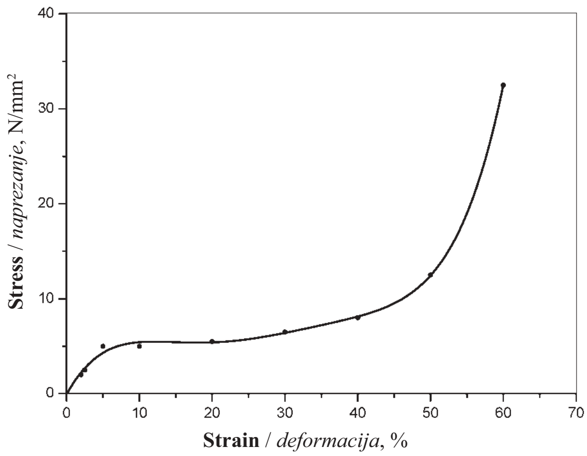

Figure 1 Typical stress-strain curve by compression for Aspen (Tabarsa and Chui, 2001)
Slika 1. Tipična krivulja naprezanja-deformacija za kompresiju drva jasike (Tabarsa i Chui, 2001)

they have displayed the beginning of the plateau at about 4 %. At the end of the plateau, the stress rises sharply (see Fig. 1). Ellis and Steiner (2002) have investigated the behaviour of five wood species in compression. All species have shown a more or less steep slope up to 2 to 3 % strain in radial or tangential compression, followed by the stress plateau described by Gibson and Ashby (1997). Depending on species and density, the stress plateau reached 20 % or 70 % strain. Numerous other investigations have led to similar results (Dwianto *et al*, 1998; Shams and Yano, 2004; Tabarsa and Chui, 2001).

Compressive tests are often conducted in connection with a densification of wood. In general, such investigations aim at the production of wood with permanently higher density. In order to densify the wood as undamaged and high as possible, it is softened or plasticized. Thus, clearly higher compressive strains are reached. However, the general devolution of the stress-strain curves does not differ from the non-plasticized wood concerning the strain values of the elastic range. The stress plateau begins at approximately 2 to 5 % (Inoue *et al*, 2008; Morsing, 2000).

This study presents and discusses the material behaviour of veneers under compressive stress in thickness direction. The aim of this study was the understanding of the material behaviour under pressure. Thereto stress-strain curves obtained from compressive tests of veneer are explained and differences between the stress-strain curves obtained for veneers and that described above are reasoned.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Compressive tests were conducted with beech veneers (*Fagus sylvatica* L.) using a universal testing machine. Thereto commercially available veneers were used, produced for decorative purposes. The flat cut veneers had no noticeable cutting checks.

There is no special standard for compression tests for veneers. For the experiments, round shaped specimens were used. The round shape ensured that the same amount of cut fibres was always stressed. The thickness of the specimens corresponded to the veneer thickness. Stress was raised uniformly till 34 N/mm², in order to reach the plastic range of the material and after that unloaded immediately. The strain measurement was conducted with the testing machine corrected with a machine stiffness correction.

30 specimens with a diameter of 15 mm and a thickness of approximately 0.5 mm were tested. The production of veneers results in a direction between radial and tangential direction as thickness direction. So the veneers were stressed perpendicularly to the fibre, but not exactly in radial or tangential direction.

In order to avoid a non-uniform pressure in the case of uneven, inclined running specimen surfaces, the upper part of the testing device was designed to be movable. The lower part of the testing device was designed to be fixed.

For investigating the deformation behaviour of the veneer, different specimens were pressured under a light microscope. To that end a mini precision compression device was used, which was stepwise closed manually. Images were taken at different pressure levels and used to exactly determine the actual thickness of the specimen. Thus it was possible to determine the strain and relate it to the stress-strain curves obtained from the testing machine.

The specimens were conditioned to 21 °C and 65 % relative humidity and tested under the same conditions.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figure 2 shows a typical stress-strain curve of a veneer compression test. After the initial flat slope of stress up to approximately 0.5 N/mm² and 10 % strain (range I), the stress rises steeply. This range II is approximately located between 10 and 20 % strain. In the range III, the slope truncates clearly, but without a distinctive plateau. With a strain of approximately 25 %, the slope becomes steeper again.

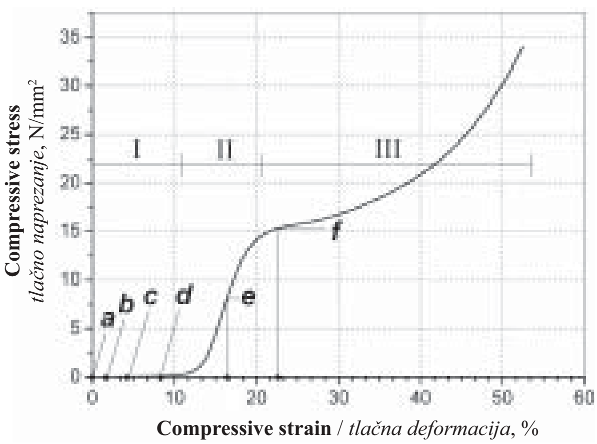

Figure 2 Stress-strain curve of a beech veneer compressive test
Slika 2. Krivulja naprezanja-deformacija za kompresijski test bukova furnira

The letters (a – f) within Figure 2 are the letters of the microscopic images in Figure 3, related to the stress-strain curve.

Figure 3 (a - f) shows the microscopic images related to the diagram in Figure 2. The borders of the compressive plates and the compression device are marked with a black line, respectively. It can be seen that the compressive plates in Figure 3d do not abut on the veneer completely. There is already a strain of 7.8 %. Only in Figure 3e the borders of the compressive plates seem to be in complete contact with veneer. A high strain of 17.1 % can be recognised there. The microscopic images show that there is a difference between macroscopic and microscopic deformation and displacement in case of compressive stress of a veneer in thickness direction. The macroscopic deformation means the straightening of the waved veneer. The thin veneers are not absolutely plane, but slightly warped. This kind of deformation is measured during the compressive test as elastic strain and occurs at a very low stress level. This first range generates the straight line in the stress-strain diagram with a very low slope and a relatively high strain (range I in Figure 2). In the following range II of the diagram, elastic and plastic strains are supposedly parallel. This conclusion can be drawn from the microscopic studies. The measurements of the alternation in thickness in the microscopic range showed that plastic strains occur during strains at a relatively low level (for example after stressing with 2.5 % strain, a permanent elongation of 0.5 % could be measured). However the values of permanent elongation are in a range of 1 to 2 µm, a dimension that cannot be detected with a testing machine. These values are in the range of the noise and cannot be measured as plastic elongation. Although this plastic elongation can be measured using the microscope, no deformed cellular tissue can be detected at 100-fold magnification. The material seems not to have suffered any damage

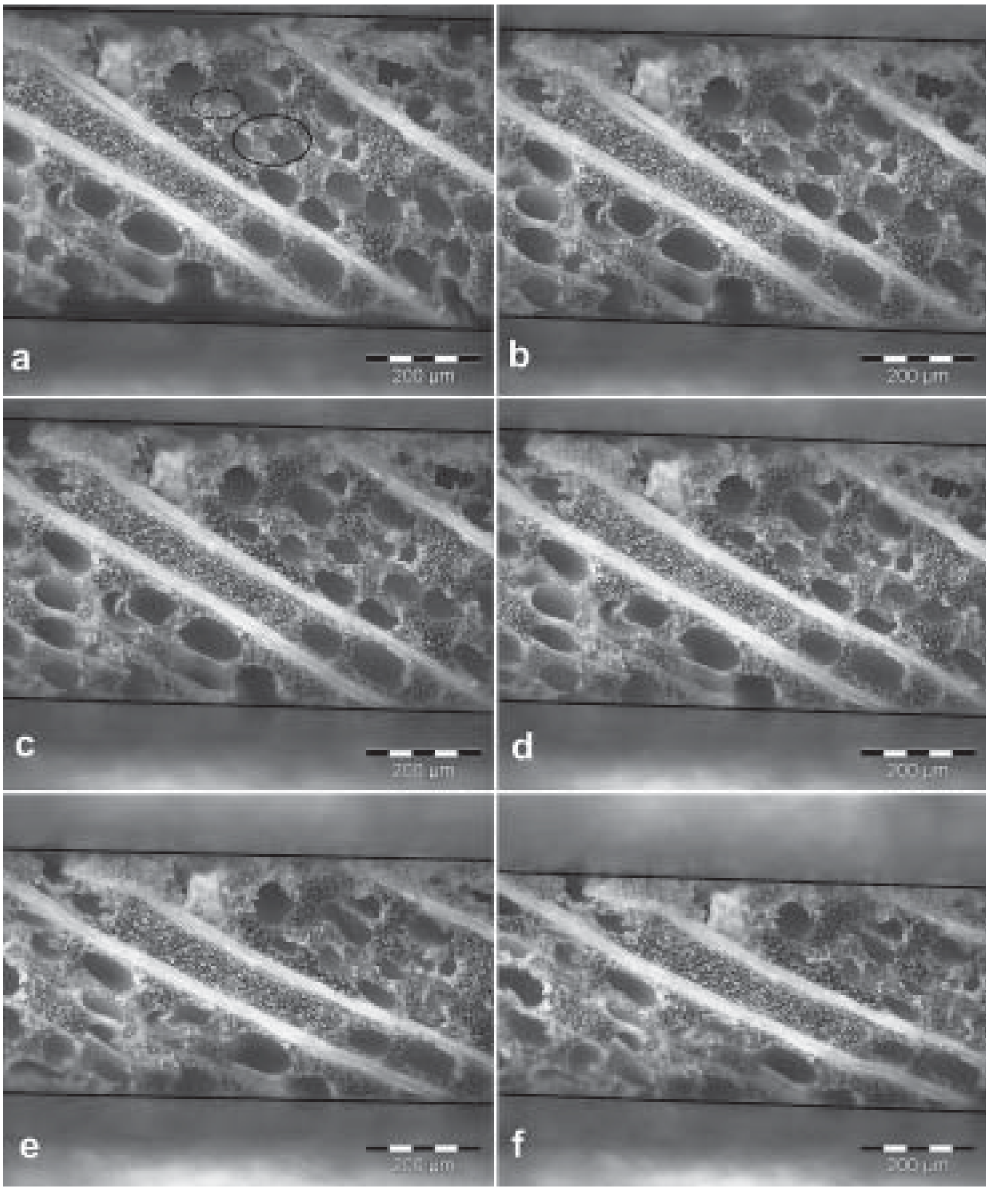

Figure 3 Microscopic images with different compressive strain situations: a) without stress, b) 1.9 % strain, c) 4.9 % strain, d) 7.8 % strain, e) 17.1 % strain, f) 23.1 % strain
Slika 3. Mikroskopske slike s različitim veličinama deformacije zbog naprezanja: a) bez naprezanja, b) deformacija 1,9 %, c) deformacija 4,9 %, d) deformacija 7,8 %, e) deformacija 17,1 %, f) deformacija 23,1 %

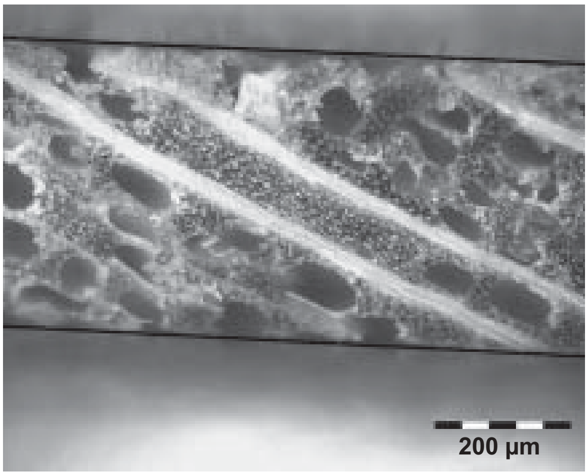

Figure 4 Specimen after the compressive test in unstressed status
Slika 4. Uzorak nakon kompresijskog testa u stanju bez naprezanja

due to the stress. Cracks and failures in the cell walls, at the rays or between the cells can already be detected before the beginning of stress (see remarked areas in Figure 3a). However, it is not verifiable if the failures are caused by the specimen preparation or the production of the veneer. Nevertheless, it can be supposed that the plastic strain portion occurs due to existing tissue damages or due to the displacement of cells or cell lines against each other. Therefore 1 to 2 µm displacement and elongation are possible, respectively.

The range III in Figure 2 is represented by the microscopic image in Figure 3f. Plastic deformations occur there. A typical distinctive stress plateau has not been established for all veneer specimens. Probably there are not enough large cell lumens that can be compressed. The few cavities available are compressed without generating a large amount of strain with constant stress. Then the stress rises strongly.

Figure 4 shows the specimen after the test in unstressed status. The permanent deformations of the cell tissue can be seen clearly.

4 CONCLUSIONS
4. ZAKLJUČCI

The stress-strain behaviour from veneers in thickness direction under compressive stress differs from that of other known stress-strain curves of wood. Due to the waved form of the veneer sheets and specimens, a considerable part of the strain occurs by straightening the veneer at a relatively low stress level. A distinctive stress plateau has not been established.

The compressive stress, applied during the coating process, amounts to 1 to 2 MPa. The veneer can endure this stress without substantial damages.

