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Časopis izlazi četiri puta u godini.

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

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70 godina časopisa Drvna industrija

Drage čitateljice i dragi čitatelji, poštovani suradnici i prijatelji časopisa *Drvna industrija*,

neumitnom protoku vremena svjedoči i časopis *Drvna industrija*. Ove godine obilježavamo 70. obljetnicu njegova neprekidnog izlaženja. Znajući koliko je rada, vremena i financijskih sredstava potrebno utrošiti za svaki broj časopisa koji se nađe u rukama čitatelja ili na zaslonima računala, 70. obljetnica časopisa vrijedna je divljenja i pohvale svima onima koji su godinama ulagali svoje znanje, trud, požrtvovnost i financijska sredstva te održali kontinuitet časopisa i u vremenima kada se to činilo nemogućim.

Časopis *Drvna industrija* međunarodno je priznat znanstveni časopis koji pod istim nazivom neprekidno izlazi od 1950. Prigoda je to za kratki povijesni osvrt, posebice za opis razvoja časopisa u posljednjih 20 godina jer je prof. dr. sc. Hrvoje Turkulin, tadašnji glavni urednik časopisa, uz 50. obljetnicu napisao iznimno sadržajnu kronologiju časopisa.

Povijesni osvrt

U novijoj povijesti časopis je imao nekoliko prijelomnih godina. Jedna od njih bila je 1990., kada izdavanje časopisa od Tehničkog centra za drvo preuzima Drvnotehnološki odsjek Šumarskog fakulteta. Te je godine završilo sedamnaestogodišnje razdoblje u kojemu je časopis vodio prof. dr. sc. Stanislav Bađun, vrsni znanstvenik, profesor i stručnjak, iznimno posvećen časopisu i drvnotehnološkoj struci. Prof. dr. sc. Marijan Brežnjak vodio je časopis od 1990. do 1991., a nakon njega za glavnog urednika izabran je prof. dr. sc. Božidar Petrić. Početci izdavanja časopisa na Šumarskom fakultetu i godine Domovinskog rata bile su teško razdoblje za opstanak časopisa. Svjedočili smo stvaranju samostalne države Republike Hrvatske i pobjedonosnom završetku Domovinskog rata. I časopis je izvojevao svoju pobjedu i opstao. Svojevrsna prijelomnica bila je i 1995. godina, kada časopis dobiva potpuno nov dizajn naslovnice i nov način tehničkog uređivanja tekstova. Otada se na naslovnici svakog broja časopisa prikazuje određena vrsta drva, a u broju se objavljuje i prilog o osnovnim svojstvima i uporabi tog drva. Prof. dr. sc. Hrvoje Turkulin preuzeo je uredništvo časopisa 1997. U godinama koje slijede kvaliteta časopisa znatno je unaprijeđena, Urednički je odbor proširen inozemnim uglednim znanstvenicima, bibliografski se podatci objavljuju dvojezično, povećan je broj radova inozemnih autora i osnažena međunarodna prepoznatljivost časopisa, ponajviše zahvaljujući iznimnoj znanstvenoj aktivnosti glavnog urednika prof. dr. sc. Hrvoja Turkulina. Zbog nedostatnih financijskih sredstava, većeg kašnjenja u izlaženju i iznimno malog broja radova za objavu, časopis je 2002. ponovo ušao u krizno razdoblje. Tijekom 2003. Izdavački savjet, čiji je predsjednik bio prof. dr. sc. Ivica Grbac, napravio je zaokret u politici časopisa i za nove članove Uredničkog odbora predložio uglavnom mlađe znanstvenike Drvnotehnološkog odsjeka. Doc. dr. sc. Ružica Beljo Lučić predložena je za glavnu urednicu, a dr. sc. Stjepan Pervan za tehničkog urednika. U svibnju 2003. u novi Urednički odbor imenovani su ovi znanstvenici Drvnotehnološkog odsjeka: Mladen Brezović, Denis Jelačić, Vlatka Jirouš-Rajković, Darko Motik, Stjepan Pervan, Silvana Prekrat, Stjepan Risović, Tomislav Sinković, Ksenija Šegotić i Jelena Trajković. Godine 2004. i 2005. kao inozemni članovi Uredničkog odbora imenovani su neki stručnjaci iz dotadašnjeg sastava, ali su u Odbor uvršteni i novi priznati znanstvenici iz inozemstva. Pred Uredništvom i Uredničkim odborom bio je velik izazov održanja kontinuiteta časopisa.

Predsjednik Izdavačkog savjeta je, zahvaljujući dobrim odnosima s gospodarstvenicima iz sektora drvne tehnologije i šumarstva, pronašao rješenja za financijsku stabilnost časopisa. Na samom početku rada novo se Uredništvo, opremljeno svom potrebnom informatičkom opremom i neopterećeno problemom financiranja časopisa, moglo posvetiti konsolidaciji i razvoju časopisa. Za redovitost izlaženja velika je prepreka i dalje bio nedostatak radova. Glavna urednica i članovi Uredničkog odbora poticali su znanstvenike Drvnotehnološkog odsjeka na pisanje i objavljivanje znanstvenih radova u časopisu, a zahvaljujući međunarodnoj znanstvenoj suradnji i osobnim poznanstvima, uspjeli su priskrbiti i kvalitetne radove inozemnih autora. Treba naglasiti da su velik doprinos stabilizaciji časopisa kao autori, ali i kao recenzenti, dali znanstvenici iz Slovenije, Slovačke, Poljske, Bugarske, Češke i drugih zemalja, s kojima je bila razvijena dobra međunarodna suradnja.

Zahvaljujući izvrsnoj suradnji s tehničkim urednikom Stjepanom Pervanom i pomoćnikom tehničkog urednika Zlatkom Biharom te članovima Uredničkog odbora, glavna je urednica ustrajno radila na uspostavljanju redovitosti izlaženja časopisa, što je bio prvi i najvažniji preduvjet za uvrštenje u priznate baze časopisa, kao i za osiguranje financijske potpore nadležnog ministarstva.

Već 2006. Povjerenstvo za izdavaštvo pri Ministarstvu znanosti, obrazovanja i športa ocijenilo je časopis izvrsnim i svrstalo ga među 10 % najboljih časopisa u biotehničkom znanstvenom području. Pri pokretanju portala hrvatskih znanstvenih časopisa Hrčak 2006., *Drvna industrija* odmah se priključila portalu te omogućuje otvoren pristup svim objavljenim člancima od 2005. Godine 2009. registrirano je i mrežno izdanje časopisa s dodijeljenim brojem ISSN 1847-1153.

Kada je tijekom 2007. u potpunosti osigurana redovitost izlaženja časopisa, poslani su zahtjevi za uvrštenje časopisa u nekoliko relevantnih svjetskih baza. Zbog kriterija napredovanja u znanstvena zvanja našim je znanstvenicima najvažniji među tim zahtjevima bilo uvrštenje časopisa u bazu *Science Citation Index Expanded* (*SCI-Exp*), koja je u to vrijeme bila u vlasništvu Thomson Reutersa. Iste, 2007. godine potvrđeno je uključenje sadržaja časopisa u informacijske proizvode tvrtke EBSCO Publishing, a 2008. potvrđen je ulazak u baze *DOAJ*, *EMBiology*, *Geobase*, *Paperchem* i *Scopus*. Urednici Thomson Reutersa pratili su časopis dvije godine, tijekom kojih se iznimno pazilo na redovitost izlaženja časopisa, kvalitetu recenzijskog postupka, ali i na stalno dopisivanje s uredom Thomson Reutersa, uvjeravajući ih u kvalitetu i važnost časopisa *Drvna industrija* za drvnotehnološku znanost i struku u Hrvatskoj, ali i u širim razmjerima. Naši suradnici iz mnogih europskih zemalja slali su im pisma preporuke za uvrštenje našega časopisa u bazu.

Napokon 2010. stiže jedna od najljepših vijesti za Uredništvo časopisa i znanstvenike Drvnotehnološkog odsjeka: časopis Drvna industrija uvršten je u bazu *Science Citation Index Expanded* i *Materials Science Citation Indeks*, koje su u sastavu baze *Web of Science*! Svi radovi objavljeni u časopisu od 2008. uvršteni su u bazu a časopis se već pojavljuje na listi *Journal Citation Reporta* za 2010. u kategoriji *Materials science, paper & wood*, s faktorom odjeka 0,146. Bila je to važna prekretnica za naš znanstveni časopis. Nakon toga ubrzano raste broj radova za objavu, časopis postaje vrlo zanimljiv ne samo hrvatskim već i europskim i svjetskim znanstvenicima, povećava se broj objavljenih radova i, što nam je bilo iznimno važno, raste i financijska potpora ministarstva nadležnoga za znanost i visoko obrazovanje. Od početnih nešto više od 7000 kuna u 2003., potpora Ministarstva dosegnula je u 2018. iznos od 146 738 kuna.

O izdavačkoj politici i financijskoj stabilnosti časopisa prof. dr. sc. I. Grbac brinuo se sve do potkraj 2015., kada predsjednikom Izdavačkog savjeta časopisa postaje prof. dr. sc. Vladimir Jambreković. Te je godine imenovan novi Urednički odbor u sastavu u kojemu i danas djeluje a u listopadu 2016. imenovani su i novi inozemni članovi Uredničkog odbora.

Prof. dr. sc. Vladimir Jambreković bio je predsjednik Izdavačkog savjeta do rujna 2018., kada je dužnost predsjednika ponovo preuzeo prof. dr. sc. Ivica Grbac. U listopadu 2018. dolazi do promjene i tehničkog urednika časopisa, kada je poslove tehničkog urednika od prof. dr. sc. Stjepana Pervana preuzeo izv. prof. dr. sc. Zoran Vlaović. S obzirom na to da je zbog velikog broja radova koji pristižu za objavu urednički posao postao vrlo opsežan i zahtjevan, za pomoćnika glavne urednice imenovan je doc. dr. sc. Josip Miklečić.

Časopis se održao i sačuvao kontinuitet zahvaljujući radu i zalaganju Uredništva, Uredničkog odbora i svih znanstvenika Drvnotehnološkog odsjeka, ali i financijskoj potpori i donacijama koje je tijekom protekloga dvadesetogodišnjeg razdoblja dobivao od Šumarskog fakulteta i znanstvenika Drvnotehnološkog odsjeka, resornog ministarstva za znanost i visoko obrazovanje, Hrvatske komore inženjera šumarstva i drvne tehnologije, poduzeća Hrvatske šume d.o.o., Hrvatskoga šumarskog društva, Exportdrva d.d., Zagrebačke županije i tvrtki iz drvnoga sektora, od kojih valja spomenuti Tvin d.d., Spin Valis d.d., Hrast Strizivojna d.o.o., PPS Galeković – Tvornica parketa, Belišće d.d., Finvestcorp d.o.o., Bernarda d.o.o. i Drvodjelac d.o.o.

U posljednjih 20 godina Uredništvo je surađivalo s nekoliko tiskara, ovisno o izboru u sklopu natječaja javne nabave, no najvećim je dijelom to bila tiskara Denona d.d., čiji su djelatnici, a posebno gospođa Ljiljana Zlatić, dali važan doprinos kvaliteti časopisa zahvaljujući visokoj razini stručnosti u pripremi i tisku časopisa.

Posljednjih 20 godina časopisa u brojevima

U razdoblju od 1999. do 2018. objavljeno je 40 brojeva časopisa na ukupno 5640 stranica, odnosno prosječno 282 stranice po volumenu. Prosječan broj objavljenih stranica u volumenu u razdoblju 1998. – 2010. bio je 230 i znatno je manji nego u razdoblju 2011. – 2018., kada je iznosio oko 360 objavljenih stranica. U posljednjih 20 godina ukupno su objavljena 493 znanstvena i stručna rada, odnosno prosječno šest radova po broju. U istom su razdoblju objavljena 324 stručna priloga, odnosno prosječno četiri priloga po broju. Tendencija broja objavljenih priloga u padu je od 1999. do danas. Nasuprot tome, broj objavljenih znanstvenih i stručnih radova po broju časopisa kontinuirano je rastao od 1999. do danas, od 3 – 4 u razdoblju do 2008., zatim 5 – 7 radova u razdoblju od 2008. do 2011., 8 – 9 u razdoblju od 2011. do 2014., a od tada do danas objavljuje se 9 – 11 radova po broju. Unatoč povećanom broju zaprimljenih radova, Urednički je odbor odlučio ne povećavati broj radova te ustrajati na kriterijima visoke razine njihove kvalitete. Od 493 objavljena rada u posljednjih 20 godina najveći je broj izvornih znanstvenih radova, njih 304, te 56 preglednih radova, 75 prethodnih priopćenja i 58 stručnih radova. S obzirom na zemlju u kojoj djeluju autori radova, najveći broj objavljenih radova, njih 311, potpisuju inozemni autori, 55 radova izrađeno je u suautorstvu inozemnih i hrvatskih autora, a 127 radova djelo je domaćih autora. U izradi objavljenih radova sudjelovala su 1483 autora (neki od tih autora višekratno), od čega 982 inozemna autora iz više od 40 zemalja. U časopisu su radove objavili autori iz Australije, Austrije, Bosne i Hercegovine, Brazila, Bugarske, Češke, Čilea, Egipta, Ekvadora, Finske, Francuske, Grčke, Irana, Irske, Italije, Japana, Kanade, Kenije, Kine, Koreje, Kosova, Kostarike, Litve, Mađarske, Makedonije, Nigerije Norveške, Njemačke, Poljske, Portugala, Rumunjske, Rusije, SAD-a, Slovačke, Slovenije, Srbije, Sudana, Španjolske, Švedske, Švicarske, Turske, Ujedinjenog Kraljevstva i Ukrajine. U razdoblju do 2009. u časopisu prevladavaju radovi domaćih autora, no nakon uvrštenja časopisa u baze *SCI-Exp* i *Scopus* u časopisu se češće objavljuju radovi inozemnih autora. Nakon 2014. posebice su aktivni znanstvenici iz Turske pa u mnogim brojevima časopisa prevladavaju njihovi radovi, a broj radova hrvatskih autora smanjuje se iz godine u godinu.

Časopis danas

Časopis je dugi niz godina izlazio pet do sedam puta u godini, i to u 2000 primjeraka, a otkako je njegov izdavač Šumarski fakultet, časopis izlazi kvartalno, u nakladi od 700 komada. Danas se radovi u časopisu pretežito objavljuju na engleskom jeziku, vrlo rijetko na hrvatskome. No Uredništvo nije prestalo njegovati strukovno nazivlje na hrvatskom jeziku te se naslovi, sažetci, ključne riječi, opisi slika i tablica u svim radovima i dalje prevode i objavljuju i na hrvatskom jeziku. Dugogodišnja izvrsna suradnja s lektoricom za hrvatski jezik gospođom Zlatom Babić, prof., i lektoricom za engleski jezik, gospođom Majom Zajšek-Vrhovac, prof., pridonijela je zavidnoj razini kvalitete tekstova i neprestanom unapređenju strukovnog nazivlja s područja drvne tehnologije.

Časopis je trenutačno indeksiran u bazama *Web of Science Core Collection* (*SCI-Exp*), *Scopus*, *CAB Abstracts*, *Compendex*, *Environment Index*, *Veterinary Science Database*, *Geobase*, *DOAJ*. Čimbenik odjeka časopisa (*impact factor*) iz godine u godinu raste s manjim varijacijama. Najviši čimbenik odjeka zabilježen na listi *Journal Citation Report* časopis je imao 2016. i iznosio je 0,712 (Q3), a *SCImago Journal Rank* bio je 0,352 (Q2).

Časopis *Drvna industrija* bio je glavni i mjerodavni svjedok razvoja tehnologije prerade drva u Republici Hrvatskoj, ali i na širim prostorima. Danas časopis svjedoči o neiscrpnim idejama znanstvenika i pomiče granice znanja o drvu kao materijalu s neograničenim mogućnostima primjene, otvara perspektive razvoju novih tehnologija i gradi mostove prema drugim znanstvenim područjima stvarajući nova znanja, nove vrijednosti i nova područja primjene drva, s posebnim naglaskom na njegovoj ekološkoj prihvatljivosti. Nekada je časopis imao zadaću povezati teoriju i praksu, danas mu je cilj povezati istraživanje i inovacije!

Zahvaljujem svim čitateljima, suradnicima i autorima te, posebno, našim vrijednim recenzentima na povjerenju i potpori koju ustrajno pružaju Uredništvu *Drvne industrije* i na taj način omogućuju nastavak bogatoga povijesnog puta jednoga od najstarijih znanstvenih časopisa s područja drvne tehnologije na ovim prostorima.

Nadam se da će se danas, kada smo *oživotvorili davno zamišljeni i zacrtani ideal: da hrvatski znanstvenici ne objavljuju svoje radove samo u prestižnim inozemnim časopisima nego da ih objavljuju u prestižnom hrvatskom časopisu koji se čita i traži u inozemstvu*, kako u Uvodniku posvećenom 50. obljetnici *Drvne industrije* navodi prof. dr. sc. Turkulin, hrvatski znanstvenici tim ostvarenjem obilato koristiti te rezultate svojih istraživanja predstavljati svjetskoj znanosti i struci u časopisu *Drvna industrija*.

Na kraju ovog uvodnika posebno želim zahvaliti prof. dr. sc. Ivici Grbcu, predsjedniku Izdavačkog savjeta, i prof. dr. sc. Stjepanu Pervanu, dugogodišnjemu tehničkom uredniku, kao i administratorici časopisa gospođi Dubravki Cvetan na uspješnoj i iznimno profesionalnoj suradnji kroz mnoge godine zajedničkog rada tijekom kojih smo se najčešće držali poruke prvoga glavnog urednika časopisa dr. Stjepana Frančiškovića *da u konstruktivnom radu zapreke i žrtve ne moraju biti kočnica već – obratno – poticaj za upornije i veće akcije*.

prof. dr. sc. Ružica Beljo Lučić
glavna i odgovorna urednica

70 Years of the Journal Wood Industry

Dear readers, contributors and friends of the journal *Wood Industry (Drvna industrija)*!

The journal *Wood Industry* has been a witness to the relentless flow of time. This year, we mark the 70th anniversary of continuous publishing of the journal. Knowing how much work, time and financial resources are required to release each journal issue in paper form or online, the 70th anniversary of the journal is the opportunity to acknowledge all those who have invested for years their knowledge, effort, devotion and financial resources and kept the continuity of the journal even at times when it seemed impossible.

Wood Industry is an internationally recognized scientific journal that has been published without interruption under the same name since 1950. It is now the occasion to make a brief historical review, focusing on the description of the journal development over the last 20 years, since Prof. Hrvoje Turkulin, then Editor-in-Chief of the journal, wrote a comprehensive journal chronology on the occasion of the journal 50th anniversary.

Historical review

In recent history, the journal had several important years. One of them was 1990 when the Department of Wood Technology of the Faculty of Forestry took over the journal publishing from the Technical Center for Wood. This was the year when the seventeen-year period when the journal was led by Prof. Stanislav Bađun, a renowned scientist, professor and expert, fully committed to the journal and woodworking technology, came to an end. Prof. Marijan Brežnjak led the journal from 1990 to 1991, after that the role of the Editor-in-Chief was took over by Prof. Božidar Petrić. The beginning of the journal publishing at the Faculty of Forestry and the years of the Croatian War of Independence were a difficult period for the survival of the journal. We have witnessed the creation of the Republic of Croatia and the victorious end of the War of Independence. The journal also won and survived. The year 1995 was also important as the journal got a completely new design of the cover and technical editing of texts. The cover of each journal issue showed a specific wood species, and this issue contained an article on the basic characteristics and use of that wood species. Prof. Hrvoje Turkulin took over the role of the Editor-in-Chief in 1997. In the years to come, the quality of the journal was substantially improved, the Editorial Board was expanded to include foreign renowned scientists, bibliographic data were published bilingually, the number of papers of foreign authors was increased and the international recognition of the journal was achieved mainly due to the outstanding scientific work of Prof. Hrvoje Turkulin. A new crisis period for the journal started in 2002 due to the lack of financial resources, publishing delays and extremely low number of papers. During 2003, the Editorial Council of the journal, led by Prof. Ivica Grbac, made a turn in the policy of the journal and suggested that the members of the Editorial Board should be younger scientists of the Department of Wood Technology. Assist. Prof. Ružica Beljo Lučić was appointed as the Editor-in-Chief and Stjepan Pervan, Ph.D. as the Technical Editor. In May 2003. the following scientists of the Department of Wood Technology were appointed as members of the new Editorial Board: Mladen Brezović, Denis Jelačić, Vlatka Jirouš-Rajković, Darko Motik, Stjepan Pervan, Silvana Prekrat, Stjepan Risović, Tomislav Sinković, Ksenija Šegotić and Jelena Trajković. The foreign members of the Editorial Board were nominated in 2004 and 2005, partly from the previous composition and partly new renowned foreign scientists were appointed as members of the Editorial Board. The Editorial Board faced a great challenge of keeping the continuity of the journal.

The Chairman of the Editorial Council, thanks to good relationship with businessmen from the Wood Technology and Forestry sector, found solutions to provide financial stability of the journal. At the very beginning of its activity, the new Editorial Board was equipped with all the necessary IT equipment and, having no financial problems, it could be dedicated to the consolidation and development of the journal. The lack of papers was still a major obstacle for providing regular publishing of the journal. The Editor-in-Chief and members of the Editorial Board encouraged the scientists from the Department of Wood Technology to write and publish scientific papers in the journal, and thanks to international scientific cooperation and personal acquaintances, they succeeded to provide high-quality papers of foreign authors. It should be stressed that scientists from Slovenia, Slovakia, Poland, Bulgaria, the Czech Republic and other countries, with whom good international cooperation has been developed, have contributed significantly to the stabilization of the journal, both as authors and reviewers.

Thanks to the excellent cooperation with the Technical Editor, Stjepan Pervan, and Assistant Technical Editor, Zlatko Bihar, as well as members of the Editorial Board, the Editor-in-Chief has consistently worked to establish regular publishing of the journal as the first and most important precondition for being listed in the relevant journal databases, and for getting financial support from the competent ministry.

Already in 2006, the Publishing Committee of the Ministry of Science, Education and Sports rated the journal as excellent and classified it among 10 % of the best journals in the field of Biotechnical Sciences. When the portal of the Croatian scientific journals, called Hrčak, was launched in 2006, the journal *Wood Industry* was immediately listed providing open access to all published articles since 2005. In 2009, the online edition of the journal was also registered with the reference No. ISSN 1847-1153.

When regular publishing of the journal was fully provided during 2007, requests for listing the journal were sent to several relevant world databases. Due to professional advancement criteria, our scientists considered that the most important was the requirement for listing the journal into the *Science Citation Index Expanded* (*SCI-Exp*) database, at that time owned by Thomson Reuters. In the same year 2007, it was confirmed that the journal content was entered into *EBSCO Publishing* database, and the entry into the databases of *DOAJ*, *EMBiology*, *Geobase*, *Paperchem* and *Scopus* was confirmed in 2008. The editors of Thomson Reuters monitored the journal for two years, during which we were extremely concerned about timely publishing of the journal and the quality of the review process. We were also in constant correspondence with Thomson Reuters, assuring them of the quality and importance of the journal *Wood Industry* for wood technology science and wood sector in Croatia, but also on a broader scale. Our associates from many European countries have sent letters of recommendation for the inclusion of the journal into the database.

Finally, in 2010 the Editorial Board of the journal and the scientists of the Department of Wood Technology received a wonderful news – the journal *Wood Industry* was listed into the database of *Science Citation Index Expanded*i *Materials Science Citation Index* that made part of the *Web of Science* database! All papers published in the journal since 2008 were listed in the database and the journal already appeared in the list of the *Journal Citation Report* for 2010 in the category *Materials science, paper & wood*s with the impact factor 0.146. It was a significant turning point for the scientific journal *Wood Industry*. Since then, the number of papers received has grown rapidly, and the journal has become interesting not only for Croatian, but also for European and world scientists. The number of published papers has been increasing, and what was extremely important, the financial support from the Ministry competent for science and higher education has also grown. From the initial slightly more than 7,000 kuna in 2003, the support of the competent Ministry has reached the amount of 146,738 kuna in 2018.

Prof. I. Grbac has implemented the publishing policy and provided financial stability to the journal until the end of 2015, when Prof. Vladimir Jambreković became the Chairman of the Editorial Council of the journal. In the same year, the members of the current Editorial Board were appointed and foreign members of the Editorial Board were appointed in October 2016.

Prof. Vladimir Jambreković was the Chairman of the Editorial Council until September 2018, when the role of the Chairman was again taken over by Prof. Ivica Grbac. In October 2018, Assoc. Prof. Zoran Vlaović took over the role of the Technical Editor after Prof. Stjepan Pervan. As, due to the large number of papers for publishing, editorial work has become very demanding, Assist. Prof. Josip Miklečić was appointed as Assistant to the Editor-in-Chief.

The journal survived thanks to the work and effort of the Editorial Board and all scientists of the Department of Wood Technology, but also due to the financial support and donations received during the last twenty years from the Faculty of Forestry and scientists of the Department of Wood Technology, the ministry responsible for science and high education, Croatian Chamber of Forestry and Wood Technology Engineers, the company Hrvatske šume d.o.o. (Croatian Forests Ltd.), Croatian Forestry Society, the company Exportdrvo d.d., the County of Zagreb and companies from the wood sector such as: Tvin d.d., Spin Valis d.d., Hrast Strizivojna d.o.o., PPS Galeković – Tvornica parketa, Belišće d.d., Finvestcorp d.o.o., Bernarda d.o.o. and Drvodjelac d.o.o.

In the last 20 years, the Editorial Board collaborated with several printing companies, depending on the choice of public procurement, but it was mostly the printing company Denona d.d., whose employees, and especially Mrs. Ljiljana Zlatić, greatly contributed to the quality of the journal due to the high level of expertise in the preparation and printing of the journal.

The journal in the last 20 years in numbers

In the period from 1999 to 2018, 40 issues of the journal were published with a total of 5,640 pages, i.e. 282 pages per issue on average. The average number of pages in an issue in the period from 1998 to 2010 was 230, which is significantly less than in the period from 2011 to 2018, when the number was approximately 360 published pages. In the last 20 years, 493 scientific and professional papers have been published, i.e. about 6 papers per issue on average. In the same period, a total of 324 professional contributions were published, with an average of four contributions per issue. The tendency of the number of published contributions has fallen since 1999 to date. On the other hand, the number of scientific and professional papers published per journal issue has risen continuously since 1999, from 3 to 4 in 2008, followed by 5 to 7 papers in the period from 2008 to 2011, 8 to 9 in the period from 2011 to 2014, and since then 9 to 11 papers. Despite the increased number of received papers, the Editorial Board decided not to increase the number of published articles but rather to keep the criteria of high quality. Out of 493 papers published in the last 20 years, 304 were original scientific papers, 56 were review papers, 75 were previous announcements and 58 professional papers. Considering authors' country of origin, most published papers, 311, were of foreign authors, 55 papers were the result of collaboration between foreign and Croatian authors, and 127 papers were written by Croatian authors. There was a total of 1483 authors (some of the authors repeatedly), of which 982 were foreign authors from more than 40 countries. The papers of the authors coming from the following countries were published in the journal: Australia, Austria, Bosnia and Herzegovina, Brazil, Bulgaria, Czech Republic, Chile, Egypt, Ecuador, Finland, France, Greece, Iran, Italy, Japan, Canada, Kenya, China, South Correa, Kosovo, Costa Rica, Lithuania, Hungary, Macedonia, Nigeria, Germany, Poland, Portugal, Romania, Russia, USA, Slovakia, Slovenia, Serbia, Sudan, Spain, Sweden, Switzerland, Turkey, United Kingdom, Ukraine.

In the period up to 2009, the papers of Croatian authors prevailed in the journal, but after listing the journal in *SCI-Exp* and *Scopus*, the papers of foreign authors were published more frequently. Since 2014, Turkish scientists have become particularly active, so their papers prevailed in many journal issues, while the number of papers of Croatian authors has been decreasing from year to year.

The journal today

For many years, the journal was released five to seven times a year in 2000 copies, and since the Faculty of Forestry became the publisher, the journal has been released quarterly in 700 copies. Today, the journal papers are mostly published in English and very rarely in Croatian. However, the editorial staff never ceased to cultivate professional terminology in Croatian, so the titles, summaries, keywords, picture and table captions in all papers are still translated and published in the Croatian language. The excellent cooperation with the Croatian language editor, Zlata Babić, prof., and the English language editor, Maja Zajsek-Vrhovac, prof., contributed to achieving high quality texts and continuously improving the professional terminology in the field of wood technology.

The journal is currently indexed in the *Web of Science Core Collection databases* (*SCI-Exp*), *Scopus, CAB Abstracts, Compendium, Environment Index, Veterinary Science Database, Geobase, DOAJ*. The impact factor has grown year after year with small variations, and the highest journal impact factor - 0.712 (Q3) was recorded on the list of the *Journal Citation Report* in 2016, while that of *SCImago Journal Rank* was 0.352 (Q2).

The journal *Wood Industry* was the main and relevant witness to the development of wood processing technology in the Republic of Croatia and beyond. Today, the journal is the witness of inexhaustible ideas of scientists and it sets boundaries of wood knowledge as a material with unlimited application possibilities. It provides opportunities for the development of new technologies and builds bridges to other areas of science by creating new knowledge, new values and new areas of wood application with special emphasis on its ecological viability. In the past, the main role of the journal was to link theory and practice, while today, the goal is to link research and innovation!

I would like to thank all the readers, contributors, authors and especially our diligent reviewers for the trust and support they continuously provide to the Editorial Board of the journal *Wood Industry* and thus enable the continuation of the development of one of the oldest scientific journals in the field of wood technology in this area.

Today, "we *have achieved the goal set long ago: that Croatian scientists do not have to publish their papers in prestigious foreign journals but have the possibility to publish them in a prestigious Croatian journal that is read and demanded abroad*". This was the goal set on the occasion of the 50th anniversary of the journal *Wood Industry* by Prof. Turkulin. I hope the Croatian scientists will use this achievement abundantly and present the results of their research to the world science and profession in the journal *Wood Industry*.

And at the end of this Editorial, I especially want to thank Prof. Ivica Grbac, the Chairman of the Editorial Council and Prof. Stjepan Pervan, the longtime Technical Editor, as well as the Administrative Assistant of the journal, Mrs. Dubravka Cvetan, for a successful and extremely professional cooperation during many years of joint work, during which we implemented the recommendation of the first Editor-in-Chief of the journal, Dr. Stjepan Frančišković, who said *"that in constructive work, obstacles and victims must not discourage us, but rather be the incentive for more persistent action"*.

Prof. Ružica Beljo Lučić
Editor-in-Chief

Michal Dobrzynski[1], Kazimierz A. Orlowski[1], Michal Biskup[2]

Comparison of Surface Quality and Tool-Life of Glulam Window Elements after Planing

Usporedba kvalitete površine i životnog vijeka alata pri blanjanju lameliranih elemenata za prozore

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ABSTRACT • *The quality of the surface of wooden elements, that have been planed, has a crucial importance in the whole production process, since the obtained effects affect the quality of wooden surface after finishing (painting). The occurrence of defects is usually the reason for qualifying a workpiece as scrap or for requiring additional work. This paper presents the selected results of research of the effect of the cutting tool wear on the surface quality of elements after planing. Research experiments were conducted on the SCM Superset Class machine tool. Glulam elements of pine wood (Pinus sylvestris L.) were researched. The raw material samples (semi-finished products), 6 m long before planing, had been machined by suppliers also by planing. These workpieces were selected according to the plant requirements, e.g. their moisture content, straightness, and other defects. This paper presents the measuring results of surface roughness and some examples of surface profiles, as well as the dependence of total length of the planed elements on the type of blade material. From an economic point of view, the results showed that the use of solid carbide blades were more cost effective.*

Key words: *planing process, pine wood, window frame, surface quality, 2D/3D surface texture*

SAŽETAK • *Kvaliteta površine drvenih elemenata obrađenih blanjanjem ima presudnu važnost u cjelokupnome proizvodnom procesu jer kvaliteta blanjanja utječe na kvalitetu površine drva nakon završne obrade (nakon bojenja). Zbog nastalih grešaka elementi za prozore najčešće se kvalificiraju kao škart ili se moraju obaviti dodatni poslovi radi uklanjanja tih grešaka. U radu su prikazani odabrani rezultati istraživanja utjecaja zatupljenja alata na kvalitetu površine elemenata nakon blanjanja. Istraživanje je provedeno na stroju SCM Superset Class. Kao uzorci odabrani su lamelirani elementi od borovine (Pinus sylvestris L.). Uzorci lameliranih elemenata (poluproizvoda), duljine 6 m, već su prije eksperimentalnog blanjanja kod dobavljača također obrađeni blanjanjem. Ti su elementi selektirani prema zahtjevima tehnološkog procesa, npr. prema sadržaju vode, ravnosti i postojećim greškama drva. U radu su navedeni rezultati mjerenja kvalitete površine elemenata, kao i neki primjeri profila površine te ovisnost ukupne duljine oblanjanih elemenata o vrsti materijala oštrice alata. Rezultati su pokazali da je s ekonomskog stajališta isplativija uporaba alata s oštricama od tvrdog metala.*

Ključne riječi: *proces blanjanja, borovina, okvir prozora, kvaliteta površine, 2D/3D tekstura površine*

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1 INTRODUCTION
1. UVOD

Surface quality of solid wood products is one of the most important properties influencing further manufacturing processes such as finishing (coating) or strength of adhesive joint (Kilic *et al.*, 2006; Aguilera and Muñoz, 2011; Ugulino and Hernández, 2016). Nevertheless, determination of surface quality in planing is a complex process depending on the heterogeneous structure of wood species (Belleville *et al.*, 2016; Malkoçoğlu and Özdemir, 2006; Malkoçoğlu, 2007; Sofuoğlu and Kurtoğlu, 2015), kinematics of the cutting process (Hernández and·Cool, 2008; Gottlöber *et al.*, 2015), and machining conditions (Jokerst and Stewart, 1976; Malkoçoğlu, 2007; Minami and Nishio, 2015; Stewart, 1980; Ugulino and Hernández, 2016).

Machinability of species of raw and thermally treated wood has been assessed based on quality of planed surfaces.

Belleville *et al.* (2016) evaluated the potential of young eucalypts growing under short rotation planting conditions, as a resource for the manufacture of high quality furniture and furnishings, which were planed with tungsten carbide cutters. In this case, the number of defects on the sample was a measure of quality acceptance.

Aguilera and Muñoz (2011) stated that better surface quality could be obtained for dense Blackwood (*Acacia melanoxylon*), as ten point height of irregularities *Rz* (ISO) was equal to 15 μm, in comparison to Redwood (*Sequoia sempervirens*), where *Rz* (ISO) was 22 μm. The experiments were conducted with a tool of ∅124 mm in diameter, equipped with 4 knives made of high speed steel, with their geometry as follows: rake angle 25° and clearance angle 17°; number of revolution 4200 rpm, and feed speed in of range of 4-11 $m \cdot min^{-1}$.

Heat treatment of selected Turkish wood species (soft and hard wood) does not affect surface roughness (Budakçı *et al.* 2013). On the other hand, Gűndűz *et al.* (2008) reported that surface roughness of modified Camiyanı Black Pine wood (*Pinus nigra* Arn. subsp. *pallasiana* var. *pallasiana*) is lower. Similar findings were stated by Kisselbach (2009) concerned modified timber for window construction. Analogous results of decreased roughness were described by Kvietková *et al.* (2015) in case of birch wood after thermal treatment. Findings of the experiments by Škaljić *et al.* (2009) revealed that roughness *R*a of thermally modified beech-wood was very close to the same values of steamed beech-wood samples. However, the surface roughness of heat-treated beech processed by milling was slightly higher than that of untreated wood (as measured by *Ra, Rq, Rt, Rk*, and *Rk+Rpk+Rvk*) (Ispas *et al.*, 2016). The latter findings were confirmed by Hacibektasoglu *et al.* (2017), who revealed that heat-treating beech (*Fagus sylvatica* L.) for 1 h and 2 h had a negligible effect on the processing roughness after planning, measured across the grain by *Rk*. Moreover, the *Rk* increased by 15 % for 3 h and 4 h of treatment and with approximately 33 % for treating the beech for 5 h and 6 h.

The researches by Škaljić *et al.* (2009) have shown that the samples of planed surface of oak-wood (*Quercus* L.) had the best quality and the samples of fir wood (*Abies alba* Mill.) had the highest values of surface roughness (*Ra*). In both cases the specimens were machined by planing in radial directions with two knives at 6, 12, 18 and 24 $m \cdot min^{-1}$ feed speed. The cutting depth of 2.0 mm was constant and knife rake angle was 15°. The machining experiments were carried out using a single cutter-block of a Weinig Powermat 400. The cutter-block with a diameter of Ø125 mm rotated at 6000 revolutions per minute (rpm) (Škaljić *et al.*, 2009).

Öhman *et al.* (2015) found that, after planing, the average surface quality of a whole batch of boards made of Scots pine (*Pinus sylvestris* L.) can be increased by adding water to the surface short before planing. However, a positive impact cannot be guaranteed for single boards (Öhman *et al.*, 2015).

After planing with dull knives, the wood cells were greatly distorted and cell walls were extensively damaged, particularly at and near the glue line. On the other hand, sharp knives caused much less damage to cell walls and the cells had a normal or near-normal appearance (Singh *et al.*, 2002).

Industrial development and international competitiveness impose higher demands on wood industry. New technologies and cutting materials are the key to successful productivity in the manufacturing process. From the industrial point of view, the frequency of tool changes should be minimised and simultaneously the production costs per each piece ought to be reduced (Aguilera *et al.*, 2003). Therefore, the aim of this paper was to evaluate the effect of the cutting tool material (wear) on the surface quality of planed semi-finished pine beams for window frames.

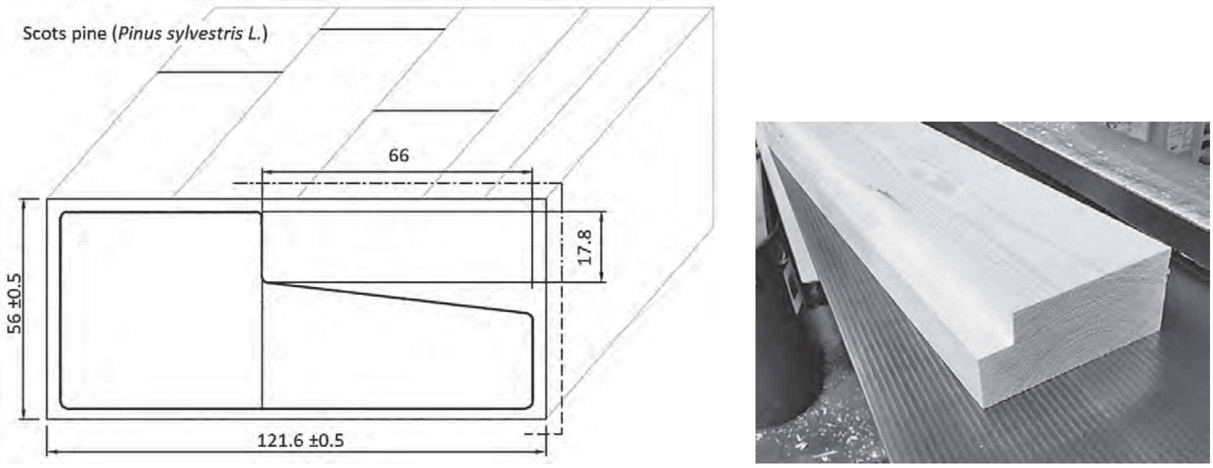
2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

The samples in the research were wooden beams made of glued laminated Scots pine lamellae (*Pinus sylvestris* L.), generally used for the production of window frames. Semi-finished products were provided in the form of 6-meter-long beams initially machined by suppliers. It should be emphasised that the total number of samples was not limited because beam planing was conducted until there were no defects on the machined surface. The working drawing of the semi-finished product includes dimensions, wood species, surface and main features as shown in Fig. 1.

2.2 Methods
2.2. Metode

Tests were carried out on the moulding machine for four-side machining type of Superset mt (the planer moulder, SCM Group SPA, Italy). This test was con-



a) b)

Figure 1 Working drawing (a) and view of semi-finished material (b)
Slika 1. a) Radni crtež za proizvodnju elemenata za prozore, b) izgled drvenoga lameliranog elementa za proizvodnju prozora

ducted on the first out of three operations in the production process and was associated with shaping of the workpiece (Fig. 2).

The test was carried on until no defects associated with the tool wear (material pulled out, cracks) could be observed on the planed surface of the element. The element was classified as unfit for further production process based on visual inspection. One of the important indicators of the process evaluation was the number of metres of machined wood meeting the quality requirements, meaning that wood surface of the remaining machined parts were of poor quality. The length of the properly cut beams could be considered as a wear factor (Aguilera *et al.*, 2016).

The occurrence of defects in the material and on the surface can be divided into those dependent and independent on humans. The first group, as previously mentioned, was associated with the occurrence of cracks and knots of the material. In the second group, there are mostly prints and scratches in the material, as well as fibres torn away from the surface.

Figure 2 View of the material after machining
Slika 2. Izgled drvenoga lameliranog elementa nakon strojne obrade

The occurrence of any of the above mentioned defects usually disqualified the material for further machining. Some of them could be corrected but it required additional machining (re-work) using sanding machines.

2.3 Tool and machine tool
2.3. Alat i stroj

A set of blades necessary to equip the planer moulder Superset mt consisted of 8 knives 80 mm long, 2 knives 130 mm long and 2 knives 150 mm long. Such equipment provided the opportunity to implement all the necessary processes in one machine setting. Table 1 presents the main woodworking information.

In the research, a Tersa® system planer head was used of 140 mm in diameter (Fig. 3). The knife was made of the standard uncoated solid carbide (HW, K a group of application according to ISO (Tersa 2014)) of micrograin quality, and additionally for comparison blades were made of chrome steel (CR, HR13%Cr (Tersa 2014)). The knives are also characterised by clearance angles (α) in the knife-in-hand system equal to 50° (CR) and 35° (HW) (Tersa 2014). Moreover, the Tersa® system is characterised by great flexibility resulting from the system's modular design of identical aluminium washers.

The quality of machined parts was evaluated taking into account various aspects, including dimensions, presence of defects of the raw material, finishing with the surface texture. As shown in the working drawing, dimension deviations were approximately ± 0.2 mm (tolerance of 0.4 mm). For this reason, they were measured with a calliper.

Before further machining, semi-finished wood elements were subjected to a thorough inspection. Moisture content *MC*, straightness of workpiece, as well as the presence of material defects, such as cracks and knots, were tested among other things.

The accepted deflection of an element of 1 m in length was 0.7 mm at the highest point. The density of the wooden element made of, for example, two or more lamellas could not be less than 500 kg/m^3. An impor-

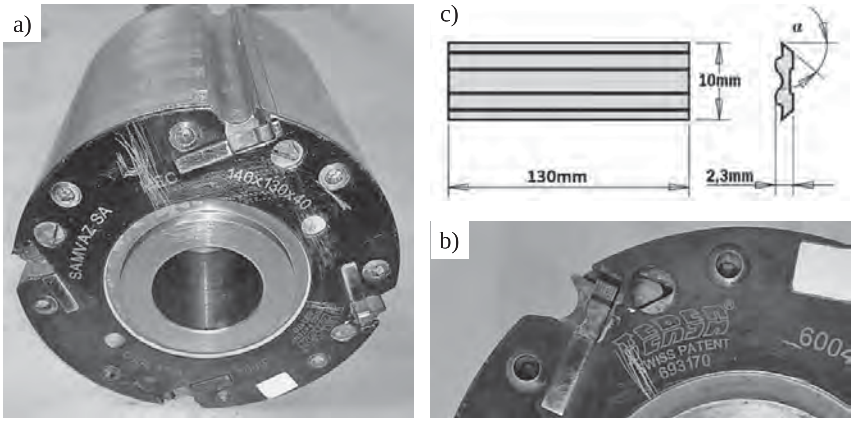


Figure 3 General (a) and detailed (b) view of Tersa® system planer head of 140 mm in diameter and main dimensions of the blade (c) (Tersa, 2018)
Slika 3. a) Prikaz cijele glave blanjalice, b) prikaz detalja u Tersa® sustavu promjera 140 mm, c) glavne dimenzije noža (Tersa, 2018.)

Table 1 Main information on experimental procedure
Tablica 1. Najvažniji podatci o procesu obrade elemenata u eksperimentu

	Machine tool *Stroj*	**No. of tool spindles** *Broj vratila*	**Tool type** *Vrsta alata*	**Cutting depth, a_p** *Visina dodatka za obradu* mm	**Feed per tooth f_z** *Posmak po zubu* mm	**Spindle speed *n*** *Frekvencija vrtnje vratila* rpm
Shaping *Oblikovanje*	SCM Superset CLASS	1	Tersa® head ∅ = 140 mm	0.8	0.5	6000
		2				
		3				
		4				
		5				
		6				

tant parameter under control was the moisture content that was to be *MC* 12 % ± 2 %.