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Prediction of Modulus of Rupture and Modulus of Elasticity of Heat Treated Anatolian Chestnut (*Castanea Sativa*) Wood by Fuzzy Logic Classifier

Predviđanje modula loma i modula elastičnosti toplinski obrađenog drva anatolskog kestena (*Castanea sativa*) modelom razvrstavanja *fuzzy* logikom

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ABSTRACT • *In this study, test samples prepared from Anatolian chestnut (Castanea sativa) wood were first exposed to heat treatment at 130, 145, 160, 175, 190 and 205 ºC for 3, 6, 9 and 12 hours. Then the values of the samples of the modulus of rupture (MOR) and modulus of elasticity (MOE) were determined and evaluated by multiple variance analysis. The aim of this study was to establish the effects of heat treatment on the MOR and MOE values of wood samples by using fuzzy logic classifier. Secondly, input and output values and rule base of the fuzzy logic classifier model were built by using the results obtained from the experiment. The developed fuzzy classifier model could predict the MOR and MOE values of test samples at the accuracy levels of 92.64 % and 90.35 %, respectively. The model could be especially employed in manufacturing stages of timber industry.*

Keywords: *wood, heat treatment, fuzzy logic classifier, modulus of rupture, modulus of elasticity*

SAŽETAK • *U radu se prikazuju istraživanju u kojima su, prije svega, pripremljeni uzorci od drva kestena te izloženi zagrijavanju na temperaturama od 130, 145, 160, 175, 190 i 205 ºC tijekom 3, 6, 9 i 12 sati. Nakon toga uzorcima su određeni modul loma (MOR) i modul elastičnosti (MOE) te je napravljena analiza varijanci dobivenih vrijednosti. Cilj provedene studije bio je utvrditi učinak toplinske obrade drva na MOR i MOE vrijednosti drvnih uzoraka uporabom modela razvrstavanja neizrazitom (fuzzy) logikom. Ulazne i izlazne vrijednosti te osnovna pravila modela neizrazitog razvrstavanja definirani su uporabom rezultata dobivenih eksperimentom. Razvijeni model neizrazitog (fuzzy) razvrstavanja moguće je primijeniti za predviđanje MOR i MOE vrijednosti drvnih uzoraka s točnošću od 92,64 % i 90,35 %. Model može biti primijenjen u proizvodnim uvjetima, posebice u procesu proizvodnje piljene drvne građe.*

Ključne riječi*: drvo, toplinska obrada, model razvrstavanja fuzzy logikom, modul loma, modul elastičnosti*

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1 INTRODUCTION
1. UVOD

Heat treatment is one of the processes used to modify wood properties (Mazela *et al*, 2004). Heat treatment, which is a wood modification method, serves to improve the natural quality of the wood, such as dimensional stability and resistance to the effects of some corrosion and provide the wood material with new properties. The heat treatment process involves exposing wood to elevated temperatures ranging from 160 to 260 °C (Militz, 2002). The duration and temperature of heat treatment range from 15 min to 24 h and from 180 °C to 280 °C depending on the wood species, sample size, moisture content of the wood sample and the desired mechanical properties (Militz, 2002; Kandem *et al*, 2002). The heat treatment reduces certain mechanical properties of wood, but the dimensional stability and the durability of wood against biological attacks increase. Also, heat treatment results in favorable changes in the physical properties of the wood (Yıldız, 2002).

Wood is a natural and complex material constituted mainly of three biopolymers: lignin, cellulose and hemicelluloses. In addition to these polymeric components, wood may contain extractives in more or less large quantities including several classes of organic compounds like sugars, tannins, terpenes, fats or waxes (Nguila *et al*, 2006). Owing to heat treatment and thermal degradation, wood loses its weight. Weight loss depends on the heat treatment temperature and time, specimen size and prevailing circumstances during the heat treatment. The main targets for industrial heat treatment are increased biological durability, enhanced weather resistance and decreased shrinking and swelling of wood (Kandem *et al*, 2002). On the other hand, as a result of heat treatment, the wood becomes more fragile, and bending and tension strength decrease in relation to the level of heat treatment conditions (Kandem *et al*, 2002; Korkut *et al*, 2008; Bekhta and Niemz, 2003; Özçifçi *et al*, 2009).

There are some studies about the effects of heat treatment on mechanical and physical properties of wood, but the application of the fuzzy logic classifier in wood industry is very limited. Nevertheless, some researchers have focused on the fuzzy logic classifier model recently. Researchers suggested a fuzzy regression approach to estimate functional relationships (Kim and Park, 1998). Other researchers proposed another fuzzy regression approach, based on asymmetric triangular fuzzy coefficients, to model the functional relationships (Chen *et al*, 2004).

The use of non-linear programming to develop fuzzy regression models for the functional relationships was also proposed (Chen *et al*, 2005). Yapıcı *et al,* (2009) used fuzzy logic classifier model for predicting the modulus of rupture and modulus of elasticity of wood composite material, called the flake board. The model agreed well with the experimental results with maximum errors for modulus of rupture and modulus of elasticity at 5% and 3%, respectively (Yapıcı *et al*, 2009). Yapici and Gologlu (2009) also used fuzzy logic classifier model for predicting thickness swelling and weight increase on heat treated *Black Pine* (*Pinus Nigra*) wood. Their model was able to predict the thickness swelling and weight increase of test samples at the accuracy levels of 99.6 % and 86.05 %, respectively. Cha and Pearson developed two dimensional finite element models to predict the elastic tensile properties of a 3-ply model on LVL. The values of the predicted and experimental strains at maximum load (max. difference of 14.3 %) as well as the predicted and experimental stresses (max. difference of 7.7 %) matched acceptably (Cha *et al*, 1994).

The temperature and time used in the heat treatment process had different effects on the chemical, physical, and mechanical properties of wood material. Measuring of the effects of each parameter is too expensive and carrying out the experiments is also time-consuming. Fuzzy logic classifier is one of the powerful approaches to model these effects. In this study, heat treatment was applied to wood specimens. Test samples were prepared from Anatolian chestnut widely used in the shipbuilding industry. Then the MOR and MOE properties of the samples were determined experimentally. The results obtained experimentally were compared with the fuzzy logic classifier model for the accuracy.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The Anatolian chestnut (*Castanea sativa*) wood was chosen randomly from timber merchants of Bartın, Turkey. The selected specimens were cut for modulus of rupture (MOR) and modulus of elasticity (MOE) (20x20x360 mm), and they were exposed to heat treatment at 130, 145, 160, 175, 190 and 205 ºC for 3, 6, 9, 12 hours. After this process, the test samples were conditioned to constant weight at 65±5 % relative humidity and at a temperature of 20±2 °C until they reached a stable weight (TS 642 1997).

To determine MOR and MOE values of test samples, Zwick/Roell Z050 universal test device was used with the capacity of 5000 kg. In testing, the loading mechanism was operated with a velocity of 6 mm/min. MOR and MOE experiments were performed (TS 2474 1976).

2.1 Statistical analyses
2.1. Statističke analize

Data were statistically analyzed. The analysis of the variance (ANOVA) was used ($p \leq 0.05$) to evaluate the significance in the difference between factors and levels. When the ANOVA indicated a significant difference among the factors, Duncan's test was done for comparing these means.

2.2 Design of fuzzy logic classifier for predicting MOR and MOE
2.2. Izrada modela razvrstavanja *fuzzy* logikom za predviđanje MOR i MOE vrijednosti

Fuzzy logic was used for the first time in 1965 by Zadeh. In his approach Zadeh developed a new consideration instead of Aristotelian logic that contained two definite and different possibilities only 1-0. Fuzzy

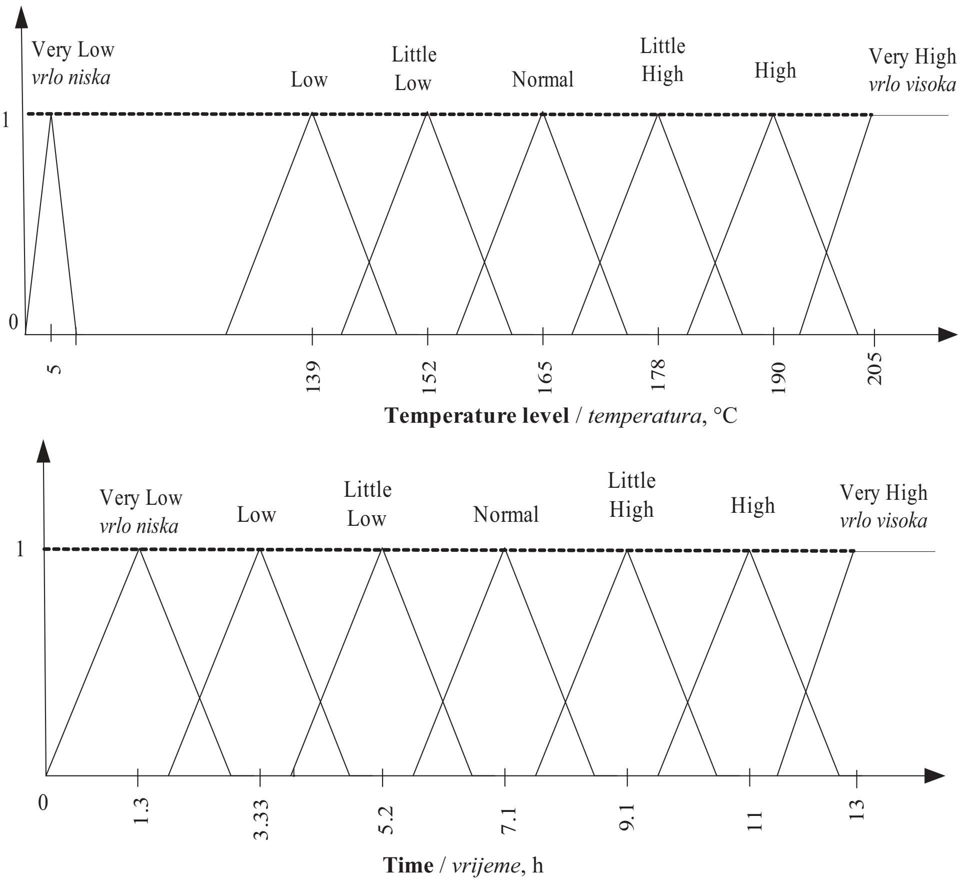

Figure 1 Input variables refer to both temperature level and time of the heat treatment process
Slika 1. Ulazne varijable koje pripadaju vrijednosti temperature i vremenu zagrijavanja

set theory provides a systematic calculus to deal with such information linguistically. Fuzzy performs numerical computation by using linguistic labels stimulated by membership functions (Zadeh, 1965). Input values contain all input parameters and information about them. Fuzzification converts each input data to degrees of membership by reference to one or more membership functions. Fuzzy rule base contains rules that include all possible fuzzy relations between input and outputs. Fuzzifier unit converts definite data in the input of the controller to the format of linguistic variables. Inference unit is a unit that performs fuzzy inference on fuzzy rules. Defuzzification unit converts the fuzzy values obtained from the output of the inference units to numerical values.

In this study, the fuzzy rules of the system were constructed according to the input and output variables, and their membership functions. Triangular membership functions were used because of the fact that it was widely preferred in the literature. The system has 71 rules.

Input variables used in the heat treatment process were designated as the value of heat treatment temperature and waiting times of the test samples. The degree of input variables refers to both temperature level and time of the heat treatment process, and they were designated as very low, low, little low, normal, little high, high, very high (see Figure 1). MOR and MOE values of test samples were used as output variables in membership function. Output variables were designated as very low, little low, low, normal, little high, high and very high, and they are presented in Figure 2.

The fuzzy logic controller model was developed by using MATLAB Simulink to predict MOR and MOE values of test samples. Input variables can be changed automatically or manually in this developed model. MOR and MOE values could be observed step by step in this model. The results obtained were simultaneously recorded to a file and to Matlab Workspace.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The variance analysis of MOR and MOE was conducted based on the heat treatment and time in the heat treatment process. Multiple variance analysis was used to determine the differences among the test samples. The results of variance are presented in Table1. According to the results of the variance analysis, it can be seen that the effects of waiting time and temperature levels on the MOR and MOE was meaningful at 95 % significance level. To identify the significance level of the differences among the other groups, Duncan test was done to establish whether it was significant or not. The results of Duncan test are presented in Table 2. It can be seen that the results obtained from experiments compared to the data predicted by fuzzy classifier were very successful.