The surface texture measurements (P – profile, R – profile, W – profile) were carried out with the surface roughness tester Hommelwerk Standard 1000. Each 1-m of the sample, where defects were observed, was cut-off from the 6-m specimen, and then measured. At each measurement point with a visible defect, three measurements were done perpendicularly to the side surface of the workpiece for averaging the results. The results of the measurement of the testing set were recorded in the measuring table, along with the obtained total length of the machined wood.

Additionally, the surface topography measurements of the processed products were made with the 3D Optical Profiler S Neox (Sensofar 2017) with objective 20× magnification and Z scanning range of 83 micrometres. This system is one of the methods of 3D optical measurements applied in the study of surface topography, which allowed us to scan the samples with a confocal technique.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of six tests of total lengths of machined frame beams (together with corresponding number of beams) are presented in Table 2. In order to perform a correct analysis, results obtained from machining with blades made of solid carbide (HW) were compared with results from the same test performed with blades made of chrome steel (CR). It should be emphasized that the productivity of the process in the first case is nearly 3.5 times higher than in the second one (length Median (HW) = 468 m and length Median (CR) = 131 m) (Fig. 4). The analysis took into account the cost of production and especially the difference in the cost of equipping the machine with a given type of knife. The total cost of equipping the heads with knives made of HW was almost twice higher than with knives made of CR. Nevertheless, the average production cost of 1 meter of material in the first case (the head equipped with HW knives) was about 30 % less than the second one (CR knives used).

Measuring the surface texture enabled the comparison of surface structure processed with the new blades and those that showed wearing. In 2D measurements (Gurau and Irle, 2017; Zhong *et al.*, 2013; Sandak and Tanaka, 2003; Sandak *et al.*, 2004; Sandak and Negri, 2005), the evaluation length amounted to 12.5 mm. During the measurements, the following parameters were adopted: evaluation length *ln* = 12.5 mm, cut off value λc = 2.5 mm, cut off ratio λc/λs = 300, sampling interval 1.5 μm and filter type ISO 11562(M1). The stylus end was conical (taper angle of cone: 60°) with a spherical tip (tip radius r_{tip} = 2 μm). These values were adopted since the main objective was to assess the surface condition on maximum possible length, which was limited by maximum measuring length of the used device.

Table 2 Total length of machined frame beams together with corresponding number of planed beams in parenthesis vs. selected types of blade material
Tablica 2. Ukupna duljina lameliranih elemenata obrađenih dvama različitim noževima za blanjanje (pripadajući broj obrađenih elemenata naveden je u zagradi)

		Total length of machined frame beams (in m) and number of planed beams in brackets / *Ukupna duljina obrađenih lameliranih elemenata (m) s pripadajućim brojem obrađenih elemenata u zagradi*					
No. of test samples *Redni broj mjerenja*		1	2	3	4	5	6
Knife material *Materijal noža za blanjanje*	Solid carbide (HW) *tvrdi metal*	389 (65)	437 (73)	499 (83)	290 (49)	569 (95)	525 (88)
	Chrome steel 13 % Cr (CR) *kromirani čelik*	100 (17)	159 (27)	200 (34)	103 (18)	79 (13)	299 (50)

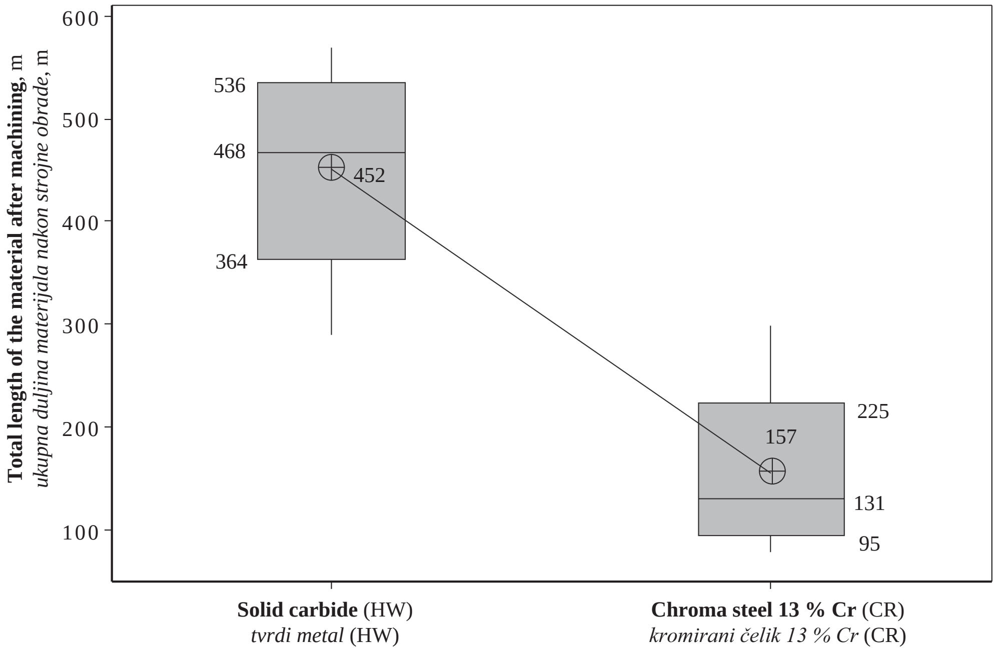


Figure 4 The mean value and value dispersion of total length of machined frame beams vs. selected types of blade material (box plot presents: the mean, median, interquartile range box and data range)
Slika 4. Srednja vrijednost i rasipanje podataka o ukupnoj duljini obrađenih lameliranih elemenata s obzirom na vrstu materijala noža (na grafu su prikazane srednje vrijednosti, medijani, interkvartilni raspon i raspon podataka)

Comparing the profiles between the sample manufactured with a set of new knives and the sample obtained after manufacturing n-meters of the product, significant changes can be noticed in the appearance of the primary profile (the profile of waviness was added for better visualisation). The profiles of the first samples, i.e. after manufacturing 6 m long beams, were smooth and the knives wear was not observed (Fig. 5). The surface texture parameters for the primary and roughness profiles were: *Ra* = (2.48 - 3.20 µm), *Rz* = (16.90 - 21.25 µm), *Rv* = (7.55 - 8.82 µm), *Rp* = (9.61 - 14.13 µm), *Pz* = (18.86 - 25.52 µm), *Pv* = (0.77 - 18.18 µm) and *Pp* = (4.08 - 14.46 µm).

Measurements of the last defect-free element were made in two areas that had been assessed as the most damaged by visual inspection. Three parallel measurements at 7-mm intervals were done perpendicularly to the side surface of the workpiece (perpendicularly to the feeding direction). The results of the measurement of the testing set, i.e. the last samples, are presented in meas-

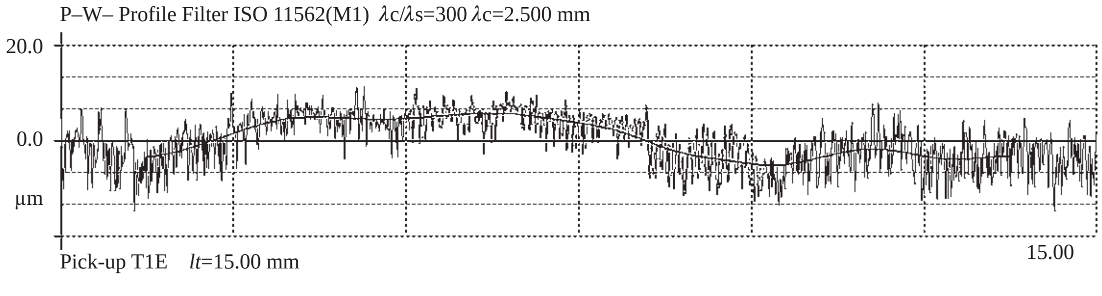


Figure 5 Example of P– and W– profile of the first machined sample
Slika 5. Primjer profila P i W za prvi obrađeni uzorak

Table 3 Roughness parameters of the last element machined by Solid Carbide Blades (HW)
Tablica 3. Parametri hrapavosti posljednjeg elementa obrađenoga noževima od tvrdog metala (HW)

No. of test samples *Redni broj mjerenja*	**No. of area** *Broj površine*	**No. of measurement** *Broj mjerenja*	**Roughness parameters** / *Parametri hrapavosti*					
			Rt, µm	*Rz*, µm	*Rp*, µm	*Rv*, µm	*Rku*	*Rsk*
1	1	3	59.89	33.33	29.64	16.41	5.151	-0.378
	2	3	52.13	33.18	15.83	12.19	5.700	-0.973
2	1	2	57.50	43.03	24.25	15.67	3.243	-0.050
	2	1	68.54	37.43	34.03	10.30	11.584	0.734
3	1	1	44.75	34.43	25.82	14.74	3.629	-0.046
	2	2	40.32	31.89	15.88	17.93	4.372	-0.748
4	1	1	33.31	21.04	17.78	9.66	5.539	-0.389
	2	2	39.00	26.52	12.51	10.97	5.603	-0.973
5	1	2	51.51	32.19	13.31	11.94	11.243	-2.165
	2	1	39.21	22.89	16.70	10.23	5.859	-0.884
6	1	2	59.66	37.54	26.75	11.49	6.712	0.222
	2	1	46.74	34.84	27.55	16.47	3.774	0.113

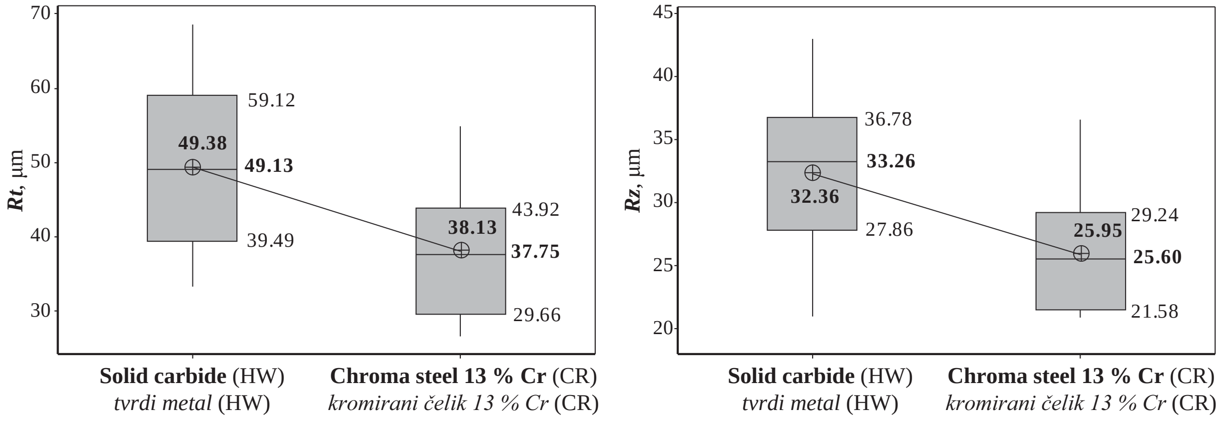
Table 4 Roughness parameters of the last element machined by Chrome Steel Blades 13 % Cr (CR)
Tablica 4. Parametri hrapavosti posljednjeg elementa obrađenoga noževima od kromiranog čelika (CR)

No. of test samples *Redni broj mjerenja*	**No. of area** *Broj površine*	**No. of measurement** *Broj mjerenja*	**Roughness parameters** / *Parametri hrapavosti*					
			Rt, µm	*Rz*, µm	*Rp*, µm	*Rv*, µm	*Rku*	*Rsk*
1	1	1	45.03	29.74	13.83	14.34	7.119	-1.163
	2	3	51.52	27.86	11.68	12.02	14.463	-2.017
2	1	3	39.22	25.70	14.74	11.52	7.044	-1.216
	2	3	40.58	29.70	18.58	11.50	4.045	-0.472
3	1	1	39.52	24.43	17.33	11.69	5.609	-1.009
	2	3	34.58	21.21	13.54	11.51	3.900	-0.557
4	1	1	26.74	20.91	8.13	11.59	3.669	-0.753
	2	3	36.28	26.14	18.56	13.36	3.679	-0.383
5	1	1	29.38	20.93	10.36	8.42*	4.433	-0.857
	2	2	29.22	25.49	13.88	12.72	3.594	-0.508
6	1	2	30.49	22.69	11.44	11.02	4.451	-0.795
	2	2	54.97	36.62	19.99	10.86	6.024	-0.827

*outlier observation from 1.5 times the interquartile range (Q3 – Q1) / *podatak koji je izvan interkvartilnog raspona (Q3 – Q1)*

urement tables (see Appendix). Taking into account maximum *Rt* values for each area of test sample, as one of texture parameters significantly affected by scratches due to its use of peak values, the data tables were created and further analysed (Table 3 and 4).

The maximum value of the total profile height– *Rt* (68.54 µm) was observed in Sample #2 for the second area (HW) and it was about 25 % greater than the maximum value for CR blade (Sample #6 second area). In both cases, the range of *Rt* parameter was significant and amounted to 33.31 – 68.54 µm (HW) and 26.74 – 54.97 µm (CR). Generally, mean and median were about 30 % greater for HW blade (Fig. 6). Similar situation occurred for maximum height of the profile (*Rz*).



a) b)

Figure 6 The mean value and value dispersion of total height *Rt* (a) and maximum height *Rz* (b) of the profile vs. selected types of blade material (the box plot presents: the mean, median, interquartile range box and data range)
Slika 6. Srednja vrijednost i rasipanje podataka: a) o ukupnoj visini *Rt* i b) o maksimalnoj visini *Rz* profila obrađene površine pri obradi dvama različitim noževima (na grafu su prikazane srednje vrijednosti, medijani, interkvartilni raspon i raspon podataka)

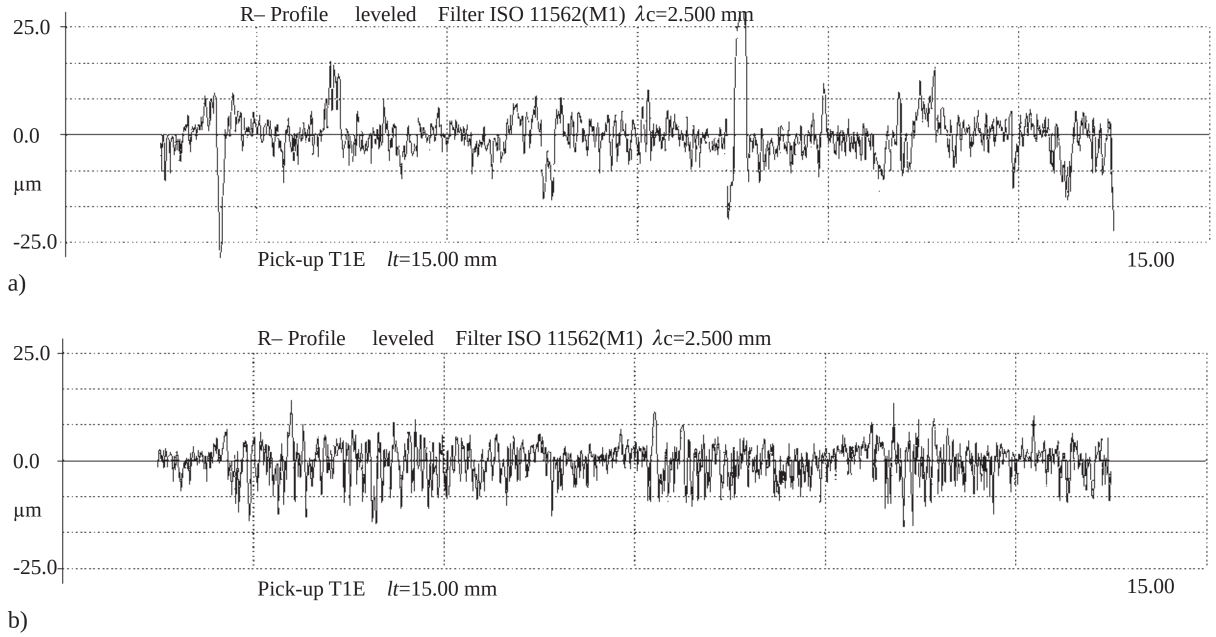


Figure 7 R–profiles of Sample #2 machined with HW blades (a) and Sample #5 planed with CR blades (b)
Slika 7. a) R-profil uzorka #2 obrađenoga nožem od tvrdog metala, b) R-profil uzorka #5 obrađenoga nožem od kromiranog čelika

However, the inter-quartile range was 8.92 µm (HW) and 7.66 µm (CR), respectively, whereas these ranges were twice as high as parameter *Rt*. This indicates a greater concentration of results around the median, which is related to the method of determining this parameter based on a sampling length and not on an evaluation length as in the case of *Rt*.

Therefore, both minimum and maximum heights are characterised by particular maximum height of the profile (*Rz*) in the range of 20 – 45 % for HW blade, and 12-45 % for CR blade, which is smaller than corresponding values of profile total height (*Rt*). The maximum difference of 45 % is presented by the example of the profile of Sample #2 second area (HW) (Fig. 7a). Moreover, the profile for the minimum value of 12 % observed in Sample #5 second area (CR) is pictured in Figure 7b. Scratches, pull-outs and other damages to the machined wooden material could be distinctly observed on profiles, especially for HW blades, (the last element that does not fulfil quality requirements).

In both cases in question, the means and medians of maximum profile valley depth (*Rv*) were on similar level, whereas in case of maximum profile peak height (*Rp*), the difference between them was about 7 µm (Fig. 8). The maximum values of *Rv* and *Rp* were 20 % and 40 % greater for HW blades, respectively. The range of the quartile box for HW blades was nearly two times higher than for CR blades. Likewise, the dispersion of measured values was doubled. However, the consideration of 8.42 µm outliers leads to the conclusion that ranges of *Rv* can be comparable.

The Skewness (*Rsk*) values for most HW samples and all CR samples indicate that the height distribution was deviated upwards. In the case of one of Samples #2 and both Samples #6 (HW), the height distribution was deviated downwards. Meanwhile, in all examined

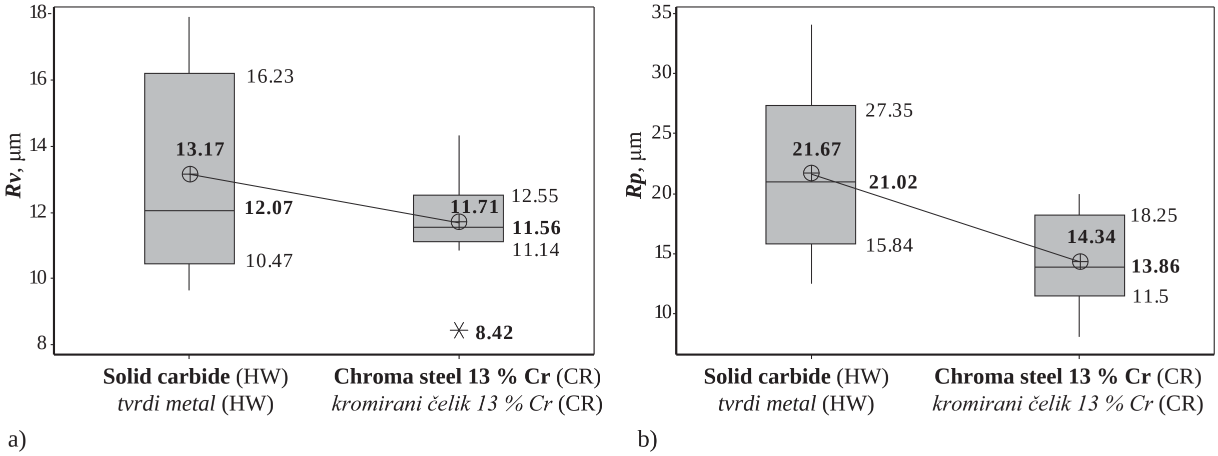


Figure 8 The mean value and value dispersion of maximum profile: valley depth *Rv* (a) and peak height *Rp* (b) vs. selected types of blade material (the box plot presents: the mean, median, interquartile range box and data range - outlier)
Slika 8. Srednja vrijednost i rasipanje podataka: a) o dubini udoline *Rv* i b) o visini vrha *Rp* maksimalnog profila površine obrađene dvama različitim noževima (na grafu su prikazane srednje vrijednosti, medijani, interkvartilni raspon i raspon podataka)

Table 5 3D surface texture parameters of the last machined element without visible defects
Tablica 5. 3D parametri teksture površine posljednjega obrađenog elementa bez vidljivih grešaka

		No. of test sample / *Redni broj mjerenja*					
		1	2	3	4	5	6
3D surface texture parameters *3D parametri teksture površine*	*Sa*, μm	5.09	10.99	6.51	7.09	4.27	7.30
	Sq, μm	7.05	17.18	8.68	9.35	5.83	12.02
	Sp, μm	23.60	25.57	57.36	31.98	26.99	65.61
	Sv, μm	55.79	117.46	51.27	57.80	44.58	80.11
	Sz, μm	79.39	143.03	108.63	89.79	71.57	145.73
	Sku	9.45	11.57	5.30	6.38	6.20	12.44
	Ssk	-2.11	-2.79	-0.51	-1.69	-1.58	-1.76
	Δ*Z*, μm	55.26	67.62	49.69	45.26	18.62	32.61
	A, °	12.16	11.61	8.13	8.63	4.08	6.91

cases, the tip geometry of peaks and valleys was sharp, Kurtosis (*Rku*) > 3.

For a more detailed analysis of the damage to the surface, some 3D measurements of the surface condition were made with 3D Optical Profiler S Neox (f. Sensofar 2017) (Fig. 9 and 10). Moreover, the 3D measurements have given a complete image of the surface condition as a critical element of the entire machining process. The obtained results are in agreement with findings by Zongh *et al.* (2013). The results of selected 3D surface texture parameters are shown in Table. 5.

In most of the samples, root mean square height (*Sq*) values were about 30 – 40 % higher than arithmetical mean height (*Sa*) values. Such differences are characteristic for irregular random profiles, where individual maximum and minimum height values, observed in the profile, have greater effect on *Sq* than on *Sa*. This was particularly noticeable in Sample #2 and Sample #6, when these differences increased to about 55 – 65 %. The unevenness evaluated using the above height parameters *Sq* and *Sa* reflects general texture of the machined wood having considered scratched areas caused by worn blades.

For Samples #1, #4 and #5, maximum height (*Sz*) values were in the range of 70 – 90 μm. However, in other cases the surface damages were very large with high scratches, values of the *Sz* parameter even up to 146 μm. The valley's depths were predominant and maximum pit depth (*Sv*) represented 62 – 82 % of maximum height (*Sz*). In Samples #3 and #6, the distribution among peak heights and valley's depths was more equal and maximum peak height (*Sp*) represented 52 % and 45 % of the maximum height (*Sz*).

Presented Skewness parameters (*Ssk*) were used to evaluate deviations in the height distribution. Nega-

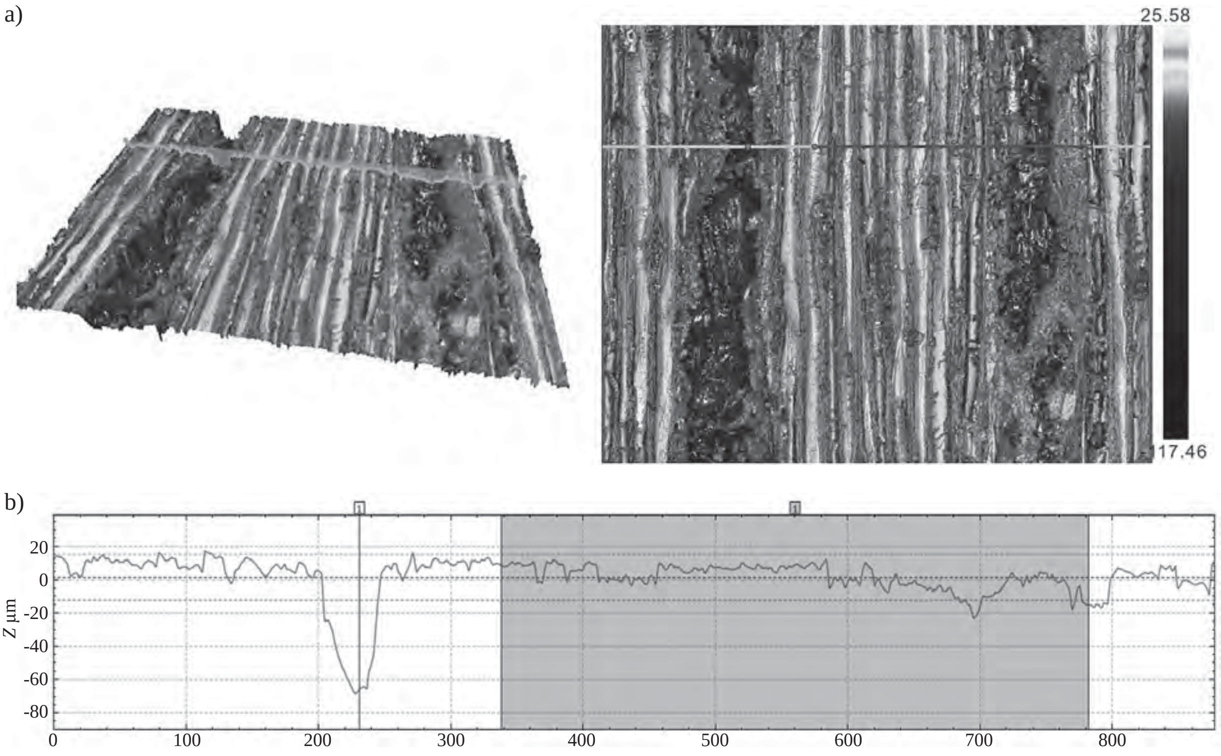


Figure 9 3D surface topography (a) and 2D profile (b) of the 2nd test sample
Slika 9. a) 3D topografija površine, b) 2D profil drugoga ispitnog uzorka

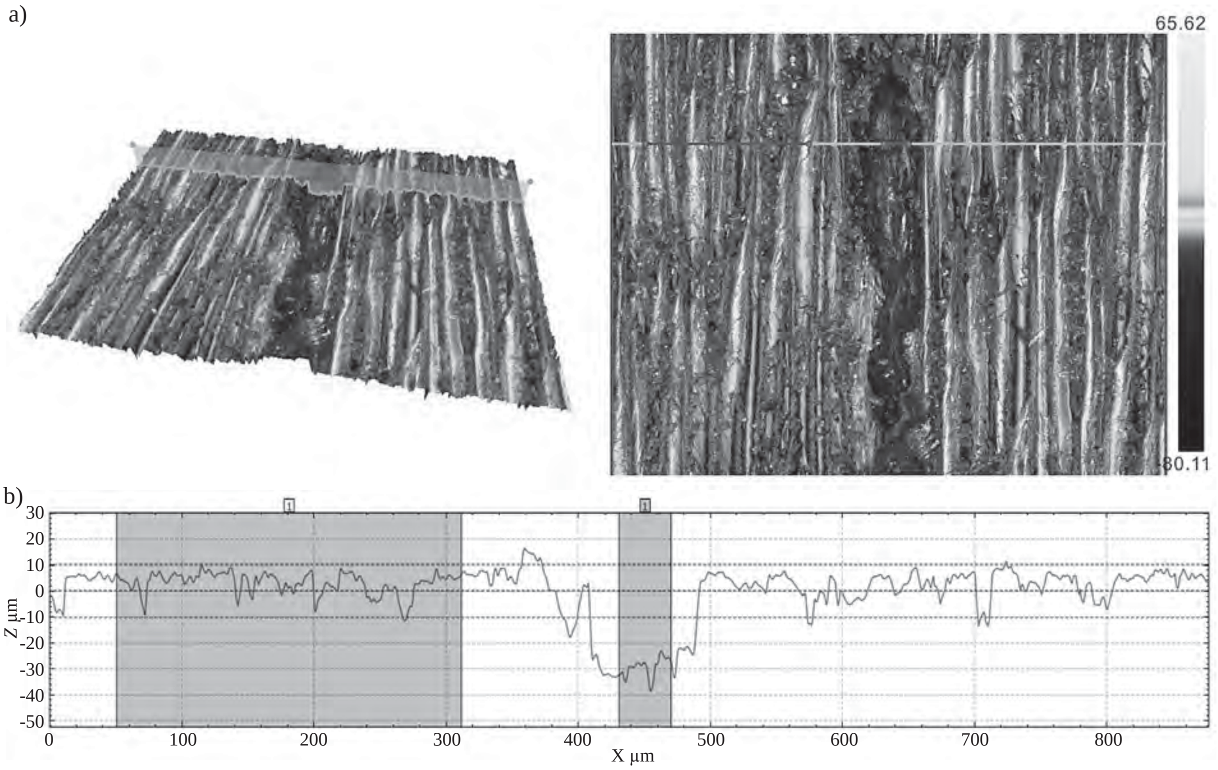


Figure 10 3D surface topography (a) and 2D profile (b) of the 6th test sample
Slika 10. a) 3D topografija površine, b) 2D profil šestoga ispitnog uzorka

tive skewness (*Ssk* = - 2.79 to - 0.51) indicates the presence of deep valleys below a smoother plateau. In all of the examined cases, Kurtosis (*Sku*) value was higher than 3, and in Sample #1, #2 and #6 exceeded 9, which indicates the presence of inordinately sharp deep valleys in the texture.

Since deep scratches are the key factor for surface quality before painting, their Δ*Z* heights were established (Table 5). This height (Δ*Z*) was calculated as a height between the points (if there is 1 extreme value – Samples #1 ÷ #4 – pink line, Fig. 9b) or central point of the mean line (if there are more extreme values – Samples #5 and #6 – pink area, Fig.10b) and central point of the mean line of the plateau (pink areas). For the above points, the angle A (Table 5), which gives the information about distance between them, was also determined. Height (Δ*Z*) and maximum pit depth (*Sv*) in Sample #1, #3 and #4 were comparable, while differences among the remaining samples were significant. In the case of Sample #5 and Sample #6, the Δ*Z* parameter was even 2.5 times smaller, meaning that height of the deep valley was smaller than *Sv* suggested. It should be emphasised that 3D surface texture parameters (ISO), together with additional parameters, are essential for defining irregular surface features.

4 CONCLUSIONS
4. ZAKLJUČAK

The conducted analysis of the planing process revealed that:

The obtained total length of machined beams was significantly higher for HW knives than for CR knives.

Even though the total cost of equipping the heads with knives made of HW was almost twice higher than those with CR knives, the production cost of 1 meter of glued pine beams was about 33 % less.

It can be stated that the surface characteristics based on 2D parameters are definitely insufficient. It is important to analyse the results of the 3D measurements, which gives a complete picture of the surface condition as a critical element of the entire machining process.

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APPENDIX – PRILOG

Table 1A Selected roughness parameters of pine wood samples planed with HW blades
Tablica 1.A) Odabrani parametri hrapavosti uzoraka od borovine obrađenih blanjanjem noževima od tvrdog metala

	No. of test samples *Redni broj mjerenja*	**No. of area** *Broj površine*	**No. of measurement** *Broj mjerenja*	**Roughness parameters** / *Parametri hrapavosti*					
				Rt, µm	*Rz*, µm	*Rp*, µm	*Rv*, µm	*Rku*	*Rsk*
HW	1	1	1	39.54	30.01	15.04	16.52	4.159	-0.848
			2	43.16	32.42	18.84	17.75	3.708	-0.585
			3	59.89	33.33	29.64	16.41	5.151	-0.378
	1	2	1	47.21	32.84	12.10	11.46	6.562	-1.274
			2	50.86	31.46	15.61	15.41	6.304	-1.061
			3	52.13	33.18	15.83	12.19	5.700	-0.973
	2	1	1	50.15	39.94	22.47	15.20	3.122	-0.295
			2	57.50	43.03	24.25	15.67	3.243	-0.050
			3	55.76	44.22	23.62	19.57	3.192	-0.136
	2	2	1	68.54	37.43	34.03	10.30	11.584	0.734
			2	54.14	35.77	19.28	13.53	8.326	-1.156
			3	54.32	32.34	14.71	9.11	11.993	-1.862
	3	1	1	44.75	34.43	25.82	14.74	3.629	-0.046
			2	37.97	32.51	19.09	13.14	3.274	-0.122
			3	39.71	30.55	18.49	14.02	3.461	-0.184
	3	2	1	30.03	26.31	12.35	16.07	3.437	-0.697
			2	40.32	31.89	15.88	17.93	4.372	-0.748
			3	36.97	27.09	15.63	15.54	3.997	-0.794
	4	1	1	33.31	21.04	17.78	9.66	5.539	-0.389
			2	28.75	19.22	9.22	9.39	4.458	-0.831
			3	28.24	22.05	9.73	10.43	4.490	-1.039
	4	2	1	32.26	23.92	14.28	5.82	3.627	-0.503
			2	39.00	26.52	12.51	10.97	5.603	-0.973
			3	30.97	20.87	11.15	7.96	4.393	-0.935
	5	1	1	50.44	28.04	9.88	11.57	23.348	-3.095
			2	51.51	32.19	13.31	11.94	11.243	-2.165
			3	32.21	21.43	11.86	11.69	5.207	-0.911
	5	2	1	39.21	22.89	16.70	10.23	5.859	-0.884
			2	29.00	23.31	8.87	12.93	5.322	-1.172
			3	30.71	23.13	10.51	9.59	3.546	-0.720
	6	1	1	57.11	33.40	23.47	9.34	11.546	-0.806
			2	59.66	37.54	26.75	11.49	6.712	0.222
			3	47.37	30.78	19.56	12.41	5.926	-0.751
	6	2	1	46.74	34.84	27.55	16.47	3.774	0.113
			2	44.17	32.26	16.19	11.57	4.308	-0.557
			3	44.71	35.04	19.74	12.44	4.288	-0.245

*the maximum parameters *Rt* of each analysed area are shaded / *najveće vrijednosti parametra Rt svakoga analiziranog područja zasjenjene su*

Table 2A Selected roughness parameters of pine wood samples planed with CR blades
Tablica 2.A) Odabrani parametri hrapavosti uzoraka od borovine obrađenih blanjanjem noževima od kromiranog čelika

	No. of test samples *Redni broj mjerenja*	**No. of area** *Broj površine*	**No. of measurement** *Broj mjerenja*	**Roughness parameters** / *Parametri hrapavosti*					
				Rt, µm	*Rz*, µm	*Rp*, µm	*Rv*, µm	*Rku*	*Rsk*
CR	1	1	1	45.03	29.74	13.83	14.34	7.119	-1.163
			2	44.39	27.69	24.80	8.93	5.001	-0.169
			3	38.86	25.47	16.65	10.89	4.558	-0.346
	1	2	1	36.79	24.00	12.85	11.01	4.331	-0.813
			2	40.66	25.59	11.26	11.59	7.373	-1.149
			3	51.52	27.86	11.68	12.02	14.463	-2.017
	2	1	1	32.63	23.86	13.11	8.73	4.034	-0.464
			2	30.71	21.98	11.28	11.04	4.763	-0.879
			3	39.22	25.70	14.74	11.52	7.044	-1.216
	2	2	1	32.12	21.65	14.57	11.88	4.839	-0.913
			2	40.00	27.33	18.80	8.69	4.629	-0.437
			3	40.58	29.70	18.58	11.50	4.045	-0.472
	3	1	1	39.52	24.43	17.33	11.69	5.609	-1.009
			2	39.08	24.32	12.38	11.49	7.848	-1.168
			3	25.53	21.37	11.85	11.47	4.419	-0.684
	3	2	1	30.44	24.18	16.77	11.86	2.754	-0.380
			2	29.84	24.17	10.64	12.57	4.066	-0.641
			3	34.58	21.21	13.54	11.51	3.900	-0.557
	4	1	1	26.74	20.91	8.13	11.59	3.669	-0.753
			2	20.90	19.37	8.26	11.53	3.249	-0.707
			3	20.90	19.12	8.55	10.44	3.236	-0.710
	4	2	1	33.46	26.44	11.00	12.84	4.047	-0.744
			2	33.62	25.23	17.01	11.27	3.915	-0.507
			3	36.28	26.14	18.56	13.36	3.679	-0.383
	5	1	1	29.38	20.93	10.36	8.42	4.433	-0.857
			2	26.65	21.17	10.51	9.39	3.507	-0.626
			3	26.35	19.78	10.59	9.01	3.802	-0.748
	5	2	1	26.41	23.22	10.67	12.45	3.309	-0.560
			2	29.22	25.49	13.88	12.72	3.594	-0.508
			3	28.94	24.37	13.43	12.44	3.169	-0.545
	6	1	1	25.68	19.82	8.36	11.07	3.867	-0.813
			2	30.49	22.69	11.44	11.02	4.451	-0.795
			3	26.11	21.70	8.14	12.56	3.868	-0.865
	6	2	1	38.57	27.61	15.14	10.28	3.440	-0.211
			2	54.97	36.62	19.99	10.86	6.024	-0.827
			3	48.84	32.50	21.62	11.21	4.284	-0.372

*the maximum parameters *Rt* of each analysed area are shaded / *najveće vrijednosti parametra Rt svakoga analiziranog područja zasjenjene su*

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Physical Properties of Juvenile and Mature Sycamore Maple (*Acer pseudoplatanus* L.) Wood from Medvednica Region

Fizička svojstva juvenilnoga i zrelog drva gorskog javora (*Acer pseudoplatanus* L.) s područja Medvednice

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ABSTRACT • *Physical properties play an important role in predicting wood quality. The aim of this study was to investigate radial variations in physical properties of sycamore maple (Acer pseudoplatanus L.) wood, to determine the border between juvenile and mature wood and to compare them with analogous variations in beech wood. Radial variation of density in absolutely dry condition, maximum density, nominal density, longitudinal, radial, tangential and volumetric shrinkage, maximum moisture content and annual ring width on five sycamore maple trees from Medvednica region in Croatia were determined. Observing the trend curves and comparing average values of physical properties, different zones in the cross section of the trunk were determined. In the first zone, from the pith to about 30th annual ring, more rapid changes in physical properties occurred. It is followed by transitional zone, which ranges roughly from 30th to 40th annual ring. After 40th annual ring, less pronounced changes in measured physical properties occurred. Sharp boundary between juvenile and mature wood zones could not be determined. According to the results, the first zone is considered to be juvenile wood, while mature wood starts after the 30th annual ring.*

Key words: *sycamore maple (Acer pseudoplatanus L.), physical properties, radial variations, juvenile wood, mature wood*

SAŽETAK • *Fizička svojstva drva imaju važnu ulogu u predviđanju njegove kvalitete. Cilj ovog rada bio je istražiti radijalne varijacije fizičkih svojstava drva gorskog javora (Acer pseudoplatanus L.), utvrditi granicu između juvenilnoga i zrelog drva te ih usporediti s odgovarajućim varijacijama u drvu bukve. Utvrđene su radijalne varijacije gustoće u apsolutno suhom stanju, gustoća pri maksimalnom sadržaju vode, nominalna gustoća, longitudinalno, radijalno, tangentno i volumno utezanje, maksimalni sadržaj vode i širina godova u drvu pet stabala gorskog javora s Medvednice u Hrvatskoj. Iz dobivenih krivulja i usporedbe prosječnih vrijednosti fizičkih svojstava drva utvrđene su različite zone na poprečnom presjeku debla. U prvoj zoni, od srčike do približno 30.*

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goda, vidljive su znatnije promjene fizičkih svojstava drva. Slijedi prijelazna zona, koja se otprilike proteže od 30. do 40. goda. Nakon 40. goda promjene fizičkih svojstava drva manje su vidljive. Oštru granicu između zona juvenilnoga i zrelog drva nije moguće odrediti. Na temelju dobivenih rezultata pretpostavljeno je da je prva zona juvenilno drvo, a nakon 30. goda počinje zrelo drvo.

Ključne riječi: *gorski javor (Acer pseudoplatanus L.), fizička svojstva, radijalne varijacije, juvenilno drvo, zrelo drvo*

1 INTRODUCTION
1. UVOD

Sycamore maple (*Acer pseudoplatanus* L.) is native mainly to the mountainous regions of Southern, South-Western, Western, Central and Eastern Europe with the extreme easterly limit at the Caspian Sea (Krabel and Wolf, 2013). It grows at 300 to 2000 meters above sea level (Spethmann and Namvar, 1985) and it grows almost always together with beech. In many parts of Europe, sycamore maple is considered invasive and exotic species, therefore causing some debate among forest breeders and conservators. Some of them believe that sycamore maple should be eradicated in areas where it threatens the ancient indigenous forests (Rusanen and Myking, 2003). Others speak of great economic value and potential of reforestation with sycamore maple as it is considered as hardwood species whose value grows in Central Europe (Kleinschmit *et al.*, 2009).

In Europe, 1.7 % of the total annual cuttings consist of sycamore maple. Approximately 0.8 % of forests in Croatia are covered with sycamore maple (Hrvatske šume, 2014). Researchers claim that the future share of ash, sycamore maple and wild cherry in Europe will double; therefore, the future share of sycamore maple harvest could increase remarkably (Thies *et al.*, 2009). These three species currently cover 4.1 % of the European forests, and in future they are expected to reach up to 8.9 % and for German speaking countries 12.1 % (Thies *et al.*, 2009). According to Kölling and Zimmermann (2007) and Kölling (2007), sycamore maple is considered a well adapted species to current and also to predicted future climate conditions in Central Europe. Due to its highly valuable timber, short generation turnover and fairly regular seed set, sycamore maple may increase in importance economically, which may encourage breeders to embark on more breeding programs (Rusanen and Myking, 2003).

Available information on physical properties of sycamore maple wood and on their radial variations is modest, and there is no science based information on many important technical properties of sycamore maple wood. Growing quantities of sycamore maple expected in the near future, along with the lack of scientifically based, confirmed and tested information on the properties of sycamore maple wood and on their radial variation, have all led to the present research. This paper describes research on physical properties and variation in their distribution from pith to bark in sycamore maple wood from Medvednica region. Mountain Medvednica represents natural habitat with mild continental climate, where sycamore maple grows together with beech, regionally characteristic community *Aceri-Fraxinetum croaticum* Horvat (Vukelić, 1998).

The aim of the study was to investigate variations in properties of sycamore maple wood in radial direction, to determine the border between juvenile and mature wood and to compare them with analogous variations in beech wood. This is partly necessary due to insufficient data on maple wood properties, partly due to habitat shared with beech and partly due to their similar diffuse porous wood structure.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

For the purpose of this research, the location of Mount Medvednica, specifically its northern slope was selected. This area is part of the "Training and Forest Research Centre Zagreb", managed by the Faculty of Forestry in Zagreb. Mountain Medvednica represents a natural habitat with mild continental climate, where sycamore maple grows together with beech.

Five representative sycamore maple trees from different diameter classes were selected using the method of random sampling. The test trees were chosen as representative of the stand according to ISO 3129:1999. After cutting down the tree, a test log of 1 m in length was sawn from each test tree. The measurement of the test log length started at breast height (1.3 m), upwards to the crown. Afterwards, these 1 m long trunks were sawn into 'bark to bark' cores, approximately 6 cm thick. One core was oriented north-to-south, and the other east-to-west (Figure 1). Cores were then submitted to natural drying. After the cores had dried to a water content of about 12 %, parts of the cores, which were in the area of the breast height (1.3 m), were sawn out into rectangular samples of 20 mm × 20 mm × 25 mm. The samples were sawn in radial direction from pith to bark and labelled with markers

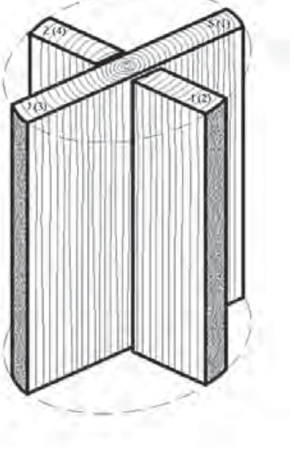

Figure 1 Bark to bark cores (north – south, east and west)
Slika 1. Srednjača (sjever – jug, istok i zapad)

indicating from which tree they were sawn, their orientation and the ordinal number from pith to bark.

Physical properties of juvenile and mature wood researched in this study were density in absolutely dry condition, maximum density and nominal density according to HRN ISO 3131:1999, longitudinal, radial and tangential shrinkage according to HRN ISO 4469:1999, volumetric shrinkage according to HRN ISO 4858:1999, maximum water content according to HRN ISO 3130:1999 and annual ring width according to HRN D.A1.042-1957.

Statistical analysis of the data and their comparison were carried out in Statistica 8. Statistical analysis has shown the number of measured samples, average value of certain measured properties, as well as their standard deviation. Comparison between properties of juvenile and mature wood was carried out by Mann-Whitney test.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Analysing data of investigated physical properties of sycamore maple wood and their distribution in radial direction, it could be assumed that there is a transitional area of juvenile wood to mature wood (Govorčin, 1996; Zobel and van Buijtenen, 1989), from around 30th to 40th annual ring. For the purpose of statistical analysis, the 30th annual ring is taken as a boundary between the zones of juvenile and mature wood.

Annual ring width has a higher average value in the zone from the 1st to the 30th annual ring (Table 1). The difference in average values of annual ring width in two investigated zones is statistically significant (Table 2). Such arrangement of annual ring width agrees with the conclusions of Petrić and Bađun (1985) and Senft (1986), who state that annual rings are usually much wider in juvenile wood than in mature wood. They also concluded that annual ring width, under normal growth conditions, decreases from pith to bark. Figure 2 shows that the annual ring width in tested sycamore trees had a growing trend in the area of 30th-40th annual ring, and then decreased towards the bark. On the contrary, Govorčin (1996) recorded that the average annual ring width in juvenile beech wood is narrower than the one in mature wood.