The fuzzy logic classifier predicted the modulus of rupture and modulus of elasticity of samples with the average accuracy of 92.64 % and 90.35 %, respec-

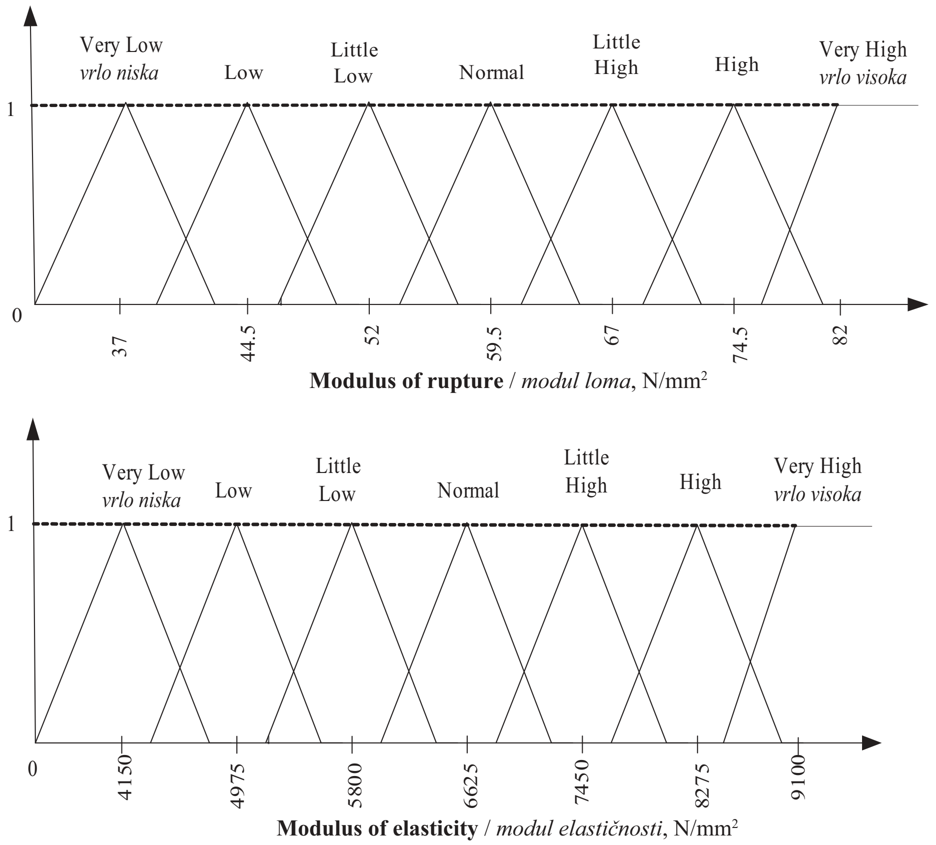

Fig. 2 Output variables refer to both modulus of elasticity and modulus of rupture
Slika 2. Izlazne varijable koje pripadaju modulu elastičnosti i modulu loma

tively. The MOR and MOE values obtained experimentally and predicted by classifier are presented according to heat treatment conditions in Table 3.

The changes of modulus of rupture and modulus of elasticity values of test samples according to condition of heat treatment are shown in Figure 3. As the temperature and time increase step by step between 0 and 205 °C, and from 0 to 12 hours, respectively, the changes of MOR and MOE values can be seen by fuzzy logic classifier model developed in this study.

Table 1 The results of variance analysis
Tablica 1. Rezultati analize varijance

	Source *Izvor*	**Type III Sum of Squares** *Zbroj kvadrata*	***df***	**Mean Square** *Kvadrat srednje vrijednosti*	***F***	**Significance** *Značajnost* (*p*<0.05)
Modulus of rupture *modul loma*, N/mm²	Corrected Model	67033.52	24	2793.06	14.33	0.00
	Intercept	1117883.18	1	1117883.18	5734.07	0.00
	Factor A	53975.45	5	10795.09	55.37	0.00
	Factor B	6309.17	3	2103.06	10.79	0.00
	A * B	4191.71	15	279.45	1.43	0.13
	Error	77981.81	400	194.95		
	Total	1456878.04	425			
Modulus of elasticity *modul elastičnosti*, N/mm²	**Source** *Izvor*	**Type III Sum of Squares** *Zbroj kvadrata*	***df***	**Mean Square** *Kvadrat srednje vrijednosti*	***F***	**Significance** *Značajnost* (*p*<0.05)
	Corrected Model	864704491	24	36029353,79	23.59	0.00
	Intercept	9885387195	1	9885387195	6472.44	0.00
	Factor *A*	789170216.2	5	157834043,2	103.34	0.00
	Factor *B*	15067481.64	3	5022493.88	3,29	0.02
	*A * B*	60456978.78	15	4030465.25	2.64	0.00
	Error	610921838.7	400	1527304.6		
	Total	13554815761	425			
Factor *A*: Temperature, ºC; Factor *B*: Time, h / *Činitelj A: temperatura, ºC; činitelj B: vrijeme, h.*						

Table 2 Duncan test results
Tablica 2. Rezultati Duncanova testa

Heat treatment conditions *Uvjeti toplinske obrade*		**MOR**		**Heat treatment conditions** *Uvjeti toplinske obrade*		**MOE**	
Temperature *Temperatura* ºC	Time *Vrijeme* h	Average *Srednja vrijednost* N/mm²	HG	Temperature *Temperatura* ºC	Time *Vrijeme* h	Average *Srednja vrijednost* N/mm²	HG
205	12	32.14	A	205	9	3683.6	A
205	9	32.83	A	205	6	3824.32	AB
205	6	36.23	AB	205	12	3929.48	ABC
190	9	43.21	BC	205	3	4118.23	ABCD
190	12	44.25	BC	175	12	4232.52	ABCD
190	6	44.55	BC	190	3	4298.75	ABCD
175	12	46.02	BC	190	6	4355.02	ABCD
175	9	46.73	BCD	175	9	4356.77	ABCD
205	3	48.35	CD	175	3	4394.82	ABCDE
190	3	50.01	CDE	190	9	4401.31	ABCDE
175	6	53.52	CDEF	160	3	4507.21	ABCDE
175	3	56.81	DEFG	190	12	4539	ABCDE
145	12	58.88	EFG	160	12	4557.45	ABCDE
130	12	59.42	EFG	175	6	4803.35	BCDE
160	12	59.73	EFG	160	6	4869.5	CDE
145	9	60.5	EFG	160	9	5042.23	DE
145	3	63.83	FGH	0	0	5354.74	E
160	9	65.1	GH	130	12	6483.66	F
145	6	65.26	GH	130	9	6810.34	F
160	3	65.29	GH	145	6	6861.74	F
160	6	65.37	GH	145	9	6888.11	F
130	9	66.61	GH	145	12	6991.91	FG
0	0	67.58	GH	145	3	7154.24	FG
130	3	74.71	HI	130	3	7813.27	G
130	6	82.02	I	130	6	9008.27	H

HG – homogenous group / *HG – homogena skupina;* MOR – modulus of rupture / *modul loma;*
MOE – modulus of elasticity / *modul elastičnosti*

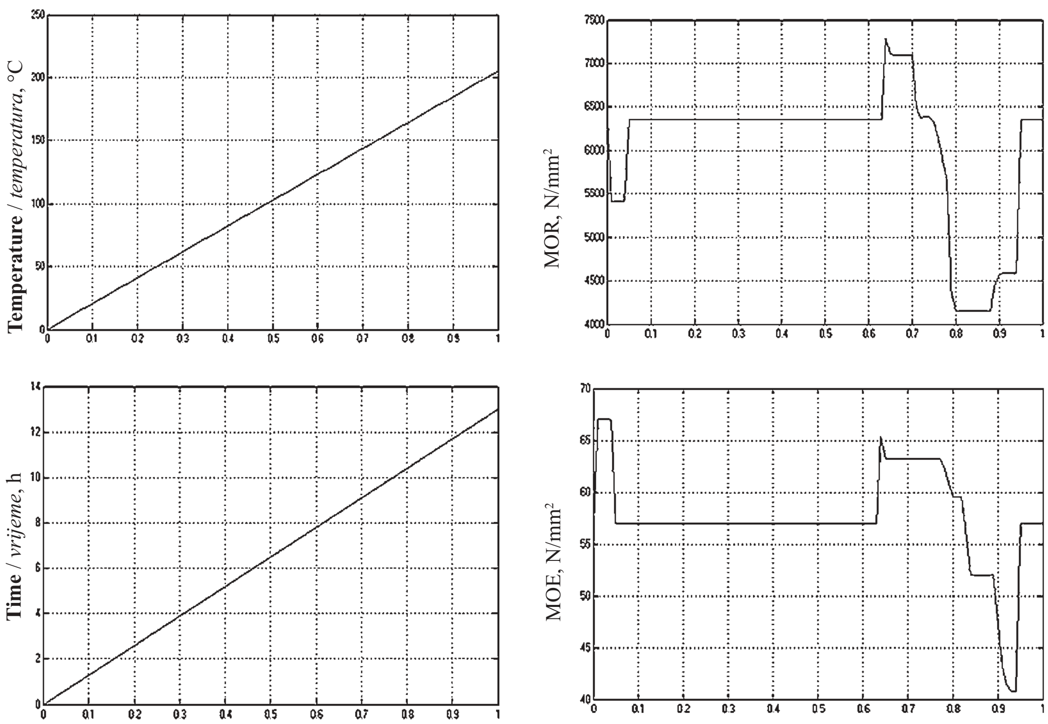

Figure 3 MOR and MOE values according to heat treatment conditions
Slika 3. MOR i MOE vrijednosti ovisno o uvjetima toplinske obrade

Table 3 Measured and prediction results
Tablica 3. Izmjereni rezultati i rezultati predviđanja

Experiment conditions *Uvjeti eksperimenta*		**Modulus of rupture** *Modul loma*, N/mm^2			**Modulus of elasticity** *Modul elastičnosti,* N/mm^2		
Temperature *Temperatura* °C	Time *Vrijeme* h	Experiment *Eksperiment*	Prediction *Predviđanje*	Accuracy level *Točnost* %	Experiment *Eksperiment*	Prediction *Predviđanje*	Accuracy level *Točnost* %
0	0	67.58	57	84.35	5354.74	6349	81.43
130	3	74.71	57	76.29	7813.27	6349	81.26
	6	82.02	58	70.72	9008.27	6410.5	71.16
	9	66.61	57	85.57	6810.34	6367.8	93.5
	12	59.42	58.3	98.11	6483.66	6421.7	99.04
145	3	63.83	67	95.04	7154.24	7040.3	98.41
	6	65.26	70.8	91.51	6861.74	6713.5	97.84
	9	60.5	63.3	95.38	6888.11	6721.6	97.58
	12	58.88	59.5	98.94	6991.91	6190.46	88.54
160	3	65.29	64.3	98.49	4507.21	5702.3	73.49
	6	65.37	67	97.5	4869.5	5639.1	84.2
	9	65.1	63.4	97.38	5042.23	6010.5	80.8
	12	59.73	59.5	99.62	4557.45	5934.3	69.79
175	3	56.81	59.5	95.27	4394.82	4538.6	96.73
	6	53.52	52	97.15	4803.35	4562.12	94.98
	9	46.73	44.5	95.22	4356.77	4176.3	95.86
	12	46.02	52	87.01	4232.52	4169.2	98.5
190	3	50.01	49.7	99.39	4298.75	4154.2	96.64
	6	44.55	41.4	92.93	4355.02	4210.4	96.68
	9	43.21	42.3	97.9	4401.31	4751.3	92.05
	12	44.25	40.8	92.2	4539	4581.4	99.07
205	3	48.35	48.3	99.9	4118.23	4160.3	98.98
	6	36.23	37	97.87	3824.32	4156.6	91.31
	9	32.83	36.9	87.61	3683.6	4165.7	86.91
	12	32.14	37.1	84.58	3929.48	4163.2	94.05
		Average accuracy: 92.64 % *Prosječna točnost: 92,64 %*			Average accuracy: 90.35 % *Prosječna točnost: 90,35 %*		

4 CONCLUSION
4. ZAKLJUČAK

Firstly, after the wood samples had been heat-treated, the MOR and MOE values were determined experimentally. It can be seen that MOR and MOE values were affected by both heat temperature and time of heat application. The results were used to build the fuzzy classifier system. Secondly, a model based on Fuzzy Logic was developed in Matlab Simulink in order to predict the values of MOR and MOE, which are among the most important mechanical features of solid wood. With the help of this model, the average MOR values were predicted to be 92.64 % accurate, while the average MOE values were predicted to be 90.35 % accurate. The MOR and MOE values of the samples could be found at any heat treatment conditions in very short time thanks to this model. Fuzzy logic classifier model can be used for prediction and optimization of mechanical and physical properties of solid wood.

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Compression Strength of Fir and Beech Wood Modified by Citric Acid

Čvrstoća na tlak jelovine i bukovine modificirane limunskom kiselinom

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ABSTRACT • *Previous articles have shown that modification of wood by citric acid (CA) improves dimensional stability and resistance of wood against fungi attack. However, chemical modification of wood also modifies its mechanical properties in some way. The compression strength of wood is one of its representative mechanical properties. Modified wood with lower values of compression strength has limited purpose. The intention of this work is to show the effect of wood modification by citric acid on the compression strength of wood.*
Fir wood (Abies alba Mill.) and beech wood (Fagus sylvatica L.) were impregnated by citric acid with sodium-dihydrogen-hypophosphite (NaH_2PO_2) as a catalyst. Part of the impregnated samples together with control samples were cured at the temperature of 140 °C for 10 hours and the remaining samples were cured in microwaves for 35 minutes. The average compression strength parallel to the grain of wood modified by CA, using different regimes of curing, was compared to the strength of unmodified wood. The average compression strength parallel to the grain of wood was retained after modification. In the case of fir wood, the average compression strength was even improved after modification. The results indicate that wood modified by citric acid may be considered for the purposes where compression strength properties are equally important as improved durability and dimensional stability of wood.

Keywords: *Fir wood (Abies alba Mill.), beech wood (Fagus sylvatica L.), chemical modification, citric acid (CA), compression strength*

SAŽETAK • *Objavljeni su radovi pokazali da se modifikacijom drva limunskom kiselinom poboljšava stabilnost dimenzija drva i njegova otpornost na djelovanje gljiva. Međutim, kemijska modifikacija drva na neki način mijenja i mehanička svojstva drva. Tlačna je čvrstoća jedno od bitnih mehaničkih svojstava drva. Modificirano drvo sniženih vrijednosti tlačne čvrstoće ima ograničenu upotrebu. Cilj rada bio je pokazati učinak modifikacije drva limunskom kiselinom (CA) na tlačnu čvrstoću drva. Drvo jele (Abies alba Mill.) i bukve (Fagus sylvatica L.) impregnirano je limunskom kiselinom uz dodatak natrij-dihidrohen-hipofosfita (NaH_2PO_2) kao katalizatora. Dio impregniranih uzoraka zagrijavan je zajedno s kontrolnim uzrocima pri temperaturi od 140 °C deset sati, a drugi je dio 35 minuta bio izložen mikrovalovima. U radu je uspoređena prosječna čvrstoća na tlak paralelno s vlakancima modificiranog drva zagrijavanoga različitim postupcima s odgovarajućom čvrstoćom nemodificiranoga drva.*
Prosječna čvrstoća na tlak paralelno s vlakancima drva zadržana je i nakon modifikacije. Prosječna čvrstoća na tlak modificirane jelovine čak je i povećana u usporedbi s nemodificiranom. Rezultati upućuju na mogućnost

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primjene drva modificiranoga limunskom kiselinom i za one namjene u kojima je uz povećanu stabilnost dimenzija i trajnost drva važna i tlačna čvrstoća drva.

Ključne riječi: *drvo jele (*Abies alba *Mill.), drvo bukve (*Fagus sylvatica *L.), kemijska modifikacija, limunska kiselina (CA), čvrstoća na tlak*

1 INTRODUCTION
1. UVOD

Wood is a natural renewable material that can be used for different purposes. In spite of its benefits, it has some disadvantages that limit its utility value. Wood can be degraded by microorganisms, xylophages (insects), UV rays. It is flammable and hygroscopic, and it changes dimensions at specific moisture contents with different air humidity. All the above mentioned disadvantages limit wood use compared to other new materials. There are many methods developed to reduce or even eliminate undesired wood properties. One of them is the chemical modification of wood. The main goal of the said modification is to improve dimensional stability and durability of wood, while retaining its mechanical properties.

The chemical modification of wood is the reaction of a chemical reagent with the hydroxyl groups of holocellulose and lignin (Militz et al, 1997).

Over 90 % of cotton textiles consist of cellulose, while the percentage of cellulose in the wood is about 40 – 50 %. Large percentage of cellulose in the wood explains the fact that impregnation solutions suitable for durable-press finishing of cellulose textile materials can be efficiently applied to the wood. One of them is 1.3 dimethylol-4.5-dihydroxyethyleneurea (DMDHEU), which is successfully introduced to wood (Nicholas and Williams, 1987; Militz, 1993; Krause *et al*, 2003; Schaffert *et al*, 2005; Wepner and Militz, 2005; Hill, 2006).

Due to chemical modification of wood, its mechanical properties may be improved, reduced or retained. Chemical modification of wood may reduce its water absorption, which can also lead to improving its mechanical properties. Mechanical properties of wood can be improved by wood acetylating (Akitsu *et al*, 1993; Goldstein *et al*, 1961; Militz, 1991). On the other hand the degradation of wood cell wall by acid chemicals and higher temperature of thermocondensation during the wood modification process (i.e. etherification with alkyl chloride) can cause loss of strength. Some authors reported great strength loss of wood modified by DMDHEU due to acid degradation of the cell wall (Nicholas and Wiliams, 1987; Hill, 2006).

Xie *et al*. (2007) reported great loss of tensile strength of thin veneer strips modified by DMDHEU, determined by a thin-veneer strip technique (Turkulin and Sell, 2002). According to them the cause is probably in the catalyst and namely magnesium chloride, which makes complex compounds with DMDHEU directly affecting the loss of wood strength. Another factor that limits the application of DMDHEU is hydrolytic formaldehyde release at elevated temperatures of processing, so new environmentally friendly chemicals have been introduced. One of them is citric acid (CA).

Katović *et al.* (1994) esterified solid fir and beech wood with citric acid (CA) and NaH_2PO_2 (SHP) as a catalyst. First results reported good improvement in wood stability giving guidelines to other researchers. Hasan *et al.* (2006, 2007) and Despot *et al*. (2008) reported multiple increasing of biological durability of pine sapwood modified by CA.

Bischof Vukusic *et al*. (2006) described the effect of wood modification by CA on the reduction of water uptake and swelling of small wooden blocks. They compared the results with those obtained using DMDHEU as the modifying chemical.

In the present study we also focus on microwave curing. Microwave dielectric heating is based on the activation of polar molecules in the treated medium (polarization phenomenon). Cellulose, hemicelluloses and lignin are polar polymers whose electric properties are defined by polarization processes that take place because of the interactions between the molecules of the wood and the external field (Torgovnikov, 1993). Microwaves allow more uniform and faster heating of the whole volume, not just the surface. An additional advantage of the MW treatment lies in the fact that the energy (heat) and the mass (water) flow are travelling in the same direction. These advantages are additional reasons to use microwaves for drying. Furthermore, the energy consumption is 60-70 % lower in the case of microwave treatment (Metaxas and Meredith, 1982).

In addition to all above, so far there has been no report on mechanical properties of wood modified by CA, although mechanical properties can also be expected to be modified. The compression strength of wood is one of its representative mechanical properties. Modified wood with lower values of compression strength has limited purpose. The intention of this work is to show the effect of wood modification by citric acid on the compression strength of wood.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Lattices with dimensions 20 x 20 x 800 mm (*T* x *R* x *L*) were sawn from air-dried radial boards of fir wood and beech wood. Samples with dimensions 20 x 20 x 40 mm (*T* x *R* x *L*) were sawn and signed in succession (Fig. 1).

In this work water solutions of citric acid (CA) have been applied with NaH_2PO_2 as a catalyst.

After conditioning at 20 °C and 65 % relative humidity, part of the samples (C_t and C_{mw}) was impregnated with citric acid solution. The part of control sam-

Table 1 Parameters in modification processes
Tablica 1. Parametri u procesima modifikacije

Treatment *Vrsta obrade*	**Agent** *Kemikalija*	**Catalyst** *Katalizator*	**Convection heating** *Konvekcijsko zagrijavanje*	**Microwave treatment** *Zagrijavanje mikrovalovima*
C1	/	/	20 °C	/
C2	H_2O	/	140 °C, t = 10 h	/
C3	H_2O	/	/	P = 750 W, t = 35 min
C-t	7 % CA	6,5 % NaH_2PO_2	140 °C, t = 10 h	/
C-mw	7 % CA	6,5 % NaH_2PO_2	/	P = 750 W, t = 35 min

ples (C2 and C3) was impregnated with distilled water, and the rest (C1) was left unimpregnated.

The number of parallel samples (series) was 30 (Figure 1).

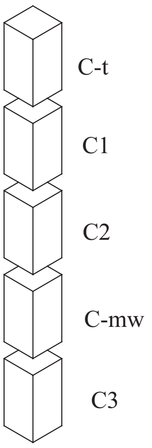

Figure 1 Succession of wood samples in quarter sawn boards
Slika 1. Redoslijed uzimanja uzoraka od četvrtača

The impregnation cycle consisted of a 5-minute initial vacuum of 2 kPa. The vacuum vessel was then filled with treating solutions and the vacuum of 2 kPa was maintained for 3 h, followed with an 18 h soaking at atmospheric pressure (Katović *et al*, 2004; Bischof Vukusic *et al*, 2006).

Impregnated samples were air-dried and then cured in oven at the temperature of 140 °C for 10 hours (C-t) or in microwaves for 35 minutes (C-mw). After thermocondensation the samples were conditioned in climate chamber (20 °C and 65 % relative humidity) before wood strength measurements. To separate the effect of curing procedures from the effect of chemical modification on mechanical properties of wood, control samples C2 and C3 were used.

Compression strength measurements parallel to the grain were performed in accordance with HRN D. A1.045 using Wolpert - universal machine for the determination of mechanical properties.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

The compression strength parallel to the grain of unmodified fir wood was 52 MPa in average and of beech wood it was 73 MPa (Table 2).

Compression strength values of unmodified wood are in accordance with other authors (Wagenfuhr, 1974; Govorčin *et al*, 2001, 2003). After curing at the temperature of 140 °C for 10 hours, the average compression strength of fir wood slightly increased (Figure 2), although not significantly, while the average compression strength of beech wood remained unchanged (Figure 3).

In the case of microwave treatment, the average compression strength of fir wood was unchanged while the average compression strength of beech wood increased slightly but not significantly after microwave treatment. This results show that curing itself at the tempera-

Table 2 Compression strength parallel to the grain of modified and unmodified wood
Tablica 2. Čvrstoća na tlak paralelno s vlakancima modificiranoga i nemodificiranog drva

Wood species *Vrsta drva*	**Type of treatment** *Vrsta obrade*	**Convection heating** *Konvekcijsko zagrijavanje*		**Microwave treatment** *Zagrijavanje mikrovalovima*	
		$\sigma_{t\,II}$ MPa	c.v.	$\sigma_{t\,II}$ MPa	c.v.
Fir wood *jelovina* (*Abies alba* Mill.)	C1	52	4	/	/
	C2	54	5	/	/
	C3	/	/	52	5
	C-t	57	9		
	C-mw	/	/	46	9
Beech wood *bukovina* (*Fagus sylvatica* L.)	C1	73	7	/	/
	C2	73	7	/	/
	C3	/	/	72	5
	C-t	76	9	/	/
	C-mw	/	/	74	7

$\sigma_{t\,II}$ - compression strength parallel to the grain / *čvrstoća na tlak paralelno s vlakancima*,
c.v. – coefficient of variation / *koeficijent varijacije*

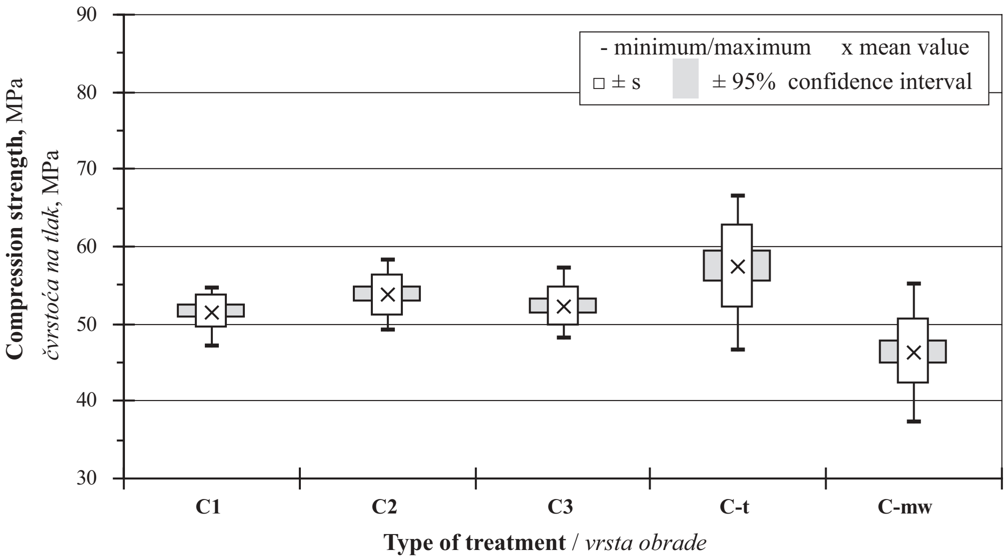

Figure 2 Statistical comparison of the compression strength of fir wood (C1 – Control samples conditioned at t = 20 °C and φ = 65 %; C2 – Control samples cured at the temperature of 140 °C; C3 – Control samples cured in microwaves; C-t – Samples impregnated by CA solution and cured at the temperature of 140 °C; C-mw – Samples impregnated by CA solution and cured by microwaves)

Slika 2. Statistička usporedba čvrstoće jelovine na tlak (C1 – kondicionirani kontrolni uzorci: t = 20 °C i φ = 65 %; C2 – kontrolni uzorci zagrijavani pri temperaturi 140 °C; C3 – kontrolni uzorci zagrijavani mikrovalovima; C-t – uzorci impregnirani otopinom CA i zagrijavani pri temperaturi 140 °C; C-mw – uzorci impregnirani otopinom CA i zagrijavani mikrovalovima)

ture of 140 °C or by microwaves has almost no influence on the average compression strength of wood.

When fir wood was modified by CA at the temperature of 140 °C, the average compression strength increased significantly from 52 MPa (unmodified wood) to 57 MPa (modified wood) (Figure 2, Table 2). However, the range of compression strength values of modified fir wood was doubled compared to the unmodified wood. In the case of beech wood, the average increase of compression strength also occurred due to wood modification, but the increase was insignificant (Figure 3, Table 2). The amount of CA bound to wood is significantly larger in fir wood (Katović *et al*, 2006). Higher average compression strength of modified fir wood can be explained by better crosslinking of CA and wood.