The average values of density in absolutely dry condition, maximum density and nominal density of

Table 1 Statistical values of researched macroscopic and physical properties of Zone 1 – 30th annual ring and Zone 31 – 77th annual ring

Tablica 1. Prikaz statističkih vrijednosti rezultata određivanih makroskopskih i fizičkih svojstava u zoni 1. – 30. goda i u zoni 31. – 77. goda

Property[a] *Svojstvo*[a]	**Unit** *Mjerna jedinica*	**Count** *Broj mjerenja*	**Min value** *Minimum*	**Max value** *Maksimum*	**Average value** *Aritmetička sredina*	**Standard deviation** *Standardna devijacija*	**Variation coefficient** *Koeficijent varijacije*
Zone 1 – 30th annual ring / *Zona 1. – 30. goda*							
ρ_o	g/cm^3	68	0.512	0.644	0.596	0.039	6.575
ρ_{max}	g/cm^3	68	1.007	1.147	1.090	0.032	2.938
ρ_y	g/cm^3	68	0.453	0.569	0.522	0.032	6.039
$\beta_{l\,max}$	%	68	0.04	0.28	0.14	0.082	57.33
$\beta_{r\,max}$	%	68	3.50	5.17	4.50	0.387	8.607
$\beta_{t\,max}$	%	68	7.23	10.95	9.21	0.904	9.818
β_{vmax}	%	68	11.18	16.54	14.26	1.207	8.463
W_{max}	%	68	100.3	133.1	109.8	8.277	7.539
Rw	mm	481	0.31	10.02	3.41	1.783	52.24
Zone 31 – 77th annual ring / *Zona 31. – 77. goda*							
ρ_o	g/cm^3	101	0.511	0.643	0.577	0.036	6.187
ρ_{max}	g/cm^3	101	1.002	1.156	1.078	0.032	2.937
ρ_y	g/cm^3	101	0.454	0.560	0.507	0.027	5.405
$\beta_{l\,max}$	%	101	0.04	0.26	0.12	0.059	47.82
$\beta_{r\,max}$	%	101	3.48	5.03	4.15	0.391	9.433
$\beta_{t\,max}$	%	101	7.70	10.87	9.36	0.761	8.122
β_{vmax}	%	101	11.48	15.99	13.87	1.029	7.415
W_{max}	%	101	100.8	133.3	113.1	8.351	7.381
Rw	mm	732	0.15	10.31	3.03	1.671	55.07

[a] ρ_0 – density in absolutely dry condition, ρ_{max} – density at maximum moisture content, ρ_y – basic density, $\beta_{l\,max}$ - total longitudinal shrinkage, $\beta_{r\,max}$ – total radial shrinkage, $\beta_{t\,max}$ – total tangential shrinkage and $\beta_{v\,max}$ – total volumetric shrinkage, W_{max} – maximum moisture content, *Rw* – annual ring width

[a] *ρ_0 – gustoća u apsolutno suhom stanju, ρ_{max} – gustoća pri maksimalnom sadržaju vode, ρ_y – nominalna gustoća, $\beta_{l\,max}$ – maksimalno longitudinalno utezanje, $\beta_{r\,max}$ – maksimalno radijalno utezanje, $\beta_{t\,max}$ – maksimalno tangentno utezanje, $\beta_{v\,max}$ – maksimalno volumno utezanje, W_{max} – maksimalni sadržaj vode, Rw – širina goda*

Table 2 Mann Whitney test of difference between researched macroscopic and physical properties of Zone 1 – 30th annual ring and Zone 31 – 77th annual ring
Tablica 2. Mann Whitney test razlike između određivanih makroskopskih i fizikalnih svojstava u zoni 1. – 30. goda i u zoni 31. – 77. goda

Property *Svojstvo*	**Rank Sum 1**	**Rank Sum 2**	Z	p
$^a\rho_o$	6749.00	7616.00	3.10653	0.001893
ρ_{max}	6617.00	7748.00	2.68334	0.007289
ρ_y	6840.00	7525.00	3.39826	0.000678
$\beta_{l\,max}$	6241.00	8124.00	0.92874	0.353026
$\beta_{r\,max}$	7451.00	6.914.00	5.35707	0.000000
$\beta_{t\,max}$	5776.50	8588.50	-0.01122	0.991047
β_{vmax}	6517,50	7847.50	2.36436	0.018062
W_{max}	4897.00	9468.00	-2.83082	0.004643
Rw	315139.0	421152.0	3.88256	0.000103

$^a\rho_0$ – density in absolutely dry condition, ρ_{max} – density at maximum moisture content, ρ_y – basic density, $\beta_{l\,max}$ – total longitudinal shrinkage, $\beta_{r\,max}$ – total radial shrinkage, $\beta_{t\,max}$ – total tangential shrinkage and $\beta_{v\,max}$ – total volumetric shrinkage, W_{max} – maximum moisture content, *Rw* – annual ring width

$^a\rho_0$ – gustoća u apsolutno suhom stanju, ρ_{max} – gustoća pri maksimalnom sadržaju vode, ρ_y – nominalna gustoća, $\beta_{l\,max}$ – maksimalno longitudinalno utezanje, $\beta_{r\,max}$ – maksimalno radijalno utezanje, $\beta_{t\,max}$ – maksimalno tangentno utezanje, $\beta_{v\,max}$ – maksimalno volumno utezanje, W_{max} – maksimalni sadržaj vode, Rw – širina goda

sycamore maple wood in the zone from the 1st to the 30th annual ring are higher than those in the zone from the 31st to the 77th annual ring. Statistical comparison of density values of these two zones in sycamore maple wood shows significant differences. According to Panshin and de Zeeuw (1980), beech wood belongs to a group of species whose wood density decreases from pith to bark. Horvat (1969) and Govorčin (1996) found that density of beech wood near the pith is slightly larger than that near the bark. According to these findings and the research results shown in Table 1 and Figures 3, 4, and 5, sycamore maple wood could even be classified in the same category as beech wood, regarding wood density.

The average value of total longitudinal shrinkage of investigated sycamore maple wood in the zone from the 1st to the 30th annual ring is higher than in the zone from the 31st to the 77th annual ring, although the difference is not statistically significant. Figure 6 shows a high variability of data in radial direction, although this variability is less pronounced from about the 30th annual ring to the bark. Different authors report that longitudinal shrinkage of juvenile wood is 5 to 10 times higher (Timell, 1986; Ayrilmis, 2008). Petrić (1986) stated, based on his research on the anatomy of common beech (*Fagus sylvatica* L.), that juvenile wood should have a greater longitudinal shrinkage than mature wood.

The average value of total radial shrinkage in the zone from the 1st to the 30th annual ring is also higher than in the zone from the 31st to the 77th annual ring. The difference is statistically significant. Figure 7 shows a trend of decrease of total radial shrinkage in the zone from the pith to approximately 30th to 40th annual ring, and then a tendency of mild decrease or stagnation to the bark. According to Govorčin (1996), radial shrinkage of beech wood is 17 % higher in juvenile wood than in mature wood. On the contrary, according to Timell (1986), radial and tangential shrinkage of juvenile wood should be lower than that of mature wood.

The average value of total tangential shrinkage in the zone from the 1st to the 30th annual ring is lower than in the zone from the 31st to the 77th annual ring, although this difference is not statistically significant. Figure 8 does not show any difference in total tangential shrinkage from pith to bark. This is in accordance with Govorčin (1996), who also found no difference between mean values of tangential shrinkage in juvenile and mature beech wood.

The average value of total volumetric shrinkage of sycamore maple wood in the zone from the 1st to the 30th annual ring is higher than that in the zone from the 31st to the 77th annual ring. The difference is statistically significant. Such ratio agrees with Brown *et al.* (1949), Horvat (1976) and Panshin and de Zeeuw (1980), who state that volumetric shrinkage increases with wood density. Figure 9 shows a high variability of data in radial direction, although this variability is less

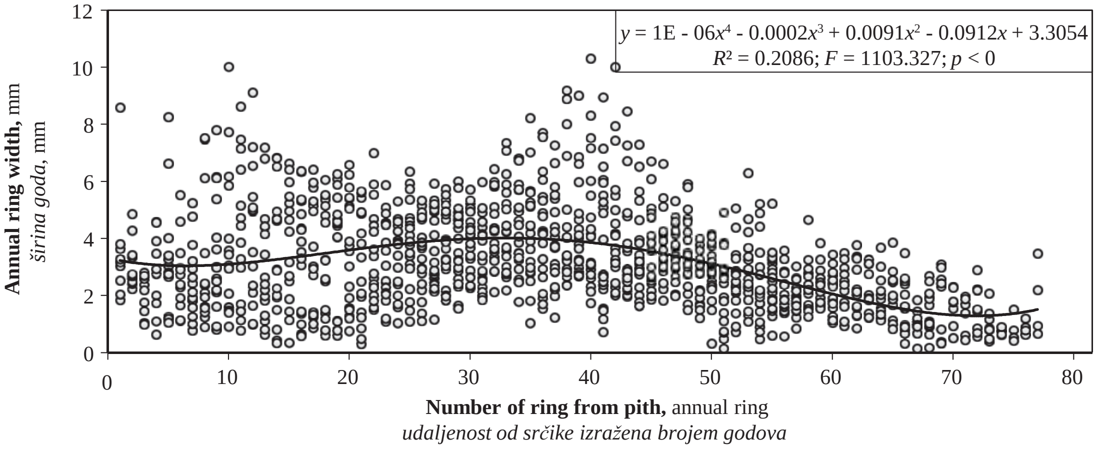

Figure 2 Radial distribution of annual ring width
Slika 2. Radijalna raspodjela širine goda

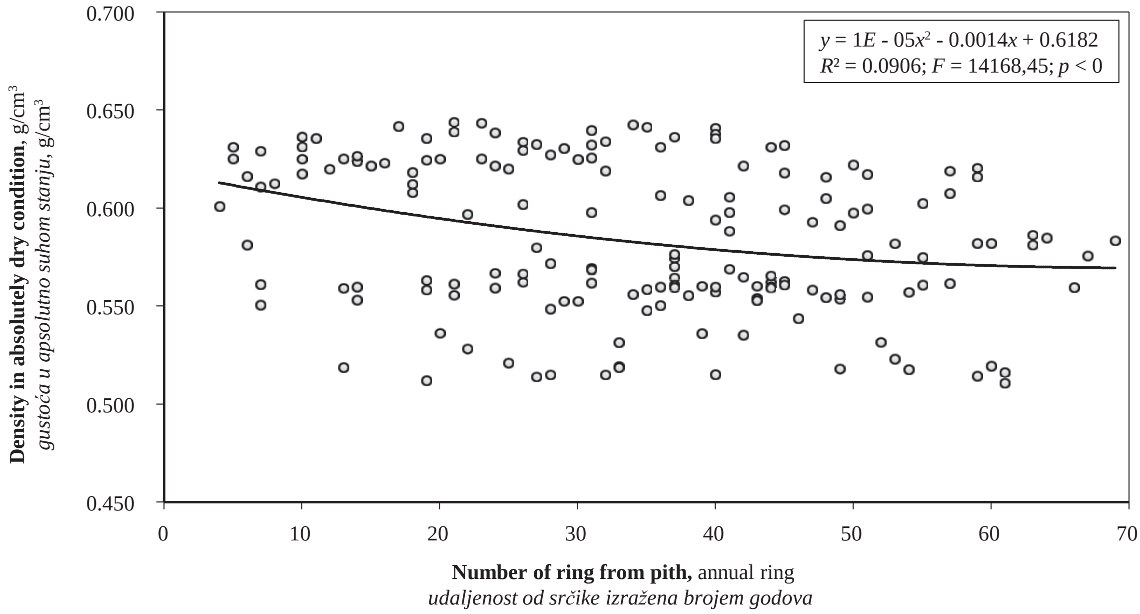

Figure 3 Radial distribution of density in absolutely dry condition
Slika 3. Radijalna raspodjela gustoće u apsolutno suhom stanju

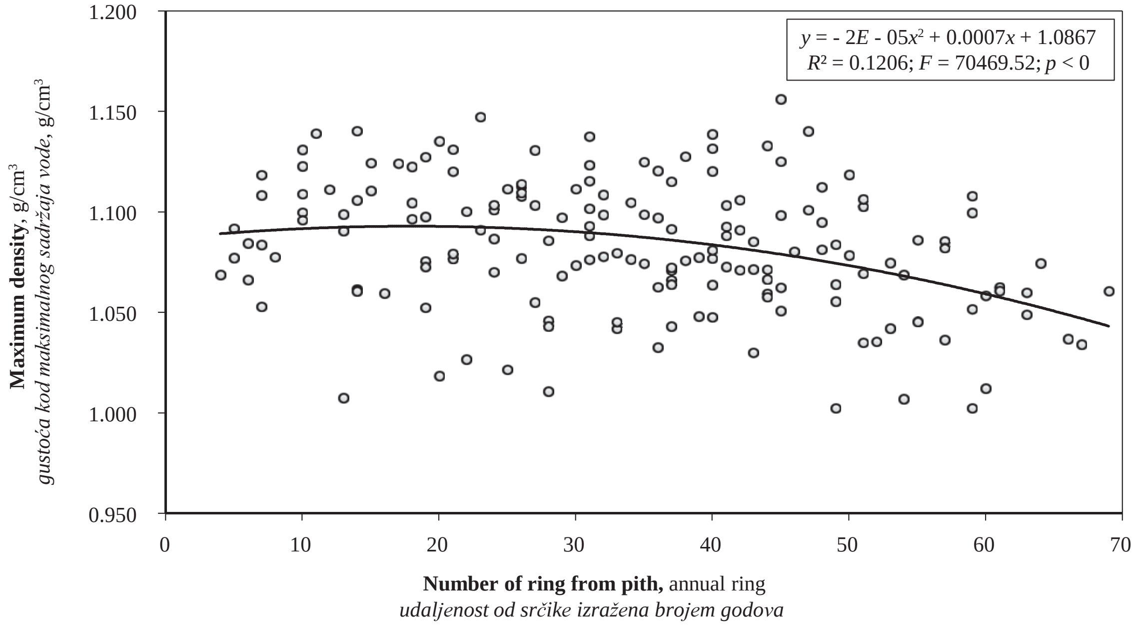

Figure 4 Radial distribution of maximum density
Slika 4. Radijalna raspodjela gustoće pri maksimalnom sadržaju vode

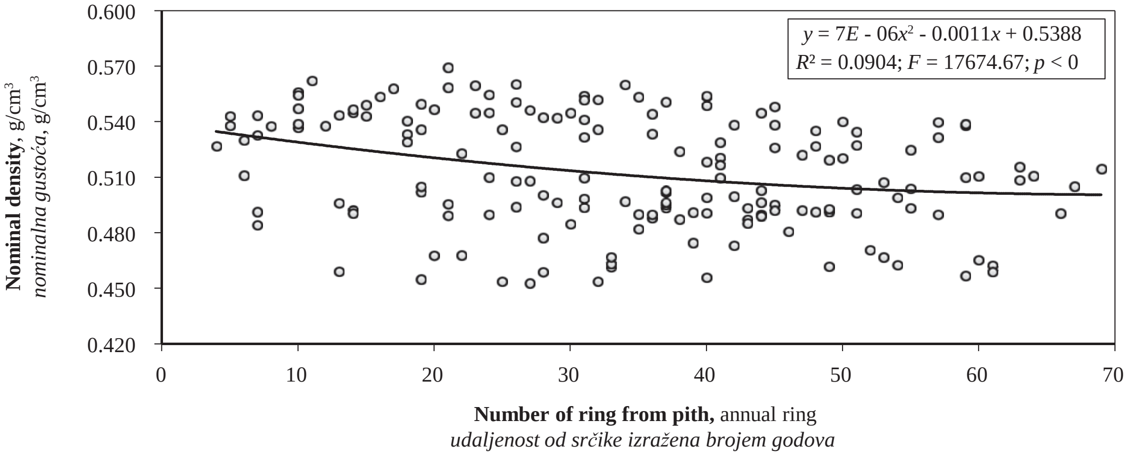

Figure 5 Radial distribution of nominal density
Slika 5. Radijalna raspodjela nominalne gustoće

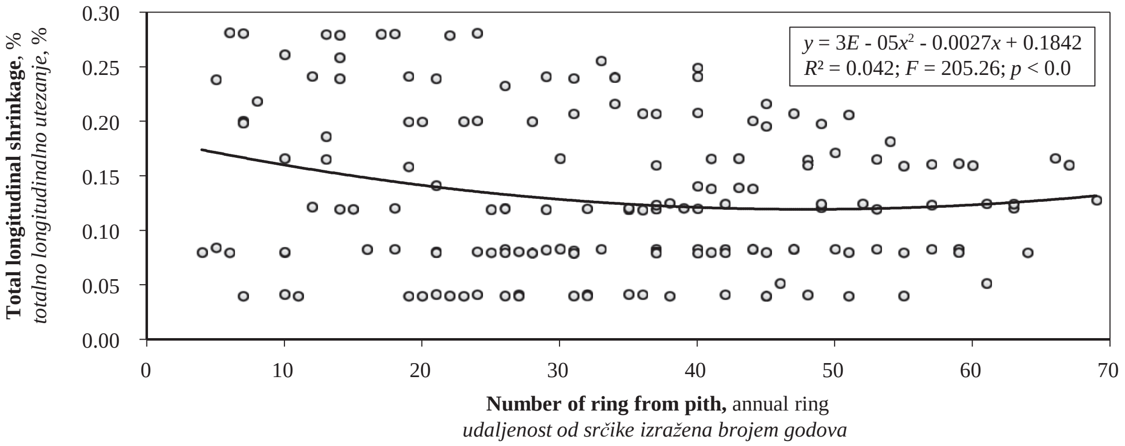

Figure 6 Radial distribution of total longitudinal shrinkage
Slika 6. Radijalna raspodjela totalnoga longitudinalnog utezanja

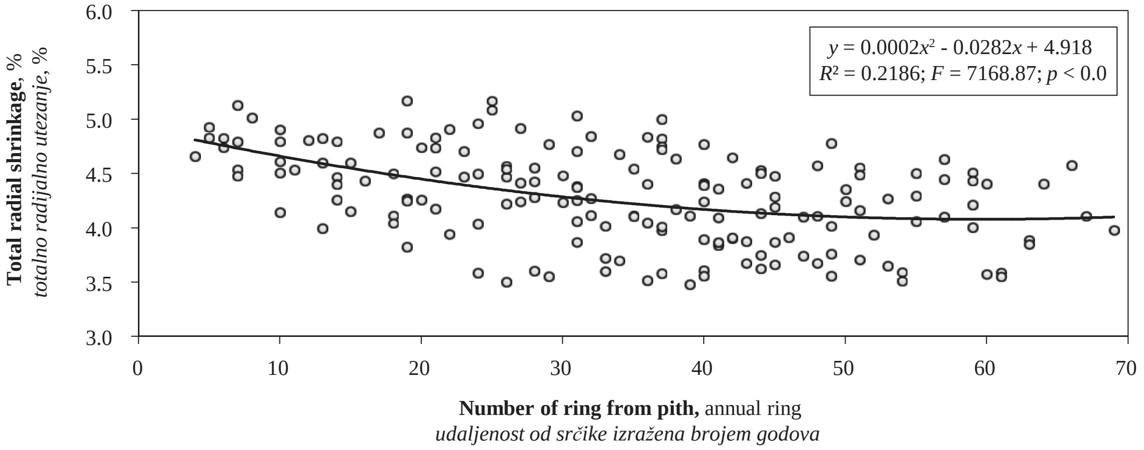

Figure 7 Radial distribution of total radial shrinkage
Slika 7. Radijalna raspodjela totalnoga radijalnog utezanja

pronounced from about 30th annual ring to the bark. According to the research of Govorčin (1996), volumetric shrinkage of juvenile wood is slightly larger than that of mature wood.

The average value of maximum moisture content in the zone from the 1st to the 30th annual ring is lower than in the zone from the 31st to the 77th annual ring. The difference is statistically significant. This is in agreement with earlier research of Krpan (1956) and Horvat (1976). They stated that moisture content in beech wood in radial direction gradually increases from pith to bark, and that differences in moisture content of the central part and the part of the tree near the bark are not great. There is no difference in maximum moisture content from pith to bark (Figure 10).

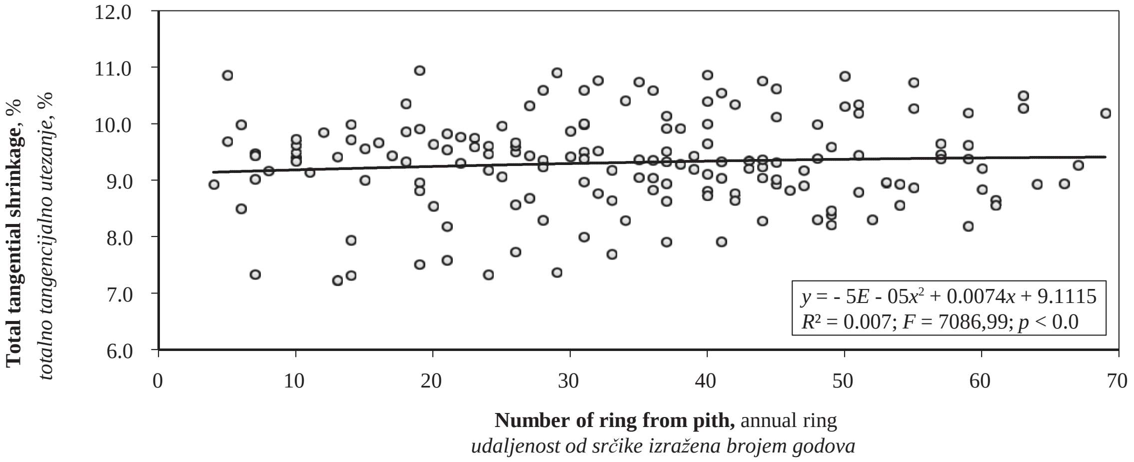

Figure 8 Radial distribution of total tangential shrinkage
Slika 8. Radijalna raspodjela totalnoga tangencijalnog utezanja

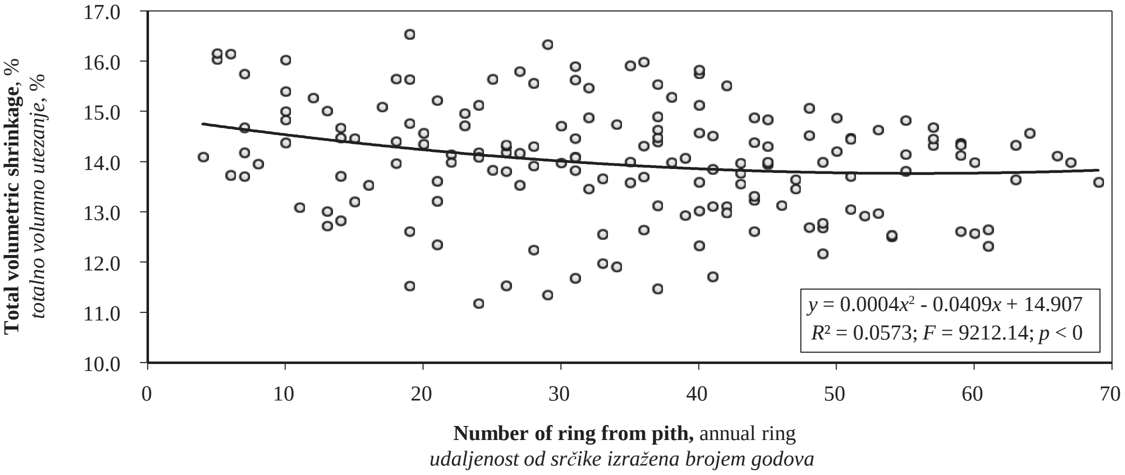

Figure 9 Radial distribution of total volumetric shrinkage
Slika 9. Radijalna raspodjela totalnoga volumnog utezanja

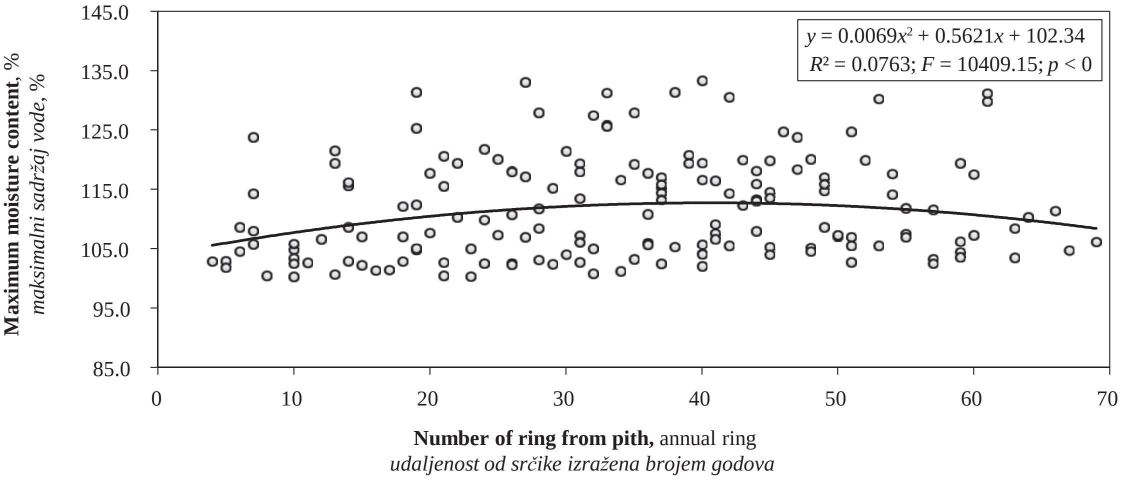

Figure 10 Radial distribution of maximum moisture content
Slika 10. Radijalna raspodjela maksimalnog sadržaja vode

4 CONCLUSIONS
4. ZAKLJUČAK

Approximately at the 30th annual ring from the pith, change in the following properties occurs: annual ring width, density in absolutely dry condition, density at maximum moisture content, nominal density, radial and volumetric shrinkage and maximum moisture content of wood.

In the cross section of sycamore maple trunk, there are two areas that differ in some studied physical properties. According to data, there is no clear distinction, although two groups show statistically significant differences. The first zone spreads from the pith to about 30th annual ring, while the other continues in the direction of the radius until the bark. Sharp boundary between the zones of juvenile and mature wood could not be determined, but transitional zone appears roughly from the 30th to the 40th annual ring from the pith.

Juvenile wood zone is recognizable by greater variability in values of studied physical properties and generally more rapid changes in property trends. Mature wood zone is characterized by less pronounced changes or even stagnation of the studied properties in comparison to juvenile wood.

Wood processing prefers high annual growth rate and uniformity in technical properties of material. For better prediction of wood quality of sycamore maple, investigation of anatomical and mechanical properties should be carried out.

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Use of Variators in Applying the Cost Calculation Methodology in Small and Medium Furniture Enterprises Based on Changes in Human Body Dimensions

Primjena varijatora korištenjem metodologije izračuna troškova u malim i srednjim tvrtkama za proizvodnju namještaja na temelju promjena dimenzija ljudskog tijela

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ABSTRACT • *Based on the research of anthropometric measures of Slovak adult population, it can be observed that during the last 25 years, anthropometric data have been rising by about 4.5-5 % in most analysed characters. As data on human body dimensions changes, the requirements for material consumption and production time, expressed by the rate of labour cost, are changing. In this context, sustainable profitability of the company can be achieved through each segment of a value chain. One of these segments is the product and its price, which is based on costs allocated in the system of full or variable costing. As the value of quantiles characteristics of anthropometric characters was used to create ergonomic, health and construction norms and standards in the furniture industry, it is necessary to review the adequacy of existing standard-size single bed. Since the dimensions of single bed are standardised, 200 cm x 90 cm or 200 cm x 100 cm, it is clear that due to the secular trend of anthropometric measure of a man, the dimensions are currently inadequate. This paper presents the use of variators when applying the most commonly used absorption costing in small and medium furniture enterprises. It shows the costs involved, when the input parameters are changed.*

Key words: *innovation, calculation, bed furniture, variator, SMEs*

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SAŽETAK • *Na temelju istraživanja antropometrijskih mjera slovačke populacije odraslih možemo primijetiti da su se u posljednjih 25 godina antropometrijski podatci o većini analiziranih značajki povećali oko 4,5 – 5 %. Kako su se mijenjale dimenzije ljudskog tijela, tako se mijenjala i potrošnja materijala te vrijeme proizvodnje, što je izraženo udjelom troškova rada. U tom kontekstu održiva se profitabilnost tvrtke može postići putem svakog dijela lanca vrijednosti. Dio lanca vrijednosti čine proizvod i njegova cijena, koja se temelji na troškovima dodijeljenima u sustavu potpunih ili varijabilnih troškova. Budući da je vrijednost kvantitativnih antropometrijskih značajki iskorištena pri izradi ergonomskih, zdravstvenih i konstrukcijskih normi u industriji namještaja, potrebno je razmotriti adekvatnost dimenzija postojećega standardnog kreveta. S obzirom na to da su standardizirane dimenzije kreveta za jednu osobu 200 cm x 90 cm ili 200 cm x 100 cm, jasno je da zbog sekularnog trenda čovjekovih antropometrijskih mjera današnje mjere standardnog kreveta više nisu adekvatne. U članku se prikazuje primjena varijatora u najčešće korištenim metodama ukupnih troškova u malim i srednjim poduzećima za proizvodnju namještaja. Također se prikazuju troškovi pri promjeni ulaznih parametara.*

Ključne riječi: *inovacija, izračun, kreveti, varijator, mala i srednja poduzeća*

1 INTRODUCTION
1. UVOD

Small and medium-sized enterprises (SMEs) represent a significant part of the economy and industrial system of every country (Buehlmann *et al.*, 2013; Bumgardner *et al.*, 2011). In the European Union, as well as in the Slovak Republic, SMEs represent more than 99 % of the total number of business entities (Slovak Business Agency, 2016). Globalization is putting the pressure on furniture SMEs to achieve innovation and modernization of technological and manufacturing processes (Barčić *et al.*, 2016; Tokarčíková and Kucharčíková, 2015).

In order to be successful in the market and to increase the competitiveness, the main role of the company is to come up with product innovations. An economic aspect is another non-negligible challenge, too. When designing housing, it is necessary to consider the basic biological needs of humans, the quality of the environment, as well as microclimatic, acoustic, optical and environmental hygiene. Therefore, it is essential to take into account the dimensions of the human body and the resulting spatial needs necessary for the performance of housing-related activities. Spatial needs and parameters for performing activities in the apartment are derived from the average body dimensions of people. However, when identifying a particular client, it is necessary to take into account his/her individual needs. Changing anthropometric parameters of a person are associated with the development and growth of generations – the secular trend. It means the change in physical dimensions between the past and present generations at the same age range. These changes do not occur suddenly but over a long-term development in one and the same territory. It is the result of improving health care, increasing the quantity, quality and availability of food, mixing ethnicity and peoples, various psychosocial changes. The secular trend is best observed when considering the human body height. Based on previous findings, it can be stated that secular trend was, on average, confirmed by 1.55 mm per year (Sedmák and Hitka, 2007).

The bed is the basic object of residential equipment. High quality demands are placed on bedding furniture. People spend a third of their life on it. From the point of view of anthropometry, physiology and hygiene, the size of the bed must be suitable for the human body taking into account the fact that the body position changes during sleep. From the anthropometric point of view, the length, width and height of the bed area is particularly important (Hitka and Hajduková, 2013; Kotradyová and Kaliňáková, 2014).

The production of furniture specific for residential space is an issue that humanity has been dealing with since prehistoric times. Primitive people created various primitive tools. Even in this activity, a man needed to sit comfortably. In ancient Egyptian times, people already thought about the way how to adapt furniture to man and his needs. A seat with a slightly inclined backrest was made for a more comfortable seating in ancient Egypt times. At the same time, the first stool was made in the form that is still used nowadays. The Rococo period, called as the style of the interior, brought other revolutionary changes. People were looking for ways how to sit comfortably for hours without pain. Gradually, serial furniture production was introduced because production was not economic. During the 2nd World War, it was possible to buy modern furniture with ergonomic shaping (Peteri, 2017; Kolena and Vodráková, 2013).

In Europe, Scandinavia has become the best country in the whole furniture production market, perhaps because the country was not hit by the war as much as most other European countries. Designers adapted to new knowledge in the field of sociology. Slowly, the first housing developments were built, requiring furniture to be adapted. At that time, everyone could buy furniture, especially because of large-scale production. It was not necessary to use inherited furniture. Thanks to this phenomenon, every family could change the furniture several times. On the other hand, the furniture was not of high quality. Later, aesthetic and emotional aspects have begun to be added. Seating furniture had becoming more and more suited to the human body (Veselovský and Kotradyová, 2009). Based on these trends, the furniture began to be broken down according to the activity it was used for. During the past decade, ergonomic research focused especially on the design of work furniture based on the biomechanics of the human body. Many researchers dealt with the principles for the design of chairs and desks in the workplace, particularly for computer system users (Burgess-Limerick *et al.*, 1999; Cook and Kothiyal, 1998; Aaras *et al.*, 1997; Villanueva *et al.*, 1996; Kumar, 1994; Naqvi, 1994). In the field of interior and furniture design, comfort was based on correct dimensions of the user or group of users. Over the last millennium, man was physically developing. This is indicated by the skull, denture, and post-skeletal skeleton, decreasing body weight and brain capacity. Changes in furniture dimensions are visible in the history of architecture and furniture development, too (varying the height of holes, ceilings, etc.). Since the Neolithic period, Europeans are still subject to the conformational-heterogeneous trend (Kolena and Vodráková, 2013). This trend is manifested by different features of the body, which are being simulated by Europeans. It is well known that the environment has a significant impact on these changes. Therefore, planners, designers and engineers should be aware of the space occupied by a person in different positions, and they should provide safety for movement and relaxation (Smardzewski, 2009).

Body dimensions, such as average body height, vary and develop in time (in comparison with the past, body dimensions are greater) (Ozer, 2007; Carrascosa *et al.*, 2004; Malina *et al.*, 2004; Krawczynski *et al.*, 2003). For example, the length of the bed has increased considerably since the Middle Ages. In addition to the increase in body height and weight, the differences in geographic segmentation increased, too. Nowadays in Europe, dimensional standards applicable to architecture and furniture industry cannot be unified because of significant differences in the population, especially between Southern, Northern and Central European regions. The European Union’s attempt to introduce uniform dimensional standards has proven to be unrealistic. The market hits the conservatism of society as a whole. Reactions to these facts are very slow. It can be seen in sectors where consumption is a major economic factor, for example the automotive industry, aerospace industry, textile industry and shoe industry (Woolliscroft *et al.*, 2015).

In literary sources, the structure of calculation formula can be found (Lazar, 2012; Poniščiaková, 2010; Popesko, 2009). It is the so called general calculation formula as the starting basis for calculation formulas for different conditions (Hradecký *et al.*, 2008). The general calculation formula includes direct and indirect (overhead) costs. Overhead costs represent a significant part of total costs (Synek *et al.*, 2007). Therefore, it is important to manage them and to define their roles so as to reduce them. Costs contribute to the economic growth, because costs are one of the main sources of its reduction. For practical management of costs, it is necessary to implement the classification of costs. It is necessary to consider the type of production, technology used, organization of internal departments. The general calculation formula is used in the methodology of absorption calculation. The absorption calculation implies a number of limitations (Popesko, 2009). These limitations are based on increasing inaccuracies, caused by disproportionate cost allocation. According to the author, this uncertainty is deepening in the context of historical changes in the share and structure of overhead cost.

The problematic factor is still the allocation of overhead costs. Variators can be used for the process of planning overhead costs (Synek *et al.*, 2007). The values give information on the percentage of costs increase, if performance or other value is increased by 1 %. They are determined as the share of variable costs in the total overhead costs as a relevant share of the specific group of overhead costs. This share reaches values in the range from zero, when all costs are fixed, eventually to one, where all costs can be considered as variable items. Thus the zero variator is the item of centre budget and its costs are total fixed costs in relation to its activity (Hradecký *et al.*, 2008). On the other hand, a variator equal to one determines costs that grow proportionally with the change of the centre size activity. The variator can be expressed as “centesimal“, “decimal“, and sometimes even as “unit“ (Lazar, 2012).

Since man is considered the scale of all things, its physical dimensions are used as the basis for all measurements. The physical dimensions are very important because small changes can have a considerable impact on health, safety, and productivity (Mokdad, 2002). The last and still used anthropometric database of our population comes from the times of Czechoslovakia. Nowadays, most of the norms and standards are based on data measured before 1955, and therefore workplace parameters are inappropriate (Kovařík, 2009; Cvičelová *et al.*, 2005). Norms and standards are outdated and, moreover, physical dimensions of each new generation are higher than those of their ancestors. The increase is significant in the long term. In general, as the statistics show, young men are higher than their fathers by about 4.5 cm, and higher than their grandfathers up to 7.5 cm (Kolena and Vodráková, 2013; Sedmák and Hitka, 2007).

The literature presents (Taifa and Desai, 2017; Kovařík, 2009; Mokdad, Al-Ansari, 2009; Smardzewski, 2009; Malina *et al.*, 2004; Krawczynski *et al.*, 2003) different approaches how to establish the basic parameters of furniture, i.e. how to determine the optimal length, width and height of single bed area from the perspective of anthropometry and ergonomics, as designing of standard furniture needs direct involvement of anthropometric measurements. In our case, we took into account the development forecast of the anthropometric dimensions of population based on the secular trend. It is possible to create a universal design by adding the standard deviations (suitable for almost the entire population). Such an approach ensures the production of furniture with dimensions suitable for present and next generation.

The furniture price is closely related to two conditions – the recoverability of the furniture material, and the energy intensity of its processing. Wood is the most frequently used material (Dušak *et al.*, 2015; Joščák *et al.*, 2012). It affects the price because it is a completely renewable resource with low power demands in processing and with easily disposable waste. Wood as a material can be used in furniture manufacturing due to its unique harmony of its aesthetic and technical-technological properties, easy workability and strength.

If a company wishes to be efficient and successful in a constantly changing environment, understanding the buying behaviour of consumers is crucial for the company. Consequently, companies producing bed furniture must modify their calculation methods of pricing to be able to forecast their financial situation in those areas, expressing causal relation between the costs and respective performance (Barroso *et al.*, 2005). Companies are subject to great competitive pressure. Offer exceeds demand in many areas, so it is important to focus on satisfying customer needs. The company needs to look for cost reduction option. Companies can only be competitive in the current dynamic environment by focusing on the future and not just on surveying the past.

Calculation formula represents the list of different types of costs that should be completed with a method of quantification of these items in relation to the calculated performance (Popesko, 2009). It is difficult to define the universal calculation formula for all products, because the enterprises compile calculation formula adapted to their own specific conditions (Macík, 2008).

The main task of SMEs is to innovate the products and to prepare new types of beds that can be used by large businesses in the future. The aim of this paper is to present the use of variators in the selected medium-size company engaged in furniture production when applying the most commonly used absorption costing in small and medium furniture enterprises.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The forecast values of the relevant body dimensions of adult population (Table 1) were used to optimise the single bed dimensions for the needs of the present and future population. The sampling unit was composed of Slovak adult population, i.e. population over the age of maturity in terms of the growth process of people, i.e. 18 years and more. A total of 3.358 students from Slovak universities were involved. The sampling unit covered the population of the whole Slovak territory, which increases its representativeness. The technique of direct survey was used to acquire the empirical data. Data were collected by measurements of selected anthropometric characters (height, shoulder width).

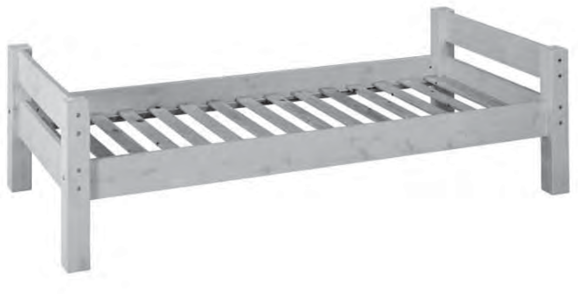

Figure 1 Single bed
Slika 1. Krevet za jednu osobu

Based on the findings of statistical properties of body dimensions of the current Slovak population, it was possible to determine the dimensions of a single bed corresponding to the population. The overall design of the single bed is given in Figure 1.

Body height of men (BH_m) was used as the factor necessary to determine the dimensions, mainly the length of the lying surface. Comfortable sleep must be provided; therefore, comfort factor (*CF*) was added. Then the total length of the lying surface (*LS*) was calculated as follows (Prokopec, 1998):

$$LS = BH_m + 2\,s_x + CF \qquad (1)$$

By summing the data stated in Eq. 1, it was possible to calculate the length of the single bed suitable for family house. Shoulder width (*SW*) was crucial for determining the minimum width of the lying area (b_1). It was necessary to enlarge the shoulder width by 50 %, and then two standard deviations were added due to trend development of population growth (Eq. 2).

$$b_1 = 1.5\,SW + 2s_x + 0.25(1.5SW + 2s_x)\ \text{(cm)} \qquad (2)$$

The final length of the lying surface was calculated as 230.5 cm. The final width of the lying surface was calculated as 102.3 cm and the final single bed height was calculated as 45.7 cm. When analysing the dimensional characteristics of the current male Slovak population, it can be clearly stated that there is a positive secular trend. A body height increase of +4.5 % was recorded. In absolute terms, it represents an average increase of +8 cm. A similar development was observed in the arms width. The parameter increased by up to 6.7 %. It represents an increase of +3 cm. This might be the result of better nutrition, better psychosocial factors and socio-economic conditions of today's population (Sedmák and Hitka, 2007).

According to the author, this variator determines the degree of dependency of overhead costs spent on specific relative value. The relation for the determination of variation is as follow (Hradecký *et al.*, 2008):

Table 1 Basic descriptive characteristics of the male population
Tablica 1. Osnovne deskriptivne značajke muške populacije

Anthropometric sign *Antropometrijska značajka*	**Original population** *Izvorna populacija*			**Current population** *Današnja populacija*		
Indicator / *pokazatelj*	$\bar{X}$	s_x	$s_{x\%}$	$\bar{X}$	s_x	$s_{x\%}$
Physical standing height / *fizička visina pri stajanju*	174.1	6.5	3.7	182.1	6.6	3.6
Shoulder width / *širina ramena*	44.7	2.5	5.7	48.3	4.4	9.2

$$V = \frac{VPOC}{TOC} \quad (3)$$

Where
V – variator,
VPOC – variable part of overhead costs,
TOC – total overhead costs.

A more detailed relation for the determination of variation is used by Potkány and Krajčírová (2015):

$$V = \frac{\frac{OC_1 - OC_0}{OC_0}}{\frac{AB_1 - AB_0}{AB_0}} = \frac{\frac{\Delta OC}{OC_0}}{\frac{\Delta AB}{AB_0}} \quad (4)$$

Where
V – variator,
1 – budgeted period,
0 – initial period,
OC – overhead costs,
AB – allocation base.

Eq. 3 and Eq. 4 were used for the determination of individual items of overheads variators.

The starting point for price determination of single bed was a general costing formula. For the determination of direct costs of the product, we started from the consumption standards and time standards. Direct material consumption standard was supported by the technical documentation. Direct material consumption was set at 4.39 m^2 for original bed dimensions of 200 cm x 90 cm. As a consequence of bed dimension increase to 230.5 cm x 102.3 cm, consumption is increased to 7.17 m^2. Unit acquisition price was planned at the level of 3.69 €/m^2. By multiplying these two factors, the amount of material consumption was quantified in value terms. The level of direct wages was determined through time consumption standards. The values were set by the enterprise in the amount of 3.20 € based on the actual need of 0.661 standard hour (*SH*) per product. For the innovated product, with increased dimensions, the time consumption standards changed to the level of 0.85 *SH*/product. The item of other direct costs (including the necessary number of connecting pins, cover caps and subsidiary material) remained unchanged.

In our case study, different allocation bases were used, so we were working with differentiated direct costing. Since all the costs were included in the calculation formula, it was the absorption costing (Poniščiaková, 2010).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Secular change seems to be a major characteristic of body physique of people in almost all countries of the world (Mokdad and Al-Ansari, 2009). Secular change was confirmed in Algeria, Australia, Cook Island, Hong Kong, India, Japan, Mexico, Poland, Spain, Turkey (Ozer, 2007; Carrascosa *et al.*, 2004; Malina *et al.*, 2004; Krawczynski *et al.*, 2003; Bolstad *et al.*, 2001; Ulijaszek, 2001; Ali *et al.*, 2000; Pheasant, 1998; Leung *et al.*, 1996; Mokdad, 1992; Roy & Singh, 1992). Secular trend was proved by the anthropometric survey conducted in Singapore and Indonesia, too. According to the research, the average male figure grew by 5 cm in the last 19 years and the female by 6.9 cm. These results are similar to other research (Mokdad and Al-Ansari, 2009). The results of anthropometric survey carried out on a sample of male and female Bahraini school children aged 6-12 years show a gradual increase from age 6 to age 12 in all body dimensions. Nutrition factors, socio-economic status, urbanization, physical activity, climate and psychosocial deprivation have contributed the growth in the dimensions of people in Singapore and Indonesia (Chuan *et al.*, 2010). Living standards and dietary habits caused the increase in the average physical dimensions of students (Jung, 2005). Based on researches, it can be stated that the positive secular trend has a global impact.