On the other hand, a significant decrease in average compression strength of modified fir wood cured by microwaves was observed. It is possible that during MW treatment in some fir wood samples micro-splits occurred due to low permeability of wood. The range

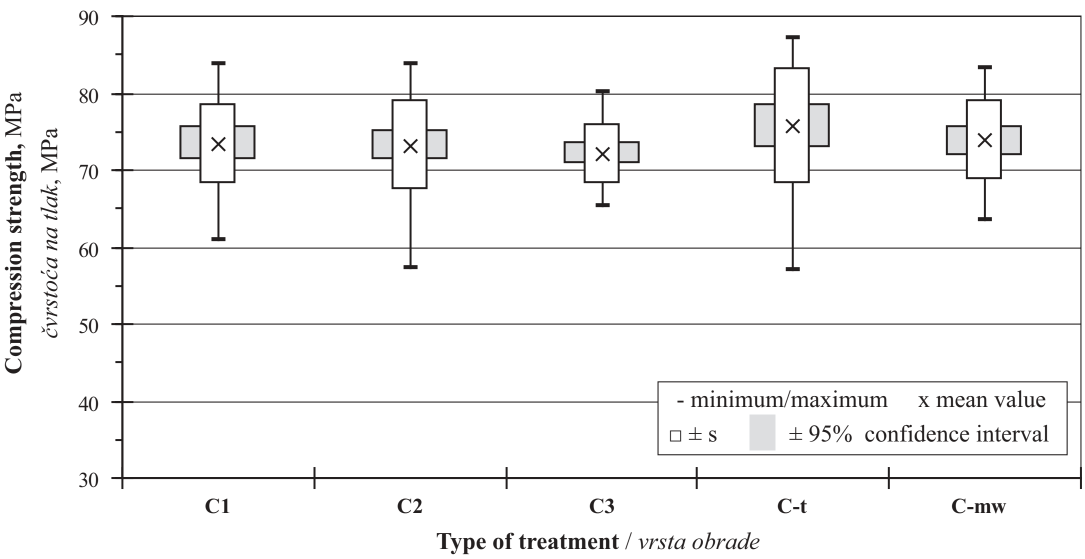

Figure 3 Statistical comparison of the compression strength of beech wood (C1 – Control samples conditioned at t = 20 °C and φ = 65 %; C2 – Control samples cured at the temperature of 140 °C; C3 – Control samples cured in microwaves; C-t – Samples impregnated by CA solution and cured at the temperature of 140 °C; C-mw – Samples impregnated by CA solution and cured by microwaves)

Slika 3. Statistička usporedba čvrstoće bukovine na tlak (C1 – kondicionirani kontrolni uzorci: t = 20 °C i φ = 65 %; C2 – kontrolni uzorci zagrijavani pri temperaturi 140 °C; C3 – kontrolni uzorci zagrijavani mikrovalovima; C-t – uzorci impregnirani otopinom CA i zagrijavani pri temperaturi 140 °C; C-mw – uzorci impregnirani otopinom CA i zagrijavani mikrovalovima) of compression strength values of modified fir wood was doubled compared to the unmodified wood. It did not happen in the case of beech wood. The compression strength of beech wood modified in microwaves was unchanged. One can assume that low permeability of fir wood in contrast to beech wood contributed to uneven distribution of chemical bound to the wood, and that both factors led to doubled range of compression strength values in modified fir wood.

These results indicate the need of control over more parameters during microwave treatment to achieve better results.

4 CONCLUSIONS
4. ZAKLJUČCI

Exposure of wood to the temperature of 140 °C for 10 hours or to intermittent power of 750 W microwaves for 35 minutes has little or no influence on changing the average compression strength of wood.

The process of fir wood and beech wood modification by CA in which wood was cured at 140 °C for 10 hours resulted in the improvement of the average compression strength of wood. The improvement was significant in fir wood and insignificant in beech wood.

One of the important goals of chemical modifications - to get wood with unchanged strength properties, has been achieved.

When intermittent power of 750 W microwaves was used for 35 minutes for curing, there was no improvement of the average compression strength. Instead, the average compression strength of fir wood decreased and in beech wood it was retained during the process.

In addition to improved dimensional stability and resistance of wood against fungi attack, retaining or even improving the average compression strength of wood modified by CA confirms CA as a successful chemical in wood modification process.

However, further research is needed on more parameters for predicting the mechanical properties of modified wood.

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Shear Modulus and Shear Strength Evaluation of Solid Wood by a Modified ISO 15310 Square-Plate Twist Method

Procjena smicajnog modula i smicajne čvrstoće cjelovitog drva modificiranom metodom prema normi ISO 15310

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ABSTRACT • *Square-plate twist (SPT) tests were conducted to measure the shear modulus and shear strength using the method, which was a modification of the International Organization for Standardization (ISO 15310) standardized method. In the SPT test, the length/thickness ratio varied. In addition, asymmetric four-point bending (AFPB) tests were conducted, and the shear modulus and shear strength obtained were compared with those obtained by the SPT tests. The shear modulus was obtained effectively by the SPT test when the specimen was thin enough. Although the shear strength was evaluated as higher than that obtained by the AFPB tests, it might be regarded as an apparent value of shear strength when the range of length/thickness is limited. To obtain the actual shear strength by the SPT test, some modification of the equation is required.*

Keywords: *shear strength, square-plate twist (SPT) test, asymmetric four-point bending (AFPB) test*

SAŽETAK • *Testovi uvijanja kvadratne ploče (SPT) provedeni su radi mjerenja smicajnog modula i smicajne čvrstoće primjenom metode koja je modificirana standardna metoda definirana međunarodnim standardom ISO 15310. U SPT testu variran je omjer duljine i debljine uzorka. Osim toga, proveden je i test asimetričnog savijanja u četiri točke (AFPB) a dobiveni smicajni moduli i smicajna čvrstoća uspoređeni su s onima dobivenim SPT testom. Stvarna vrijednost smicajnog modula dobije se SPT testom ako su uzorci dovoljno tanki. Premda su vrijednosti smicajne čvrstoće veće od onih dobivenih AFPB testom, moguće ih je promatrati kao vrijednosti smicajne čvrstoće kada je omjer duljine i debljine uzoraka ograničen. Da bi se SPT testom dobile stvarne vrijednosti smicajne čvrstoće, nužna je modifikacija jednadžbi za određivanje smicajne čvrstoće.*

Ključne riječi: *smicajna čvrstoća, test uvijanja kvadratne ploče (SPT), test asimetričnog savijanja u četiri točke (AFPB test)*

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1 INTRODUCTION
1. UVOD

Various testing methods have been proposed for determining the shear properties of solid wood (Yoshihara, 2006). Among them, torsion testing is attractive because a rather pure shear stress condition can be induced in the material (Timoshenko and Goodier, 1987). Square-plate twist (SPT) testing is an application of torsion testing, and it has been standardized as a way of measuring the edgewise shear modulus of plywood and fiber-reinforced plastics in ASTM D3044-94 (ASTM, 2005) and ISO 15310-99 (ISO, 1999), respectively. These standards determine the measurement of shear modulus alone. If the SPT enables the proper measurement of shear strength as well as that of shear modulus, however, it will be applied frequently because it is an application of torsion testing and can be conducted easily. In the present research, we examined the validity of a modified ISO 15310 method for the measurement of shear strength using Sitka spruce.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Sitka spruce (*Picea sitchensis* Carr.) lumber was used for the tests. The density was 400 kg/m^3 at 12 % moisture content. The specimens cut from the lumber were side matched. During cutting the specimens, the defects such as knots, grain distortion, and grain orientation were removed, so the specimen could be regarded as "small and clear." Seven specimens were used for each test condition.

Figure 1 shows a diagram of the SPT test according to the modified ISO 15310 method. Specimen B was 140 long and 140 mm wide; its thickness, H, varied from 3 to 15 mm at intervals of 3 mm. The x, y, and z directions coincided with the longitudinal (L), tangential (T), and radial (R) directions, respectively, so the shear stress and shear strain in the LT plane are designated τ_{LT} and γ_{LT}, respectively. In the ASTM D 3044 method, a metal plate must be attached to each corner of the specimen for applying the loads just at the corners. The corner plates may restrict the saddle-like deformation in the specimen, and a combined stress condition induced at the corners may distribute widely in the specimen. In contrast, these plates are not required in the ISO 15310 method, so the saddle-like deformation is not restricted. The ISO 15310 method was, therefore, adopted in this experiment. Figure 2(a) shows the photograph of the ISO 15310 SPT test actually conducted in this investigation.

The specimen was supported and loaded at the moment arm, W, of 130 mm (Fig. 1). The radius of the support and loading points was 15 mm. Load P was applied at a crosshead speed of 5 mm/min until the specimen separated into two pieces. The loading-line deflection, δ, was obtained from the crosshead movement. The total testing time was about 5-10 min. The shear stress at the center of the LT plane, τ_{LT}, in the SPT test was obtained from the following equation (Timoshenko and Goodier, 1987):

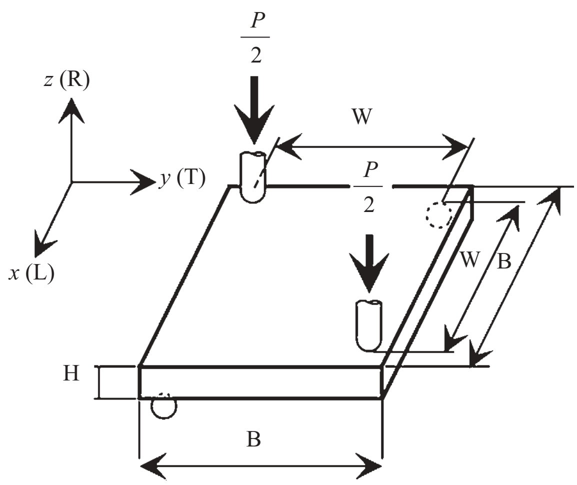

Figure 1 ISO 15310 square-plate twist method; L, T, and R, represent the longitudinal, tangential, and radial directions, respectively
Slika 1. Metoda uvijanja kvadratne ploče prema normi ISO 15310; L, T i R označavaju uzdužni, tangencijalni i radijalni smjer

$$\tau_{LT} = \frac{3 \cdot P \cdot W}{2 \cdot B \cdot H^2} \quad (1)$$

Using δ, γ_{LT} was also obtained as follows (ISO 15310 1999):

$$\gamma_{LT} = \frac{2 \cdot W \cdot H}{K \cdot B^3} \cdot \delta \quad (2)$$

where K is the correction factor for the shifted position of the loading points, which is derived as follows (ISO 15310 1999):

$$K = 3\left(\frac{W}{B}\right)^2 - 2\left(\frac{W}{B}\right) - 2\left(1 - \frac{W}{B}\right)^2 ln\left(1 - \frac{W}{B}\right) \quad (3)$$

The shear modulus in the LT plane G_{LT} was determined from the initial slope of the τ_{LT}-γ_{LT} relationship. The shear strength in the LT plane, S_{LT}, was determined by substituting the maximum load into Eq. (1).

The asymmetric four-point bending (AFPB) test, the validity of which was verified in a previous study (Yoshihara, 2009), was conducted using a notched specimen, and G_{LT} and S_{LT} obtained were compared with those obtained from the SPT method. Figure 2(b) shows the photograph of the AFPB test. A beam specimen with the dimensions of 340 (L) × 30 (T) × 12 (R) mm^3 was initially prepared. Straight-through notches were cut at mid-span of the top and bottom surfaces of the specimen, which corresponded to the LR planes, by a circular saw (thickness = 3 mm). The depth of the notch was 10 mm, so the distance between the notch roots was 10 mm. A biaxial strain gauge, which was similar to that used in the SPT test, was bonded at both centers of the side surfaces (LT plane) to measure the shear strain γ_{LT}. The total span length was 300 mm, and the specimen was supported eccentrically at two trisected points. Load P was applied to the remaining two trisected points at the crosshead speed of 2 mm/min until the load markedly decreased. The total testing time was about 5 min. τ_{LT} in the AFPB test was obtained using the following equation:

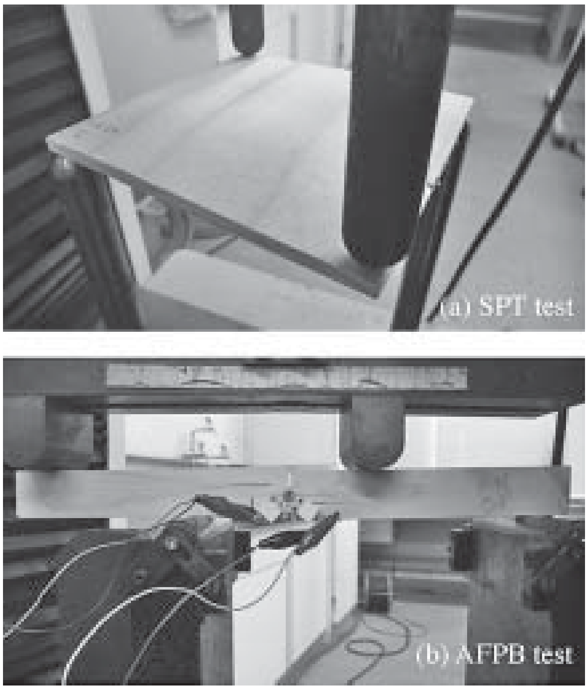

Figure 2 Photographs of the (a) ISO 15310 square-plate twist (SPT) test and (b) asymmetric-four point bending (AFPB) test
Slika 2. a) Fotografija testa uvijanja kvadratne ploče (SPT testa) prema normi ISO 15310; b) fotografija testa asimetričnog savijanja u četiri točke (AFPB testa)

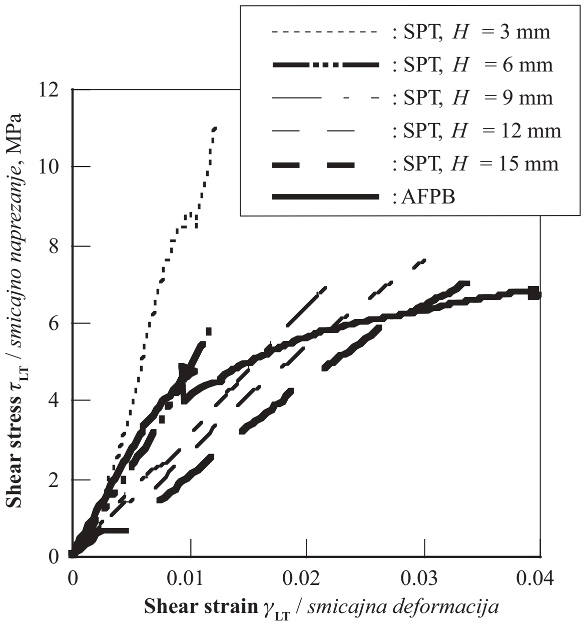

Figure 3 Comparison of the shear stress/shear strain relationships obtained by the different methods (SPT – square-plate twist method; AFPB – asymmetric four-point bending method)
Slika 3. Usporedba odnosa smicajnog naprezanja i deformacija dobivenih različitim metodama (SPT – metoda uvijanja kvadratne ploče; AFPB – metoda asimetričnog savijanja u četiri točke)

$$\tau_{LT} = \frac{P}{2 \cdot b \cdot h} \quad (4)$$

where b is the width of the specimen and h is the distance between the notches. γ_{LT} was obtained from the strain gauge output. Similar to the SPT twist method, G_{LT} was measured from the initial slope in the τ_{LT}-γ_{LT} relationship, whereas S_{LT} was derived from the maximum stress.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figure 3 shows typical τ_{LT}-γ_{LT} relationships obtained by the SPT and AFPB tests. In the SPT test, τ_{LT} continuously increases with the increase of γ_{LT}. This tendency is different from that obtained from the AFPB test, which is convex. It is attributed to the geometrical nonlinearity in loading. Equation (1) is derived on the basis that the load is applied vertically to the specimen. When the specimen has a small thickness, however, the deflection increases so markedly that the load is applied obliquely to the surface of the specimen. The shear stress obtained using Eq. (1) is therefore larger than that actually induced and the concavity in τ_{LT}-γ_{LT} relationship is induced.

Figure 4 shows a comparison of G_{LT} obtained from the SPT and AFPB tests. Statistical analysis of the difference between the G_{LT} values obtained using the SPT and AFPB tests revealed that the G_{LT} value was significantly smaller than the results obtained by the AFPB test, except for that with H = 3 mm, at the significance level of 0.01. In addition, the G_{LT} value obtained using the SPT test decreases with the increase of thickness of specimen. The statistical analysis also revealed they are different from each other at the significance level of 0.01. These tendencies, which were similar to the results obtained in a previous work (Yoshihara and Sawamura, 2006), are the consequence of the three-dimensional effect. When the global deflection is measured, the shear stress in the radial-tangential plane τ_{RT} is significant and it reduces the measured value of G_{LT} as the plate gets thicker.

Figure 5(a) shows a comparison of S_{LT} values obtained from the SPT and AFPB tests. The statistical analysis for the S_{LT} values obtained from the SPT and AFPB tests reveals that the values of S_{LT} obtained from the SPT test are significantly larger than those obtained from the AFPB test at the significance level of 0.01 except for that of H = 6 mm. The large value of S_{LT} obtained by the SPT is because of the large deflection during the test. Due to large deflection, the load is applied obliquely to the specimen surface. The torsional moment induced by oblique loading is smaller than that induced by vertical loading, so the shear stress actually induced may be smaller than that derived by Eq. (1). As shown in Figure 5(b), which shows the maximum deflection δ_{max} corresponding to the specimen's thickness H, the value of δ_{max} of H = 3 mm is significantly larger than those of the specimen with the larger thickness, so the deflection may influence the measurement of S_{LT}. According to the previous study (Yoshihara and Sawamura, 2006), the edgewise shear modulus can be measured appropriately by the modified ISO 15310 AFPB test when the specimen is thin enough. Nevertheless, the result described above suggests that

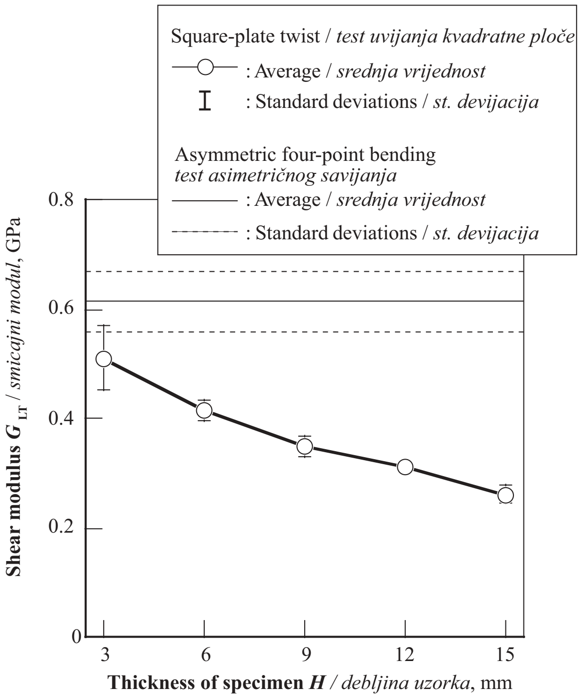

Figure 4 Shear modulus corresponding to the thickness of the specimen obtained by the square-plate twist test, and comparison with results obtained by the asymmetric four-point bending tests

Slika 4. Ovisnost smicajnog modula o debljini uzorka dobivena testom uvijanja kvadratne ploče i usporedba s rezultatima dobivenim testom asimetričnog savijanja u četiri točke

the specimen should not be thin for measuring the shear strength of wood by the AFPB test.

When conducting the statistical analysis for the S_{LT} values obtained using the SPT tests, there are no differences among the values of S_{LT} of H = 6, 9, 12, and 15 mm. The statistical analysis for the δ_{max} values also reveals that there are no differences among the values of δ_{max} in this range of H. The shear strength of solid wood is often evaluated by the shear-parallel-to-grain test method standardized in the ASTM D143 (ASTM 2005) although the shear strength obtained is regarded as an apparent property and is not the actual strength of the material. The results obtained here suggest the feasibility that the S_{LT} value obtained from the SPT test might be regarded as an apparent value of shear strength when the range of length/thickness is limited while reducing the large deflection during the test.

In many shearing tests, including the ASTM D143 test, specimen often fails at the loading and/or supporting points of the specimen where the combined stress condition is induced. In the SPT test, however, it should be noted that the specimen failed along the fiber direction at the mid-plane of wider surface, which is far from the loading and supporting points. This issue indicates the advantage of the SPT test over the other tests, and shows why it is attractive to conduct the SPT test. Further research should be conducted to modify Eq. (1) for obtaining the shear strength of solid wood more properly while considering the large deflection.

4 CONCLUSIONS
4. ZAKLJUČCI

A modified ISO 15310 square-plate twist test of Sitka spruce was conducted to obtain the shear strength in the longitudinal-tangential plane using specimens with various thicknesses. In addition to the square-plate twist test, the asymmetric four-point bending test

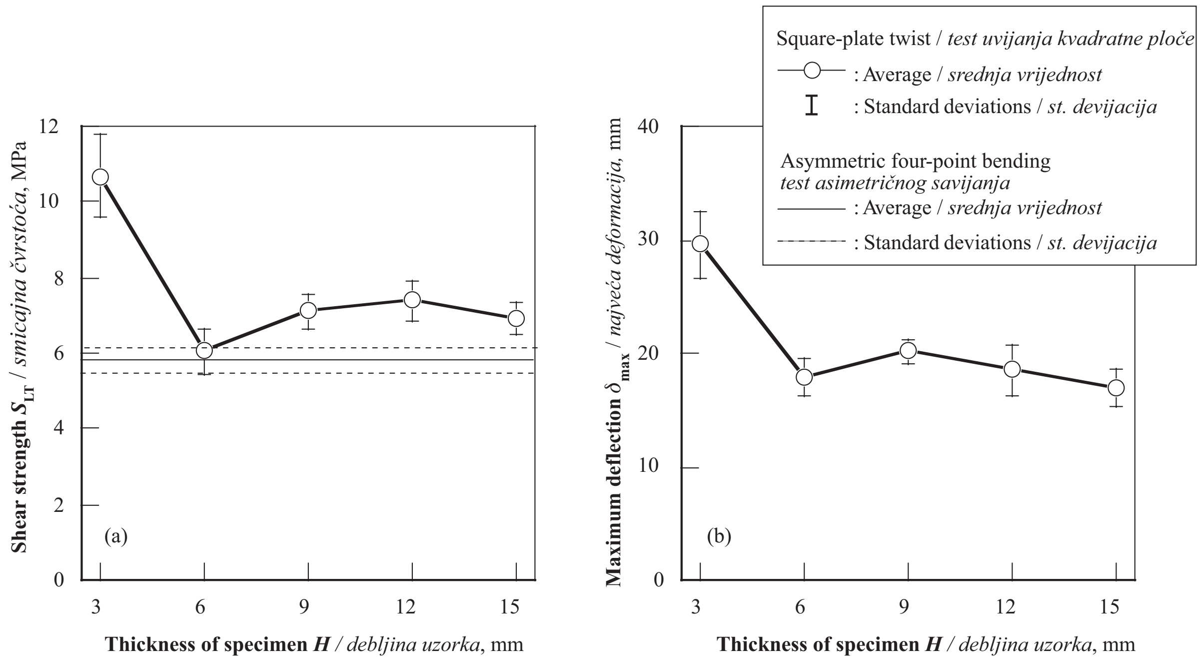

Figure 5 (a) Shear strength corresponding to the thickness of the specimen obtained by the square-plate twist test, and comparison with results obtained by the asymmetric four-point bending tests, and (b) Maximum deflection corresponding to the thickness of the specimen obtained by the square-plate twist test

Slika 5. Ovisnost smicajne čvrstoće o debljini uzorka dobivena testom uvijanja kvadratne ploče i usporedba s rezultatima dobivenim testom asimetričnog savijanja u četiri točke, b) ovisnost maksimalne deformacije o debljini uzorka dobivena testom uvijanja kvadratne ploče was performed, and the results were compared with those of the square-plate twist tests.

It is feasible that shear strength obtained from the square-plate twist method could be regarded as an apparent value of shear strength, which is larger than that obtained by the asymmetric four-point bending test because of the large deflection. To increase the accuracy of the measurement, further research should be undertaken to modify the equation for obtaining the shear strength while considering the large deflection.

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Maja Moro, profesorica matematike i fizike, obranila je 21. prosinca 2011. g. na Šumarskom fakultetu Sveučilišta u Zagrebu doktorski rad s naslovom *Modeli predviđanja stanja na tržištu namještaja i ostalih drvnih proizvoda*, pred povjerenstvom u sastavu prof. dr. sc. Tomislav Grladinović (Šumarski fakultet Sveučilišta u Zagrebu), izv. prof. dr. sc. Darko Motik (Šumarski fakultet Sveučilišta u Zagrebu) i izv. prof. dr. sc. Leon Oblak (Biotehniška fakulteta Univerze v Ljubljani), i time stekla akademski stupanj doktora znanosti s područja biotehničkih znanosti, znanstvenog polja drvne tehnologije, znanstvene grane organizacija proizvodnje. Mentor rada bio je izv. prof. dr. sc. Darko Motik.

PODACI IZ ŽIVOTOPISA

Maja Moro rođena je u Splitu, 22. lipnja 1966. g. Osnovnu i srednju školu pohađala je i završila u Splitu. Maturirala je 1984. u Matematičko-informatičkom obrazovnom centru (MIOC) i stekla zvanje matematičara-informatičara. Apsolvirala je 1988. *razrednu nastavu* na Filozofskom fakultetu u Zadru, Odsjek u Splitu. Diplomirala je na Prirodoslovno-matematičkom fakultetu u Zagrebu, smjer profesor matematike i fizike, na kojemu je 1999. obranila rad s naslovom *Geometrijske konstrukcije u nastavi*.

U razdoblju od 1988. do 1989. radila je u Splitskoj banci u Zagrebu, 1990. na YMCA-u u Auburn-Lewistonu (Maine, SAD), a od 1991. do 1993. u Centru za industrijsko oblikovanje i dizajn u Zagrebu. Od 1993. do 1995. zaposlena je u Međunarodnom bankarskom udruženju (MBU) u Zagrebu, a od 1996. do 1997. radi za OSCE (Organization for Security and Co-operation in Europe). Od 1999. godine, kao profesorica matematike i fizike, radila je u Osnovnoj školi Voltino, u Osnovnoj školi Josip Juraj Strossmayer u Zagrebu, u VII. gimnaziji, u IX. gimnaziji te u Gimnaziji Lucijana Vranjanina u Zagrebu. Godine 2001. položila je stručni ispit za zvanje profesora matematike i fizike.

Od 2001. do 2006. radila je na Katedri za matematiku i fiziku Sveučilišta u Splitu - Odjela za stručne studije u Zagrebu, na preddiplomskim studijima: Računarstvo, Malo poduzetništvo, Računovodstvo i financije, a povjereno joj je održavanje nastave iz kolegija Elementarna matematika, Matematika, Poslovna matematika, Primijenjena matematika (MATLAB). Od 2003. do 2006. radila je kao vanjska suradnica i na Šumarskom fakultetu Sveučilišta u Zagrebu, gdje joj je dodijeljeno održavanje vježbi za predmete Matematika, Uvod u informatiku i Informatika.