The influence of these impacts is presented in our research for assessing the changes in production of a specific type of furniture - single bed. Items of production overheads were divided into technological and general section. The overhead tariff of 3.50 €/*SH* was determined for the technological production overheads. The overhead rates were also determined for other overheads. For general production overheads, the value of direct wages was selected as allocation base. For supply overhead costs, the amount of direct costs was selected, while for administrative overheads and sales and distribution overhead costs, it was the amount of production costs. Table 2 presents the initial situation and the calculation per single bed after the increase of its dimensions. In this case, we consider that the values of overhead rates have remained unchanged, despite the change in consumption of direct (technological) material and direct (technological) wages.

We determined new overhead rates by using of the variator method. The fact that the fixed part of the overheads remains unchanged and only the variable component of indirect costs changes was taken into account.

The variator value for supply overhead costs (*SOC*) was determined at the level of 68 %, in the general production overheads (*GPO*) at 43 % and at 37 % of the sales and distribution overhead costs (*SDOC*). Only fixed costs represent the administrative overheads (*AOC*), and therefore the variator value is quantified at the level of 0. Data on percentage increase, shown in Table 2, were used for this calculation. Changes in overheads volume after increase in bed dimensions were detected by the determination of increase in the cost components by the value of the variable component of relevant overheads and its percentage increase after the increase of dimensions. After level change recalculation of relevant overheads, these overheads were used for the determination of the new overhead rate. The original value of allocation base after dimension increase of single bed was used as the allocation base for the hypothetical production volume of 1.000 pieces. The determination of the current level of overhead rates on variator level is methodically determined as follows:

$$\Delta SO = \left[SO \cdot \left(0.68 \cdot 54.86\ \%\right) + SO \right] =$$
$$= 20.360 \cdot 37.3\ \% + 20.360 = 27.954\ €$$

$$\%SOC\ Rate = \frac{27.954}{31.530} \cdot 100 = 88.66\ \%$$

$$\%GPO\ Rate = \frac{1.797}{4.110} \cdot 100 = 43.72\ \%$$

$$\%AOC\ Rate = \frac{31.240}{68.100} \cdot 100 = 45.87\ \%$$

$$\%SDOC\ Rate = \frac{15.994}{68.100} \cdot 100 = 23.49\ \%$$

Table 2 also presents the modified calculation of initial and new dimensions after application of new overhead rates.

Based on findings shown in Table 2, it can be concluded that, using of the traditional approach of compiling calculation, an increase of more than 52 % can be expected in total output costs after the increase in bed dimensions. While preserving the original level of 15 % profit, there would be an increase in the sales price of the product to the level of 156.63 € excluding VAT (which is an enormous increase of 52.59 %). This enormous increase would be caused by absence of overhead rates updates and proportionality of costs of a fixed nature in individual overheads items.

After the application of overhead rates determined by variators, the increase in total costs was about 21.92 % (Table 2). The same percent increase occurred in the sales price of single bed at the constant relative profit level. More exact information on total product costs was obtained by applying the variator method in updating overhead rates.

With the increasing economic importance, customers are becoming increasingly demanding (Ma *et al.*, 2017). These demands put pressure on businesses to establish innovations in their work, for example by outsourcing the maintenance operations for building equipment (David *et al.*, 2017; Gilson *et al.*, 2016). Factors such as price, performance, and design of the product are crucial for the customer when purchasing the product. Product safety and environmental impact have also become important criteria. The improvement of the customer satisfaction level is conducive to meeting customers' demands (Zheng *et al.*, 2017). Accountability to customers in this area can be expanded in providing good service at a fair price, in handling complaints, in undertaking the communication with the customer, etc. If the company wants to be successful in long term, business activities must be systematic, controlled and based on purposeful innovation. Through successful innovation, companies try to get an important and long-term sustainable competitive advantage. In this context, sustainable profitability can be achieved through each segment of a value chain. One of these segments is the product and its price.

Compared to previous calculations, the difference is more than 27 € in favour of lower product price.

Table 2 Basic descriptive characteristics of the male population
Tablica 2. Osnovne deskriptivne karakteristike muške populacije

Costs / *Troškovi*	**Initial dimensions 200 cm x 90 cm** *Početne dimenzije 200 x 90* cm		**Traditional approach** *Tradicionalni pristup* **New dimensions of construction 230.5 cm x 102.3 cm** *Nove dimenzije konstrukcije 230,5 x 102,3* cm		**Variator method** *Metoda varijatora* **New dimensions of construction 230.5 cm x 102.3 cm** *Nove dimenzije konstrukcije 230,5 x 102,3* cm	
	Calculation data *Podatci za izračun*	€	**Calculation data** *Podatci za izračun*	€	**Calculation data** *Podatci za izračun*	€
Direct material / *izravni materijal*	4.39 m^2	16.20	7.17 m^2	26.46	7.17 m^2	26.46
Direct wages / *izravne plaće*	0.661 *SH / PU*	3.20	0.85 *SH / PU*	4.11	0.85 *SH / PU*	4.11
Other direct costs / *ostali izravni troškovi*		0.96		0.96		0.96
∑ Direct costs / ∑ *izravni troškovi*		20.36		31.53		31.53
Supply overhead costs *opći troškovi nabave*	100 %	20.36	100 %	31.53	88.66 %	27.95
Production (technological) overheads *proizvodni (tehnološki) opći troškovi*	3.50 €/*SH*	2.31	3.50 €/*SH*	2.98	3.50 €/*SH*	2.98
Production (general) overheads *proizvodni opći troškovi*	50 %	1.60	50 %	2.06	43.72 %	1.80
Production costs / *proizvodni troškovi*		44.63		68.10		64.26
Administration overheads *administrativni opći troškovi*	70 %	31.24	70 %	47.67	45.87 %	29.48
Product costs / *troškovi proizvoda*		75.87		115.77		93.74
Sales and distribution overhead costs *opći troškovi prodaje i distribucije*	30 %	13.39	30 %	20.43	23.49 %	15.09
Total costs / *ukupni troškovi*		89.26		136.20		108.83
Profit 15 % / *dobit 15 %*		13.39		20.43		16.32
Price / *cijena*		102.65		156.63		125.15

Thus determined price is more acceptable for customers in terms of marketing principles. However, it still needs to be taken into consideration that the methodology of absorption costing was used, while it would be necessary to determine the overhead rates of individual groups also in the context of the complete product portfolio information. The most ideal solution is to use price decision-making principles of variable costing. This calculation is only made with the variable costs, where the most important element in comparing the efficiency of products is the level of contribution margin (difference between price and variable costs of product) (Synek *et al.,* 2007). This calculation considers fixed costs as items, which are essential for ensuring the business operation in a particular period. These costs are subsequently added to the economic result for the whole period (by deduction from the total level of contribution margin). According to the author, variable costing is based on the assumption of fixed costs stability. By the calculation based on the cost breakdown to fixed and variable components, the knowledge of costs level can be achieved by performance unit and also evoked separately by other capacity scope decisions (Poniščiaková, 2010). In our case, the principle of variable costing was partially used. By the method of variators, the separation analysis of variable and fixed overheads was carried out. By updated overhead rates, the effect of proportionality of fixed costs was eliminated. Our aim was to eliminate undesirable inaccuracies caused by absolute and relative increase of fixed capital due to differences in capacity utilization (Poniščiaková, 2010).

4 CONCLUSIONS
4. ZAKLJUČAK

Secular trend of anthropometric dimensions of the adult population of Slovakia resulted in the consideration of dimensional changes in bed furniture. Based on the results of the long-term research of anthropometric measurements of Slovak adult population, it can be stated that the observed variables have been rising by about 4.5-5 % during 25 years. Our research was further aimed at reconsidering these changes for standardised dimensions of a specific type of furniture - single bed. The dimensions we proposed are as follow (length = 230.5 cm; width = 102.3 cm, and height = 45.7 cm). With the change of dimensions, it was necessary to consider the increase of the production costs. The required principle is the choice of the calculation technique, which would allocate an adequate part of the overhead costs to the innovative products respecting the changes in direct costs. The ideal solution would be the implementation of variable costing principles. However, in this paper we have presented the traditional system of absorption costing with the possibility of using the methods of variators. Although the problem of allocating the overhead variable costs could not be avoided, this method eliminates the effect of proportionality of fixed costs. Our intention was to preserve the traditional and still preferred system of calculations in the furniture companies in Slovakia. Using the variator method for each group of indirect costs in the areas of supply, production, sales, distribution, and administrative overhead, the change in direct costs (+11.17 €) resulted in a change in overhead costs. Compared to the traditional absorption calculation, based on rate constancy, the minimum change in overhead costs (+8.4 €) was caused by eliminating the impact of the proportionality of fixed costs.

The actual essence of innovation is the overheads rates update and monitoring of variator values. The essence of our proposal is to monitor overhead costs in the most detailed classification with the determination of the appropriate types of allocation bases. These allocation bases should reflect as accurately as possible the ratio of the change in overheads and the actual value of these bases. This dependence could be assessed using a correlation and regression analysis to determine the level of correlation coefficient. Correlation coefficient can be quantified by comparing the past data of the variables, such as the specific groups of overhead costs, and the considered allocation bases. Certainly, the ideal solution would be the parallel use of variable costing system, which would require additional investments in information base change, software support and personnel training. We consider our solutions to be innovative in the area of application of the available calculation methods.

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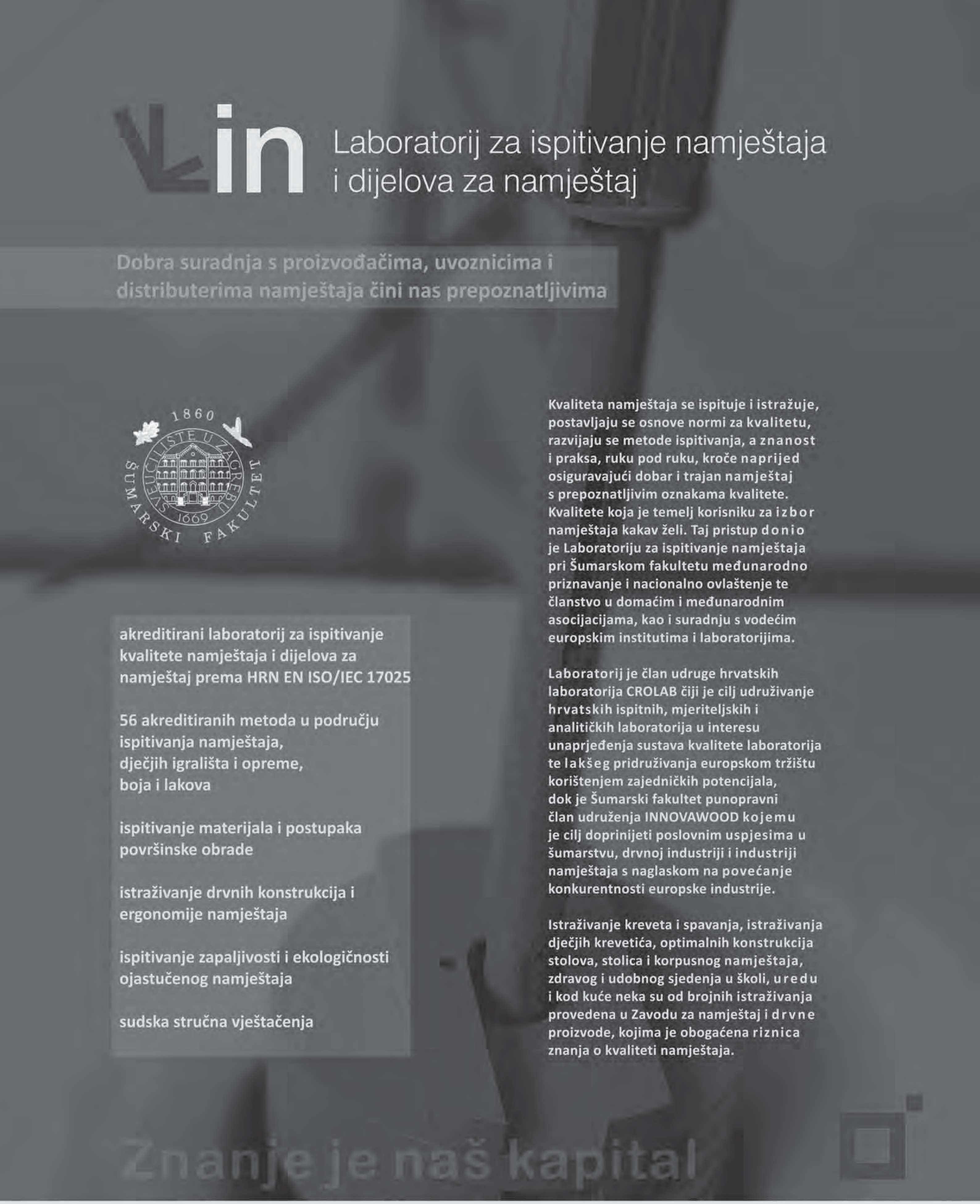

Lin Laboratorij za ispitivanje namještaja i dijelova za namještaj

Dobra suradnja s proizvođačima, uvoznicima i distributerima namještaja čini nas prepoznatljivima

akreditirani laboratorij za ispitivanje kvalitete namještaja i dijelova za namještaj prema HRN EN ISO/IEC 17025

56 akreditiranih metoda u području ispitivanja namještaja, dječjih igrališta i opreme, boja i lakova

ispitivanje materijala i postupaka površinske obrade

istraživanje drvnih konstrukcija i ergonomije namještaja

ispitivanje zapaljivosti i ekologičnosti ojastučenog namještaja

sudska stručna vještačenja

Kvaliteta namještaja se ispituje i istražuje, postavljaju se osnove normi za kvalitetu, razvijaju se metode ispitivanja, a znanost i praksa, ruku pod ruku, kroče naprijed osiguravajući dobar i trajan namještaj s prepoznatljivim oznakama kvalitete. Kvalitete koja je temelj korisniku za izbor namještaja kakav želi. Taj pristup donio je Laboratoriju za ispitivanje namještaja pri Šumarskom fakultetu međunarodno priznavanje i nacionalno ovlaštenje te članstvo u domaćim i međunarodnim asocijacijama, kao i suradnju s vodećim europskim institutima i laboratorijima.

Laboratorij je član udruge hrvatskih laboratorija CROLAB čiji je cilj udruživanje hrvatskih ispitnih, mjeriteljskih i analitičkih laboratorija u interesu unaprjeđenja sustava kvalitete laboratorija te lakšeg pridruživanja europskom tržištu korištenjem zajedničkih potencijala, dok je Šumarski fakultet punopravni član udruženja INNOVAWOOD kojemu je cilj doprinijeti poslovnim uspjesima u šumarstvu, drvnoj industriji i industriji namještaja s naglaskom na povećanje konkurentnosti europske industrije.

Istraživanje kreveta i spavanja, istraživanja dječjih krevetića, optimalnih konstrukcija stolova, stolica i korpusnog namještaja, zdravog i udobnog sjedenja u školi, uredu i kod kuće neka su od brojnih istraživanja provedena u Zavodu za namještaj i drvne proizvode, kojima je obogaćena riznica znanja o kvaliteti namještaja.

Znanje je naš kapital

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CROLAB INNOVAWOOD LGA AIDIMA

Beate Buchelt, André Wagenführ[1]

Investigation of Friction Coefficients of Veneers as a Function of Fibre Direction and Moisture Content

Istraživanje faktora trenja između furnira kao funkcije smjera protezanja vlakanaca i sadržaja vode

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ABSTRACT • *During the manufacture of veneer based moulded parts, veneers move against one another. Friction is caused due to this movement. Different conditions, such as gluing or fibre direction, could influence the friction coefficients and thus the moulding process. For a better understanding of the manufacturing process of veneer based moulded parts, it is important to know which parameters influence friction and friction coefficients. In this paper, results of friction investigations are presented. Thereby the moisture content of the used veneers was varied as well as the fibre direction. Considering the manufacture conditions, the investigations were also conducted with glue-coated veneers. The results prove an influence of fibre direction but this influence depends on moisture content.*

Key words*: *veneer, friction, friction coefficients, wood moulded parts

SAŽETAK • *Tijekom proizvodnje furnirskih otpresaka furniri se gibaju jedan nasuprot drugome. Zbog toga gibanja nastaje trenje. Različiti uvjeti kao što su lijepljenje i smjer protezanja vlakanaca mogu utjecati na faktor trenja, a time i na proces izrade otpresaka. Za bolje razumijevanje procesa proizvodnje furnirskih otpresaka važno je znati koji čimbenici utječu na trenje i faktor trenja. U ovom su radu prezentirani rezultati istraživanja trenja između furnira. Varirani su sadržaj vode upotrijebljenih furnira, kao i smjer protezanja vlakanaca. Uzimajući u obzir i proizvodne uvjete, istraživanje se provodilo i s furnirima premazanim ljepilom. Rezultati su potvrdili utjecaj smjera protezanja vlakanaca, ali taj utjecaj ovisi o sadržaju vode u furniru.*

Ključne riječi: *furnir, trenje, koeficijent trenja, drveni otpresci*

1 INTRODUCTION
1. UVOD

Moulded parts made of laminated wood are used as chair shells, built-in parts in sophisticated interior furnishing, loudspeaker enclosure or the like. In general, the manufacture of three-dimensional veneer-based moulded parts is conducted in heatable shaping presses. Thereby several veneer layers are stacked. During the moulding process, veneers shift against one another, causing friction. Depending on the layering of veneers (parallel or crosswise stacked veneer), there are different shift scenarios. The relative movement between veneer layers can also take place at an angle of 45°, depending on the used mould.

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Investigations addressed to the friction of wood are mostly instigated by the wood machining process. Hence, these studies are focused on the friction between wood and metal (McKenzie, 1991; Seki *et al*., 2016; Svensson *et al*., 2009). The friction between wood and wood was investigated by McKenzie and Karpovich, 1968; Murase, 1984 and Ramananantoandro *et al*., 2007. Other studies are addressed wood based materials (Bejo *et al*., 2000; Seki *et al*., 2016).

In the referred studies, different influencing variables were considered, such as sliding speed, normal load, temperature, moisture content or fibre direction. In each study different wood species were used. All scientists in the referred studies have determined the static (μ_{st}) and sliding (μ_{sl}) friction coefficient.

The influence of sliding speed was investigated by McKenzie and Karpovich (1968) and Ramananantoandro *et al*. (2007). McKenzie and Karpovich (1968) have presented a basic study concerning the friction of wood. They investigated a variety of wood species. A milling machine was used for applying friction to the wood. The use of a milling machine indicates the background of these investigations: friction and wear during the wood machining process. The sliding speed was varied between 0 and 2000 mm/min. Ramananantoandro *et al*. (2007) conducted friction tests with oak with a newly developed friction testing machine that performs the friction by a linear movement. Whereas McKenzie and Karpovich (1968) found an influence of sliding speed on friction coefficients, Ramananantoandro *et al*. (2007) could not ascertain an influence.

The influence of the normal load was investigated by Ramananantoandro *et al*. (2007) and Murase (1984). Murase (1984) has conducted friction tests with Western hemlock. Murase has varied the normal load between 2.3 kPa and 65 kPa, and Ramananantoandro *et al*. (2007) between 23 kPa and 228 kPa. According to both studies, the friction coefficients are independent of the normal load.

The influence of moisture content was the object of investigations conducted by McKenzie and Karpovich (1968) and Murase (1984). McKenzie and Karpovich (1968) investigated wood conditioned to 12 % moisture content and wet, water soaked and dripping wood. The main conclusion concerning the wood-wood friction resulting from their study was that water soaked samples have clearly higher friction coefficients than wood with 12 % moisture content. They did not differentiate between the varieties of wood species they had investigated. Murase (1984) has varied the moisture content of wood between air dry and water saturation in four steps. He has confirmed the results of McKenzie and Karpovich (1968) and found that both friction coefficients increase when moisture content increases. Murase (1984) explained that the increase in friction coefficients with increasing moisture content is due to a higher adhesion between wood and wood. The hydrogen bonding is considered to be responsible for this adhesion.

The fibre direction, as an influencing variable, was investigated by McKenzie and Karpovich (1968) and Ramananantoandro *et al*. (2007). McKenzie and Karpovich (1968) have investigated three sliding situations: a) surface parallel to the fibre direction, sliding parallel to the fibre direction; b) surface parallel to the fibre direction, sliding perpendicular to the fibre direction (cross-cut); c) surface perpendicular to the fibre direction (cross-cut), sliding perpendicular to the fibre direction (cross-cut). They have found only small differences due to fibre orientation. Thus, all results were averaged. Ramananantoandro *et al*. (2007) have determined friction coefficients at different anatomical planes and directions, but the fibre and sliding direction from unmoved and moved surfaces were always the same. They have concluded that the fibre direction has no influence on the static frictional behaviour, while influence was observed on the sliding frictional behaviour. Thus, in the considered fibre directions of both studies, no influence of the fibre direction on the static friction coefficient could consistently be found. Considering the sliding frictional behaviour, Ramananantoandro *et al*. (2007) have found an influence, while McKenzie and Karpovich (1968) could not find any influence. However, both authors have investigated different fibre directions and situations of unmoved and moved planes.

The literature review consistently confirms the independence of friction coefficients on the normal load. Also, the dependence of moisture content was consistently confirmed. There are contradictions about the influence of fibre direction and sliding speed.

Considering the above mentioned background of these investigations, in this study friction coefficients for the moulding process of stacked veneer layers were determined. Subsequently, these coefficients shall be used for modelling this process. Thereby, the investigated influencing parameters were chosen to be similar to conditions occurring during the moulding process. Different combinations of movement directions were investigated considering the manufacture of three dimensional, veneer-based moulded parts. Such combinations of fibre and sliding direction are not known from literature.

To achieve higher degrees of deformation, veneers are mostly moistened. Furthermore, the veneers have to be glued for manufacturing moulded parts. That is why different moisture conditions and glued veneers were investigated.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Industrial sliced beech veneer (*Fagus sylvatica* L.; 1.2 mm thick) was used for the investigations because it represents the most commonly used species for manufacturing veneer based moulded parts. Industrially produced veneers do not have a strictly anatomically oriented surface. The created plane is a cross of the longitudinal plane in one direction and the radial and tangential plane in the other direction. Hence, the tests were conducted with veneers of the L-RT plane. Friction tests were conducted referring to DIN EN

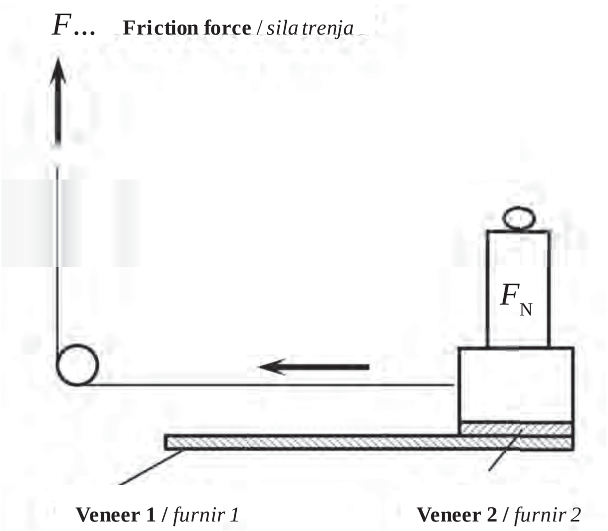

Figure 1 Schematic diagram of friction test apparatus
Slika 1. Shematski prikaz uređaja za ispitivanje trenja

14882 (2005) (Figure 1) in a standard atmosphere at 20 °C, 65 % rh.

The bottom veneer (veneer 1) was the stationary counterpart. Its dimensions were 70 mm x 130 mm. The moving veneer (veneer 2) was pulled across the stationary veneer with a constant normal load and sliding speed. The arrows show the direction of movement. The moved veneer had dimensions of 50 mm x 50 mm and was fixed to a block. This veneer was pulled over a distance of 100 mm across its counterpart, veneer 1. During this movement, the load F was measured. This load is considered to determine the friction force. The load peak (F_{st}), occurring just before the movement, was used for calculating the static friction coefficient μ_{st} (Eq. 1).

$$\mu_{\mathrm{st}} = \frac{F_{\mathrm{st}}}{F_{\mathrm{N}}} \tag{1}$$

The normal load F_N amounted to 59 N.

In order to calculate the sliding friction coefficient μ_{sl}, all load values between 10 mm and 100 mm during the sliding process were averaged. The values below 10 mm were not considered in order to exclude the influence of the sliding start. The coefficient was calculated in analogy to Eq. 1, as follows:

$$\mu_{\mathrm{sl}} = \frac{F_{\mathrm{sl}}}{F_{\mathrm{N}}} \tag{2}$$

According to different scenarios of movements and fibre directions in a veneer batch during the moulding process, different sliding situations were investigated (Figure 2). The sliding situation describes the fibre directions relative to the sliding direction. The large arrow in Figure 2 indicates the direction of movement (sliding direction). The lines in the veneer illustrations indicate the fibre direction. 0° means the fibre direction of the veneer is the same direction as the sliding direction; 90° means the fibre direction runs 90° in relation to the sliding direction, 45° means the angle between fibre direction and sliding direction amounts to 45°.

Friction coefficients were determined on air-dried samples (air-conditioned at 20 °C / 65 % rel. humidity, $\omega = 11.7$ %), on water-saturated samples (water logged for 24 h; surface water dapped, $\omega = 83$ %) and veneers coated with adhesive. For the last sliding situation, the lower veneer (veneer 1) was coated with UF resin KAURIT® glue 325 fluid. The veneer was coated with 180 g/m² glue. The moved veneer (veneer 2) was not coated with glue; it was air-dried at 20 °C / 65 % rh.

Every sliding situation was conducted 5 times, whereas each veneer was used only once. The veneer surfaces were damaged during the friction tests thus each test had to be conducted with new veneer samples. The sliding speed amounted to 400 mm/ min.

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

Figure 3a-c and Figure 4a-c show the test results. Basically, the static friction coefficient is higher than the sliding friction coefficient. That was to be expected, considering the literature. McKenzie and Karpovich (1968) determined a coefficient of static friction (μ_{st}) of 0.6 and a coefficient of sliding friction (μ_{sl}) of 0.45 for wood with a moisture content of 12%. Concerning the water soaked samples, μ_{st} was determined

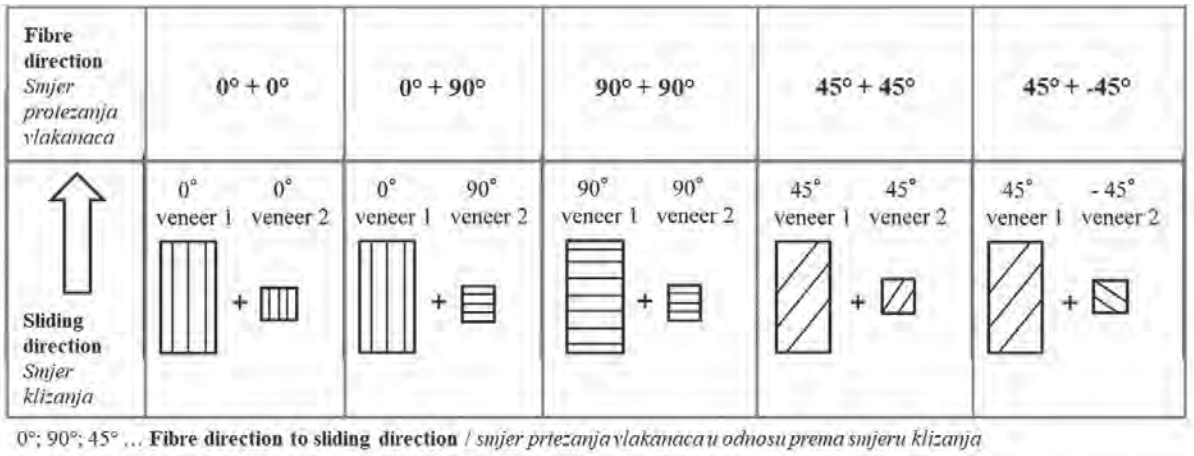

Figure 2 Combinations of fibre directions and their denotation
Slika 2. Kombinacije smjera vlakana i njihove oznake

to be 0.85 and μ_{sl} varied between 0.38 and 0.64, depending on sliding speed. Murase (1984) determined the static friction coefficient μ_{st} to be at 0.8 and the sliding friction.

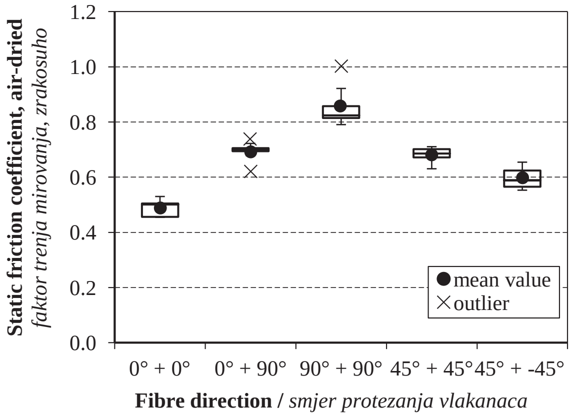

Figure 3a Static friction coefficients of air-dried samples
Slika 3.a) Faktor trenja mirovanja zrakosuhih uzoraka

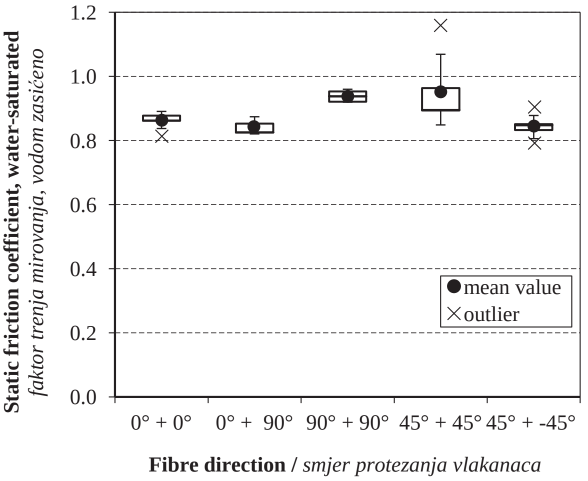

Figure 3b Static friction coefficients of water-saturated samples
Slika 3.b) Faktor trenja mirovanja uzoraka zasićenih vodom

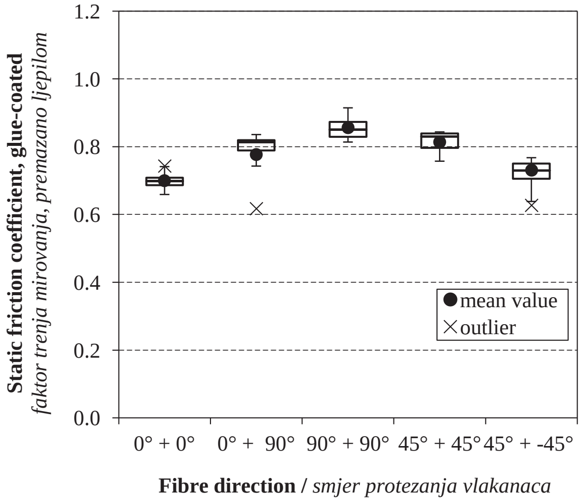

Figure 3c Static friction coefficients of adhesive-coated samples
Slika 3.c) Faktor trenja mirovanja uzoraka premazanih ljepilom

The comparison of different sliding situations shows an influence of fibre direction on friction coefficients. The ANOVA-test ($p<0.05$) results in the proof

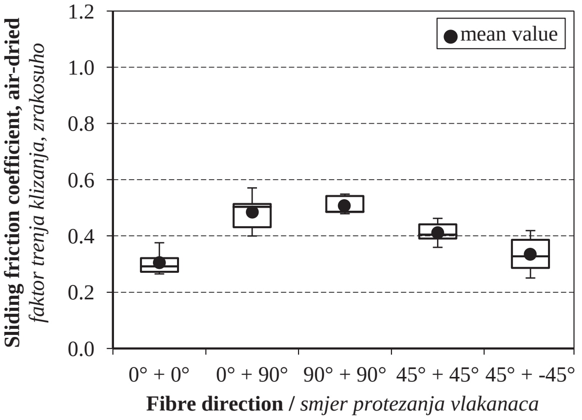

Figure 4a Sliding friction coefficients of air-dried samples
Slika 4.a) Faktor trenja klizanja zrakosuhih uzoraka

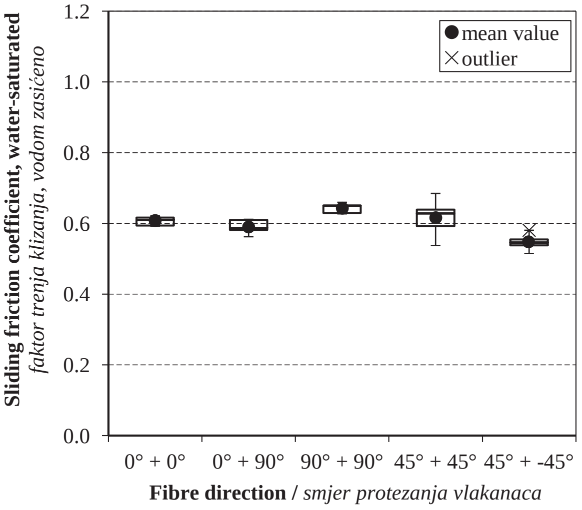

Figure 4b Sliding friction coefficients of water-saturated samples
Slika 4.b) Faktor trenja klizanja uzoraka zasićenih vodom

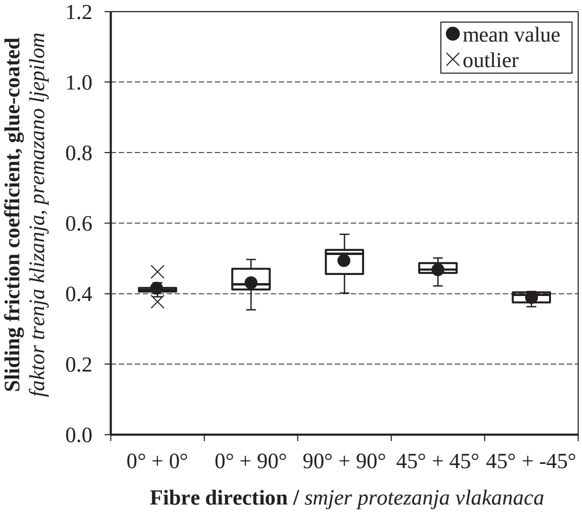

Figure 4c Sliding friction coefficients of adhesive-coated samples
Slika 4.c) Faktor trenja klizanja uzoraka premazanih ljepilom

of significant differences between the mean values of the friction coefficients of the tested sliding situations. This statistical significance could be proven for static as well as for sliding friction for air-dried, water-saturated and adhesive-coated samples. Thereby, the air-dried samples show the clearest differences between the various sliding situations. The highest friction values were obtained by movement of two surfaces in the fibre direction of 90°.

According to the available literature, the combinations of fibre and sliding direction (the sliding situations) measured in this study have never been measured before. In this respect the results cannot be compared with literature values (McKenzie and Karpovich, 1968; Ramananantoandro *et al*., 2007).

Basically, the results of this study prove differences of friction coefficients when different fibre directions slide over each other. Previous studies did not result in such clear differences.

The friction coefficients of water-saturated samples are clearly higher than the coefficients of the air-dried samples. That was basically also to be expected, considering the literature, but the known findings could be extended for the regarded sliding situations.

An interesting fact is that the results indicated only small differences between the sliding situations.

In contrast to the air-dried samples that were sliding continuously, all water-saturated samples showed a slip-stick effect. That means a continuous jerking occurred, which might be regarded as alternating between static and sliding friction. Figure 5a shows an example of measuring values of a smooth-running air-dried sample, and Figure 5b of a water-saturated sample with slip-stick. The diagram shows that sliding force peaks reach or approach the initial force required to set the specimen in motion, which indicates that the specimen repeatedly stopped during the test. This effect might amplify the sliding friction coefficients because this

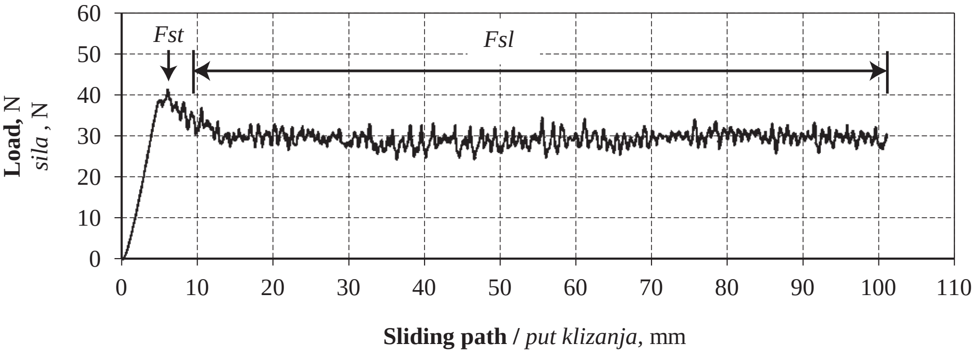

Figure 5a Behaviour of friction force (exemplarily) of air-dried samples
Slika 5.a) Ponašanje sile trenja (kao primjer) zrakosuhih uzoraka

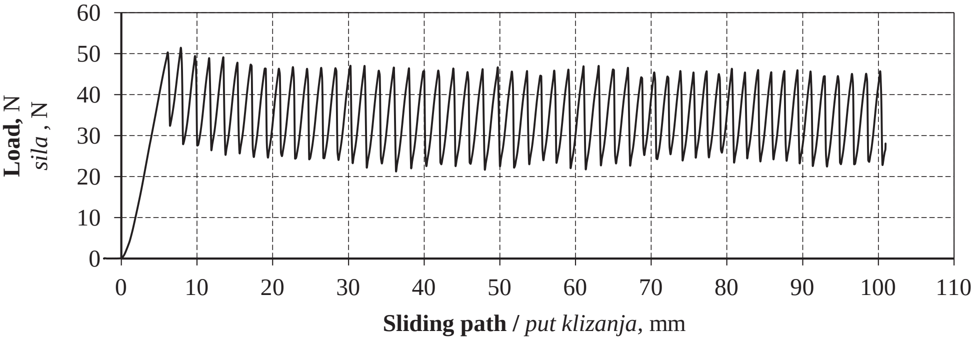

Figure 5b Behaviour of friction force (exemplarily) of water-saturated samples
Slika 5.b) Ponašanje sile trenja (kao primjer) uzoraka zasićenih vodom

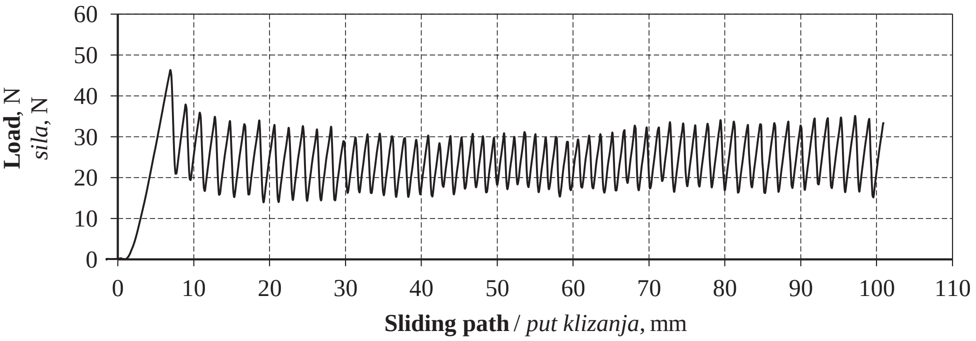

Figure 5c Behaviour of friction force (exemplarily) of glue-coated samples
Slika 5.c) Ponašanje sile trenja (kao primjer) uzoraka premazanih ljepilom

coefficient is averaged using all load values. McKenzie and Karpovich (1968) and Murase (1984) explain the higher coefficients of wet samples with some additional hydrogen bonding between the two counterparts. The additional hydrogen bonding might be one reason, but other things might increase the friction of water-saturated samples, as well. Due to the high moisture content of wet samples, the samples are swollen. Because of the raised fibres, the roughness is increased (Csanády *et al*., 2015). Although Ramananantoandro (2007) could not prove a correlation between roughness and friction coefficients, an obstruction of the movement due to raised fibres is conceivable.

Furthermore, the water softens the veneers. Thus, the upper (moving) veneer can be pressed into the counterpart veneer by the normal load, generating a dent. Therefore, a higher drag is created against the movement. That might also explain the slip-stick: the sample sinks in causing it to stop and high power is necessary to restart the movement (power peak); then the sample stops because of sinking in again.

The friction coefficients of the samples coated with adhesive behave similarly to the water-saturated samples in terms of differences of fibre directions, but the friction coefficients are lower. The differences between the sliding situations are clearly reduced. 80 % of the tests showed a slip-stick. Figure 5c shows a sample diagram. The adhesive layer is very thin. Part of the adhesive will certainly be absorbed by the surface and soften the surface like the water-saturated samples. Probably, therefore, the adhesive cannot undertake the function of a lubricant. A possible reason for the slip-stick effect of these samples is the additional adhesion between wood and adhesive that the UF resin elicits. In contrast to water, the adhesive is sticky and thus inhibits the motion.

The results show that neither the water nor the glue act as lubricants. The friction is increased by using either of the two fluids. Independently of the kind of the fluids between the friction counterparts, the differences between the fibre directions are clearly reduced due to the presence of fluids. Nevertheless, the differences are statistically significant.

4 CONCLUSIONS
4. ZAKLJUČAK

The following conclusions can be drawn:

- The sliding situation and the fibre direction have an influence on the friction. This influence depends on moisture content.
- The differences between the friction coefficients are clearly reduced by water-saturated samples and samples coated with adhesive. Thus, the moisture equalizes the coefficients, but it also increases the friction.
- The glue layer does not work as a lubricant. The friction is increased due to the fluid adhesive. The presence of adhesive elicits a slip-stick-effect by most of the investigated samples.

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Finite Element Analysis of Heat Treated Wood Filled Styrene Maleic Anhydride (SMA) Copolymer Composites

Analiza kompozita od kopolimera stirena i anhidrida maleinske kiseline (SMA) punjenih pregrijanim drvom metodom konačnih elemenata

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ABSTRACT • *The computer aided three dimensional static analyses of the specimens was done by using the Finite Element Method (FEM) and obtained data was compared with actual test data. The aim of this study is to compare the deformation/stress analyses with FEM analysis results of styrene maleic anhydride (SMA) copolymer composites. The heat treated wood/SMA copolymer composites were produced from different loadings (from 10 to 30 wt. %) of heat treated and untreated eastern white pine wood flours (Pinus strobus L.). All formulations of wood flour/SMA copolymer composites were produced by melt compounding through injection molding. The deformation/stress results obtained from the experimental solutions are very close to the results obtained from the numerical solutions (SAP2000 V17). As a result, it can be said that it is beneficial to use the FEM in the engineering design approach after the data obtained by the experimental solutions as meaningful values after application of the FEM.*

Key words: *wood polymer composite, styrene maleic anhydride (SMA), finite element method*

SAŽETAK • *Računalom potpomognuta trodimenzionalna statička analiza uzoraka provedena je metodom konačnih elemenata (FEM). Dobiveni su podatci uspoređeni sa stvarnim ispitnim podatcima. Cilj rada bio je usporediti analizu deformacija/naprezanja s rezultatima FEM analize kompozita od kopolimera stirena i anhidrida maleinske kiseline (SMA). Kompoziti od pregrijanog drva i SMA kopolimera bili su izrađeni s različitim udjelom (od 10 do 30 % težine) drvnog brašna od pregrijanoga i nepregrijanog drva američkog borovca (Pinus strobus L.). Sve formulacije kompozita od drvnog brašna i SMA kopolimera bile su izrađene injekcijskim prešanjem. Re-*

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zultati deformacija i naprezanja dobiveni eksperimentalno vrlo su slični rezultatima dobivenim računskim putem (SAP200 V17). Može se zaključiti da je analiza metodom konačnih elementa, kombinirana s eksperimentalno dobivenim podatcima, korisna u inženjerskom projektiranju.

Ključne riječi: *drvno-plastični kompoziti, SMA, metoda konačnih elemenata*

1 INTRODUCTION
1. UVOD

In the recent years, more interest has been reported on wood composites as engineering materials because of renewable, biodegradable resources, no waste problems, and superior mechanical properties (Mackerle, 2005). Wood plastic composite (WPC) has gained the interest of material engineers because of its structural properties (El-Haggar and Kamel, 2011). Some of its main properties are high durability, low maintenance, strength and stiffness, lower prices and decrease in bio-degradation, which makes the composites suitable for outdoor applications. Some of the applications of these composites are: decking, sheathing, roof tiles, window trim and automobile parts. WPCs perform like conventional wood; however, they are not stiff and may require special fasteners or design changes. WPCs are still stiffer than plastics (Clemons and Caufield, 2005).

A developing class of materials, including WPC has favorable attributes – they are cost effective and have good performance (Bledzki *et al*., 2002; Aydemir *et al*., 2014a; Aydemir *et al*., 2014b; Aydemir *et al*., 2015a; Aydemir *et al*., 2015b; Zor *et al*., 2016; Bardak *et al*., 2016; Sözen *et al*., 2017). The industrial manufacturing arena has paid superior attention to the use of wood as reinforcing filler for thermoplastics (Kishi *et al*., 1988; Maidas *et al*., 1988; Woodhams *et al*., 1984; Yam *et al*., 1990). The injection molding process and thermoforming of interior parts is used along with styrene maleic anhydride (SMA) copolymer in the automotive industry (ARCO Chemical Company, 1990). The main reason for the choice of maleic anhydride is to enhance the properties of the copolymer. The importance of using SMA lies in the fact that it demonstrates a similar behavior to maleic anhydride polypropylene (MAPP) (Takase and Shiraishi, 1989).

In the last four decades, the finite element method (FEM), used in numerous areas of structural analysis, has been used in the engineering application process, as well. Structural analysis should determine the effects of the loads on physical structures and their components. These physical structures and their components, subjected to this type of analysis, have to withstand loads, pressures, torques and moments in accordance with parameters that act on them (Figure 1).

Use of fiber composite material in load bearing applications usually requires a careful study and design of the component or product to be made. This can be achieved using numerical modeling software, such as finite element analysis (FEA) software (Lim *et al*., 2003). However, the accuracy of the input parameters, such as mechanical and physical properties of the material, loading and constraint conditions, plays an important role in the correct prediction of the structural behavior of the composite obtained by numerical analysis. The finite element method (FEM) is a numerical technique used in the analysis of the behavior of materials or systems (Gustafsson 1995, 1996). The FEM is used for structural analysis and modeling of materials that are subject to static or dynamic loads. Similarly, furniture components and systems are designed with the aid of structural design procedures (Eckelman, 1966).

In spite of the academic and industrial interest in heat treated wood, only few studies of heat treated lignocellulosic filled polymer composites have been pub-

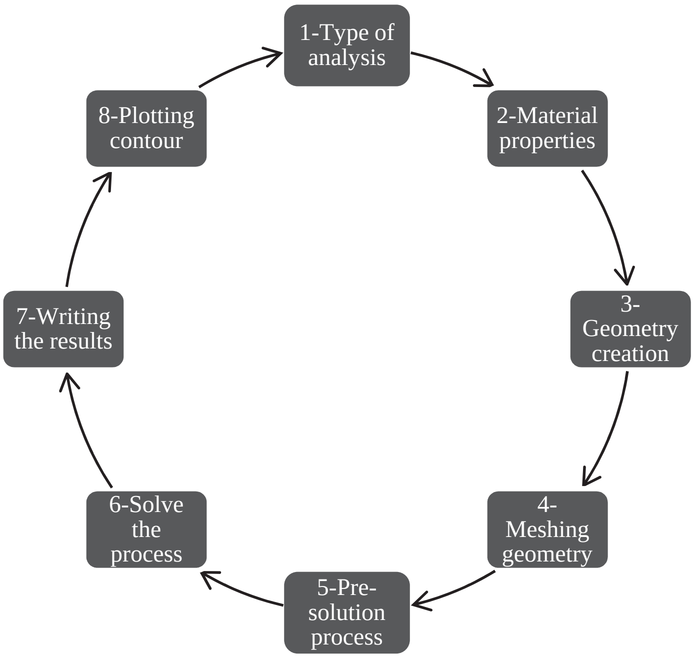

Figure 1 Process of FEM
Slika 1. Postupak analize metodom konačnih elemenata

lished in the literature (Ayrılmış *et al*., 2011; Aydemir *et al*., 2015c; Zor *et al*., 2018). To the best of authors' knowledge, there is no information related to simulation analysis of heat treated lignocellulosic-filled SMA thermoplastic composites. The aim of the study is to compare the deformation analysis with the help of the open and close numerical modeling solution with the FEM.

2 EXPERIMENTAL APPROACH
2. EKSPERIMENTALNI PRISTUP

2.1 Materials
2.1. Materijali

The SMA (XIRAN® SE700) was supplied by Poyscope Polymer, USA. It has a density of 1.08 g/cm^3 (Maleic anhydride contents 10 % wt., melt flow 22 g/10min at 240 °C/10.0 kg). The eastern white pine (*Pinus strobus* L.), used as filler in this study, was kindly supplied by Wicks Lumber in Pittsfield, ME, USA.

2.2 Heat treatment
2.2. Pregrijavanje

Pine wood samples were cut from sapwood of a radial board of eastern white pine (*Pinus strobus* L.). Cubic samples with dimensions of 360 mm x 20 mm x 20 mm were cut with clear faces, kept in a conditioned room at 20 ºC and 50 % relative humidity for 3 weeks and weighed afterwards. The heat treatment was made in an oven heated by electric coils located in the walls and with exhaustion of the heated gases by natural convection through an opening in the oven wall. The treatment was applied at a temperature of 212 ºC for 8 h (Aydemir *et al*. 2015b). The treatment started by putting the samples at ambient temperature in the oven. The time to reach the treatment temperature was about 60 min. After heat treatment, the solid wood board samples were removed from the oven and ground in a grinder. Wood flour of pine greater than 60 mesh was used as raw material to prepare the wood flour/SMA copolymer composites. Untreated samples were used as the control.

2.3 Processing of composite materials
2.3. Proizvodnja kompozita

The wood flour retained on 60-mesh size sieve was dried to a moisture content of less than 1 % using a conventional oven at 105 °C for 16 h. This mixture was compounded in a twin-screw extruder (C. W. Brabender 20 m Clamshell Segmented). The temperature profile used during the extrusion was 210/220/220/220/220/210 °C in the respective feeding/ mixing/matrix zones with rotation of 60 rpm. The SMA-wood flour compounds were granulated using a lab-scale grinder. The ground particles were dried in an oven at 105 °C for 16 h before being injection molded into ASTM test specimens. All materials were injection molded using a barrel temperature of 230 °C, mold temperature of 220 °C and injection pressure of 17 MPa. The composition of the composites is shown in Table 1.

Table 1 Composition of SMA, untreated and heat treated composites
Tablica 1. Sastav kompozita od SMA, nepregrijanoga i pregrijanog drva

SMA, %	Untreated wood, % *Nepregrijano drvo, %*	Heat treated wood, % *Pregrijano drvo, %*	Specimen mark *Oznaka uzorka*
100	-	-	Control
90	10	-	10UT
80	20	-	20UT
70	30	-	30UT
90	-	10	10T
80	-	20	20T
70	-	30	30T

3 NUMERICAL SOLUTION
3. RAČUNSKI PRISTUP

3.1 Material properties
3.1. Svojstva materijala

Finite element analysis of wood flour filled SMA composite elements was carried out using the SAP2000 V17 program. Analyses were performed by creating numerical design models based on experimental data. It was compared to the normal stresses obtained from the numerical model and the normal stresses obtained from the experiment by using the maximum load, elastic modulus and density data with 3-point bending test. The value of vertical deformation at any point of the bar is obtained by the finite element method. Since the contribution of deformation to numerical solutions is very little, the weight of the material has been neglected. Some mechanical values entered into the program for numerical analysis of the model are given in Table 2.

Table 2 Mechanical properties of materials entered into the program
Tablica 2. Mehanička svojstva materijala unesena u program

Material properties *Mehanička svojstva*	**Control** *Kontrola*	UT*			T**		
		%10	%20	%30	%10	%20	%30
Density / *gustoća*, g/cm^3	1.05	1.07	1.10	1.11	1.08	1.09	1.12
Elasticity modulus of bending / *modul elastičnosti*, GPa	1.96	2.52	2.69	3.50	2.66	2.99	3.81
Poisson ratio / *Poissonov omjer*	0.3						
Bending stress / *čvrstoća na savijanje*							
Max fracture load / *najveća sila loma*, N	128	120	119	121	119	120	121
Sample properties / *dimenzije uzorka*	127 mm × 22 mm × 3.2 mm (height × weight × thickness)						

* UT – untreated wood / *nepregrijano drvo*; **T – heat treated wood / *pregrijano drvo*

3.2 Finite element method (open solution)
3.2. Metoda konačnih elemenata (otvoreni pristup)

The Finite Elements Method (FEM) is a numerical method used in engineering to analyze the behavior of materials or systems against external factors (force, heat, electricity, etc.). FEM contains the numerical solution of the mathematical model established by equalizing stiffness matrix [*K*], deformation vector {*u*} and force vector {*F*} in structural static calculations. The force vector, {*F*}, was determined as (Eq. 1):

$$\{F\} = [K]\{U\} \tag{1}$$

Where {*F*} is the force vector, [*K*] is the stiffness matrix, {*u*} is the deformation vector.

When the force is applied to the material, the extensions of the material are proportional to stretching within the elastic limits. This is called the "Hooke Law". The modulus of elasticity is a characteristic feature of the material. The modulus of elasticity, *E*, was determined as (Eq. 2):

$$E = \frac{\sigma}{\varepsilon} \tag{2}$$

Where *E* is the modulus of elasticity, σ is the stress, ε is the deformation.

In a beam subjected to bending, the normal stress is as given in Eq. 3.

$$\sigma_{(z)} = \frac{M}{I_x} y_{(z)} \tag{3}$$

Where $\sigma_{(z)}$ is the normal stress along section height, *M* is the bending moment at any distance of the bar, $y_{(z)}$ is the distance of cross-section, I_x is the moment of inertia.

If the same beam is subjected to a force (tension or compression) only in the *z*-axis direction (first local axis of the bar), a constant σ_0 strain occurs along the rod and section height as given in Eq. 4.

$$\sigma_{(z)} = \sigma_0 = \frac{P}{A} \tag{4}$$

Where σ_0 is the stress, *A* is the cross-sectional area.

3.3 Finite element modeling (close solution)
3.3. Modeliranje konačnih elemenata (zatvoreni pristup)

The maximum force obtained by the 3 point bending test was compared with the normal stresses obtained from the normal tensile test obtained from the numerical model using the elastic modulus and density data. In addition, the value of vertical deformation at any point of the bar is obtained by the finite element method. In this study, vertical deformations were given at the midpoint of the bar where the force was applied. Vertical deformation (Eq. 5) at any *z* distance of a beam subjected to 3 point bending test is shown in Figure 2. 3D view of finite element model is given in Figure 3.

$$\delta y = \frac{P \cdot L^3}{48 \cdot E \cdot I} \tag{5}$$

Where δy is the vertical deformation, *P* is the applied maximum force (N).

Figure 2 Example of beam subjected to 3 point bending test
Slika 2. Primjer savijanja grede u tri točke

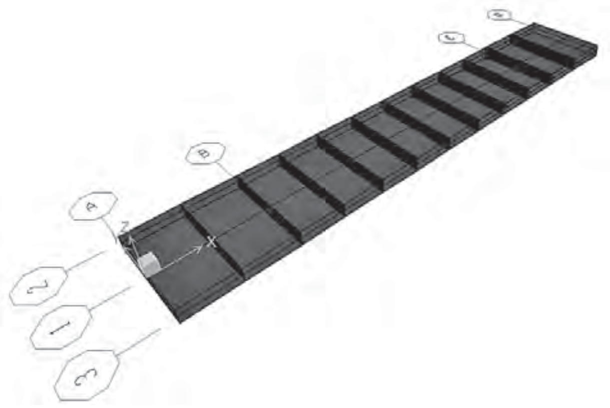

Figure 3 3D view of finite element model of the design example
Slika 3. 3D prikaz modela konačnih elemenata na projektiranom primjeru

The steps that are followed in the program to solve the problem with the FEM are given below. 1. Creating the Model 2. Identification of Material Properties 3. Implementation of border conditions 4. Meshing 5. Analysis and evaluation of results.

3.4 Deformation analysis with finite element modeling
3.4. Analiza deformacije metodom konačnih elemenata

The comparison of the experimental deformation results with the data obtained with the aid of Eq. 5 is given in Table 3. Liner elastic behavior obtained by neglecting the weight of the material was analyzed numerically using the SAP2000 V17 program.

According to the 3 point bending load, the deformation results obtained with Eq. 5 and SAP2000 V17 numerical deformation results are very close to each other.

Table 4 shows the results of the maximum stresses obtained from numerical modeling with the maxi-

Table 3 Comparison of open and numerical solutions with 3-point bending load
Tablica 3. Usporedba otvorenog pristupa i zatvorenoga računskog pristupa sa savijanjem u tri točke

Materials *Materijali*	**Open solution, mm** *Otvoreni pristup,* mm	**Numerical (close) solution, mm** *Računski (zatvoreni) pristup,* mm	**Difference, %** *Razlika,* %
Control	11.59	11.66	0.60
10UT	8.45	8.49	0.47
10T	7.87	7.91	0.50
20UT	7.85	7.98	1.62
20T	7.30	7.34	0.54
30UT	6.08	6.11	0.49
30T	5.45	5.47	0.36

Table 4 Comparison of numerical solution and experimentally obtained stresses with 3-point bending load
Tablica 4. Usporedba računskog pristupa i eksperimentalno dobivenih naprezanja sa savijanjem u tri točke

Materials *Materijali*	**Experimental solution, MPa** *Eksperimentalni pristup,* MPa	**Numerical (close) solution, MPa (Eq. 4)** *Računski (zatvoreni) pristup,* MPa *(Eq. 4)*	**Difference, %** *Razlika,* %	**Open solution, MPa** *Otvoreni pristup,* MPa	**Difference, %** *Razlika,* %
Control	70.21	68.18	*2.89*	68.18	*2.89*
10UT	69.25	63.89	*7.74*	63.92	*7.70*
10T	68.9	62.86	*8.76*	63.38	*8.01*
20UT	63.89	60.39	*5.47*	63.38	*0.8*
20T	70.89	65.52	*7.57*	63.92	*9.83*
30UT	71.5	63.92	*10.6*	64.45	*9.86*
30T	70.97	63.39	*10.68*	64.45	*9.19*

Figure 4 Total deformation diagram of the bar
Slika 4. Dijagram ukupne deformacije

mum stress obtained after the experimental analysis of the samples subjected to bending strength.

In order to determine the accuracy of the experimental data in the 3-point bending load, with data obtained by the numerical model technique that used the SAP2000 V17 software, it was seen that close results were found. These results show that the sample distribution varies in the 30 % composite groups. This is because, as the wood flour ratio increases during the production of the injection molding machine, the material cannot be obtained homogeneously at the desired temperature under high temperature, and the material does not exhibit the behavior of the linear isotropic material.

The maximum stress and deformation of the 3-point bending result of the pure SMA samples, which are the control samples, are shown as examples in Figures 4 and 5.

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

When exposed to 3-point bending, the close solutions of the control group are received as 2D stress value of 68.18 MPa and the deformation value of -11.66 mm. According to the experimental and open solution approaches, the deformation value difference is 0.6 % and the stress value difference is 2.89 %.

When exposed to 3-point bending, the close solutions of 10 % UT group composite are received as 2D stress value of 63.89 MPa and the deformation value of -8.49 mm. According to the experimental and open solution approaches, the deformation value difference is 0.47 % and the stress value difference is 7.74 %. When exposed to 3-point bending, the close solutions of 10 % T group composite are received as 2D stress value of 62.86 MPa and the deformation value of -7.91 mm. According to the experimental and open solution approaches, the deformation value difference is 0.50 % and the stress value difference is 8.76 %.

When exposed to 3-point bending, the close solutions of 20 % UT group composite are received as 2D stress value of 60.39 MPa and the deformation value of

Figure 5 3D and 2D view of maximum principle stress contour diagrams (MPa)
Slika 5. 3D i 2D prikaz najvećih kontura naprezanja (MPa)

-7.98 mm. According to the experimental and open solution approaches, the deformation value difference is 1.62 % and the stress value difference is 5.47 %. When exposed to 3-point bending, the close solutions of 20 % T group composite are received as 2D stress value of 65.52 MPa and the deformation value of -7.34 mm. According to the experimental and open solution approaches, the deformation value difference is 0.54 % and the stress value difference is 7.57 %.

When exposed to 3-point bending, the close solutions of 30 % UT group composite are received as 2D stress value of 63.92 MPa and the deformation value of -6.11 mm. According to the experimental and open solution approaches, the difference value of deformation is 0.49 % and the stress value difference is 10.60 %. When exposed to 3-point bending, the close solutions of 30 % T group composite are received as 2D stress value of 63.39 MPa and the deformation value of -5.47 mm. According to the experimental and open solution approaches, the deformation value difference is 0.36 % and the stress value difference is 10.68%.

5 CONCLUSIONS
5. ZAKLJUČAK

This study investigated the design possibilities for engineering materials by linear elastic analysis using SAP2000 V17 software. The deformations obtained by simulation were compared with experimental data. As a result of the numerical solutions carried out by finite element analyses, normal stresses were obtained along the bending beam.

When the normal stress values obtained from numerical solutions using SAP2000 V17 software are compared with the open solution using Eq. 3, it is seen that the results are very close to each other. When these values were compared with the experimental results, it was observed that the differences in the values obtained for the composites containing 30 % wood flour were increased. For this reason, it can be said that the material starts to lose its homogeneous, isotropic and linear behavior. When the numerical analysis and the deformation values obtained by using Eq. 5 are compared, it is seen that the results are very close to each other.

Based on the findings obtained from the present study, it was concluded that SAP2000 V17 simulation software could be used in the calculation of the component displacements, strains, and stresses for composite/engineering materials under internal and external loads. This reduces the need for a large number of prototypes; it requires fewer product development cycles and means lower costs (time/cost), as well as the improvement of the quality of engineering applications.

Due to the use of computer technology in the design and analysis of wood or wood based composite elements, it is possible to provide important information to product designers who can obtain preliminary information about the impacts of the loads to which a product will be exposed at the usage site before the production of a specific material.

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HRVATSKA KOMORA
INŽENJERA ŠUMARSTVA
I DRVNE TEHNOLOGIJE

HRVATSKA KOMORA INŽENJERA ŠUMARSTVA I DRVNE TEHNOLOGIJE

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Stress and Strain Analysis of Plywood Seat Shell

Analiza naprezanja i deformacije furnirskog otpreska sjedala

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ABSTRACT • *In this paper, the stress and strain analysis of common laminated wood seat shell is performed. Experimental stiffness evaluation is conducted by measuring displacement of the point on the backrest, and experimental stress analysis is carried out by tensometric measuring at the critical transition area from the seat to the backrest. Finite element analysis is carried out layer by layer with a "2D linear elastic model" for orthotropic materials. Good matching is found between numerical and experimental results of displacement. It is also shown that the results of the principal stress in the measurement points of the seat shell compare favourably with experimental data. The applied in-plane stress analysis of each individual veneer is not applicable for interlaminar stress calculations that are a significant factor in curved forms of laminated wood. Curved forms of laminated wood products require more complex numerical analysis, but the method can be used to achieve approximate data in early phase of product design.*

Keywords: *laminated wood, seat shell, tensometric measuring, strain gauges, stress, strain, FEM*

SAŽETAK • *U radu je provedena analiza naprezanja i deformacija uobičajenog otpreska sjedala. Eksperimentalna procjena krutosti napravljena je mjerenjem pomaka točke na naslonu sjedala, a eksperimentalna analiza naprezanja obavljena je tenzometrijskim mjerenjem na kritičnom prijelazu između sjedala i naslona. Analiza metodom konačnih elemenata provedena je sloj po sloj 2D linearnim elastičnim modelom za ortotropne materijale. Dobivena je dobra podudarnost računskih i eksperimentalnih rezultata pomaka. Također je potvrđeno da su rezultati glavnog naprezanja u mjernim točkama furnirskog otpreska sjedala usporedivi s eksperimentalnim podatcima. Odabrana analiza naprezanja u ravnini svakoga pojedinačnog furnira nije primjenjiva za izračun interlaminarnih naprezanja, koja su važan čimbenik zakrivljenog oblika uslojenog drva. Naime, takvi oblici uslojenog drva zahtijevaju složeniju računsku analizu, no metoda se može primijeniti za postizanje približnih podataka u ranoj fazi projektiranja proizvoda.*

Ključne riječi: *uslojeno drvo, otpresak sjedala, tenzometrija, davač pomaka, naprezanje, deformacija, FEM*

1 INTRODUCTION
1. UVOD

Laminated wood composites, such as plywood and curved veneer products, have a wide range of application in furniture industry. Plywood shells are common and basic elements of a certain type of chair constructions. Today, there is a considerable interest in developing new complex forms of the seat shells due to rapid trend changes. A better understanding of specific mechanical and physical properties of laminated structure can lead to quality improvement of curved veneer products.

Laminated wood products have a balanced construction made of veneer sheets and their properties depend on properties of individual veneers, veneers layout and parameters of production process. Different fibre orientations, fibre deviations and moisture con-

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tent variations before moulding have a clear impact on shape stability of the laminated veneer products both after moulding and during use (Blomqvist *et al*., 2013). Basic concepts of laminated wood analysis are based on knowledge of the elastic parameters of individual laminae and its composition (Boding, 1993). More extended analytic model can be found in studies of analytic evaluation of radial stress unfolding failure of composite materials (Gonzalez-Cantero *et al*., 2014). The possibility of applying computer programs for the evaluation of mechanical properties of laminated wood and choosing the optimal material for product development is demonstrated by Brezović *et al.* (2018). The results of experimental analysis of plywood tensile strength through a change of the position of layers in the panel structure around the central axis show that different veneer layouts in plywood structure have a remarkable impact on plywood tensile strength (Jakimovska Popovska, *et al.*, 2017). Numerical methods, such as the ‘finite element method’, are applicable and effective for the analysis of laminated wood, and the numerical results depend on simplifications and assumptions introduced in the numerical model. Numerical determination of stresses and deformations developed during the veneer products manufacture show that heating, pressure and fibre orientation in the veneers have a noticeable influence on the distortion of the chair seat (Sandberg and Ormarsson, 2007). The numerical analysis of the effect of veneer composition on the mechanical properties of rectangular and curved form of laminated wood has been tested and the results show that curved forms require more complex analysis (Hajdarevic *et al.*, 2017). Veneer properties are considered as design tool affecting the behaviour of laminated wood structure (Nestorović *et al*., 2011). Design possibilities for seat shells using linear elastic analysis have been explored by Vratuša *et al*. (2017).

The aim of this study was to determine stiffness and stress of the laminated wood complex structure obtained by numerical method and to compare the results of numerical calculation with test results in order to determine the effects of numerical method, assumptions and simplifications used in the numerical calculation of a structure stiffness and stress. The objective was to show the results that can be expected, depending on complex forms of structure and approach to structural design. In this study, experimental and numerical method (FEM) was used for the analysis of the stiffness and normal stress of the seat shells. The stiffness and stress distribution in the complex laminated wood construction used in this study was determined in order to explore and demonstrate capabilities of numerical calculation in design optimization.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

The plywood seat shell taken from manufacturing process was analyzed (Figure 1). The seat, B x D x H = 400 mm x 442 mm x 434.5 mm, was made from eight plies of beech veneer. Urea-formaldehyde adhesive (UF) with catalyst (NH4Cl) was used to bond veneers with a spread rate of 160 g/m^2. The veneers were oriented longitudinally, except the third and sixth layer, with transverse oriented veneers. The thickness of all veneers was 1.5 mm, except the externals ones, whose thickness was 0.75 mm. Mean value of plywood thickness was 10.5 mm.

Loading diagram of seat shell is shown in Figure 2. The position of the concentrated force direction was defined by the distances h = 264.5 mm and d = 209 mm. The seat part of the shell was fixed in the zone of connection with pedestal. The load was applied to the backrest in a manner that corresponds to statically testing the backrest. The seat shell was loaded and unloaded five times on a universal testing machine. The maximum force F = 500 N was applied to the backrest across the curved shape metal plate. The displacement

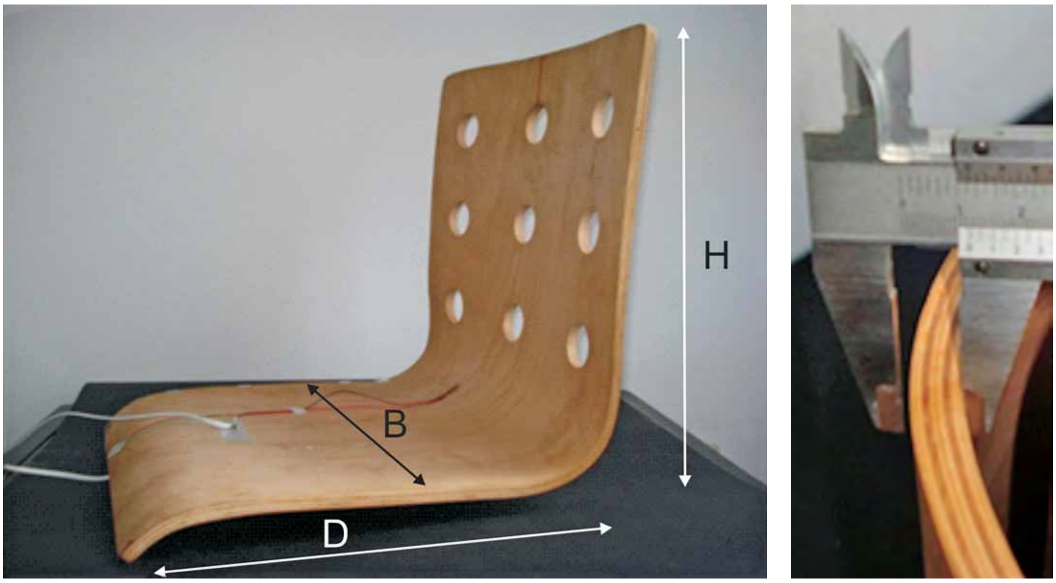

Figure 1 Shape of plywood seat shell (left) and orientation of plywood layers (right)
Slika 1. Oblik furnirskog otpreska sjedala (lijevo) i smjer protezanja slojeva furnirskog otpreska (desno)

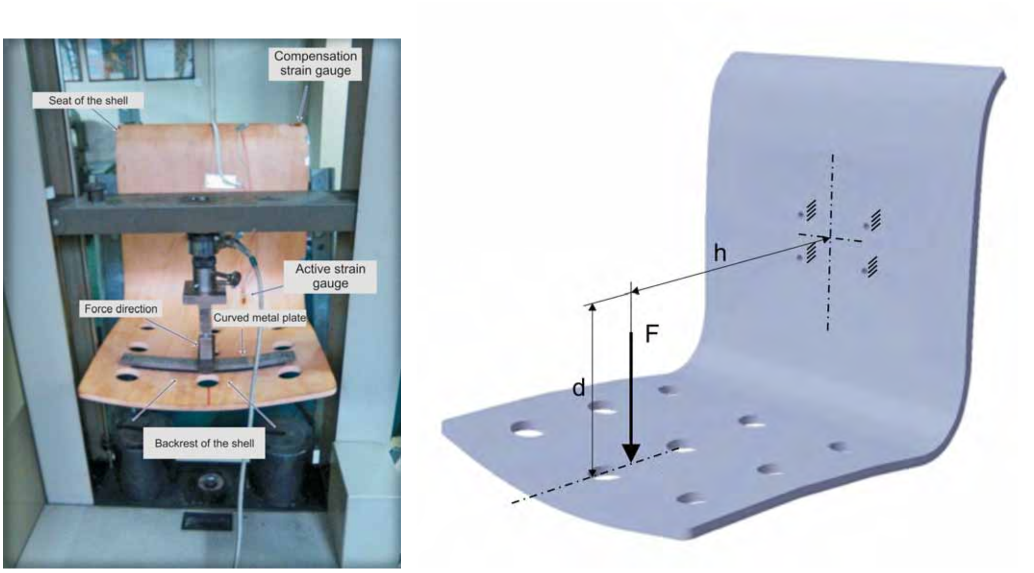

Figure 2 Testing of seat shell (left) and test static scheme (right)
Slika 2. Ispitivanje otpreska sjedala (lijevo) i statička shema ispitivanja (desno)

of the backrest point in the direction of the force F and stress in two critical points of the shell were measured during the testing.

Tensometric measurement equipment was used to monitor the value of the dominant principal stress in the critical transition area from the seat to the backrest. Four strain gauges (HMB type 6/120 LY11) connected in two Wheatstone quarter bridge were used. The active strain gauges were placed on the two opposite sides (faces and back) of the seat shell in the direction of the appearance of maximum and minimum principal stresses, i.e. fibre direction of external ply of beech veneer (Figure 3). Compensating strain gauges were placed near the edge of a seat shell in the no-strain zone and they were used to compensate the effect of temperature on the measurement. Two channels data acquisition system was used. Display and processing of measurement results were performed using the HBM Catman software.

Numerical model was solved by a method based on the finite element as a 2D problem with shell elements. Each layer was defined by a unique set of wooden material properties and orientation. Adhesive was neglected. Calculations were performed using the Catia software package (Figure 4).

Calculation was carried out for beech wood (*Fagus sylvatica* L.). The elastic properties of the wood used in calculations are presented in Table 1 (Smardze-

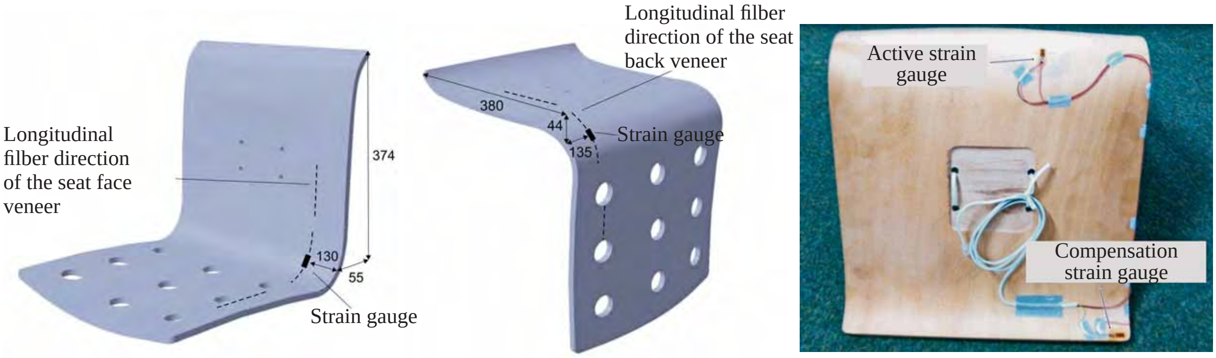

Figure 3 Position of active strain gauges (left), and position of active and compensating strain gauges at the back of the seat shell (right)
Slika 3. Položaj aktivnih davača pomaka (lijevo) i položaj aktivnih i kompenzacijskih davača pomaka na stražnjoj strani otpreska sjedala (desno)

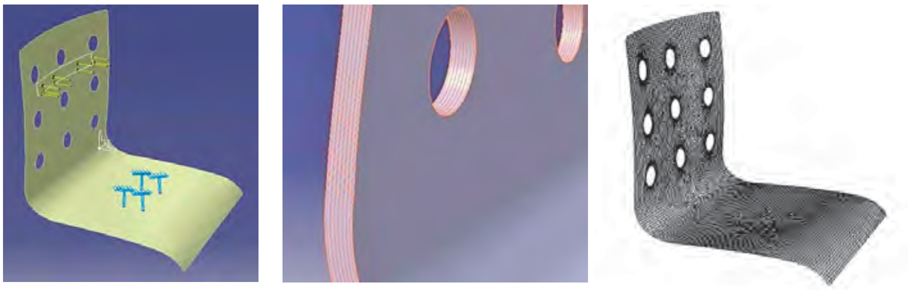

Figure 4 Numerical model: boundary conditions (left), layers (middle) and mesh (right)
Slika 4. Računski model: granični uvjeti (lijevo), slojevi (sredina) i mreža (desno)

Table 1 Elastic properties of beech wood (*Fagus sylvatica* L.), ρ = 0.75 g/cm^3 (Smardzewski, 2008)
Tablica 1. Elastična svojstva bukovine (*Fagus sylvatica* L.), ρ = 0,75 g/cm^3 (Smardzewski, 2008.)

Modulus of elasticity, GPa *Modul elastičnosti,* GPa			**Rigidity modulus,** GPa *Modul loma,* GPa			**Poisson´s ratio** *Poissonov koeficijent*					
E_L	E_R	E_T	G_{LR}	G_{LT}	G_{RT}	v_{LR}	v_{LT}	v_{RT}	v_{TR}	v_{RL}	v_{TL}
13.969	2.284	1.160	1.645	1.082	0.471	0.450	0.510	0.750	0.360	0.075	0.044

wski, 2008). Appropriate elastic properties for analysis in the LT plane were selected.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The experimental result of displacement of the backrest point in the direction of the force F is shown in Figure 5. The data obtained from test were used in a regression analysis. The linear regression model for the data was well fitted and the results of this analysis are shown in Figure 5. A proportional relationship between the displacement and the force for the load level up to 500 N was found. The load was below the limit of proportionality and only elastic deformation appeared.

The results of the numerical calculation comprising displacement of the backrest point in the direction of the force F is shown in Figure 6. The seat shell was loaded with a force of 300 N, i.e. the approximate value used to test the maximum distance of displacement of the backrest of some types of chairs.

The numerical result of displacement of the backrest point in the direction of the force F = 300 N was 17.8 mm, while the experimentally obtained result, i.e. obtained by regression analysis was 20.1 mm. Percentage difference between values of displacement ob-

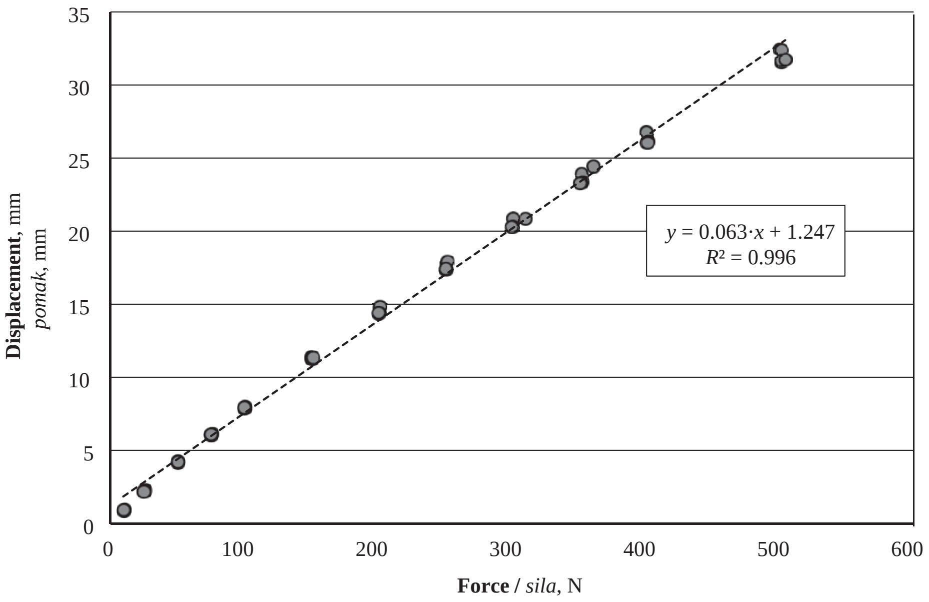

Figure 5 Experimental result of displacement of the backrest point in the direction of force F
Slika 5. Eksperimentalni rezultati pomaka točke naslona u smjeru sile F

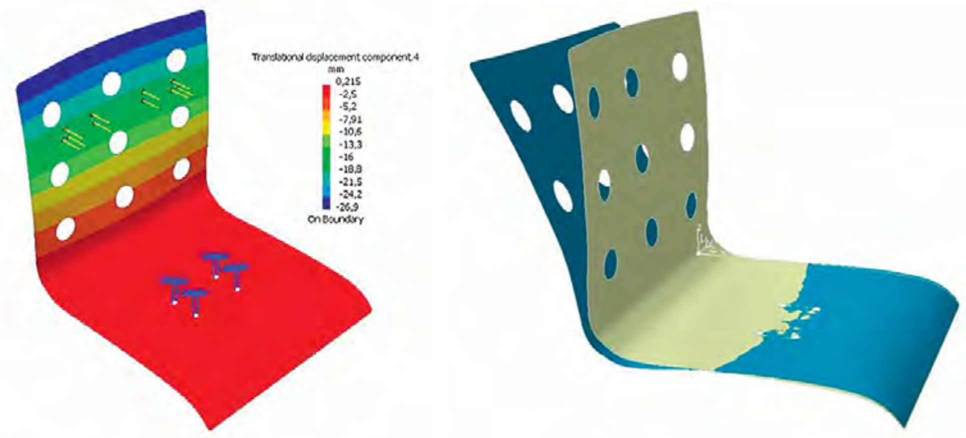

Figure 6 Numerical result of strain analysis: distribution of translational displacement component in the direction of force F (left), deformation of seat shells (right)
Slika 6. Računski rezultati analize deformacije: raspodjela pomaka u smjeru sile F (lijevo), deformacije otpreska sjedala (desno)

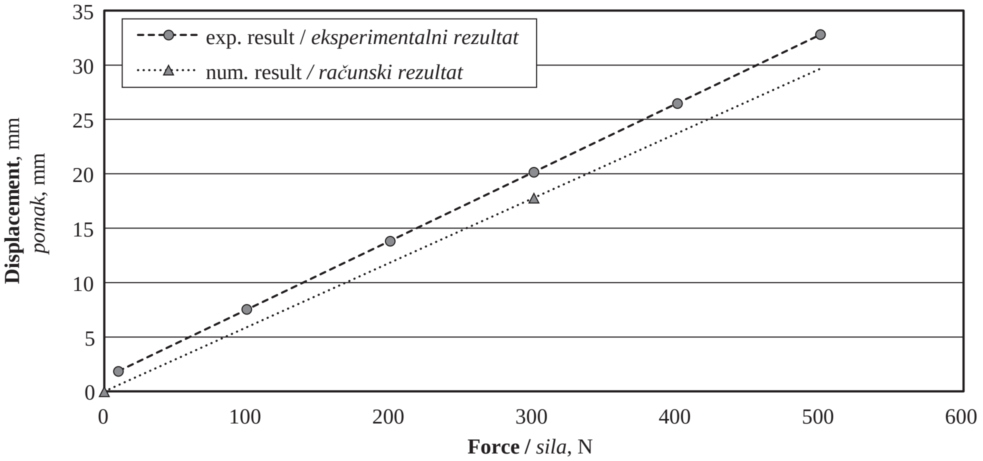

Figure 7 Experimental and numerical results of displacement of the backrest point in the direction of the force F
Slika 7. Eksperimentalni i računski rezultati pomaka točke naslona u smjeru sile F

tained experimentally and from numerical calculation is 12.13 %. The numerical result showed smaller displacement of the point, i.e. higher rigidity of the structure than the displacement measured in the testing (Figure 7).

The change of relative deformations recorded by strain gauges, placed on the face and back of the seat shell during load application, is shown in Figure 8. The relative deformation at the seat face was positive (fibres were subjected to tension), while the relative deformation at the seat back was negative (fibres were subjected to pressure). The curves are not symmetrical i.e. the absolute values of deformation at the two measuring points were not the same. Unexpected decrease of deformations occurred in ~500 seconds of the test due to the sudden slipping of the backrest under the curved shape metal plate at the load greater than 500 N.

The experimental result of relative deformation in the function of the force F at the two measuring points of the critical transition area is shown in Figure 9. A regression analysis was applied to the data obtained by testing and a proportional relationship between the relative deformation and the force for the load level up to 500 N was determined.

The relative deformations at the measuring points measured by the strain gauges are the dominant principal strains (ε_1 at the seat face and ε_3 at the seat back). The directions of dominant principal strains coincided with longitudinal direction of outer wood veneers. The dominant principal stresses at the measuring points (σ_1 at the seat face and σ_3 at the seat back) are determined by the Hooke's law:

$$\sigma_1 = E_L \cdot \varepsilon_1 \text{ and } \sigma_3 = E_L \cdot \varepsilon_3 \qquad (1)$$

Where the index 1 and 3 denote the extreme values in a spatial analysis, and E_L (Pa) is longitudinal modulus of elasticity of beech wood (Table 1).

The experimental results of normal stress (principal stress) in the function of the force *F* at the two measuring points of the critical transition area are shown in Figure 10. The proportional relationship between the normal stress and the force for the load level up to 500 N shows that the tensile stress at the seat face is greater than compressive stress at the symmetrical seat back.