Od 1. siječnja 2006. zaposlena je na Šumarskom fakultetu Sveučilišta u Zagrebu u suradničkom zvanju i na radnome mjestu asistentice na Zavodu za procesne tehnike, u znanstvenom području prirodnih znanosti, znanstvenom polju matematika, znanstvenoj grani teorije vjerojatnosti i statistike. Povjereno joj je održavanje nastave kolegija Matematika, Matematika za inženjere, Osnove statistike, Statistika za inženjere te Primijenjena statistika, dijelom na preddiplomskim studijima Šumarstvo i Urbano šumarstvo, zaštita prirode i okoliša na Šumarskom odsjeku, na preddiplomskom studiju Drvna tehnologija na Drvnotehnološkom odsjeku te dijelom na diplomskim studijima Oblikovanje proizvoda od drva i Drvnotehnološki procesi na Drvnotehnološkom odsjeku. Istodobno, od 2006. do 2009. kao vanjska suradnica održavala je nastavu na Sveučilištu u Splitu – Odjelu za stručne studije u Zagrebu.

Sudjeluje kao istraživačica u interdisciplinarnim znanstvenim projektima Ministarstva znanosti obrazovanja i sporta, i to od 2006. u projektu pod nazivom *Matematički i statistički modeli za praćenje stanja i gospodarenja u šumarstvu* (068-0681966-1969), voditeljice izv. prof. dr. sc. Anamarije Jazbec, te od 2008. u znanstvenom projektu *Modeli povećanja konkurentnosti u izvozu finalnih proizvoda od drva* (068-0683446-3512), voditelja izv. prof. dr. sc. Darka Motika. Poslijediplomski studij Drvna tehnologija na Šumarskom fakultetu Sveučilišta u Zagrebu upisuje 2007. Prelazi u područje rada biotehničke znanosti, znanstveno polje drvna tehnologija, pod matičnim brojem 278253 iz Upisnika znanstvenika.

Od 1999. godine članica je Hrvatskoga matematičkog društva (HMD-a). Aktivno se služi engleskim jezikom u govoru i pismu. Aktivno sudjeluje na domaćim i međunarodnim znanstvenim i stručnim skupovima te na konferencijama, na kojima je prezentirala rezultate znanstvenoga i stručnog rada (četiri predavanja na engleskome i četiri rada prezentirana posterima na međunarodnim konferencijama te dva predavanja na hrvatskome, na kongresima matematičara). Do sada je objavila 20 radova, od toga sedam znanstvenih radova u drugim časopisima, sedam znanstvenih radova u zbornicima skupova s međunarodnom recenzijom, pet drugih radova u zbornicima skupova s recenzijom te jedan rad u zborniku skupa bez recenzije. Od 1. siječnja 2012. na Šumarskom fakultetu Sveučilišta u Zagrebu raspoređena je i radi u suradničkom zvanju više asistentice u znanstvenom području biotehničkih znanosti, znanstvenom polju drvne tehnologije, znanstvenoj grani organizacije proizvodnje.

PRIKAZ DOKTORSKOG RADA

Doktorski rad Maje Moro s naslovom *Modeli predviđanja stanja na tržištu namještaja i ostalih drvnih proizvoda* sastoji se od 224 stranice (IX + 215) te sadržava 96 slika, 59 tablica, 122 navoda citirane literature i disertaciju u elektroničkom obliku (CD).
Doktorski rad ima ovakvu strukturu:

Sadržaj,
Ključna dokumentacijska kartica,
Key words documentation,
1. Uvod (3 str.),
2. Problematika, hipoteze i cilj istraživanja (65 str.),
3. Materijal i metodologija istraživanja (22 str.),
4. Rezultati istraživanja (94 str.),
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Literatura,
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Životopis.

1. Uvod

U *Uvodu* je ukratko opisana važnost drvne industrije za gospodarstvo Republike Hrvatske. Tržište namještaja i ostalih drvnih proizvoda, kao najznačajniji segment hrvatske drvne industrije, karakteriziraju brojne promjene koje nosi suvremeni poslovni svijet, a specifičnosti u kretanjima nekih ključnih makroekonomskih varijabli obilježavaju različita turbulentna razdoblja hrvatske povijesti. Poznavanje stanja na tržištu namještaja i ostalih drvnih proizvoda izravno utječe na sva poduzeća u sektoru, na njihov razvoj, rast i uspješnost poslovanja u budućem razdoblju, te je potrebno težiti novim standardima primjene ekonomskih teorija radi kvalitativne i kvantitativne ekonomske analize tržišta drvnih proizvoda.

2. Problematika, hipoteze i cilj istraživanja

Poglavlje *Problematika, hipoteze i cilj istraživanja* podijeljeno je na dva potpoglavlja. *Problematika istraživanja*, prvo potpoglavlje, detaljno prikazano s četiri daljnja potpoglavlja: *Razvoj, uloga i značaj prerade drva i proizvodnje namještaja na prostorima današnje Republike Hrvatske* (Povijesne značajke hrvatskih drvnih proizvoda i namještaja; Razvoj tržišta drvom kroz povijesni razvoj šumarstva u našim krajevima; Povijesni razvoj hrvatske drvne industrije), *Gospodarstvo, šume, prerada drva i proizvodnja namještaja u novijoj povijesti* (Makroekonomski pokazatelji gospodarstva Republike Hrvatske; Hrvatske šume – sirovinska baza hrvatske drvne industrije; Pojmovno određenje i karakteristike hrvatskog tržišta namještaja i ostalih drvnih proizvoda), *Pokazatelji tržišnog stanja hrvatske drvne industrije* (Proizvodnja namještaja i ostalih drvnih proizvoda; Zaposlenost u drvnoj industriji; Vanjskotrgovinska aktivnost; Izvedeni pokazatelji tržišnog stanja), te *Ekonomska analiza tržišnih pokazatelja*.

U drugom potpoglavlju, *Hipoteze i cilj istraživanja,* u skladu s problematikom istraživanja postavljene su polazne hipoteze da postoje trendovi u vrijednostima *uvoza*, *izvoza, pokrivenosti uvoza izvozom, proizvodnje, potrošnje, prodaje proizvoda hrvatskih proizvođača na domaćem tržištu, prihoda po zaposlenom* te *broja zaposlenih* na tržištu namještaja (C 31), na tržištu ostalih drvnih proizvoda (C 16), te na cjelokupnome tržištu drvnom materijom (C 31 i C 16), analiziranom u razdoblju od 1994. do 2010. g. Cilj je istraživanja na temelju ekonomske analize vremenskih serija (nizova) podataka pokazatelja tržišnog stanja, izgraditi model vremenskih serija za predviđanje budućih vrijednosti analiziranih varijabli na tržištu namještaja i ostalih drvnih proizvoda. Primjenom izrađenih modela poduzeća u industriji drvnih proizvoda moći će definirati strategiju budućeg poslovanja. Istraživanja će također pomoći i institucijama pri donošenju odluka i provođenju strategija razvoja struke.

3. Materijal i metodologija istraživanja

To je poglavlje podijeljeno na dva potpoglavlja. U prvome, *Materijal istraživanja*, prikazani su prikupljeni podaci različitih državnih ustanova o četiri ključne makroekonomske varijable (proizvodnji, uvozu, izvozu i zaposlenosti), za dva područja drvne industrije: za područje proizvodnje namještaja i područje prerade drva. Definirane su oznake za prikupljene podatke na način da je od svakoga polaznog pokazatelja tržišnog stanja uzeto prvo slovo riječi (*Proizvodnja, Uvoz, Izvoz i Zaposlenost*), a uz nj su, kao indeks, upotrijebljena slova *n* - za područje *Proizvodnae namještaja* (sadašnji C 31, bivši DN 36) i *d* - za ostale drvne proizvode, tj. za područje *Prerada drva i proizvoda od drva i pluta, osim namještaja* (sadašnji C 16, bivši DD 20). Nadalje, iz osnovnih (polaznih) pokazatelja tržišnog stanja izračunana su još četiri (izvedena) pokazatelja: pokrivenost uvoza izvozom (*B*), prodaja proizvoda hrvatskih proizvođača na domaćem tržištu (*D*), potrošnja (*G*) te prihod po zaposlenome (*H*), kako za tržište namještaja (C 31) i tržište ostalih drvnih proizvoda (C 16), tako i za cjelokupno tržište drvnih proizvoda (C31 i C 16).

U drugom potpoglavlju, *Metodologija istraživanja*, u skladu s postavljenim ciljevima istraživanja te radi dokazivanja postavljenih hipoteza primijenjene su razne matematičke i statističke metode i tehnike kojima su analizirani vremenski nizovi vrijednosti pokazatelja stanja na tržištu namještaja i ostalih drvnih proizvoda, a detaljno je prikazano u četiri nova potpoglavlja: *Analiza vremenskih nizova; Model A – trend model na temelju prosječne stope promjene za promatrano razdoblje; Model B – linearni trend model* te *Model C – model višestruke linearne regresije.*

4. Rezultati istraživanja

Poglavlje *Rezultati istraživanja* nudi sustavni prikaz i analizu rezultata u zaokruženim i logički obrađenim cjelinama, a podijeljeno je na sedam potpoglavlja: *Uvoz i izvoz na drvnim tržištima; Pokrivenost uvoza izvozom; Zaposlenost na tržištu namještaja i ostalih drvnih proizvoda; Prihod po zaposlenom na tržištima proizvoda od drva; Proizvodnja na tržištu namještaja i ostalih drvnih proizvoda; Potrošnja na tržištima drvnih proizvoda; Prodaja proizvoda hrvatskih proizvođača na domaćem tržištu.*

Grafički i brojčano analizirani su svi vremenski nizovi (serije) pokazatelja tržišnog stanja (ukupno 24 varijable, po tri za svako promatrano tržište). Za brojčanu analizu vremenskih nizova korišteni su aritmetička sredina, varijanca, standardna devijacija te koeficijent varijacije. Od relativnih pokazatelja dinamike vremenskog niza primijenjeni su individualni indeksi (bazni i verižni). Individualnim je indeksima uspoređeno stanje svakoga pojedinog tržišnog pokazatelja u različitim vremenskim intervalima. Izračunanim je prosječnim stopama promjene za pokazatelje tržišnog stanja u promatranim razdobljima omogućeno predviđanje stanja u budućem razdoblju, uz pretpostavku da neće doći do njezine promjene (tzv. *ceteris paribus* predviđanje). Radi predviđanja stanja na tržištu namještaja i ostalih drvnih proizvoda, izgrađene su dvije vrste modela vremenskih serija: *modeli A* – prognostički modeli na temelju prosječne stope promjene i *modeli B* – linearni trend-modeli. Nakon procjene parametara obavljena je analiza reprezentativnosti linearnih trend-modela, odnosno ispitana je sposobnost modela da se njime objasne promjene vrijednosti pokazatelja tržišnog stanja u ovisnosti o vremenu. Uz ocjenu parametara, reprezentativnost linearnih trend-modela analizirana je na temelju odgovarajućih pokazatelja: varijance, standardne pogreške, koeficijenta varijacije, koeficijenta determinacije, korigiranog koeficijenta determinacije i koeficijenta linearne korelacije. Testiranje razlika modelima A i modelima B predviđenih vrijednosti sa stvarnim vrijednostima pokazatelja tržišnog stanja na promatranim tržištima provedeno je analizom varijance (ANOVA) u programu *Statistica 7.1,* u kojemu su izrađeni i grafički prikazi provedenih analiza varijance. Svi ostali grafički prikazi izrađeni su u programu *MS Excel*. Modelima višestruke linearne regresije (*modeli C*) procijenjeno je koji od analiziranih makroekonomskih pokazatelja tržišnog stanja utječu na vrijednosti proizvodnje na promatranim tržištima drvnih proizvoda. Reprezentativnost konstruiranih modela C – modela višestruke linearne regresije za procjenu vrijednosti proizvodnje na promatranim tržištima drvnih proizvoda, uz procjenu parametara modela, te standardnih pogrešaka procjene parametara, prikazana je i procjenama standardnih devijacija regresije, koeficijentima višestruke korelacije, koeficijentima višestruke determinacije, korigiranim koeficijentima višestruke determinacije i koeficijentima varijacije.

5. Rasprava

U tom poglavlju dana je detaljna, iscrpna i znanstvenim činjenicama utemeljena rasprava o rezultatima predočenima u prethodnom poglavlju. Poglavlje *Rasprava* podijeljeno je na tri potpoglavlja: *Vanjskotrgovinska aktivnost na tržištu namještaja i ostalih drvnih proizvoda; Proizvodnja, potrošnja i prodaja proizvoda hrvatskih proizvođača na domaćem tržištu drvnim proizvodima* te *Zaposlenost i prihod po zaposlenom na tržištu namještaja i ostalih drvnih proizvoda*. Različita turbulentna razdoblja hrvatske povijesti obilježena su, između ostalim, i kretanjima nekih ključnih makroekonomskih varijabli kao što su zaposlenost, proizvodnost te vanjskotrgovinska aktivnost na tržištu drvnih proizvoda. Posebnost geostrateškog položaja Republike Hrvatske i gospodarsko-povijesni procesi imaju velik utjecaj na dugoročni razvoj hrvatskog tržišta namještaja i ostalih drvnih proizvoda. Brojne promjene koje nosi suvremeni poslovni svijet karakteriziraju i hrvatsko tržište drvnih proizvoda, te je potrebno težiti novim standardima primjene ekonomskih teorija, kvalitativne i kvantitativne ekonomske analize pokazatelja tržišnog stanja u prošlosti i sadašnjosti, radi predviđanja stanja u budućem razdoblju. Pomoć na strateškoj, taktičkoj i/ili operativnoj razini planiranja i odlučivanja u upravljanju drvnim sektorom te poduzećima naše drvne industrije može biti i primjena metoda koje do sada nisu tradicionalno primijenjivane.