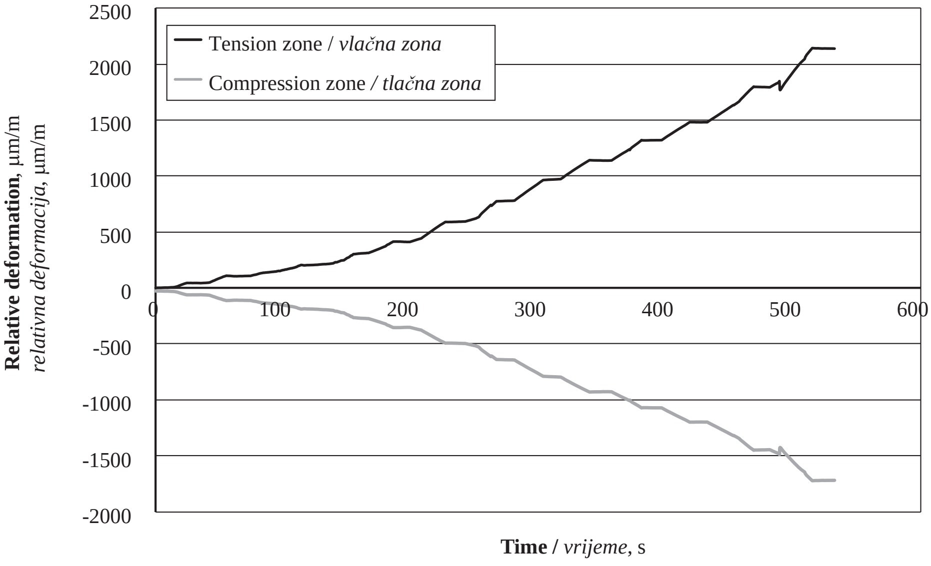

Figure 8 Change of relative deformation recorded by strain gauges placed on the face and back of the seat shell
Slika 8. Promjene relativne deformacije zabilježene davačima pomaka postavljenima na licu i naličju otpreska sjedala

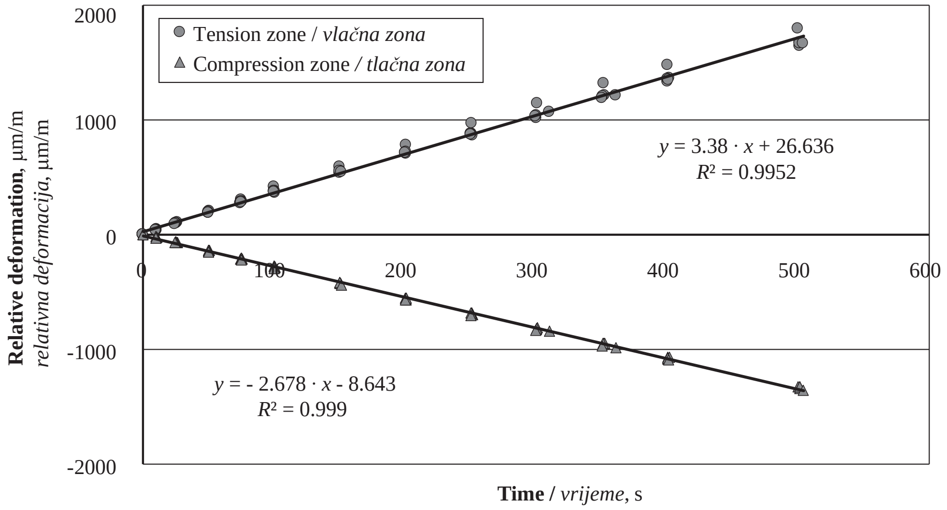

Figure 9 Experimental result of relative deformation in the function of force F at two measuring points
Slika 9. Eksperimentalni rezultati relativne deformacije u odnosu prema sili za dvije mjerne točke

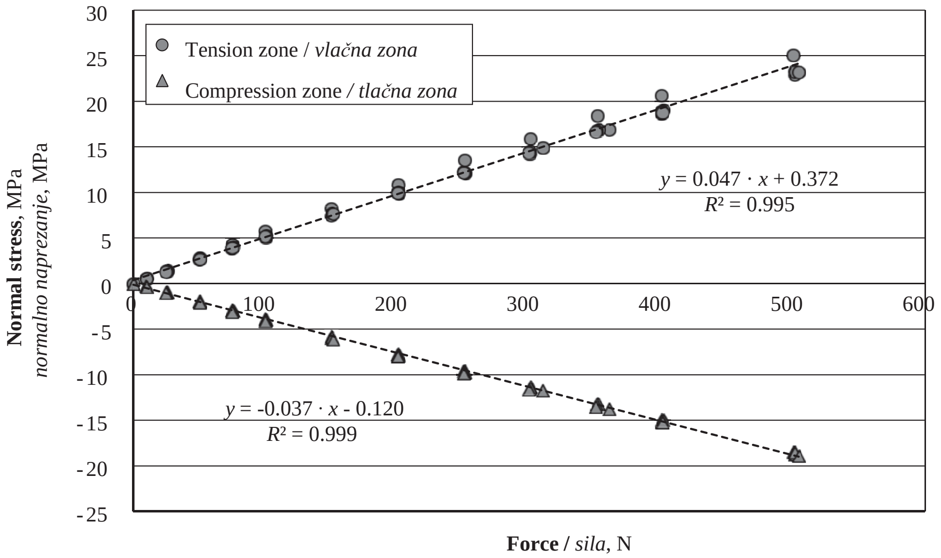

Figure 10 Experimental results of normal stress in the function of force *F* at two measuring points
Slika 10. Eksperimentalni rezultati normalnog naprezanja u odnosu prema sili za dvije mjerne točke

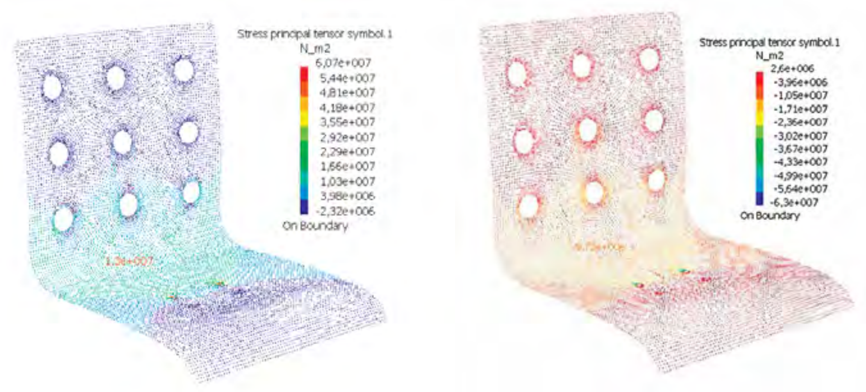

Figure 11 Numerical results of normal stress (in-plane principal stress): distribution of σ_1 in external veneer ply at the seat face (left), distribution of σ_2 in external veneer ply at the seat back (right)
Slika 11. Računski rezultati normalnog naprezanja (u ravnini glavnog naprezanja): raspodjela σ_1 u vanjskom sloju furnirskog otpreska na prednjoj strani sjedala (lijevo), raspodjela σ_2 u vanjskom sloju furnirskog otpreska na stražnjoj strani sjedala (desno)

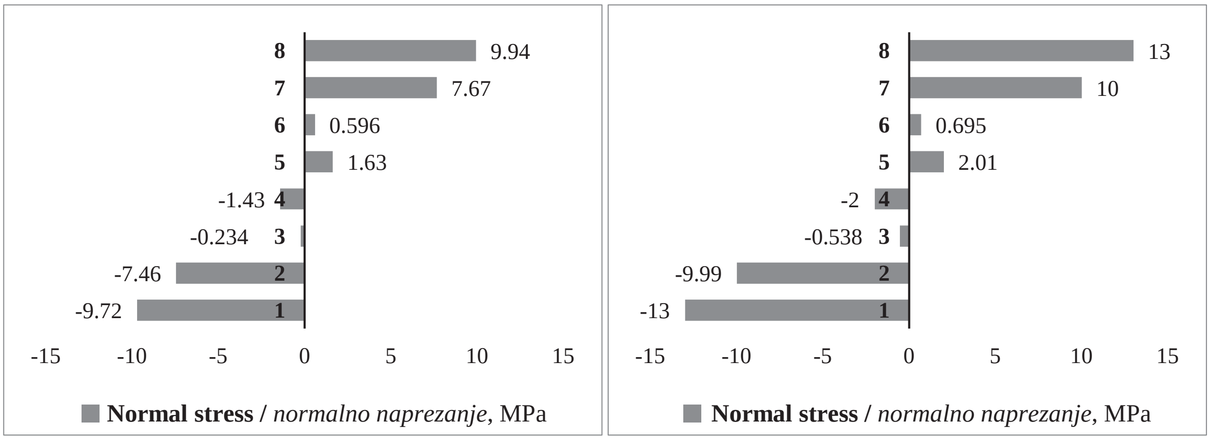

Figure 12 Numerical results of normal stress (principal stress) at half thickness of 8 veneer sheets: the point measured by strain gauges at the seat face (left), point measured by strain gauges at the seat back (right)

Slika 12. Računski rezultati normalnog naprezanja (glavno naprezanje) na pola debljine otpreska od osam listova furnira: mjereno davačima pomaka na prednjoj strani sjedala (lijevo) i na stražnjoj strani sjedala (desno)

The experimental results of normal stress (principal stress), obtained by regression analysis, at points in the critical transition area for the force *F* = 300 N were 14.53 MPa at the seat face and -11.34 MPa at the seat back. Distributions of the normal stress (principal stress σ_1 and σ_2 obtained by in-plane analysis) in the two external veneer plies and for the same force intensity obtained by numerical calculation are shown in Fig. 11. When using orthotropic elasticity and to describe the stress and strain state in individual veneer plies of a seat shell, a plane stress system was introduced. The normal and shear stress were recognized only in a veneer plane. The numerical results of normal stress (principal stress σ_1 at the seat face and σ_2 at the seat back) at the points of the critical transition area were 13 MPa at the half thickness of the seat face veneer and -9.72 MPa at the half thickness of the seat back veneer.

The numerical results of normal stress at the cross section of the half thickness of 8 veneers in seat face and seat back zones are shown in Figure 12.

The numerical results show that the tensile stress was greater than compressive stress at the cross-section and that longitudinally oriented veneers sustained higher stress than veneers with tangential orientation. The neutral axis and the centroidal axis of the cross-section were not coincident, and also the stress did not vary linearly from the neutral axis. An approximate linear estimate of the normal stress on the outer surfaces and at the two measuring points was 14 MPa at the point of the seat face veneers and -10.46 MPa at the point of the seat back veneers. Percentage difference between values of normal stress for the force *F* = 300 N obtained numerically and experimentally was 3.76 % for the point at the seat face and 8.07 % for the point at the seat back (Figure 13).

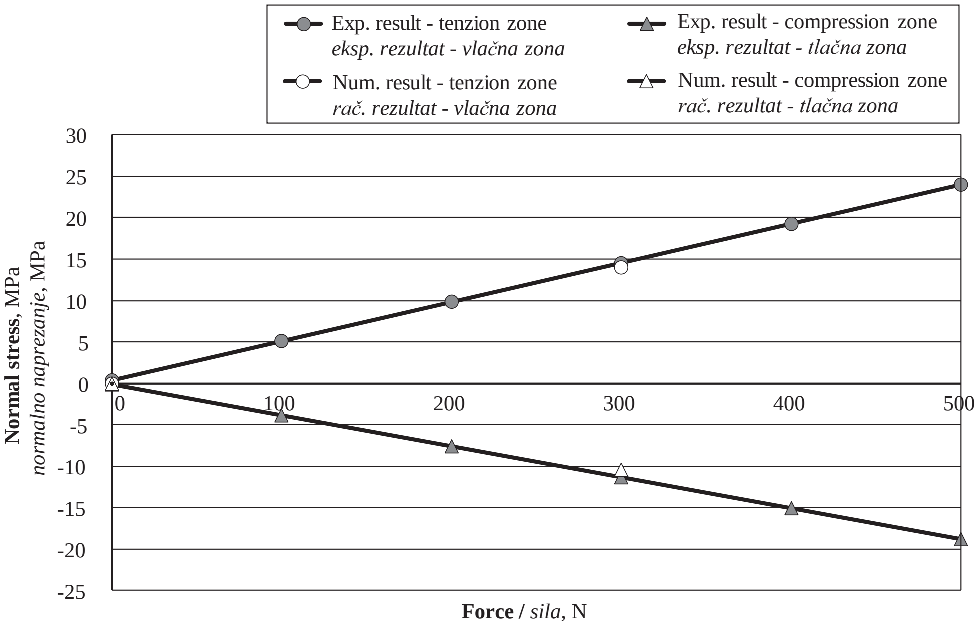

Figure 13 Experimental (Exp.) and numerical (Num.) results of normal stress at two measuring points of critical transition area (tension zone - the seat face and compression zone – the seat back)

Slika 13. Eksperimentalni (*eksp.*) i računski (*rač.*) rezultati normalnog naprezanja za dvije mjerne točke u kritičnom prijelaznom području (vlačna zona – prednja strana sjedala i tlačna zona – stražnja strana sjedala)

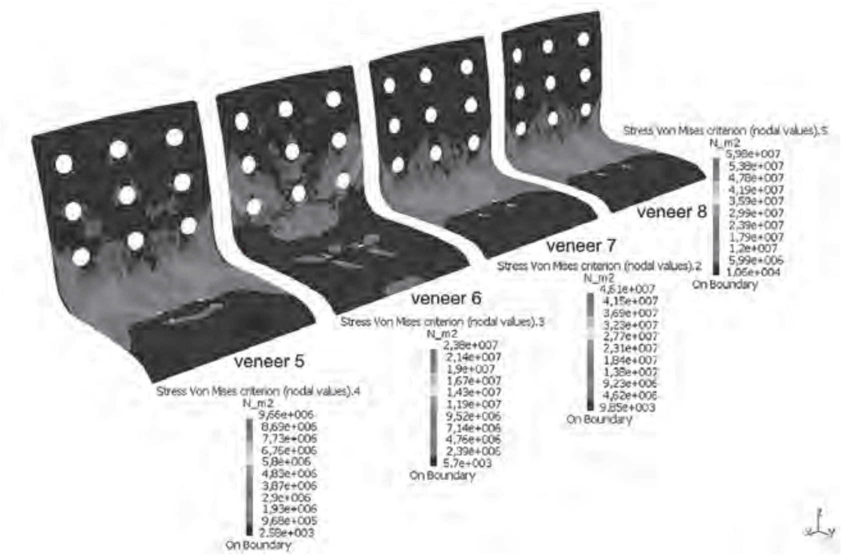

Figure 14 Distribution of Von Mises stress – tension zone (veneers 5, 6, 7 and 8)
Slika 14. Raspodjela Von Misesova naprezanja – vlačna zona (furniri 5., 6., 7. i 8.)

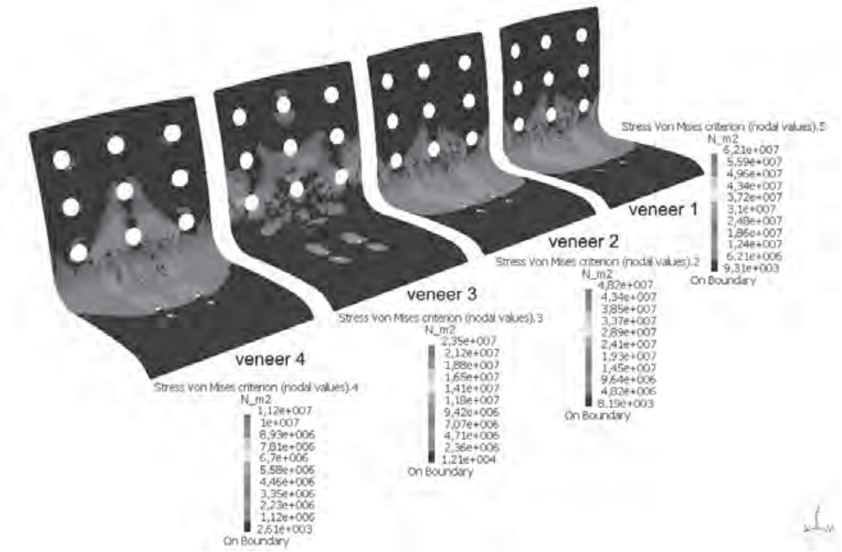

Figure 15 Distribution of Von Mises stress – compression zone (veneers 4, 3, 2 and 1)
Slika 15. Raspodjela Von Misesova naprezanja – tlačna zona (furniri 4., 3., 2. i 1.)

The distribution of the Von Mises stress in the plane of all the eight veneers is shown in Figure 14 and 15. The Von Mises stress, commonly used approximation that assumes that the material is isotropic, can be a sufficiently good indicator of the stress state of the loaded construction made of orthotropic material. The maximum and increased values of this stress occurred in the fixing zone, critical transition area from the seat to the backrest and around the lower row of circular holes on the backrest. Veneers (3 and 6), tangentially oriented, had a different stress distribution and sustained smaller stress than veneers with longitudinal orientation.

The applied in-plane stress analysis revealed the circumferential (normal) stress in the curved areas of the seat shell. The analysis is not capable to calculate the radial (interlaminar) stresses. Radial stress is usually smaller than the circumferential stress and is low where the circumferential stresses are large (Young, 2001). It is not a major subject of consideration in compact material but it is a remarkable factor and the main cause of failure in curved forms of laminated wood. A radial stress that is larger than tensile strength perpendicular to fibres in a laminated wood leads to veneer delamination i.e. its separation into layers. The numerical analysis should be extended to calculate the radial (interlaminar) stresses on the real laminated veneer product.

4 CONCLUSIONS
4. ZAKLJUČAK

Similarity between numerical and experimental results of stress and strain analysis of the plywood seat shell allows the conclusion that the research models were designed correctly. The experimental results show proportional, linear relationship between the applied force (up to 500 N) and displacement and applied force and stress that occurred in the observed points. Good matching was found between the numerical and experimental results of displacement at the backrest point, as well as between the numerical results and results of the tensometric analysis of the principal stress in the points at the critical transition area of the seat shell. The research revealed that the numerical procedure used in the study provides a convenient method of obtaining the information needed for determining the basic mechanical properties of laminated wood of complex shape. The applied in-plane stress analysis of each individual veneer is not capable of calculating the radial (interlaminar) stresses that are a remarkable factor and the main cause of failure in curved forms of laminated wood. Curved forms require more complex analysis. The results of numerical simulation of the loaded seat shell show that the numerical procedure can be successfully used to achieve approximate data in early design phase and development of laminated wood of any complex shape in order to reduce time and costs significantly.

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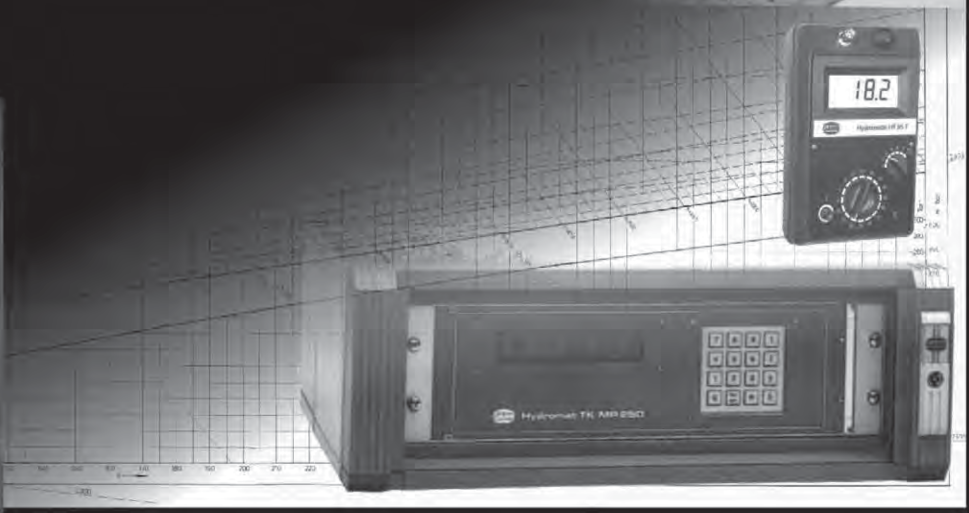
18.2
Hydromat TK MP 250

Jože Kropivšek[1], *Petra Grošelj*[2]

Long-term Financial Analysis of the Slovenian Wood Industry Using DEA

Dugoročna financijska analiza slovenske drvne industrije primjenom metode DEA

Original scientific paper • Izvorni znanstveni rad
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ABSTRACT • *Long-term financial analysis is an important tool for assessing the financial position of a company and/or sector. The aim of the research was to analyze selected financial indicators of the Slovenian wood industry in sub-sectors C16 (wood processing – except furniture) and C31 (manufacture of furniture) for the last 10 years (from 2007-2016). The efficiency evaluation was performed by DEA (Data Envelopment Analysis) window analysis. Other comparisons between two sub-sectors were performed by analysis of time series of financial indicators and by t-test. We have analyzed 40 financial indicators, 15 of which in more detail. Some models, analyzed by DEA method, show relative deterioration in efficiency in the years 2007-2010, but in most cases efficiency has increased in recent years. With this, we have proven that the efficiency of both sub-sectors is improving. For all models, the performance of the sub-sector C16 is better than that of C31. It has been proven by t-test that the difference between these two sub-sectors is statistically significant, as differences of more than half of the financial indicators between the two sub-sectors are statistically significant. Therefore, improvements in profitability ratios at the company's level should be done and appropriate measures within the sectoral economic policies should be taken to achieve the conditions needed for greater efficiency and success.*

Keywords: *financial analysis, financial indicators, wood industry, Slovenia, DEA, t-test*

SAŽETAK • *Dugoročna financijska analiza važan je alat za procjenu financijskog stanja poduzeća i/ili sektora. Cilj istraživanja bio je analizirati odabrane financijske pokazatelje slovenske drvne industrije posljednjih deset godina (2007. – 2016.) u podsektorima C16 (prerada drva – osim namještaja) i C31 (proizvodnja namještaja). Procjena učinkovitosti provedena je primjenom analize omeđivanja podataka (DEA – Data Envelopment Analysis). Ostale usporedbe dvaju podsektora obavljene su analizom vremenskih serija financijskih pokazatelja i t-testom. Analizirano je 40 financijskih pokazatelja, od kojih 15 detaljno. Neki modeli analizirani DEA metodom pokazuju relativno pogoršanje učinkovitosti u razdoblju 2007. – 2010., ali se u većini modela učinkovitost tijekom posljednjih nekoliko godina povećala. Time je dokazano da se učinkovitost obaju podsektora poboljšava. Za sve je modele učinak podsektora C16 bolji od učinka podsektora C31. Primjenom t-testa dokazana je statistički značajna razlika između dva promatrana podsektora jer su razlike statistički značajne za više od polovice financijskih pokazatelja koji se odnose na ta dva podsektora. Stoga je potrebno poboljšati omjer profitabilnosti na razini poduzeća i uvesti odgovarajuće mjere u sklopu sektorskih ekonomskih politika kako bi se postigli uvjeti za veću učinkovitost i uspjeh.*

Ključne riječi: *financijska analiza, financijski pokazatelji, drvna industrija, Slovenija, DEA, t-test*

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1 INTRODUCTION
1. UVOD

The financial and operating position of a sector, which is understood as “group of companies that produce and sell similar or identical products or services” (Samuelson and Nordhaus, 2002), depends on various factors of business environment, which is constantly changing. This causes a number of challenges for companies, especially in terms of their performance, and impacts both the conditions and development of the sector as a whole (Kropivšek *et al.*, 2017). In addition, the situation with regard to purchasing and sales markets, and functioning of the sector and/or companies operating within it, is strongly influenced by the general situation in the economic environment of a country, and by the role of particular sector in strategic national economic policy. A sector that plays a strategically important role in a national economy is more likely to be the focus of a number of economic measures, such as: 1) public tenders to subsidize investments in research and development, and 2) carrying out promotional activities in order to achieve greater visibility of the sector, thus raising its position within society. For companies operating within a focal sector, this last point is reflected in the form of easier entry into the market, better positioning due to the good reputation of the sector, and a greater ability to attract and retain the most capable professional staff, something which is the heart of a firm’s development. According to some estimates, the wood-processing industry in Slovenia has experienced relatively stable growth in the last few years (Likar and Valentinčič, 2017). After the unfavorable position of the wood-industry sector in Slovenia in the national economic policies adopted before 2010, significant improvements have occurred in recent years (Kropivšek *et al.*, 2017). There is evidence of the growing consumption and processing of wood in Slovenia, and it is thus vital for the sector to take advantage of the currently favorable conditions.

The success of business operations can be quantitatively measured in a variety of ways (Tekavčič, 2002; Rebernik, 2008). In most cases, it is measured by the amount of profit, growth of assets and ability to assure solvency. The first two criteria are particularly important for long-term success, and the last one for short-term success. For a wider picture of the long- and short-term performance and development of both corporate and industry development orientations, it is necessary to monitor many economic and financial indicators of companies and the economy as a whole. One of the most important tools for assessing the financial position and success of a company and/or sector is financial analysis (Helfert, 2001; Vance, 2003). This is a set of tools and techniques, including fiscal indicators and forecasting, that can be used to measure the current fiscal conditions and performance of a business, and predict their trends (Friedlob and Schleifer, 2003; Palepu *et al.*, 2004). Gitman (2004) pointed out that the only data sources available for financial analysis are firm’s financial statements, in which a large amount of data is reduced to a few key parameters. Financial analysis also ensures comparability between companies and/or sectors (Slapničar, 2004), and the main users of such analysis are lenders/creditors, owners/investors and managers.

By analyzing different financial indicators, the performance of the whole sector can be estimated, thus obtaining the key information needed for the creation and modification of sectoral strategies. Financial analysis can reveal certain disadvantages (weaknesses) and risks, and enables a deeper understanding of the entire sector. As such, the results can greatly affect the future development and performance of the sector (Kropivšek and Jošt, 2013).

In general, there are two different methods of financial analysis: (1) horizontal and vertical analysis, and (2) financial ratio analysis (Peterson and Fabozzi, 1999). The method of financial ratio analysis is the most common for evaluating the conditions of a specific company and a sector or industry as a whole, where the resulting ratio is an expression of a mathematical relationship between two quantities (Peterson *et al.*, 2010). However, a single value of a financial ratio is not meaningful by itself, and more important is the time-series analysis of ratios, which involves examining the pattern of ratios over time.

The aim of the current research is to analyze selected financial indicators of the Slovenian wood industry sector for the last 10 years (from 2007-2016). We have assumed (Hypothesis 1) that the situation in the wood industry has been improved in recent years, based on the improving economic stability in general of the Slovenian economy (UMAR, 2017). We have also assumed (Hypothesis 2) that there are some differences between two wood-industry sub-sectors C16 (wood processing – except furniture) and C31 (manufacture of furniture) (Braunsberger *et al.*, 2010). We will analyze financial data and selected financial indicators in time series in the period from 2007 to 2016, and the comparison between the two sub-sectors (C16 and C31) will be performed using t-test. The efficiency evaluation of the two wood-industry sub-sectors will be carried out using data envelopment analysis (DEA), which is a management tool used to evaluate the relative efficiency of a number of decision units regarding a set of inputs and a set of outputs, based on linear programming.

Although the wood-industry sector in Slovenia has already been analyzed from a financial point of view (Kropivšek *et al.*, 2017; Kropivšek and Jošt, 2013; Kropivšek *et al.*, 2011; Tratnik *et al.*, 2001), the DEA method has not yet been applied, although this approach is widely used around the world for evaluating the efficiency of sectors in addition to the use of financial indicators (Halkos and Tzeremes, 2012a; Halkos and Tzeremes, 2012b; Hoang Bui *et al.*, 2016; Li and Wu, 2016; Fenyves *et al.*, 2015).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

As mentioned above, in calculating the indicators, the data for all registered (and functioning) companies and sole proprietors operating in sub-sectors C16 (wood processing-except furniture) and C31 (manufacture of furniture) were considered according to the sub-sector level data in the classification of economic activities NACE (Nomenclature of Economic Activities) rev.2 classification (NACE, 2018). The research was based on searching and preparing data from official statistical databases (Ajpes JOLP, 2017; Analitika GZS, 2018), collected and calculated in aggregate form. The indicators were calculated for the period from 2007 to 2016 (10 years).

The sample size differs slightly in different years due to the various changes in the number of companies in sectors, although the changes were small: in sub-sector C16 cca. 1.470 companies and in C31 around 1,050 companies on average, in total more than 2,500 companies. In Slovenia, the majority (more than two-thirds) of companies in each sub-sector are sole proprietors, and more than 98 % of the companies are micro and small size companies (according to: ZGD-1-UPB3, 2009): in the sub-sector C31 there is one large company, while in C16 there are three of them (Bisnode, 2018). Before the economic downturn in the year 2008/09, the number of employees was about the same for both sub-sectors, and this number was much higher than in recent years, when the situation changed dramatically. Especially in the sub-sector C31, the number of employees fell by half from 2008 to 2014, and has stayed the same since then, while in sub-sector C16, the decrease was not so dramatic, down by only around 20 %, and the number of people employed in this area has even increased slightly since 2015. In total, the number of employees in the wood industry sector fell from more than 20,000 in 2007 to less than 11,500 in 2014, and increased slightly to 12,000 in 2016.

The key issue of successful financial analysis is in the right selection of key performance financial indicators. The indicators must be adapted to the intended use, and the number of indicators has to be small (Slapničar, 2004). In order to facilitate a more focused and purposeful selection of indicators, some authors (Pratt, 1990; Rees, 1995; Higgins, 1995; Elliot and Elliot, 1996; Hornby *et al.*, 1997; Mramor, 2002; Tekavčič, 2002; Fabozzi and Peterson, 2003; Slapničar, 2004; Brigham and Huston, 2009; Peršak, 2011; Ajpes FI=PO, 2018) classify indicators into different groups, taking into account the content connectivity of indicators. For the purpose of this research, financial indicators were divided into five categories of ratios: (1) liquidity ratios (which provide information on a firm's ability to meet its short-term obligations), (2) profitability ratios (providing information on how well the company is managing its expenses), (3) activity ratios (with information on a firm's ability to manage its resources efficiently), (4) leverage ratios (including information on the degree of a firm's fixed financing obligations and its ability to satisfy these obligations), and (5) efficiency ratios (indicating a firm's operating efficiency and explaining its business results in relation to various investments that have been made in the business process). Forty financial indicators were analyzed in this research, and the majority of them have been examined in similar studies (Pirc Barčić *et al.*, 2017; Delen *et al.*, 2013; Sayari and Simga Mugan, 2016; Gombola and Ketz, 1983). There were different numbers of indicators in each group, as shown in parentheses: leverage ratios (13), liquidity ratios (3), profitability ratios (7), efficiency ratios (12) and activity ratios (5). However, for further and detailed analysis only 15 indicators were selected (Table 1).

According to Berger and Humphrey (1997), many different approaches can be used for measuring the efficiency of business units. The most notable non-parametric approach is data envelopment analysis

Table 1 A list of analyzed financial indicators
Tablica 1. Popis analiziranih financijskih pokazatelja

Group / *Skupina*	**Financial indicator** / *Financijski pokazatelj*	
Leverage ratio / *omjer financijske poluge*	Debt to equity ratio / *omjer duga i kapitala*	D/E
	Total debt (short- and long-term financial debt) to total assets ratio / *omjer ukupnog duga (kratkoročni i dugoročni financijski dug) prema ukupnoj aktivi*	TDA
	Total liabilities to total sources of funds ratio / *omjer ukupnih obveza prema svim izvorima sredstava*	TLTSF
Liquidity ratio / *omjer likvidnosti*	Current ratio / *trenutačni omjer*	CR
	Quick ratio / *brzi omjer*	QR
	Cash ratio / *novčani omjer*	CashR
Profitability ratio / *omjer profitabilnosti*	Return on equity / *povrat na kapital*	ROE
	Return on assets / *povrat sredstava*	ROA
	Return on sales / *povrat od prodaje*	ROS
Activity ratio / *omjer aktivnosti*	Gross value added per employee ratio / *omjer bruto dodane vrijednosti po zaposleniku*	GVA
	Asset turnover ratio / *omjer prometa imovine*	ATR
	Current asset turnover ratio / *omjer obrtanja aktive*	CAT
Efficiency ratio / *omjer učinkovitosti*	Earnings before interest, taxes, depreciation, and amortization / *dobit prije kamata, poreza, deprecijacije i amortizacije*	EBITDA
	Total efficiency ratio / *omjer ukupne učinkovitosti*	E
	Asset utilization ratio / *omjer iskorištenja imovine*	AU

(DEA), which measures the relative efficiency of production units (from small productive units to entire countries), and the use of this approach is increasing rapidly in both the literature and practice (Hollingsworth and Smith, 2003).

The current study applies DEA window analysis. This is based on the principle of the moving averages (Cooper *et al*., 2007), and can detect the performance trend of decision-making units (DMUs) over time. In DEA window analysis, each sub-sector in a different period is treated as if it was a different unit, which increases the number of DMUs. This can be convenient when the number of such units is small compared to the number of inputs and outputs. The DEA window analysis is based on windows, which present a fixed number of successive time periods included in the analysis. Since it is assumed that there are no technical changes within each window, narrow windows are recommended. In order to have a narrow window and a sufficiently large sample, five-year windows have been chosen (Asmild *et al*., 2004). In the first window, data from the year 2007 to 2011 were included. The second window included data from the year 2008 to 2012, while in the last, sixth window, data from the year 2012 to 2016 were included (Table 2).

Table 2 Five-year windows for DEA window analysis
Tablica 2. Petogodišnji prozori za DEA analizu

Window / *Prozor*	**Years** / *Godine*
Win 1	2007-2011
Win 2	2008-2012
Win 3	2009-2013
Win 4	2010-2014
Win 5	2011-2015
Win 6	2012-2016

In the analysis, DEA-Solver-LV (8.0), model WIN-I-C, denoting the input-oriented model with constant return to scale, was used (Asmild *et al*., 2004).

We can consider N decision units (DMUs), $n=1, ..., N$ observed for T periods, $t=1,\dots,T$ that use r inputs to produce s outputs. The sample has $N\times T$ observations and an observation n in period t, namely DMU_t^n, has an r-dimensional input vector $x_t^n=\left(x_{1t}^n, x_{2t}^n, ..., x_{rt}^n\right)$ and a s-dimensional output vector $y_t^n=\left(y_{1t}^n, y_{2t}^n, ..., y_{st}^n\right)$. The window k_w with $k\times w$ observations starts at time k, $1 \le w \le T$, and has the width w, $1 \le w \le T-k$. Its input matrix is given as follows:

$$X_{k_w}=\begin{bmatrix} x_k^1 & x_k^2 & \cdots & x_k^N \\ x_{k+1}^1 & x_{k+1}^2 & \cdots & x_{k+1}^N \\ \vdots & \vdots & \ddots & \vdots \\ x_{k+w}^1 & x_{k+w}^2 & \cdots & x_{k+w}^N \end{bmatrix} \quad (1)$$

and its output matrix as follows:

$$Y_{k_w}=\begin{bmatrix} y_k^1 & y_k^2 & \cdots & y_k^N \\ y_{k+1}^1 & y_{k+1}^2 & \cdots & y_{k+1}^N \\ \vdots & \vdots & \ddots & \vdots \\ y_{k+w}^1 & y_{k+w}^2 & \cdots & y_{k+w}^N \end{bmatrix} \quad (2)$$

The input-oriented DEA window problem, under the constant return to scale (CRS) assumption for $DMU_t^{'}$ is then presented by linear program. For further details about DEA models see Cooper *et al*. (2007).

In our study, five DEA window models were considered. In Model 1, the absolute values of financial data were used, while for the four other models the values of ratios were used (Table 3). The first model was intended to measure the technical efficiency of sub-sectors. The technical efficiency is the most common efficiency concept for the conversion of physical inputs (I) into outputs (O). The selected inputs and outputs are presented in Table 3.

For models 2-5, the efficiency of sub-sectors was measured by financial ratios. Financial ratios have been used in DEA models in many studies (Hoang Bui *et al*., 2016; Li and Wu, 2016; Fenyves *et al*., 2015; Halkos and Tzeremes, 2012a; Halkos and Tzeremes,

Table 3 Inputs and outputs of models 1-5 of DEA window analysis
Tablica 3. Ulazi i izlazi modela 1. – 5. DEA analize prozora

Model *Model*	**Inputs** / *Ulazi*		**Outputs** / *Izlazi*	
Model 1	Assets (A) / *imovina* (A)		Net Sales Revenues (NS) / *neto prihodi od prodaje* (NS)	
	Capital (C) / *kapital* (C)		Gross Profit (EBIT) / *bruto dobit* (EBIT)	
	Number of Employees (NE) / *broj zaposlenih* (NE)		Gross Value Added (VA) / *bruto dodana vrijednost (VA)*	
Model 2	Leverage ratio *omjer financijske poluge*	D/E	Liquidity ratio *omjer likvidnosti*	CR
		TDA		QR
		TLTSF		CashR
Model 3	Leverage ratio *omjer financijske poluge*	D/E	Profitability ratio *omjer profitabilnosti*	ROA
		TDA		ROE
		TLTSF		ROS
Model 4	Leverage ratio *omjer financijske poluge*	D/E	Activity ratio *omjer aktivnosti*	GVA
		TDA		ATR
		TLTSF		CAT
Model 5	Leverage ratio *omjer financijske poluge*	D/E	Efficiency ratio *omjer učinkovitosti*	EBITDA
		TDA		E
		TLTSF		AU

2012b, Nikoomaram *et al*., 2010; Oberholzer and van derWesthuizen, 2004). Based on these previous studies, three indicators were selected from each of five groups of indicators. Leverage ratios were set up as inputs of all models 2-5, liquidity ratios for outputs of model 2, profitability ratios for outputs of model 3, activity ratios for outputs of model 4 and efficiency ratios as outputs of model 5. The selected inputs and outputs are presented in Table 3.

The data in DEA models should be non-negative. When this is not the case, the data should be appropriately translated (Pastor and Ruiz, 2007). The translations were conducted by gross profit (EBIT) and by ROA and ROE indicators. For the input indicators, debt to equity ratio (D/E), TDA and TLTSF, smaller values are more desirable. In order to include these into the models, they were multiplied by (-1) and an appropriate translation process was conducted to gain positive values (Seiford and Zhu, 2002).

For all indicators included in inputs and outputs from models 1-5 (Table 3), the time series in the period from 2007 to 2016 were analyzed and two sub-sectors were compared using t-test.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Analysis of time series of indicators
3.1. Analiza vremenskih serija pokazatelja

Most of the analyzed indicators show an improvement in both sub-sectors within the 10-year period examined in this work. In the years following the economic crisis (2008-2010), their values deteriorated markedly. The greatest deterioration was observed in all profitability ratios, while both the companies and sector as a whole showed significant losses during this period. The efficiency and activity ratios also decreased during this period. Some of them fell by more than 20 %, indicating a serious problem in ensuring effective and efficient operations. Interestingly, the liquidity ratios did not significantly deteriorate during this period, which is probably due to the relatively low indebtedness of companies in the sector. Comparing two sub-sectors, the economic crisis and other changes in economic and political environment influenced the C31 sub-sector more than C16. On the other hand, the values of most indicators for both sub-sectors have improved since 2013. This is especially true for the profitability ratios as well as for some other indicators, where the values in 2016 reached or even exceeded those seen before the crisis in 2007, showing clearly an improvement in the companies performance.

3.2 Comparison of sub-sectors
3.2. Usporedba podsektora

The inputs and outputs between the two sub-sectors were compared using *t*-test. For Model 1, the results show that there are statistically significant differences between the two sub-sectors for Assets (t=10.172, p<0.001), Capital (t=7.488, p<0.001), Net Sales Revenue (t=7.869, p<0.001), Gross Profit (t=3.726, p=0.002) and Gross Value Added (t=5.634, p<0.001). For Models 2, 3, 4 and 5 there are statistically significant differences between the two sub-sectors for ROA (t=2.646, p=0.016), ROE (t=2.653, p=0.016), ROS (t=2.714, p=0.014), GVA (t=2.970, p=0.008), CAT (t=3.527, p=0.002), EBITDA (t=6.258, p<0.001) and E (t=2.856, p=0.010).

There are statistically significant differences for more than half of the financial indicators between the two sub-sectors, confirming Hypothesis 2, that there are differences between the two wood-industry sub-sectors (C16 and C31).

3.3 DEA analysis
3.3. DEA analiza

Descriptive statistics of inputs and outputs of Models 1-5 are presented in Tables 4 and 5.

The results of DEA window analysis for Models 1 are presented in Table 6 and Figure 1, for other models (Model 2-5) only the window averages for both sub-sectors C16 and C31 are presented in Figures 2-5.

The efficiency of converting assets, capital and employees into revenue, profit and value added (Table 6) for the whole period is higher in sub-sector C16 than in sub-sector C31. The results suggest that efficiency has been increasing in sub-sector C16 in recent years, and reached the highest value in the last period. On the other hand, in sub-sector C31 efficiency was increasing in the early years of the study period, and then fell in the last few years, indicating a decline in the efficiency of this sector (Figure 1).

If three indicators from the leverage group, which show the methods of financing the related business, are taken as inputs and the remaining groups of indicators (liquidity, profitability, activity and efficiency ratios) as outputs, similar conclusions are obtained (Figures 2-5). For all models, the performance in sub-sector C16 is better than that in C31, which seems to have been more strongly affected by the economic downturn and other

Table 4 Descriptive statistics of variables in Model 1 (all values in €; except NE whose values are expressed in numbers)
Tablica 4. Deskriptivna statistika varijabli u modelu 1. (sve su vrijednosti u EUR, osim NE, koja je iskazana brojem)

Financial indicator *Financijski pokazatelj*	**Mean**	**Min**	**Max**	**Std. Dev.**
Assets (A) / *imovina* (A)	605,630,777.34	349,402,733.00	824,705,096.00	180,456,671.33
Capital (C) / *kapital* (C)	243,555,942.40	142,445,079.00	416,013,111.00	82,537,071.67
Number of Employees (NE) / *broj zaposlenih* (NE)	7,299.08	4,334.57	10,703.20	1,983.45
Net Sales Revenues (NS) / *neto prihodi od prodaje* (NS)	593,058,209.41	315,411,300.00	949,992,339.00	200,230,054.89
Gross Profit (EBIT) / *bruto dobit* (EBIT)	14,393,133.18	-10,199,137.00	57,836,755.00	19,505,698.61
Gross Value Added (VA) / *bruto dodana vrijednost* (VA)	179,650,068.50	105,524,633.00	269,211,748.00	51,194,051.42

Table 5 Descriptive statistics of variables in Models 2, 3, 4, and 5
Tablica 5. Deskriptivna statistika varijabli u modelima 2., 3., 4. i 5.

Group *Skupina*	**Financial indicator** *Financijski pokazatelj*	**Mean**	**Min**	**Max**	**Std. Dev.**
Leverage ratio *omjer financijske poluge*	D/E	1.424	0.910	1.750	0.219
	TDA	0.299	0.206	0.348	0.041
	TLTSF	0.565	0.454	0.619	0.041
Liquidity ratio *omjer likvidnosti*	CR	1.098	0.980	1.390	0.102
	QR	0.713	0.610	0.960	0.092
	CashR	0.175	0.120	0.360	0.062
Profitability ratio *omjer profitabilnosti*	ROA	0.008	-0.045	0.069	0.033
	ROE	0.015	-0.129	0.182	0.082
	ROS	0.005	-0.051	0.061	0.033
Activity ratio *omjer aktivnosti*	GVA	24,963.567 €	17,920.860 €	35,594.670 €	5,047.188 €
	ATR	0.972	0.830	1.150	0.098
	CAT	2.321	1.940	2.610	0.192
Efficiency ratio *omjer učinkovitosti*	EBITDA	45,750,741.100 €	14,108,627.000 €	97,855,636.000 €	25,624,651.697 €
	E	1.009	0.950	1.070	0.033
	AU	1.007	0.870	1.180	0.099

Table 6 A five-year window analysis of Model 1
Tablica 6. Analiza petogodišnjih prozora modela 1.

Model 1	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Average**
C16, Win 1	1.0000	1.0000	0.8903	0.9343	1.0000						0.9649
C16, Win 2		1.0000	0.8728	0.9230	0.9864	1.0000					0.9564
C16, Win 3			0.8873	0.9419	0.9929	1.0000	1.0000				0.9644
C16, Win 4				0.9419	0.9929	1.0000	0.9991	1.0000			0.9868
C16, Win 5					0.9941	1.0000	0.9991	1.0000	1.0000		0.9987
C16, Win 6						1.0000	0.9991	1.0000	1.0000	1.0000	0.9998
C16, Average	1.0000	1.0000	0.8835	0.9353	0.9933	1.0000	0.9993	1.0000	1.0000	1.0000	0.9785
C31, Win 1	1.0000	0.9877	0.8270	0.8910	0.8787						0.9169
C31, Win 2		1.0000	0.8517	0.9893	0.9352	0.9216					0.9396
C31, Win 3			0.9508	1.0000	0.9708	0.9472	1.0000				0.9737
C31, Win 4				1.0000	0.9703	0.9265	0.9779	0.9889			0.9727
C31, Win 5					1.0000	0.9371	0.9334	0.9716	1.0000		0.9684
C31, Win 6						0.9144	0.8738	0.9450	0.9668	1.0000	0.9400
C31, Average	1.0000	0.9939	0.8765	0.9701	0.9510	0.9294	0.9463	0.9685	0.9834	1.0000	0.9519

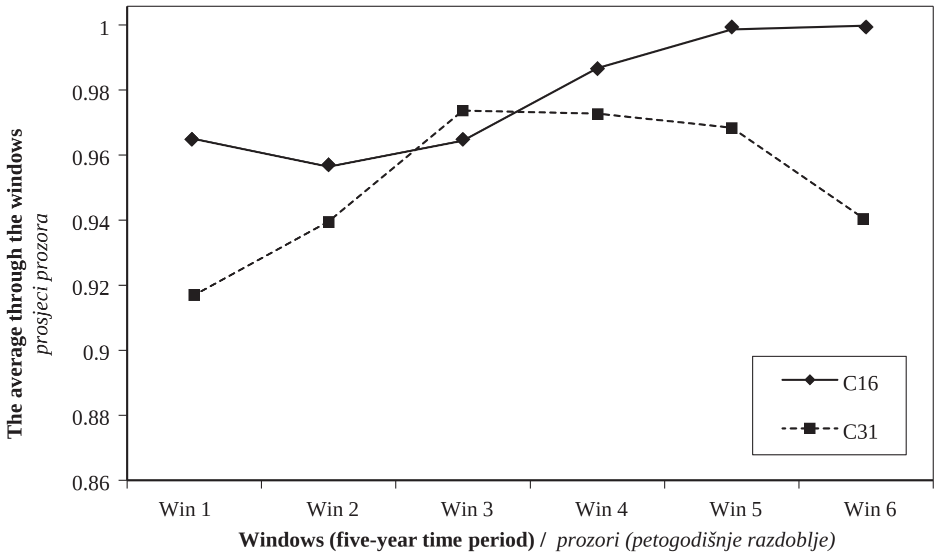

Figure 1 Window averages of sub-sectors C16 and C31 for Model 1
Slika 1. Prosjeci prozora za podsektore C16 i C31 za model 1.

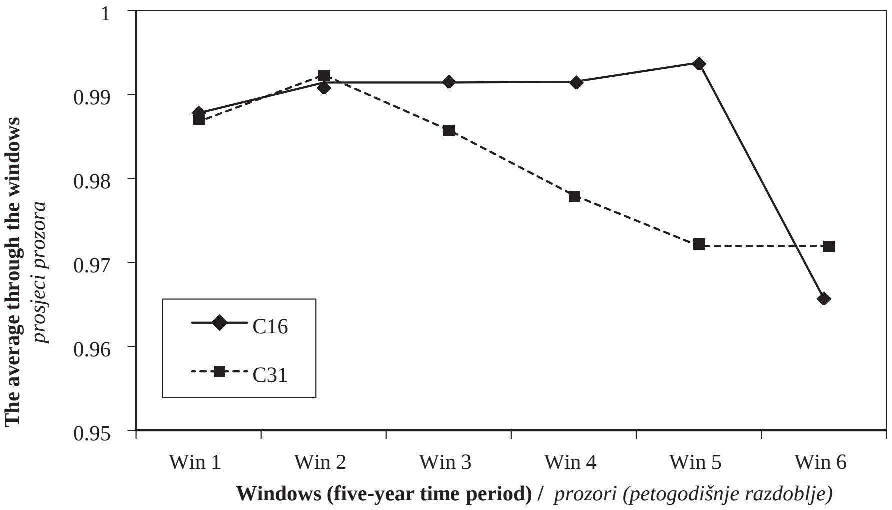

Figure 2 Window averages of sub-sectors C16 and C31 for Model 2
Slika 2. Prosjeci prozora za podsektore C16 i C31 za model 2.

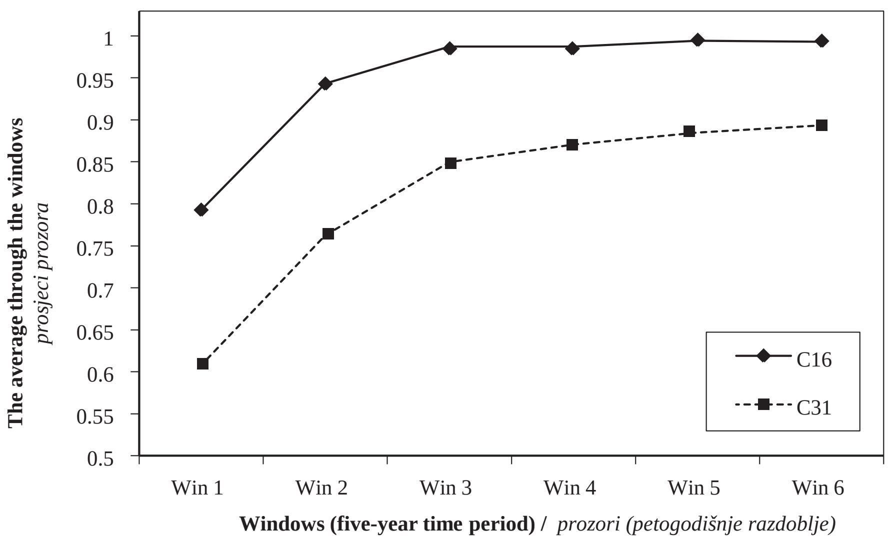

Figure 3 Window averages of sub-sectors C16 and C31 for Model 3
Slika 3. Prosjeci prozora za podsektore C16 i C31 za model 3.

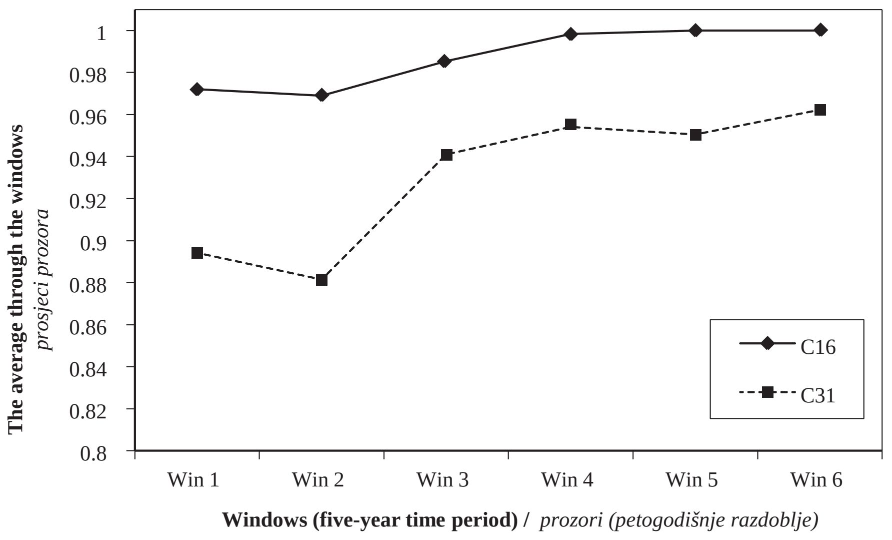

Figure 4 Window averages of sub-sectors C16 and C31 for Model 4
Slika 4. Prosjeci prozora za podsektore C16 i C31 za model 4.

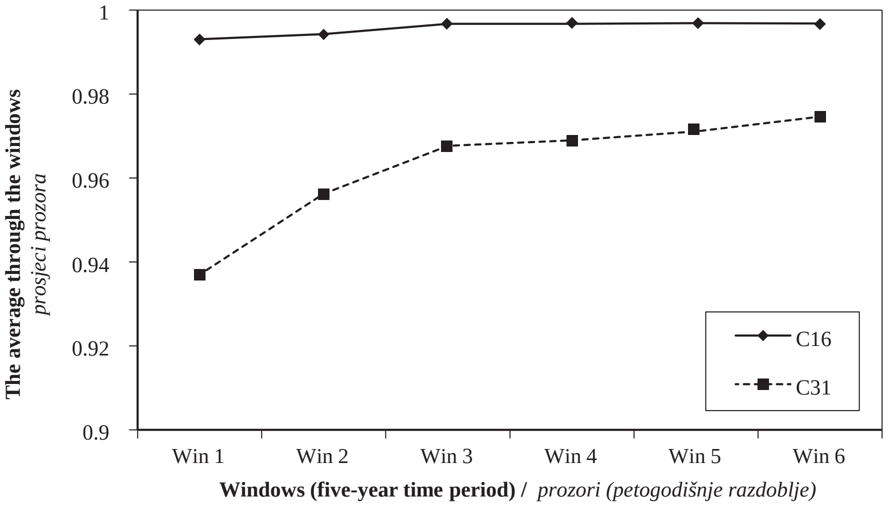

Figure 5 Window averages of sub-sectors C16 and C31 for Model 5
Slika 5. Prosjeci prozora za podsektore C16 i C31 za model 5.

(economic) impacts. In absolute terms, sub-sector C31 shows the worst performance in profitability ratios (Figure 3) (the window averages range from 0.61 to 0.89) and the best performance in efficiency ratios (Figure 5) (the window averages range from 0.94 to 0.97). However, a remarkable improvement in efficiency for both sub-sectors has been seen in recent years. A similar improvement can be seen in the activity ratios (Figure 4), while for the liquidity ratios the average window values have been falling in recent years (for both sub-sectors), although their absolute values are still very high (more than 0.96) (Figure 2). Based on the DEA analysis, it has been proved that sub-sector C16 is more efficient than C31, and the analysis of the indicators time series and DEA show that hypothesis 1 is confirmed.

4 CONCLUSIONS
4. ZAKLJUČAK

One of the most important tools for assessing the financial position and success of a company and/or sector is financial analysis. Economic stability and growth in general have recently improved in Slovenia (UMAR, 2017). Additionally, some important (political) measures have been taken to improve the condition in wood-industry sector (see Kropivšek *et al.*, 2017).

For both wood industry sub-sectors C16 (wood processing-except furniture) and C31 (manufacture of furniture), improvements have been observed in the last few years. We analyzed 40 financial indicators, of which 15 were examined in more detail, and found a noticeable deterioration in the years following the economic crisis (2008-2010), something that is especially true for sub-sector C31. However, since 2013 the values of most indicators for both sectors have improved. With DEA analysis measuring the relative efficiency of production units (in our case sectors), the results showed that in general the efficiency of sub-sector C16 is higher than in C31. Some models, as confirmed by DEA analysis, show a relative deterioration in efficiency for the years 2007-2010, but in most cases improvements have occurred in recent years. With these findings, it has been proven that the efficiency of both sub-sectors is increasing, which is a necessary condition for their long-term development. Sub-sector C31 shows the worst performance in profitability ratios and the best in efficiency ratios. However, a remarkable improvement in the efficiency of these ratios has been seen in recent years, which is also true for the activity ratios. For all models, the performance of sub-sector C16 is better than that of C31. The results of t-test prove that the difference between these two sub-sectors is statistically significant, as the differences of more than half of financial indicators between them are statistically significant.

Since the sector consists of individual companies, its effectiveness depends on the efficiency of each particular company within the sector. It is necessary to ensure effective operations at the company's level based on the appropriate (business) decisions of their managers. The results of the current study indicate that much needs to be done in the field of profitability and value added, as weaknesses in these areas have caused low(er) efficiency of the activity ratios. On the other hand, managerial decisions often depend on sectoral economic policies, whose creators need to have as much information as possible in order to create more favorable conditions for the business environment. As such, the in-depth financial analysis presented in this work also has high practical value.

This work has the following limitations. First, it only compared two sub-sectors, and thus there were only two DMUs in the DEA models. Moreover, despite the use of DEA window analysis, which increased the sample size, it still remained small, as can be seen in the relatively large number of results with an efficiency equal to 1. In the future, we intend to broaden our analysis by examining other European countries, which will increase the number of DMUs and also enable us to compare Slovenian achievements to those seen in other countries.

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Abrasion Resistance of Thermally and Chemically Modified Timber

Otpornost toplinski i kemijski modificiranog drva na habanje

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ABSTRACT • *Wood modification is an appropriate way of improving the natural durability and dimensional stability of wood without the use of biocides. Different thermal and chemical wood modification processes are available for this purpose, very differently affecting the structural integrity of wood. In this study, thermally modified, melamine resin treated, acetylated, furfurylated, and mDMDHEU treated wood underwent abrasion tests according to two different methods representing different loads in practice. The Taber Abraser method caused crosswise cutting into the wood surface, while the Shaker method challenged mainly the specimen edges with dynamic loads. Abrasion resistance of wood was affected by all types of cell wall modification, but the effects were strongly dependent on the type of modification and the applied load type. For characterising the suitability of wooden materials with respect to wear resistance under outdoor conditions, it is recommended to apply a set of methods rather than a single test procedure to fully reflect the loads occurring in practice.*

Keywords: *flooring, chemical wood modification, Shaker method, Taber Abraser, thermally modified wood, wear*

SAŽETAK • *Modifikacija drva prikladan je način poboljšanja njegove prirodne trajnosti i dimenzijske stabilnosti bez upotrebe biocida. Za tu namjenu dostupni su različiti postupci toplinske i kemijske modifikacije, ali oni vrlo različito utječu na strukturni integritet drva. U ovom su istraživanju toplinski modificirano drvo, drvo modificirano melaminskom smolom, acetilirano i furfurilirano drvo te drvo modificirano mDMDHEU-om podvrgnuti ispitivanju otpornosti na habanje, i to primjenom dviju različitih metoda koje u praksi rezultiraju različitim opterećenjima. Metoda Taber abraser uzrokovala je poprečno habanje površine drva, a metoda Shaker dinamičkim je opterećenjima uglavnom prouzročila habanje rubova uzoraka. Na otpornost drva na habanje utjecale su sve vrste modifikacija drvnih stanica, ali učinci su izrazito ovisili o vrsti modifikacije i vrsti opterećenja. Za karakterizaciju prikladnosti drvnih materijala s obzirom na otpornost na habanje u vanjskim uvjetima preporučuje se primijeniti skup metoda, što je bolje od primjene samo jedne vrste ispitivanja kako bi se u potpunosti simulirala opterećenja koja se pojavljuju u praksi.*

Ključne riječi: *podovi, kemijska modifikacija drva, metoda Shaker, metoda Taber abraser, toplinski modificirano drvo, habanje*

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1 INTRODUCTION
1. UVOD

Wood modification aims at the improvement of different wood properties such as dimensional stability and natural durability without using biocides. Some types of impregnation modifications also have the potential to increase elasto-mechanical properties of wood (e.g. Lande *et al*., 2004, Behr *et al*. 2017). Some, such as thermal modification, have a negative effect on the latter because the wood becomes more brittle (Tjeerdsma *et al*., 1998, Epmeier *et al*., 2004, Shida and Saito, 2007, Brischke *et al*., 2012). Surface hardness of chemically modified wood is often increased as reported for acetylated wood (Larsson and Simonson, 1994), furfurylated wood (Lande *et al*., 2004, Esteves *et al*., 2011), DMDHEU treated wood (Emmerich *et al*., 2017), or melamine resin impregnated wood (Behr *et al*., 2017). In contrast, the hardness of thermally modified wood is reduced (Gunduz *et al*., 2009, Meyer *et al*., 2011).

Wooden floorings are exposed to various physical, mechanical, chemical, and finally biological loads especially if they are exposed outdoors (Brischke, 2010). Due to its hygroscopic character, moisture dynamics find a response in swelling and shrinking of floor boards. Hereby, the anisotropy of wood can lead to drastic deformations and warping of whole decks. Cell wall modification of wood has the potential to reduce such dimensional changes (Hill, 2006). Furthermore, aesthetic impairments of wood surfaces can result from UV degradation combined with leaching of lignin fragments and colonization of dark coloured molds leading to more or less homogeneous graying of the surface. In addition, some wood materials, e.g. sapwood portions, are susceptible to discoloration by blue stain fungi (Huckfeldt, 2009). However, all these biophysical degradation processes have in common that they affect the optical appearance only; the functionality of the flooring will not be compromised.

In contrast, mechanical loads occur in terms of wear, abrasion, and erosion and can significantly impact on the functional performance of wooden flooring. The wear effect of walking persons is often intensified by abrasive particles, e.g. sand, dust, winter grit, and other more or less sharp-edged particles. The resistance against abrasion strongly depends on the material – anatomic differences become evident, e.g. in the form of washboard effect as a result of differences between earlywood and latewood (Sell and Feist, 1986). A standardized method for determining the abrasion resistance of solid wood is still lacking. Hence, the Taber Abraser method, as referred to by EN 438-2 (2016), ISO 9352 (2012), and ASTM D 1044 (2013), has been occasionally used for this purpose, although it is originally intended for testing the abrasion resistance of high-pressure laminated papers (Militz *et al*., 2011). As previously shown by Welzbacher *et al*., (2009), the loads occurring during Taber Abraser tests provoked by rotating sandpaper under defined grinding pressure do not necessarily reflect the exposure conditions of an outdoor exposed flooring, for example a terrace decking. As shown for timber structures in the marine environment by Brischke *et al*. (2005) and Williams *et al*. (2010), it is rather necessary to use a set of test methods to fully reflect the in-situ conditions to which wood is exposed outdoors. Brischke *et al*. (2014) applied the so-called Shaker method for testing the abrasion resistance of wet and dry wood specimens made from various wood species and found that the abrasion resistance of wood is generally increasing with higher densities. However, they also reported about exceptions such as Douglas fir (*Pseudotsuga menziesii* Franco) that reveals high abrasion resistance at rather moderate density. Apparently, anatomical features such as the regularly alternating early and latewood sections of Douglas fir positively affect its abrasion resistance, which is in line with a theory of shock-absorbance effects formulated by Williams *et al*. (2010). Similar tests using a concrete mixer and shingles were performed by Williams *et al*. (2010) to characterize the performance of different wood species used for groynes.

The Shaker method has been previously applied on thermo-mechanically densified and thermally modified wood, which showed significantly increased abrasion compared to untreated wood (Wehsener *et al*., 2017). Earlier work by Baird (2007), Militz *et al*. (2011) and Mahnert (2013) indicated that different kinds of chemical wood cell wall modification have an effect on the abrasion resistance of wood as well. The aim of this study was, therefore, to determine the abrasion resistance of differently chemically and thermally modified timber in comparative tests using the Taber Abraser and the Shaker test method.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Specimens were prepared from differently modified Scots pine sapwood (*Pinus silvestris* L.) and European beech (*Fagus sylvatica* L.) as well as untreated reference specimens from both wood species as shown in Table 1. Thermal modification was conducted at 230 °C by Timura Holzmanufaktur (Rottleberode, Germany) using the Vacu³- process.

Heat treated beech wood was additionally modified with methylolated melamine formaldehyde resin (MMF) Madurit MW 840/75WA (Ineos Melamines GmbH, Germany). Boards were impregnated in an impregnation plant at -0.60 mbar for 0.5 h followed by a pressure phase of 12 bar for 2 h. Specimens were dried and cured in a laboratory oven at maximum temperature of 120 °C for 24 h.

Commercially sized boards of beech were acetylated in the plant of Accsys Technologies in Arnhem, the Netherlands, using an industrial process. Prior to and after the acetylation, the dimensions and weight of the boards were measured. Since the process was not adapted, the acetylated beech showed a high amount of surface checks, but in general the degree of modification was uniform to high levels.

The modification process of furfuylation was carried out at KEBONY, Skien, Norway. Boards of beech

Table 1 Wood materials under test
Tablica 1. Ispitivani drvni materijali

Wood species *Vrsta drva*	**Botanical name** *Botanički naziv*	**Treatment** / *Modifikacija*	**Abbreviation** *Oznaka*	**Weight percent gain, %** *Postotak porasta mase, %*
European beech *obična bukva*	*Fagus sylvatica* L.	None / *nemodificirano*	Beech	-
		thermally modified / *toplinski modificirano*	Beech TMT	-
		thermally modified and melamine resin *modificirano toplinski i melaminskom smolom*	Beech TMT+M	15.4
		melamine resin / *modificirano melaminskom smolom*	Beech M	16.7
		acetylated / *acetilirano*	Beech AC	20.7
		furfurylated / *furfurilirano*	Beech FA	30.3
Scots pine sapwood / *bjeljika običnog bora*	*Pinus silvestris* L.	none / *nemodificirano*	Pine	-
		modified Dimethylol – dihydroxy – ethyleneurea treated / *modificirano mDMDHEU-om*	Pine mDMDHEU	19.4

were impregnated with furfuryl alcohol and subsequently dried and cured in an industrial plant.

Scots pine sapwood boards were impregnated in an autoclave at -0.98 bar for 1 h and at 12 bar for 2 h with a solution of modified 1.3-dimethylol-4.5-dihydroxyethyleneurea (mDMDHEU) in the following concentration: 36 % of mDMDHEU stock solution and 2 % magnesium nitrate hexahydrate relative to the mass of mDMDHEU as catalyst. After impregnation, the samples were cured in steam atmosphere at 120 °C. The mean weight percent gain (WPG) was 19.4 %.

2.2 Determination of oven-dry density
2.2. Određivanje gustoće apsolutno suhog drva

Specimens of 35 (ax.) x 8.5 x 8.5 mm³ were oven dried at 103 °C till constant mass, weighed to the nearest 0.01 g, and the dimensions were measured to the nearest 0.01 mm. The oven dry density was calculated according to Eq. 1:

$$\rho_0 = \frac{m_0}{V_0} \left[\frac{g}{cm^3}\right] \quad (1)$$

ρ_0 – oven-dry density (g/cm³)
m_0 – oven-dry mass (g)
V_0 – oven-dry volume (cm³)

2.3 Abrasion resistance tests – Shaker method
2.3. Ispitivanje otpornosti na habanje – metoda Shaker

The resistance against abrasion was determined according to the Shaker method described by Brischke *et al*. (2005). Five oven-dry specimens of (35 (ax.) x 8.5 x 8.5) mm³ were laid in polyethylene flasks (V = 500 ml) together with 400 g stainless steel balls of 6 mm diameter and moved in an overhead shaker at 28 revolutions min^{-1} for 72 h. In total, five by five specimens of each material were tested. Distances d between opposite corners of the oven-dried specimens were measured to the nearest 0.01 mm before and after abrasion. The percentage loss in dimension Δd was determined as a measure of abrasion according to the following Eq. 2 for each block and an average determined:

$$\Delta d = \frac{\frac{d_{1,1}+d_{1,2}}{2} - \frac{d_{0,1}+d_{0,2}}{2}}{\frac{d_{0,1}+d_{0,2}}{2}} \cdot 100 \quad (2)$$

Δd – abrasion (%)
$d_{0,1}$ – diagonal 1, before abrasion (mm)
$d_{0,2}$ – diagonal 2, before abrasion (mm)
$d_{1,1}$ – diagonal 1, after abrasion (mm)
$d_{1,2}$ – diagonal 2, after abrasion (mm)

2.4 Abrasion resistance tests – Taber Abraser method
2.4. Ispitivanje otpornosti na habanje – metoda *Taber abraser*

The resistance against abrasion was determined according to the Taber Abraser method (EN 438-2, 2005). The following modifications of the Taber Abraser test were made in order to allow testing of solid wood: Specimens of (100 (ax.) x 100 x 7) mm³ were prepared and conditioned at 20 °C/65 % RH. The tree rings of all specimens were oriented 45° to their cutting edges. After weighing and measuring the thickness at four points, the specimens (n = 5) were clamped into the Taber Abraser and abraded with sanding paper S-42 with approx. 60 min^{-1} for 1,000 revolutions. Afterwards, the decrease in thickness by abrasion was determined. The percentage loss in thickness Δt was determined as a measure of abrasion according to the following Eq. 3 for each specimen and an average determined:

$$\Delta t = \frac{t_0 - t_1}{t_0} \cdot 100 \quad (3)$$

Δt – abrasion (%)
t_0 – thickness, before abrasion (mm)
t_1– thickness, after abrasion (mm)

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The abrasion resistance of wood was significantly affected by different modification processes, but the respective effect was strongly dependent on the method applied for testing the resistance to abrasion. Abrasion according to the Taber Abraser method was expressed as percentage reduction in thickness of the specimens (*Δt*) and decreased with increasing oven-dry density of the wood material (Figure 1). Thermal modification and modification with mDMDHEU led to a decrease in abrasion resistance according to the Taber Abraser method compared to the untreated references,

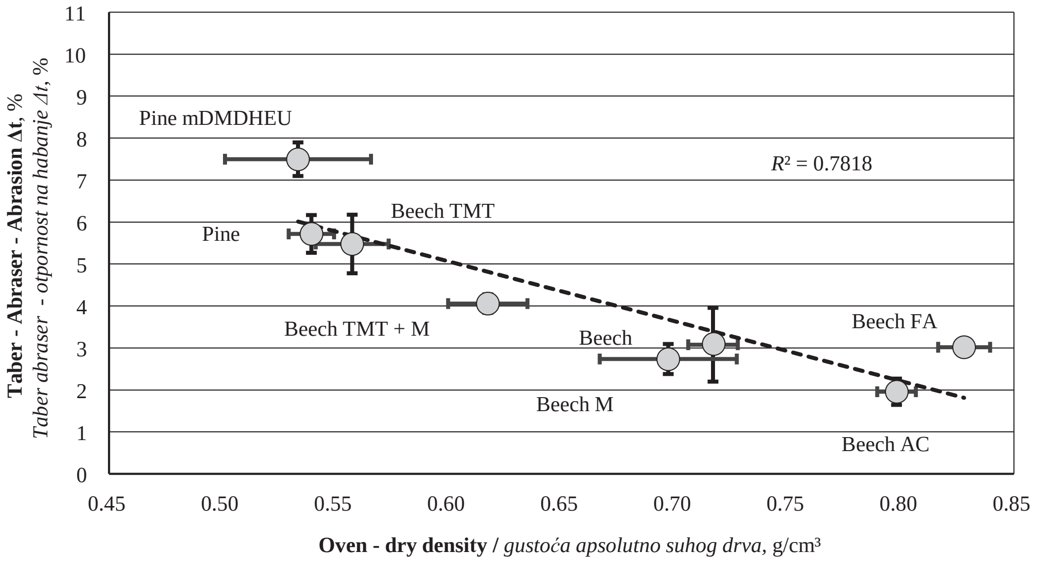

Figure 1 Relationship between oven-dry density and abrasion according to Taber Abraser method. Dots represent mean values per wood species. Standard deviation is indicated by error bars.
Slika 1. Odnos između gustoće apsolutno suhog drva i otpornosti na habanje prema metodi Taber abraser. Točke predočuju srednje vrijednosti za pojedine vrste drva. Standardna je devijacija označena trakom pogreške.

which coincides with previous findings by Emmerich *et al*. (2017) and Brischke *et al*. (2012), who reported on increased brittleness of these materials. In contrary, acetylation improved the abrasion resistance of wood. Furfurylation and an impregnation with melamine resin did not affect the abrasion of wood significantly, but a melamine treatment of heat treated beech led to an improvement of its abrasion resistance.

Abrasion of specimens challenged by shaking together with abrasive steel balls according to the Shaker method was clearly not correlated with the oven-dry density of the material. While the lighter wood of Scots pine showed clearly higher abrasion in the Taber Abraser compared to beech wood, both wood species showed only insignificantly different abrasion in the Shaker test (Figure 2). Only, acetylation led to a slight increase in abrasion resistance of wood, all other modification processes reduced its abrasion resistance. Scots pine treated with mDMDHEU, thermally modified beech with and without subsequent melamine treatment suffered from the highest abrasion in Shaker tests. The effect of the different modifications on the abrasion resistance of wood coincided fairly well with previous findings by Brischke et al. (2012) who reported that the structural integrity of wood was negatively affected by cell wall modification in the following order: Furfurylation < melamine resin treatment < mDMDHEU treatment.

Consequently, it was expected that abrasion determined with the help of both test methods was not correlated as shown in Figure 3. Acetylated beech showed less abrasion, and mDMDHEU treated Scots pine the most, if considering both methods. The test material was differently challenged by the two test methods. In the Taber Abraser, wood specimens were subject to cutting

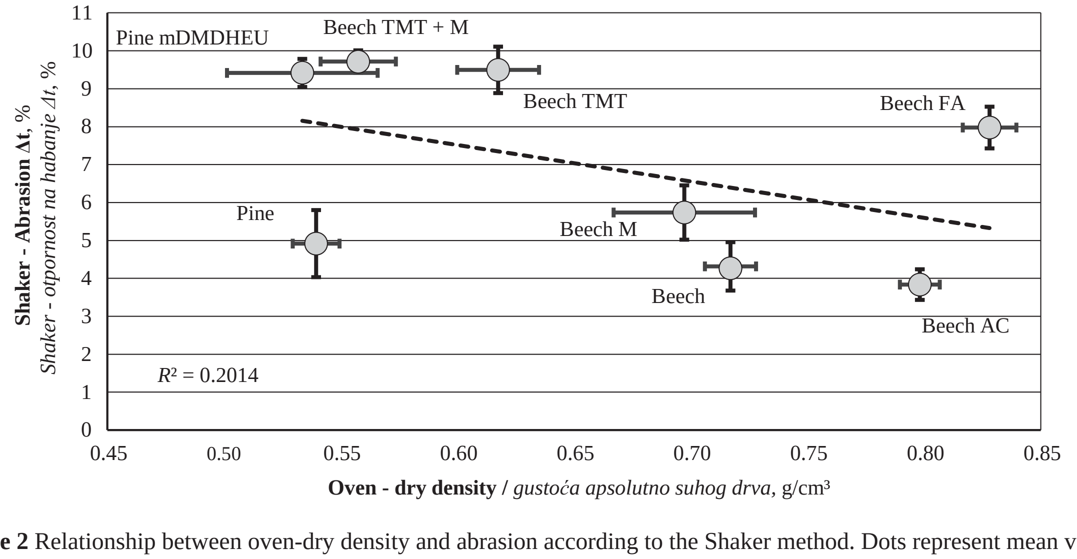

Figure 2 Relationship between oven-dry density and abrasion according to the Shaker method. Dots represent mean values per wood species. Standard deviation is indicated by error bars.
Slika 2. Odnos između gustoće apsolutno suhog drva i otpornosti na habanje prema metodi Shaker. Točke predočuju srednje vrijednosti za pojedine vrste drva. Standardna je devijacija označena trakom pogreške.

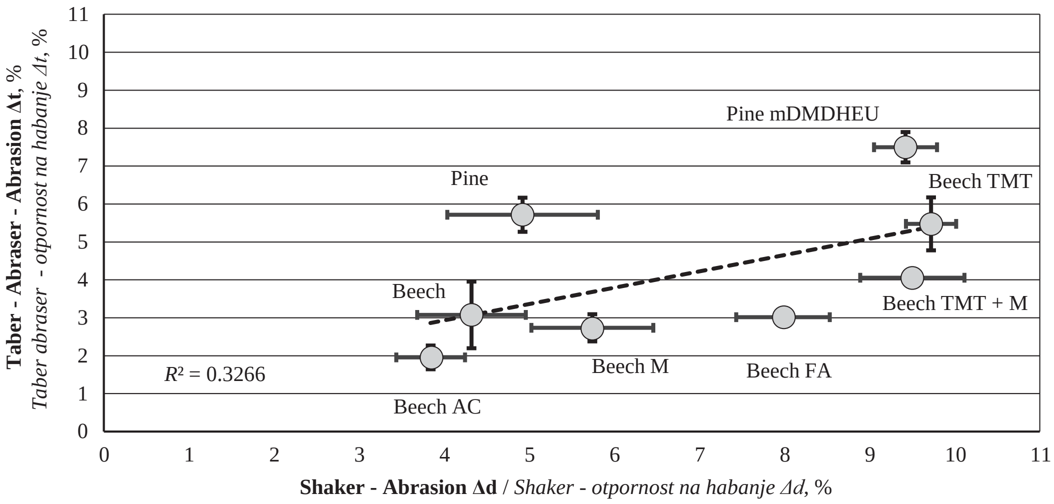

Figure 3 Relationship between oven-dry density and abrasion according to the Shaker method. Dots represent mean values per wood species. Standard deviation is indicated by error bars.
Slika 3. Odnos između gustoće apsolutno suhog drva i otpornosti na habanje prema metodi Shaker. Točke predočuju srednje vrijednosti za pojedine vrste drva. Standardna je devijacija označena trakom pogreške.

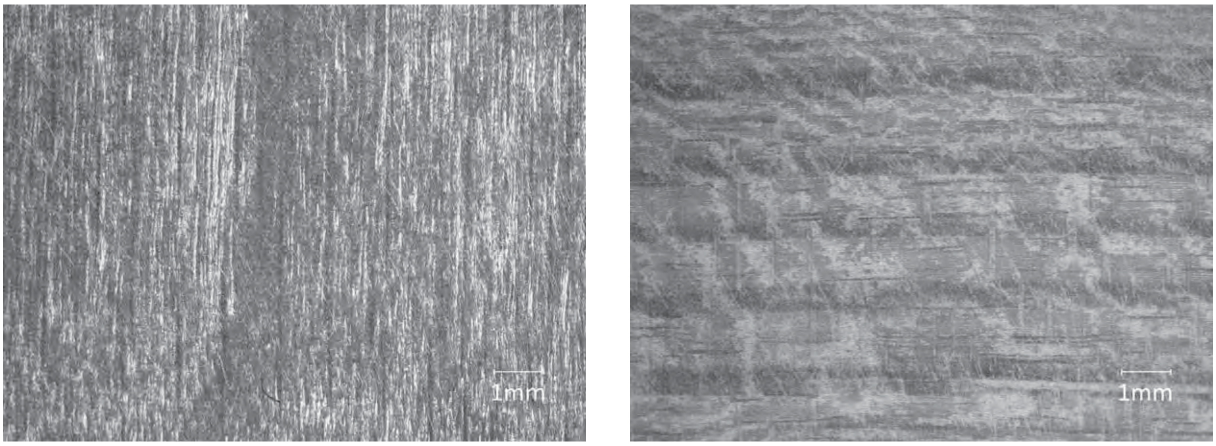

Figure 4 Scratched surface of test specimens after 1,000 revolutions in a Taber Abraser
Slika 4. Izgrebena površina uzoraka nakon 1000 ciklusa ispitivanja na uređaju Taber abraser

by aluminium oxide abrasive on the sanding paper, which is applied under pressure and a rotational movement. This particular type of wear becomes evident by crosswise cutting traces on the specimens' surfaces as shown in Figure 4. In contrast, the steel balls used for the Shaker test caused a multiple, but slight dynamic impact on the specimens, to which their longitudinal edges were particularly subjected and suffered from break offs. The rounding of the specimens' edges can be seen from their cross sections as illustrated in Figure 5.

In accordance with the percentage abrasion, two groups of materials can be distinguished by visual appearance: Untreated Scots pine and beech as well as melamine treated and acetylated beech showed only slight rounding of edges, while furfurylated, thermally modified beech with and without melamine treatment as well as mDMDHEU-treated Scots pine had significantly rounded edges.

Wooden flooring in use under outdoor conditions can suffer from both scratching and dynamic loads transversally to the surface leading to break offs and rounding of edges. To characterize the suitability of wood-based materials, especially treated and modified wood, consequently requires the application of different test methods reflecting the full spectrum of loads occurring in practice.

4 CONCLUSIONS
4. ZAKLJUČAK

Wood cell wall modification had generally a significant and mostly negative effect on the abrasion resist-

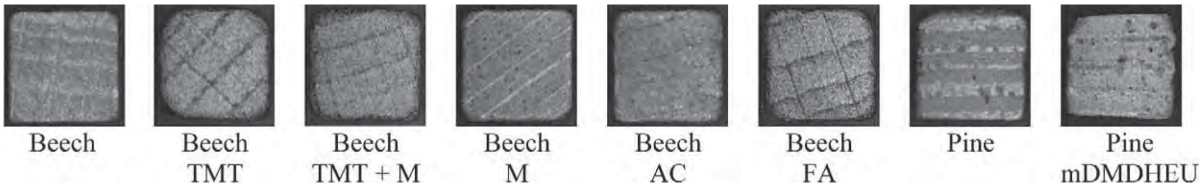

Figure 5 Cross section of Shaker test specimens after 72 h abrasion
Slika 5. Poprečni presjek uzoraka ispitivanih na uređaju *Shaker* nakon 72 sata habanja

ance of wood, but was strongly dependent on the type of modification and the test method applied. The Taber Abraser method caused crosswise cutting into the wood surface. In contrast, the Shaker method challenged mainly the specimen edges with dynamic loads. Both types of wear occur frequently in practice when wooden floorings are exposed outdoors. In addition, further parameters, such as static and dynamic hardness, as well as susceptibility to deformations and their possible impact on wooden flooring, have the potential to interact with abrasion resistance. Future research will, therefore, focus on comparative analysis of wear parameters obtained in laboratory tests and under real exposure conditions.

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Analytical Analysis of Distribution of Bending Stresses in Layers of Plywood with Numerical Verification

Analiza raspodjele naprezanja u slojevima furnirske ploče pri savijanju, s računskom provjerom

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ABSTRACT • *The study presents methods for accurate estimation of bending stresses in the 3-point flexural bending test of plywood, i.e. a wood-based laminate with an alternate crosswise ply configuration. The characteristic bending strength (MOR) and mean modulus of elasticity (MOE) of standard beech plywood was determined using European Standard bending tests EN 310. Correlations were determined between empirically determined bending moduli of the plywood and material moduli of the veneer layer. Calculations were conducted based on the classical plate theory for thin panels comprising the theory of elasticity including the Kirchhoff-Love hypothesis. Rigidity of individual layer was established theoretically in the axial configuration of transformed rigidity matrix values. Numerical laminate models were developed and simulation tests were conducted. Results of experimental and analytical studies were verified using the Finite Element Method (FEM). Analyses were performed in two plywood cross-band arrangement variants. An analysis of the distribution of stresses in individual layers of plywood used an analytical and numerical method assuming the plywood specimen to be a rhombic-anisotropic material.*

It was found that the bending load capacity of plywood depends on the configuration of individual layers (veneers). Values of stresses originating from bending do not only depend on the distance of the considered plywood layer from the middle layer but also on stiffness in the direction of operating stresses. Bending strength varies in individual directions of the plywood panel. Therefore, the distribution of stresses in individual layers differs from that resulting from the stress distribution for homogeneous isotropic materials. Results are presented in the form of tables, bitmaps, graphs and photographs. The tests were conducted based on the BFU-BU-18 standard beech plywood thickness of 18 mm.

Keywords: *plywood, stress distribution, veneers, layers, FEM, numerical analysis*

SAŽETAK • *U radu se opisuju metode točne procjene naprezanja pri testu savijanja furnirske ploče u tri točke, tj. pri savijanju laminata na bazi drva s naizmjenično okomito postavljenim slojevima. Karakteristični modul loma (MOR) i srednja vrijednost modula elastičnosti (MOE) standardne furnirske ploče od bukovine utvrđeni su*

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prema EN 310. Uočena je povezanost između empirijski određenih modula na savijanje furnirskih ploča i modula na savijanje slojeva furnira. Izračuni su provedeni na temelju klasične teorije za tanke ploče, koju čine teorija elastičnosti i Kirchhoff-Loveova hipoteza. Krutost pojedinog sloja utvrđena je teorijski u aksijalnoj konfiguraciji izmijenjenih vrijednosti matrice krutosti. Razvijeni su računski modeli laminata i provedena su simulacijska ispitivanja. Rezultati eksperimentalnih i analitičkih ispitivanja potvrđeni su metodom analize konačnih elemenata (FEM). Analize su provedene na dvije vrste furnirskih ploča s okomito usmjerenim slojevima furnira. Za analizu raspodjele naprezanja u pojedinim slojevima furnira furnirske ploče primijenjena je analitička i računska metoda, uz pretpostavku da je uzorak furnirske ploče rombo-anizotropni materijal. Utvrđeno je da kapacitet savijanja furnirske ploče ovisi o konfiguraciji pojedinih slojeva (furnira). Vrijednosti naprezanja koje proizlaze iz savijanja ne ovise samo o udaljenosti promatranog sloja od srednjeg sloja furnirske ploče, već i o krutosti u smjeru naprezanja. Čvrstoća na savijanje u pojedinim smjerovima furnirske ploče varira. Stoga se raspodjela naprezanja u pojedinim slojevima razlikuje od raspodjele naprezanja za homogene izotropne materijale. Rezultati su prikazani uz pomoć tablica, grafova i fotografija. Ispitivanja su provedena na standardnoj furnirskoj ploči od bukovine debljine 18 mm BFU-BU-18.

Ključne riječi: *furnirska ploča, raspodjela naprezanja, furniri, slojevi, FEM, računska analiza*

1 INTRODUCTION
1. UVOD

Plywood as a structural material exhibits properties comparable to those of composite materials. Thanks to its mechanical properties, plywood is a superior wood-based panel material. It is a building material consisting of veneers (thin wood layers) bonded with an adhesive. Depending on its type and properties, it has numerous applications in various sectors of industry, such as furniture making, joinery, construction engineering, e.g. in concrete forming, as well as boat building, aircraft and glider design, etc. Plywood is used in a variety of structural applications, such as floors, siding, formwork and engineered wood products prefabricated I-joists, box beams, and panel roofs (Stark *et al.,* 2010). Plywood is particularly useful in construction engineering as an engineered wood-based material with properties comparable to those of glulam. It is strengthened by cellulose fibers arranged along the tree stem or trunk and surrounded by a matric composed mainly of lignin. The macroscopic structure of plywood is created by gluing alternately arranged, thin cross-bands, i.e. veneers of various thickness. The cross-laminated veneer layers give plywood excellent strength characteristics, stiffness and dimensional stability (Youngquist, 1999). Physical and mechanical properties of plywood are dependent primarily on wood species, thickness, orientation of glued veneer sheets as well as the type of adhesive and the applied gluing method (Youngquist, 1999; Hráskỳ and Král, 2005; Stark *et al.,* 2010). Plywood is a major type of wood-based composite material for structural use. By identifying its properties and their modification focusing on performance characteristics in technological processes of plywood manufacture and thanks to its combination with other materials, the so-called modified plywood may be produced. Such an innovative structural material, e.g. with an aluminum core, has considerably extended applicability in various branches of industry. Additionally, such plywood is superior to other materials thanks to its increased strength and the simultaneously reduced effect of material defects. The application of plywood in structures as a load-transferring element occasionally requires an analysis of its rigidity and strength, particularly in critical areas of stress accumulation. It is crucial when the effect of stress accumulation determines the performance and load bearing capacity of the entire structure. This study investigates analytical and numerical methods to determine stress values in individual layers of plywood subjected to a three-point bending test. Analytical calculations were performed at the assumptions resulting from the classical theory of plates. The classical laminated plate theory (CLPT) is an extension of the classical plate theory to composites laminates (Reddy, 1997):

- Layers are permanently bound and their interface is indefinitely thin and prevents interlayer shear,
- Strains change edgewise in a continuous or constant manner depending on load (due to the varying layer thickness),
- A change in stresses at the interfaces is stepwise and edgewise of individual plies and it occurs in a continuous or constant manner,
- The Kirchhoff-Love theory referring to thin plate bending is binding: a straight line perpendicular to the mid-surface remains unchanged after the administration of a load acting in the mid-surface and the normal section to the mid-surface does not change in length ($\varepsilon_z = 0$),
- A composite as a whole forms a single layer, but with properties constituting a resultant of properties of individual layers,
- The assumption of small displacements is binding.

The proposed method of analytical calculations is relatively complex in comparison with other methods for the determination of strength parameters in wood and wood-based materials. Thanks to this approach, more accurate results can be obtained concerning the distribution of stresses in individual layers, particularly at their arbitrary arrangement in the laminated material (Kljak and Brezović, 2006). As most tests for mechanical properties are destructive in nature, they tend to be costly and time-consuming. It would, therefore, be worthwhile to examine current technology to adopt solutions that save time and are cost-effective. A recent approach to analyzing the mechanical behaviour of plywood is the Finite Element Method (FEM), which has been used to solve many special problems in timber design. However, this method is not commonly applied to analyze the mechanical properties of plywood specimens.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Experimental tests on plywood were performed in accordance with the PN-EN 310:1994 standard on small specimens cut from one sheet of commercial 18 mm thick beech plywood. A total of twelve specimens were collected in two variants differing in the arrangement of cross-bands, i.e. outer layers. In the first six specimens of variant I (0/90/0/90/0…), the direction of cross-band grain was parallel to specimens length, while in the other six specimens of variant II (90/0/90/0/90…), the arrangement was transverse. Geometrical dimensions of specimens are given in Table 1.

Tests were performed on a strength testing machine in a 3-point bending system with the computer measuring equipment recording values of loading force and displacement (Brancheriau et al., 2002). Bending forces were applied on specimens in the elastic-linear and plastic range until a complete sample failure. A total of 12 panels of plywood were used for each thickness in the cutting plan of (EN 310).

The dimensions, shape and load of the test specimens for the determination of bending strength of plywood specimens are presented in Figures 1.

Each plywood panel was cut into two groups of bending test specimens, 6 pieces parallel 0° to the grain direction and 6 pieces perpendicular 90° to the grain direction. The test specimen was rectangular with the width (b), 50 ± 1 mm, and the length 20 times the nominal thickness (t). The test specimens were conditioned to a constant mass in an atmosphere with a relative humidity of 65±5 % and a temperature of 20±2 °C. A cylindrical loading head with the diameter 30.0±0.5 mm was placed parallel to the supports. The load applied to

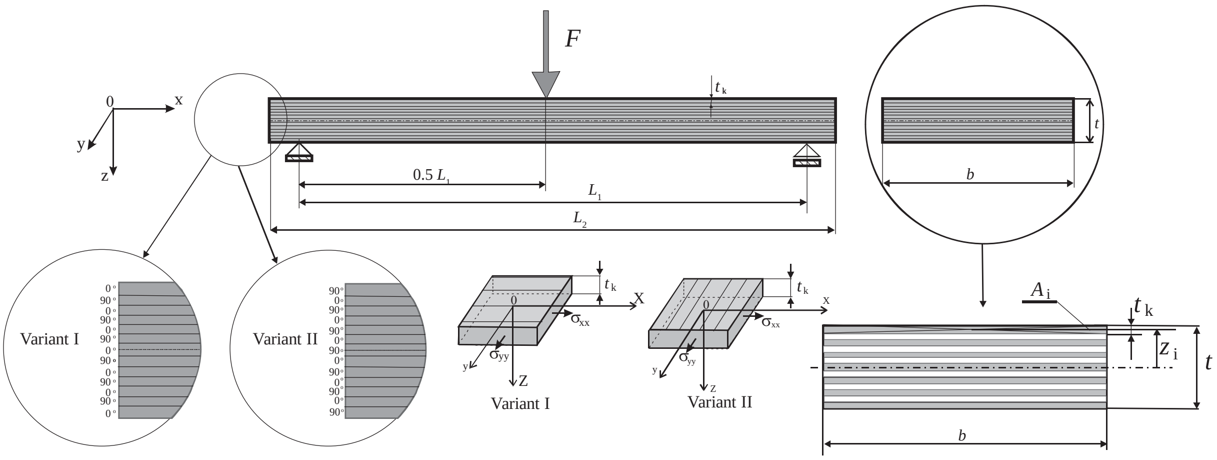

Figure 1 Dimensions and orientation of layers of plywood specimens
Slika 1. Dimenzije i smjer protezanja slojeva uzoraka furnirske ploče

Table 1 Dimensions of specimens
Tablica 1. Dimenzije uzoraka

Plywood / *Furnirska ploča*										
Number of specimen *Broj uzorka*	**Cross-sectional area of the layer** *Površina poprečnog presjeka sloja*	**Variant I** / *Varijanta I.* (0/90/0/90/0/90/0/90/0/90/0/90/0)				**Cross-sectional area of the layer** *Površina poprečnog presjeka sloja*	**Variant II** / *Varijanta II.* (90/0/90/0/90/0/90/0/90/0/90/0/90)			
		Length *Dužina*		Thickness *Debljina*	Width *Širina*		Length *Dužina*		Thickness *Debljina*	Width *Širina*
	A_i	L_1	L_2	t	b	A_i	L_1	L_2	t	b
	mm²	mm				mm²	mm			
1	901.45	360	410.09	17.95	50.22	894.33	360	410.09	17.78	50.30
2	894.13		409.89	17.79	50.26	895.01		409.89	17.79	50.31
3	893.48		410.42	17.77	50.28	889.92		410.42	17.77	50.08
4	889.63		410.07	17.75	50.12	892.65		410.07	17.75	50.29
5	891.58		410.31	17.75	50.23	892.29		410.31	17.75	50.27
6	887.09		410.20	17.71	50.09	892.58		410.20	17.71	50.40
Mean *Srednja vrijednost*	892.89		410.17	17.79	50.20	892.80		410.16	17.76	50.26

Table 2 Bending properties of plywood (Variant I)
Tablica 2. Savojna svojstva furnirske ploče (varijanta I.)

Specimen No. *Broj uzorka*	**Plywood Variant I** / *Furnirska ploča, varijanta I.* (0/90/0/90/0/90/0/90/0/90/0/90/0)					
	Maximum Load *Najveće opterećenje*	**Modulus of elasticity** *Modul elastičnosti*	**Modulus of rapture** *Modul loma*	**Increment of load** *Povećanje opterećenja*	**Increment of deflection** *Povećanje progiba*	
					Experimental *Eksperimentalno*	**Numeric** *Računski*
	F_{max}	MOE	MOR	F_2-F_1	a_2-a_1	f_{FEM}
	N	N/mm^2	N/mm^2	N	mm	
1	2482	9455	82.13	744	3.16	3.20
2	2266	8913	76.93	679	3.14	3.12
3	2448	9337	83.26	734	3.25	3.16
4	2164	9002	74.00	649	3.00	2.79
5	2420	9510	82.57	726	3.17	3.12
6	2587	9596	88.92	776	3.39	3.33
Mean *Srednja vrijednost*	2394	9302	81.42	718	3.18	3.12

Table 3 Bending properties of plywood (Variant II)
Tablica 3. Savojna svojstva furnirske ploče (varijanta II.)