6. Zaključci

U poglavlju *Zaključci* sažeto su prikazana glavna postignuća istraživanja. Polazna hipoteza o postojanju trendova u vrijednostima tržišnih pokazatelja na promatranim tržištima u razdoblju 1994 – 2010. g. potvrđena je. Osnovne tendencije i obilježja razvoja odabranih varijabli uočene su uz pomoć grafičkih prikaza, a za analitičke svrhe utvrđene su vrijednosti brojčanih pokazatelja tržišnog stanja, relativni pokazatelji dinamike vremenskih serija promatranih varijabli te prosječne stope promjene, čime je postignut potpuniji uvid u kretanje analiziranih pokazatelja u vremenu. Prema koeficijentima varijacije analiziranih vremenskih nizova, najjači trendovi zabilježeni su u uvozu (od 44 do 49 %), zatim u izvozu (od 29 do 37 %), a najslabiji trendovi zabilježeni su u zaposlenosti na analiziranim tržištima (od 4 do 7 %). Na temelju utvrđenih trendova u vrijednostima polaznih i izvedenih pokazatelja tržišnog stanja konstruirani su *modeli A,* čime je potvrđena hipoteza da se modelima na temelju prosječne stope promjene za promatrano razdoblje mogu opisati postojeći trendovi na promatranim tržištima drvnih proizvoda. Djelomično je potvrđena i hipoteza da se regresijskom analizom vrijednosti tržišnih pokazatelja kao zavisnih varijabli i vremena kao nezavisne varijable mogu opisati postojeći trendovi, te su za polazne i izvedene pokazatelje tržišnog stanja konstruirani *modeli B*. Analizom varijance provedeno je testiranje razlika *modelima A* i *modelima B* predviđenih vrijednosti sa stvarnim vrijednostima pokazatelja tržišnog stanja. Višestrukom regresijskom analizom procijenjeni su modeli utjecaja vrijednosti uvoza, vrijednosti izvoza, broja zaposlenih te vremena (kao nezavisnih varijabli) u razdoblju 1996 – 2009. g. na vrijednosti proizvodnje (kao zavisne varijable) na promatranim tržištima. Uz pretpostavku da modeli zadovoljavaju sve statističko-teorijske uvjete, te uz pretpostavku da se makroekonomski uvjeti neće bitno mijenjati, konstruirani *modeli A* za sve polazne i izvedene pokazatelje stanja na drvnim tržištima, *modeli B* za uvoz, izvoz, proizvodnju, potrošnju i prihod po zaposlenome na promatranim tržištima te *modeli C* za predviđanje budućih vrijednosti proizvodnje na tržištu namještaja, tržištu ostalih drvnih proizvoda i na cjelokupnom tržištu mogu postati temelj budućim akcijama, s ciljem boljeg iskorištenja raspoloživih mogućnosti te skladnijega i bržeg razvoja tržišta namještaja i ostalih drvnih proizvoda. Primjenom izrađenih modela poduzeća u industriji namještaja i ostalih drvnih proizvoda moći će definirati strategiju budućeg poslovanja, a istraživanje će pomoći i institucijama pri donošenju odluka te u provođenju strategija razvoja struke.

OCJENA DOKTORSKE DISERTACIJE

U doktorskom radu *Modeli predviđanja stanja na tržištu namještaja i ostalih drvnih proizvoda* Maja Moro istražuje važnu temu za razvoj industrije namještaja i ostalih drvnih proizvoda. Osnovno pitanje na koje nastoji odgovoriti u svom istraživanju jest kolike će biti vrijednosti pojedinih ekonomskih pokazatelja u budućem razdoblju. Na temelju rezultata istraživanja drvna struka i institucije koje imaju utjecaj na struku mogu razvijati strategiju poticanja određenih aktivnosti.

Pristupnica je u radu na temelju istraživanja četiriju ključnih varijabla (proizvodnje, izvoza, uvoza i zaposlenosti), te četiriju izvedenih varijabla (potrošnje, pokrivenosti uvoza izvozom, prodaje proizvoda hrvatskih proizvođača na hrvatskom tržištu te prihoda po zaposlenome), analizirala tržište namještaja i ostalih drvnih proizvoda u razdoblju od 1994. do 2010. g. Također su napravljena istraživanja po skupinama proizvoda, i to za tržište namještaja, tržište ostalih drvnih proizvoda i cjelokupno tržište drvnih proizvoda. Za potrebe predviđanja budućih kretanja pokazatelja tržišnog stanja (polaznih i izvedenih varijabli), dinamičkom su ekonomskom analizom vremenskih serija izgrađene dvije vrste modela vremenskih serija: modeli na temelju prosječne stope promjene za promatrano razdoblje i linearni trend-modeli. Primijenjena je i višestruka linearna regresija pri predviđanju vrijednosti proizvodnje na tržištu drvnih proizvoda. Metode primijenjene u radu u potpunosti zadovoljavaju potrebe istraživanja i disertacije. Sustavnom analizom stanja na tržištu namještaja i ostalih drvnih proizvoda Maja Moro, prof. matematike i fizike, prihvatila je u potpunosti ili djelomično navedene hipoteze. U rezultatima istraživanja pristupnica je testirala razlike u tri vrste modela predviđanja stanja na temelju prikupljenih podataka te analiziranih polaznih i izvedenih varijabli za tri skupine proizvoda. Uz pretpostavku da modeli zadovoljavaju sve statističko-teorijske uvjete te da se makroekonomski uvjeti neće bitno mijenjati, konstruirani *modeli A* za sve polazne i izvedene pokazatelje stanja na tržištu drvnim proizvodima, zatim *modeli B* za uvoz, izvoz, proizvodnju, potrošnju i prihod po zaposlenom te *modeli C* za predviđanje budućih vrijednosti proizvodnje na istraživanom tržištu mogu postati temelj budućih istraživanja, s ciljem boljeg iskorištenja raspoloživih mogućnosti te bržeg razvoja tržišta namještaja i ostalih drvnih proizvoda. Zaključci su znanstveno, ispravno i logički interpretirani na temelju dobivenih rezultata, a odnosi pojedinih modela pri predviđanju stanja na tržištu namještaja i ostalih drvnih proizvoda znače nov pristup rješavanju problema i kvalitetan znanstveni doprinos istraživanju budućih kretanja polaznih i izvedenih varijabli.

Može se utvrditi da je disertacija znatan znanstveni doprinos boljem razumijevanju stanja na tržištu namještaja i ostalih drvnih proizvoda. Modeli koje je pristupnica Maja Moro prikazala nov su način pristupa problemu razumijevanja predviđanja pojedinih značajnih varijabli te su pomoć svakome tko teži boljim spoznajama o tržištu namještaja i ostalih drvnih proizvoda.

Sama tema doktorskog rada pokazuje visoku razinu interdisciplinarnosti te mogućnosti primjene u industriji namještaja i ostalih drvnih proizvoda.

izv. prof. dr. sc. Darko Motik

KOSIPO

NAZIVI

Kosipo je naziv drva botaničke vrste *Entandrophragma candollei* Harms iz porodice *Meliaceae*. Trgovački naziv te vrste je kosipo (Njemačka, Francuska); heavy sapele, omu (Velika Britanija); kossipo (Nizozemska). Lokalni su trgovački nazivi lifuco (Angola); kosipo, vroudi (Obala Bjelokosti); omu, penkwa (Gana); atom, atom-assié, klatié (Kamerun); esaka (Demokratska Republika Kongo).

NALAZIŠTE

Stabla kosipa rastu pojedinačno ili rijetko raspršeno na suhim i vlažnim područjima tropskih šuma Zapadne i Srednje Afrike: u Gvineji, osobito u Obali Bjelokosti i Nigeriji, Kamerunu, Kongu, Angoli te istočnije, do Ugande.

STABLO

U svojoj domovini kosipo naraste do 50 m, pa i više, ima ravno čisto deblo visine od 20 do 25 m, prsnog promjera od 0,7 do 1,2 m.

DRVO

Makroskopska obilježja

Drvo kosipa je jedričavo. Srž je u svježem stanju crvenkasta, a na zraku potamni i postane crvenosmeđa, katkada i ljubičastog tona. Bjeljika je uska, sivkasta do blijedosmeđa, širine od 25 do 75 mm. U suhom stanju radijalni su presjeci srži prugasti i sa zlatnim sjajem. Granica goda je vidljiva, ali može biti i nevidljiva; ponekad je izražena zbog jasno vidljivih vrpci marginalnog parenhima i manje gustoće pora. Drvo je rastresito porozno. Pore su na svim presjecima vidljive okom, često ispunjene tamnim sadržajem.

Na tangentnom presjeku vrpčasti se aksijalni parenhim vidi u obliku tamnijih lukova koji se preklapaju, a na radijalnome je vidljiv u obliku finih linija, obično tamnijih od staničja vlakanaca. Česta je dvostruka usukanost koja na radijalnim površinama stvara izrazite uzdužne pruge.

Mikroskopska obilježja

Traheja su pojedinačne, raspoređene u malim skupinama ili u kratkim radijalnim nizovima (2 – 3 pore). Promjer traheja je 70...155...215 mikrometara, gustoće 1...4...8 na 1 mm^2 poprečnog presjeka. Prosječna duljina pojedinačnog članka traheje iznosi 500 do 600 mikrometara. Volumni se udio traheja kreće oko 12 %. Tila nema, no ima ostalih crvenkastosmeđih sadržaja. Ploča perforacije je jednostavna. Intervaskularno je jažičenje naizmjenično razmaknuto (alternirajuće). Aksijalni je parenhim paratrahealno vrpčast, do 12 stanica širok. Vrpce postoje na granici goda i unutar njega, mnogo su šire od drvnih traka, manje-više jednako široke kao promjer pora. Aksijalni je parenhim paratrahealno vazicentričan, konfluentan i unilatrealan. Volumni udio aksijalnog parenhima iznosi oko 18 %. Drvni su traci heterogeni, visine 200...400...500 mikrometara, odnosno 7...13...18 stanica, širine 20...50...75 mikrometara, odnosno 1...4...6 stanica. Gustoća drvnih trakova je 5 do 6 na 1 mm tangentnog presjeka. Volumni udio drvnih trakova iznosi oko 25 %. U stanicama drvnih trakova i aksijalnog parenhima zamjetni su silikati u obliku sitnih zrnaca.

Drvna su vlakanca libriformska, dugačka 1400...1700...1900 mikrometara. Dvostruka debljina staničnih stijenki vlakanaca iznosi 2,3...4,6...4,7 mikrometara, a promjer lumena 11,0...17,0...22,0 mikrometara. Lumen vlakanaca često je ispunjen crvenkastosmeđim sadržajem. Volumni udio vlakanaca kreće se oko 45 %.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	oko 650 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	600...800 kg/m^3
Gustoća sirovog drva, ρ_s	900...930...950 kg/m^3
Poroznost	oko 57 %
Radijalno utezanje, β_r	oko 4,3 %
Tangentno utezanje, β_t	oko 6,0 %
Volumno utezanje, β_v	10,1...12,0 %

Mehanička svojstva

Čvrstoća na tlak	48...53 MPa
Čvrstoća na vlak, okomito na vlakanca	1,6...2,1 MPa
Čvrstoća na savijanje	87...93 MPa
Čvrstoća na smik	oko 6,0 MPa
Tvrdoća (prema Brinellu), paralelno s vlakancima	37...46...57 MPa
okomito na vlakanca	oko 16 MPa
Modul elastičnosti	oko 8,1 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro ljušti i reže, no preporučuje se prethodno parenje. Silikati u drvu zatupljuju oštrice alata.

Poželjan je kut rezanja pri blanjanju od 20°, da se izbjegne trganje drva s dvostruko usukanom žicom. Prije spajanja vijcima ili čavlima drvo je potrebno izbušiti.

Savijanje uz pomoć pare nije preporučljivo. Lako se lijepi i površinski obrađuje. Za vanjsku uporabu drvo je potrebno premazati pigmentiranim lakovima kako bi se boja zaštitila od djelovanja UV zraka. Za unutarnju uporabu poželjno je upotrijebiti transparentne (mat ili sjajne) premaze, često i nakon bojenja (bajcanja) kako bi se naglasio ljubičasti ton drva. Adhezija premaza može biti otežana zbog smole u drvu. Da bi se brušenjem postigla glatka površina, preporučljivo je prije brušenja zapuniti pore.

Sušenje

Građa se sporo suši. Moguća je pojava vitoperenja, raspucavanja i nastanak kolapsa, osobito na piljenicama veće debljine. Zato je piljenice većih debljina prije početka sušenja u sušionicama uputno prirodno prosušiti do sadržaja vode oko 30 %. Nakon sušenja drvo je srednje stabilnih dimenzija u upotrebi.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva kosipa svrstava se kao trajna (klasa 2) i srednje trajna (klasa 3). Srž je nepermeabilna za zaštitna sredstva.

Uporaba

Drvo kosipa može se upotrijebiti za izradu vanjske i unutarnje stolarije, furnira, namještaja visoke klase, furnira za prednju ili stražnju stranu šperploča, parketa, stuba, ploča za vanjsku uporabu, šindre i lameliranog drva.

Sirovina

Kosipo na tržište dolazi u obliku trupaca duljine 5 m i više, promjera od 60 centimetara naviše i u obliku piljene građe.

Napomena

Slične vrste su sapelli (*Entandrophragma cylindricum* Sprague) i sipo (*Entandrophragma utile* Sprague). Kosipo je jedina vrsta roda *Entandrophragma* u kojoj ima silikata.

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