Specimen No. *Broj uzorka*	**Plywood Variant II** / *Furnirska ploča, varijanta II.* (0/90/0/90/0/90/0/90/0/90/0/90/0)					
	Maximum Load *Najveće opterećenje*	**Modulus of elasticity** *Modul elastičnosti*	**Modulus of rapture** *Modul loma*	**Increment of load** *Povećanje opterećenja*	**Increment of deflection** *Povećanje progiba*	
					Experimental *Eksperimentalno*	**Numeric** *Računski*
	F_{max}	MOE	MOR	F_2-F_1	a_2-a_1	f_{FEM}
	N	N/mm^2	N/mm^2	N	mm	
1	1946	6119	66.08	583	3.88	3.89
2	1893	6044	64.20	568	3.87	3.79
3	1918	6104	65.49	575	3.91	3.83
4	1908	5931	65.03	572	4.00	3.79
5	1864	6119	63.55	559	3.79	3.73
6	1823	5997	62.27	547	3.80	3.62
Mean *Srednja vrijednost*	1892	6052	64.44	567	3.87	3.78

the test specimen was adjusted so that the maximum load was reached within 60 ±30 s throughout the test.

The modulus of rigidity (MOR) of each test pieces is calculated as follows:

$$\mathrm{MOR} = \frac{3\cdot F_{max}\cdot L_1}{2\cdot b\cdot t^2} \quad (\mathrm{N/mm^2}) \qquad (1)$$

The modulus of elasticity (MOE) of each test pieces is calculated as follows:

$$MOE = \frac{L_1^3\cdot(F_2-F_1)}{4\cdot b\cdot t^3\cdot(a_2-a_1)} \quad (\mathrm{N/mm^2}) \qquad (2)$$

Where:
F_{max} –maximum load (N),
L_1 – distance (mm) between the centre of two supports (mm),
b – width (mm) of test pieces,
t – thickness (mm) of test pieces as depicted in (Figure 1).
(F_2 - F_1) – increment of load on straight line portion of the load–deflection curve, where F_1 was approximately 10 % and F_2 was approximately 40 % of the maximum load F_{max},
(a_2 - a_1) – increment of deflection corresponding to (F_2 - F_1) in the load–deflection curve.

The results of MOE, MOR and deflection in all tested directions of plywood specimens are shown in Tables 2 and 3.

3 ANALYTICAL CALCULATIONS
3. ANALITIČKI IZRAČUNI

Strength analysis in the macroscopic scale of wood-based composite was conducted taking into consideration the theory of thin plate bending (Bodig and Jayne, 1982; Goodman and Bodig, 1970; German, 1996). Mechanical properties of plywood as a whole are mainly dependent on the properties of its individual layers (Kljak and Brezović, 2007; Makowski, 2014). These parameters have been successfully described by the rhomboid-anisotropic material model in the range of linear-elastic values (Goodman and Bodig, 1970; Lekhnitskii, 1982; Reddy, 1997). Layers in a standard plywood are rotated at an angle of 90°, which corresponds to the so-called symmetric laminate with an alternate layers arrangement. Each layer contains two main material axes: longitudinal and transverse. In the conducted theoretical and numerical analyses, the following material data were used (Keylwerth, 1951; Goodman and Bodig, 1970; Neuhaus, 1994) corresponding to mean values of beech wood (*Fagus sylvatica* L.): density ρ=690 kg/m^3, 12 % moisture content, coefficient of elasticity $E_L=E_{11}$=14000 N/mm^2, $E_T=E_{22}$=1160 N/mm^2, $G_{12}=G_{LT}$=1080 N/mm^2, $\nu_{LT}=\nu_{12}$=0.52 (major), $\nu_{TL}=\nu_{21}$=0.043 (minor), where E_L,E_T, and E_R are Young's moduli in the longitudinal (L), tangential (T) and radial (R) directions of the veneer. Based on the above-mentioned data using the indirect method, a correlation was described between Young's modulus of layers and the modulus of the laminate. In analytical calculations in the plane perpendicular to the panel, the former modulus was estimated at bending parallel to cross-band grain and the latter - at bending perpendicular to grain. It was assumed that flexural rigidity of the layer system depended on the flexural rigidity of its individual layers, which is consistent with the assumptions of the Kirchhoff-Love theory. Applying denotations from Figure 1, the equation of rigidity for the laminated material may be written as follows (Bodig and Jayne, 1982; Wang and Chang, 1978; Lemaitre and Chaboche, 1990; Tsai and Hahn, 1980).

$$E_{gx} I_y = \sum_{i=1}^{n} E_{xi} I_{iy}^{(o)} \tag{3}$$

Where:

E_{gx} – modulus of elasticity at laminate bending,

E_{xi} – modulus of elasticity at laminate layer bending,

I_y – moment of inertia for cross-section in relation to neutral axis y,

n – number of layers with an identical orientation of veneers,

$I_{iy}{}^{(o)}$ – moment of inertia for cross-section of the *i*-th layer in relation to the neutral axis y,

$I_{iy}^{(o)} = I_{iy}^{'} + A_i (z_i^{'})^2$- acc. with Steiner's theorem (Figure1), $I_{iy}^{'} = \frac{b \cdot t_k^3}{12}$

Taking into consideration the crosswise arrangement and geometrical symmetry of laminate layers the above dependence may be expressed as follows:

$$E_{gx} I_y = 2\sum_{i=1}^{n} E_{xi}^{0} \cdot I_{iy}^{0} + 2\sum_{i=1}^{n} E_{xi}^{90} \cdot I_{iy}^{90} + E_x^m \cdot I_{my} \tag{4}$$

Where: m – denotes the direction of grain arrangement in the core.

Based on the above-mentioned dependencies, the theoretical bending moduli were estimated:

- for the laminate with a 0° angle of cross-band layer orientation:

$$E_{gx}^{0} = \frac{2}{I_y}\left\{\sum_{i=1}^{n} E_{xi}^{0} \cdot I_{iy}^{0} + \sum_{i=1}^{n} E_{xi}^{90} \cdot I_{iy}^{90} + \frac{1}{2} E_x^m \cdot I_{my}\right\} = \\ = \frac{2}{I_y}\left\{E_{xi}^{0} \sum_{i=1}^{n} I_{iy}^{0} + E_{xi}^{90} \sum_{i=1}^{n} I_{iy}^{90} + \frac{1}{2} E_x^m \cdot I_{my}\right\},$$

Where: $E_{\mathrm{xi}}^{0} = 14000 \ \frac{\mathrm{N}}{\mathrm{mm}^2}$; $E_{\mathrm{xi}}^{90} = 1160 \ \frac{\mathrm{N}}{\mathrm{mm}^2}$;

$I_{\mathrm{y}} = \frac{b \cdot t^3}{12} = 24300 \ \mathrm{mm}^4$; $I_{\mathrm{m}} = \frac{b \cdot t_{\mathrm{k}}^3}{12} = 11.43 \ \mathrm{mm}^4$;

$E_{\mathrm{x}}^{m} = E_{\mathrm{xi}}^{0}$

$$E_{\mathrm{gx}}^{0} = 9076.9 \frac{N}{\mathrm{mm}^2}$$

- for the laminate with a 90° angle of cross-band layer orientation:

$$E_x^m = E_{xi}^{90^o}$$

$$E_{gx}^{90} = \frac{2}{I_y}\left\{\sum_{i=1}^{n} E_{xi}^{90} \cdot I_{iy}^{90} + \sum_{i=1}^{n} E_{xi}^{0} \cdot I_{iy}^{0} + \frac{1}{2} E_x^m \cdot I_{my}\right\} = \\ = \frac{2}{I_y}\left\{E_{xi}^{90} \sum_{i=1}^{n} I_{iy}^{90} + E_{xi}^{0} \sum_{i=1}^{n} I_{iy}^{0} + \frac{1}{2} E_x^m \cdot I_{my}\right\},$$

$$E_{\mathrm{gx}}^{90} = 6108.6 \frac{N}{\mathrm{mm}^2}$$

Flexural moduli, calculated using this method, differ slightly from the results of laboratory experiments: $E_{\mathrm{gx}}{}^{0}$=9076.9 N/mm^2, $E_{\mathrm{gx}}{}^{90}$=*6108.6* N/mm^2. The values in parentheses refer to empirical results. Scatter of comparative results is very limited, for the longitudinal modulus amounting to 2.42 % and for transverse modulus - to 0.9 %, respectively. This shows that the adopted methodology of determining plywood parameters is appropriate. As a result, for these material data, it was decided to establish analytically the distribution of stresses in plywood layers subjected to bending tests. By limiting the study to linear relationships in terms of applicability of Hooke's law, the following dependencies between stresses and strains are obtained (Bodig and Jayne, 1982; Reddy, 1997; Tsai and Hahn, 1980; Stefańczyk *et al.*, 2005):

$$\{\sigma\} = [\mathbf{Q}][\mathbf{T}]\{\varepsilon\} = \left[\mathbf{Q}^*\right]\{\varepsilon\};$$
$$\begin{Bmatrix} \sigma_{\mathrm{xx}} \\ \sigma_{\mathrm{yy}} \\ \tau_{\mathrm{xy}} \end{Bmatrix} = \begin{bmatrix} \mathrm{Q}_{11}^{*} & \mathrm{Q}_{12}^{*} & \mathrm{Q}_{16}^{*} \\ \mathrm{Q}_{12}^{*} & \mathrm{Q}_{22}^{*} & \mathrm{Q}_{26}^{*} \\ \mathrm{Q}_{16}^{*} & \mathrm{Q}_{26}^{*} & \mathrm{Q}_{66}^{*} \end{bmatrix} \begin{Bmatrix} \varepsilon_{\mathrm{xx}} \\ \varepsilon_{\mathrm{yy}} \\ \gamma_{\mathrm{xy}} \end{Bmatrix} \tag{5}$$

The reduced matrix of rigidity [Q*] for any given layer k in the axial configuration, expressed in terms of engineering constants, takes the form:

$$[\mathbf{Q}^*]^k = [\mathbf{Q}]^k = \begin{bmatrix} mE_{11} & m\nu_{12}E_{22} & 0 \\ m\nu_{21}E_{11} & mE_{22} & 0 \\ 0 & 0 & G_{12} \end{bmatrix}^k = \begin{bmatrix} \mathrm{Q}_{11} & \mathrm{Q}_{12} & 0 \\ \mathrm{Q}_{21} & \mathrm{Q}_{22} & 0 \\ 0 & 0 & \mathrm{S}_{66} \end{bmatrix}^k \tag{6}$$

Where: $m=(1-\nu_{12}\nu_{21})^{-1}$ assuming that $\nu_{12}/\mathrm{E}_{11}= \nu_{21}/\mathrm{E}_{22}$, E_{11} - the so-called longitudinal Young's modulus, E_{22} - the so-called transverse Young's modulus, G_{12} – shear modulus, ν_{12} – the so-called major Poisson's ratio, ν_{21} – the so-called minor Poisson's ratio.

Elementary component layers of the laminated material have various reduced rigidity matrices $[Q^*]^k$. The constitutive equation of any k-th layer is written as:

$$\begin{Bmatrix} \sigma_{\mathrm{xx}} \\ \sigma_{\mathrm{yy}} \\ \tau_{\mathrm{xy}} \end{Bmatrix}^k = \left[\mathbf{Q}^*\right]^k \begin{Bmatrix} \varepsilon_{\mathrm{xx}} \\ \varepsilon_{\mathrm{yy}} \\ \gamma_{\mathrm{xy}} \end{Bmatrix}^k \tag{7}$$

From Eq. 5, values of stresses found in any laminate layer may be calculated having an a priori knowledge of the value of its strain. Strains were calculated using geometrical relationships linking strain and curvature of the laminate mid-surface:

$$\begin{aligned}\varepsilon_{\mathrm{xx}} &= \varepsilon^0_{\mathrm{xx}} - zk_{\mathrm{x}}\\ \varepsilon_{\mathrm{yy}} &= \varepsilon^0_{\mathrm{yy}} - zk_{\mathrm{y}}\\ \gamma_{\mathrm{xy}} &= \gamma^0_{\mathrm{xy}} - zk_{\mathrm{xy}}\end{aligned} \tag{8}$$

Thus the relationships from Eq. 7 may be written as:

$$\begin{Bmatrix}\sigma_{\mathrm{xx}}\\ \sigma_{\mathrm{yy}}\\ \tau_{\mathrm{xy}}\end{Bmatrix}^k = \left[\mathbf{Q}^*\right]^k \begin{Bmatrix}\varepsilon^0_{\mathrm{xx}} - zk^0_{\mathrm{x}}\\ \varepsilon^0_{\mathrm{yy}} - zk^0_{\mathrm{y}}\\ \varepsilon^0_{\mathrm{xy}} - zk^0_{\mathrm{xy}}\end{Bmatrix}^k \tag{9}$$

By replacing stresses with external forces acting on the laminate (external forces N and bending moments M), the above equation takes the form:

$$\begin{Bmatrix}N\\ M\end{Bmatrix} = \begin{bmatrix}\mathbf{A} & \mathbf{B}\\ \mathbf{B} & \mathbf{D}\end{bmatrix}\begin{Bmatrix}\varepsilon^0\\ k^0\end{Bmatrix} \tag{10}$$

Where: **A** – longitudinal rigidity matrix,
B – coupling rigidity matrix,
D – bending rigidity matrix.

At bending of symmetric laminates (an odd number of plies), the coupling matrix in the absence of external forces N=0 flexing the composite is reduced to zero [**B**]=0. The above equation takes the form:

$$\{M\} = [\mathbf{D}]\{k^0\} = \begin{bmatrix}\mathrm{D}_{11} & \mathrm{D}_{21} & 0\\ \mathrm{D}_{12} & \mathrm{D}_{22} & 0\\ 0 & 0 & \mathrm{D}_{66}\end{bmatrix}\begin{Bmatrix}k^0_x\\ k^0_Y\\ k^0_{xY}\end{Bmatrix} \tag{11}$$

By transforming the equation in terms of the bending curvature of the laminate in the neutral surface the following is obtained:

$$\{k^0\} = [\mathbf{D}]^{-1}\{M\} \quad \text{or}$$

$$\begin{Bmatrix}k^0_{\mathrm{x}}\\ k^0_{\mathrm{y}}\\ k^0_{\mathrm{xy}}\end{Bmatrix} = \begin{bmatrix}\mathrm{D}_{11} & \mathrm{D}_{21} & 0\\ \mathrm{D}_{12} & \mathrm{D}_{22} & 0\\ 0 & 0 & \mathrm{D}_{66}\end{bmatrix}^{-1}\{M\} \tag{12}$$

Where: bending moment for cross-section width is expressed as follows:

$$\{M\} = \begin{Bmatrix}M^{'}/b\\ 0\\ 0\end{Bmatrix} \tag{13}$$

Where $M'=0.5\cdot F\cdot 0.5\cdot L_1$ – maximum resultant moment of bending of plywood specimens in the linear-elastic range ($F=F_2-F_1$). Components of the bending rigidity matrix depending on the type of laminated material, i.e. regular and symmetric with a cross-wise ply arrangement, are expressed as follows (German, 1996):

$$D_{11} = \frac{Q_{11}t^3}{12}\frac{1}{n^3}\left[P(4P^2-3) + \frac{E_{22}}{E_{11}}R(4R^2-3)\right]$$

$$\mathrm{D}_{22} = \frac{Q_{22}t^3}{12}\frac{1}{n^3}\left[P(4P^2-3) + \frac{E_{11}}{E_{22}}R(4R^2-3)\right] \tag{14}$$

$$D_{12} = \frac{Q_{12}t^3}{12},\ D_{66} = \frac{Q_{66}t^3}{12},\ D_{16} = D_{26} = 0$$

Where: t - total laminate thickness, n - number of layers 13, P - number of layers oriented at α=0°, R - number of layers oriented at α = 90°.

3.1 Results of analytical calculations
3.1. Rezultati analitičkih izračuna

Reduced rigidity matrices for the 0° layer and the 90° layer based on (Eq.6) may be determined as:

$$[\mathbf{Q}]^k = [\mathbf{Q}^*]^{0^o} = \begin{bmatrix}14320 & 617 & 0\\ 617 & 1186 & 0\\ 0 & 0 & 1080\end{bmatrix}\frac{\mathrm{N}}{\mathrm{mm}^2}$$

$$[\mathbf{Q}]^k = [\mathbf{Q}^*]^{90^o} = \begin{bmatrix}1186 & 617 & 0\\ 617 & 14320 & 0\\ 0 & 0 & 1080\end{bmatrix}\frac{\mathrm{N}}{\mathrm{mm}^2}$$

Bending moment for variant I based on equation (Eq.13), using data contained in Table 2 and Figure 1, is as follows:

$$\{M\} = -\begin{Bmatrix}\dfrac{0.5\cdot 0.718\ \mathrm{kN}\cdot 180\,\mathrm{mm}}{50\,\mathrm{mm}}\\ 0\\ 0\end{Bmatrix} = -1.292\ \mathrm{kN\ mm/mm}$$

Taking into consideration the above results and after algebraic calculations, the elements of the bending rigidity matrix $[\mathbf{D}]_0$ for the 0° core layer at P=7, R=6, are as follows:

$$[\mathbf{D}]_0 = \begin{bmatrix}\mathrm{D}_{11} & \mathrm{D}_{21} & 0\\ \mathrm{D}_{12} & \mathrm{D}_{22} & 0\\ 0 & 0 & \mathrm{D}_{66}\end{bmatrix} = \begin{bmatrix}4501.663 & 299.862 & 0\\ 299.862 & 3033.187 & 0\\ 0 & 0 & 524.880\end{bmatrix}\mathrm{kNmm}$$

while elements of the inverse bending rigidity matrix are:

$$[\mathbf{D}]^{-1}_0 = \begin{bmatrix}2.2361 & -0.2211 & 0\\ -0.2211 & 3.3187 & 0\\ 0 & 0 & 19.0519\end{bmatrix}10^{-4}\frac{1}{\mathrm{kNmm}}$$

Estimated curvatures of the bending neutral layer, according to formula (Eq.12) for plywood variant I, are as follows:

$$\begin{Bmatrix}k^0_{\mathrm{x}}\\ k^0_{\mathrm{y}}\\ k^0_{\mathrm{xy}}\end{Bmatrix} = \begin{bmatrix}D_{11} & D_{21} & 0\\ D_{12} & D_{22} & 0\\ 0 & 0 & D_{66}\end{bmatrix}^{-1}\begin{Bmatrix}M_{\mathrm{x}}\\ 0\\ 0\end{Bmatrix} = \begin{Bmatrix}-2.8899\\ 0.2857\\ 0\end{Bmatrix}10^{-4}\frac{1}{\mathrm{mm}}$$

For plywood variant II, calculations for its parameters are as follows:
The bending moment is:

$$\{M\} = -\begin{Bmatrix}\dfrac{0.5\cdot 0.567\,\mathrm{kN}\cdot 180\,\mathrm{mm}}{50\,\mathrm{mm}}\\ 0\\ 0\end{Bmatrix} = -1.021\ \mathrm{kNmm/mm}$$

Curvature values:

$$\begin{Bmatrix}k^0_{\mathrm{x}}\\ k^0_{\mathrm{y}}\\ k^0_{\mathrm{xy}}\end{Bmatrix} = \begin{bmatrix}D_{11} & D_{21} & 0\\ D_{12} & D_{22} & 0\\ 0 & 0 & D_{66}\end{bmatrix}^{-1}\begin{Bmatrix}M_x\\ 0\\ 0\end{Bmatrix} = \begin{Bmatrix}-3.3871\\ 0.2256\\ 0\end{Bmatrix}10^{-4}\frac{1}{\mathrm{mm}}$$

Knowing values of these curvatures referring to the neutral surface, values of true strain in individual layers may be estimated. Assuming the linear character of strain distribution, their values are dependent on the distance from the laminate middle layer. In the analysis, the distribution of shear stresses was disregarded as

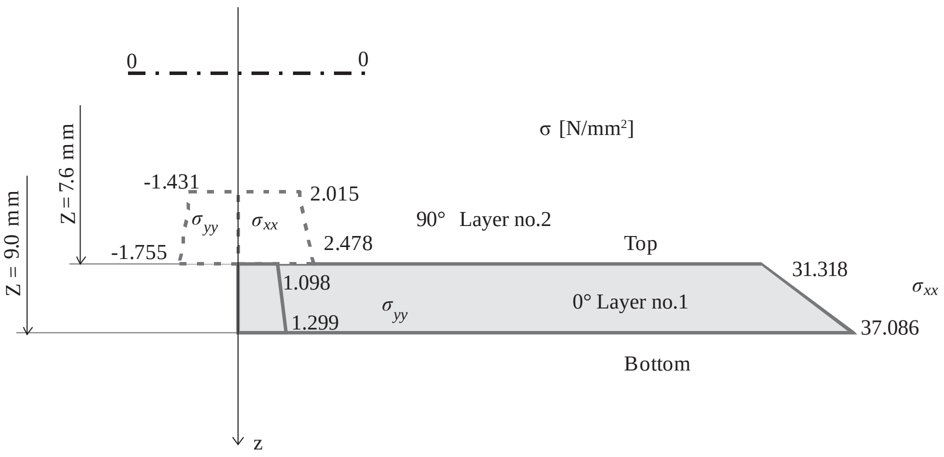

Figure 2 Distribution of stresses in the bottom layer No. 1 of variant I
Slika 2. Raspodjela naprezanja u donjem sloju (sloju br. 1.) za varijantu I.

small in relation to the t/L_1 ratio. A detailed algorithm to calculate stresses using the analytical method for an arbitrarily selected layer No.1 from variants I and II is as follows:
Calculations for variant I

$$[\sigma]_z=[\mathbf{Q}^*]\{\varepsilon\}$$

The bottom surface of layer 1
Data: $z = 9$ mm, $\varepsilon_x^0 = \varepsilon_y^0 = 0$
$\varepsilon_{xx} = \varepsilon_x^0 - z\,k_x = 2.6009\ 10^{-3}$
$\varepsilon_{yy} = \varepsilon_y^0 - z\,k_y = -\ 0.2571\ 10^{-3}$

$$\begin{Bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{Bmatrix}^{9} = \left[\mathbf{Q}^*\right]_{0^o}\begin{Bmatrix}\varepsilon_{xx}^0 - zk_x^0\\ \varepsilon_{yy}^0 - zk_y^0\\ \varepsilon_{xy}^0 - zk_{xy}^0\end{Bmatrix} = \begin{Bmatrix}37.086\\ 1.299\\ 0\end{Bmatrix}\frac{\mathrm{N}}{\mathrm{mm}^2}$$

The upper surface of layer 1
Data: $z = 7.6$ mm, $\varepsilon_x^0 = \varepsilon_y^0 = 0$
$\varepsilon_{xx} = \varepsilon_x^0 - z\,k_x = 2.1963\ 10^{-3}$
$\varepsilon_{yy} = \varepsilon_y^0 - z\,k_y = -0.2172\ 10^{-3}$

$$\begin{Bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{Bmatrix}^{7.6} = \left[\mathbf{Q}^*\right]_{0^o}\begin{Bmatrix}\varepsilon_{xx}^0 - zk_x^0\\ \varepsilon_{yy}^0 - zk_y^0\\ \varepsilon_{xy}^0 - zk_{xy}^0\end{Bmatrix} = \begin{Bmatrix}31.318\\ 1.098\\ 0\end{Bmatrix}\frac{\mathrm{N}}{\mathrm{mm}^2}$$

Calculations for variant II
The bottom surface of layer 1
Data: $z = 9$ mm, $\varepsilon_x^0 = \varepsilon_y^0 = 0$
$\varepsilon_{xx} = 3.0484\ 10^{-3}$
$\varepsilon_{yy} = -0.2031\ 10^{-3}$

$$\begin{Bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{Bmatrix}^{9} = \begin{Bmatrix}3.490\\ -1.027\\ 0\end{Bmatrix}\frac{\mathrm{N}}{\mathrm{mm}^2}$$

The upper surface of layer 1
Data: $z = 7.6$ mm, $\varepsilon_x^0 = \varepsilon_y^0 = 0$
$\varepsilon_{xx} = 2.574\ 10^{-3}$
$\varepsilon_{yy} = -0.1715\ 10^{-3}$

$$\begin{Bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{Bmatrix}^{7.6} = \begin{Bmatrix}2.947\\ -0.867\\ 0\end{Bmatrix}\frac{\mathrm{N}}{\mathrm{mm}^2}$$

The other results of calculations for normal stresses for both plywood variants in individual layers are analogous, while the results for overall calculations are presented in graphs in Figures 7 and 8.

4 NUMERICAL CALCULATIONS
4. MATEMATIČKI IZRAČUNI

Numerical analysis of the two plywood model variants was based on the Finite Element Method (FEM) using a professional Algor ® Version 13.08 WIN programme. The concepts for the fundamentals and application of FEA are described in detail in literature (Zienkiewicz and Taylor, 1988). Components of laminate elements are modelled using finite elements, which disregard edgewise changes in mechanical parameters of the layers. In the simulation, the material parameters along with load values and restrain conditions were assumed to be identical as in analytical calculations. When creating numerical models, an orthotropic material model was assumed, which was subjected to physical digitization using 8-node Linear Brick Elements as spatial finite elements (Smardzewski, 1998; Spyrakos, 1994; Tanakut *at al.*, 2014;). The numerical model was composed of 1485 nodes with a total number of 1040 finite elements. Results of the numerical analysis were analyzed using the program presented in Figures 3-4 and 5-6. Images of displacement and stress distribution in the form of bitmaps are described as maximum in the middle of the specimen span. In this model, a lack of displacement between the model components was assumed.

5 RESULTS AND DISCUSSION
5. REZULTATI I RASPRAVA

Experimental tests and analytical calculations including the numerical simulation in the 3-point bending test provided data on strength properties of a wood-based composite material (Tables 2 and 3 and Figures 3 and 5). Results for both plywood variants present markedly different stress distributions in its individual layers, resulting in varied bending strength properties. This was confirmed in empirical, analytical and numerical studies. It may be observed that stress

Figure 3 Values of vertical displacement (mm) in the model of plywood variant I
Slika 3. Vrijednosti vertikalnog pomaka (mm) u modelu za furnirsku ploču varijante I.

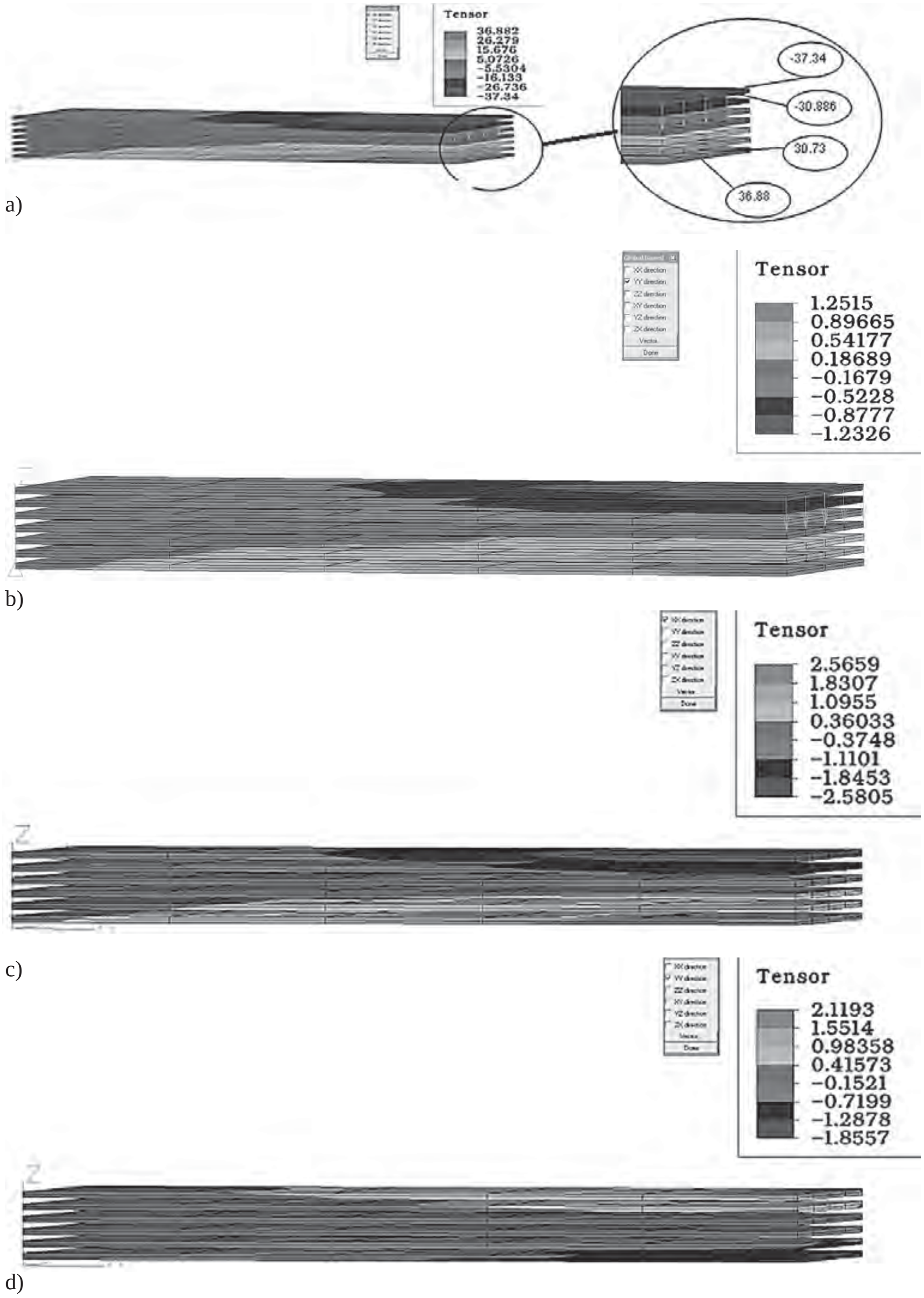

Figure 4 Stress distribution in layers at cross-section of plywood FEM model variant I: a), b) normal stresses σ_{xx} N/mm^2 and σ_{yy} N/mm^2 in plywood layers oriented at $\alpha=0^o$, c), d) normal stresses σ_{xx} N/mm^2 and σ_{yy} N/mm^2 in plywood layers oriented at $\alpha=90^o$
Slika 4. Raspodjela naprezanja u slojevima na poprečnom presjeku furnirske ploče, FEM model varijante I.: a), b) normalna naprezanja σ_{xx} N/mm^2 i σ_{yy} N/mm^2 u slojevima furnirske ploče orijentiranima pri $\alpha = 0°$, c), d) normalna naprezanja σ_{xx} N/mm^2 i σ_{yy} N/mm^2 u slojevima furnirske ploče orijentiranima pri $\alpha = 90°$

Figure 5 Values of vertical displacement (mm) in plywood model variant II

Slika 5. Vrijednosti vertikalnog pomaka (mm) u modelu za furnirsku ploču varijante II.

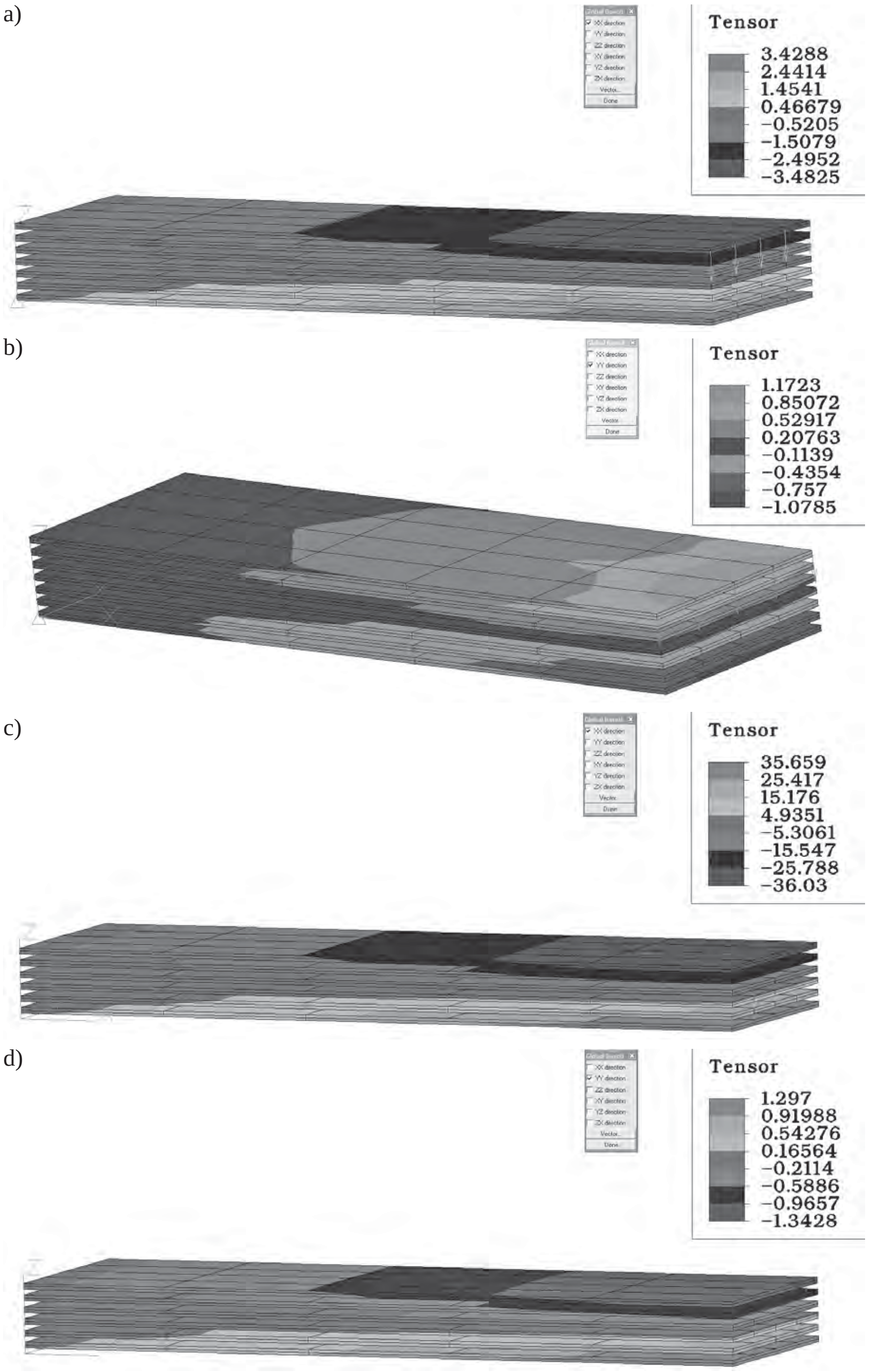

Figure 6 Stress distribution in layers at cross-section of plywood FEM model variant II: a), b) normal stresses σ_{xx} N/mm^2 and σ_{yy} N/mm^2 in plywood layers oriented at α=90^o, c), d) normal stresses σ_{xx} N/mm^2 and σ_{yy} N/mm^2 in plywood layers oriented at α=0^o

Slika 6. Raspodjela naprezanja u slojevima na poprečnom presjeku furnirske ploče, FEM model varijante II.: a), b) normalna naprezanja σ_{xx} N/mm^2 i σ_{yy} N/mm^2 u slojevima furnirske ploče orijentiranima pri α = 90°, c), d) normalna naprezanja σ_{xx} N/mm^2 i σ_{yy} N/mm^2 u slojevima furnirske ploče orijentiranima pri α = 0°

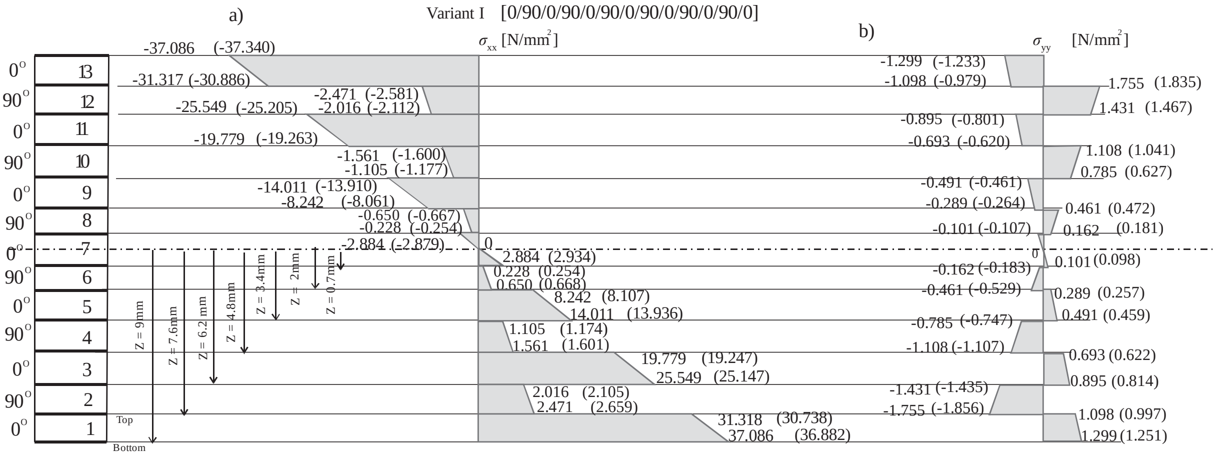

Figure 7 Graphic presentation of edgewise normal stresses in the linear range for plywood variant I: a) σ_{xx} N/mm^2, b) σ_{yy} N/mm^2 (Values given refer to numerical calculations-FEM)

Slika 7. Grafički prikaz normalnih naprezanja na rubovima u linearnom rasponu za furnirsku ploču varijante I.: a) σ_{xx} N/mm^2, b) σ_{yy} N/mm^2 (navedene se vrijednosti odnose na matematičke izračune – FEM)

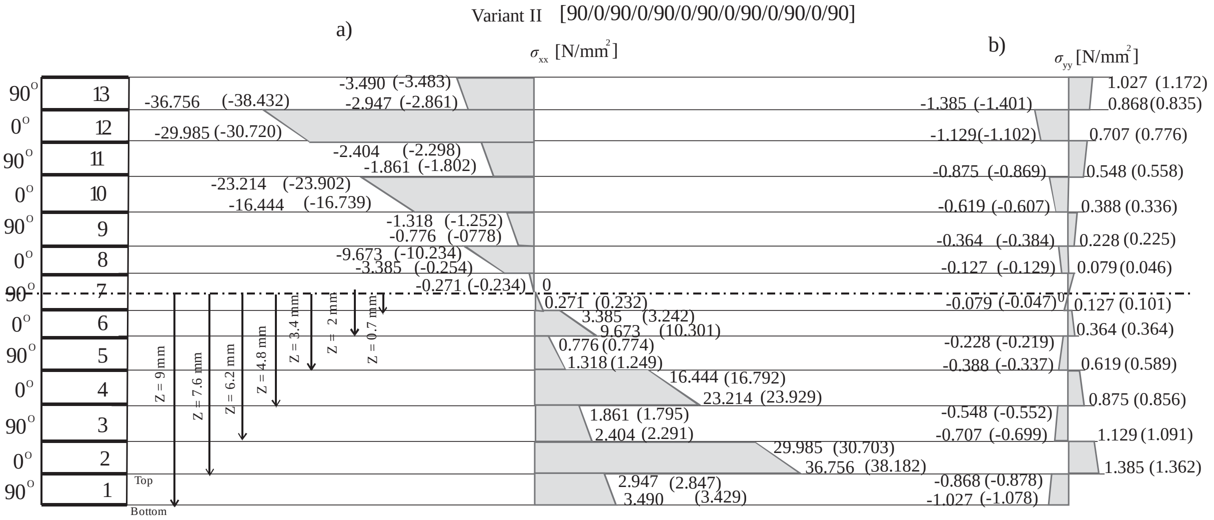

Figure 8 Graphic presentation of edgewise normal stresses in the linear range for plywood variant II: a) σ_{xx} N/mm^2, b) σ_{yy} N/mm^2 (Values given refer to numerical calculations-FEM)

Slika 8. Grafički prikaz normalnih naprezanja na rubovima u linearnom rasponu za furnirsku ploču varijante II.: a) σ_{xx} N/mm^2, b) σ_{yy} N/mm^2 (navedene se vrijednosti odnose na matematičke izračune – FEM)

distribution within the range of elastic deformation is linear in layers with an identical grain orientation. The edgewise distribution of normal stresses σ_{xx}, σ_{yy} is linear; however, it varies between veneers depending on their mechanical properties. Estimated values are almost identical. Slight discrepancies were observed in the distribution of normal stresses in the middle cross-section of plywood estimated using analytical and numerical methods. Depending on the values of deformation and the modulus of elasticity for individual veneers, stresses change stepwise. It is particularly evident in individual plywood layers (Figures 2, 4 and 6). Plywood models with more veneers in their structure, that run parallel to the span of the loaded panel, have greater values of bending strength MOR and modulus of elasticity in bending MOE (Table 2). The differences in the values of bending strength in different directions of the plywood panel are a result of the orientation of wood fibres in the plywood structure in relation to the direction of the action of bending moment. This means that the orientation of veneers in the plywood structure has a direct impact on plywood bending strength. The bending strength of wood is greater in the direction of wood fibres. The image of experimental failure of selected samples for both plywood variants in the bending test is presented in photographs (Figure 9). The character of failure is primarily dependent on the applied veneer orientation, particularly that of outer layers. The produced damage indicates that short-term strength is exceeded in lower plies. Lengthwise fibre effort in cross-bands (α=0° variety I, Figure 9a) exceeded tensile strength with fragmentary loosening of bottom veneers. In turn, in veneers of variant II (crossband angle α=90°, Figure 9b), lignin in the veneer was damaged as a result of their delamination. Moreover, fibres in adjacent lower veneers were partially broken and a comparable interlayer failure was observed.

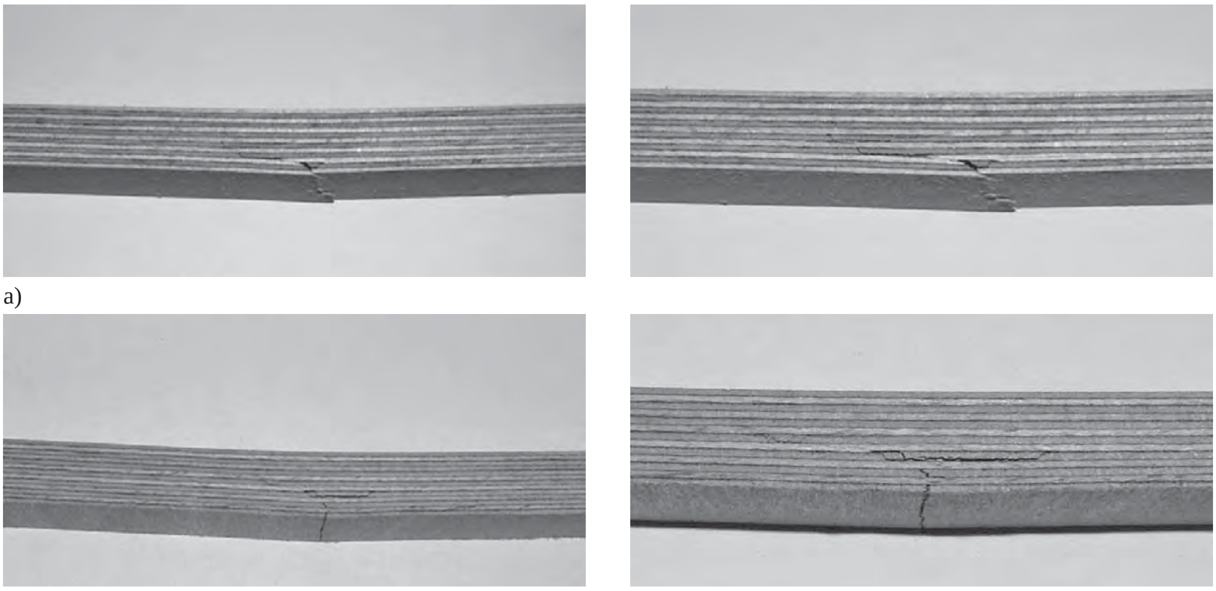
a)
b)

Figure 9 Failure variants of test specimens for the determination of bending properties of plywood: a) variant I, b) variant II
Slika 9. Varijante loma ispitivanih uzoraka pri određivanju savojnih svojstava furnirske ploče: a) varijanta I., b) varijanta II.

6 CONCLUSIONS
6. ZAKLJUČAK

Based on the analyses, it may be stated that the adoption of the thin plate bending theory including Kirchhoff's hypothesis in analytical calculations confirms its applicability in such structures. For this reason, it may be assumed that the method adopted to determine the distribution of normal stresses in the multi-layer wood-based laminated material, including orthotropic material properties, is appropriate for practical analyses of multi-layer systems. This confirms the thesis included in the research hypothesis that the load-bearing capacity of plywood is dependent on the configuration of its individual layers, which was confirmed when evaluating plywood displacement in both empirical and numerical analyses. This is particularly related to a detailed analysis of the distribution of stresses and deformations in a multi-layer wood-based material subjected to elastic bending. The stresses σx, σy are different because of the values of the deformation are different on directions x and y, respectively, and different stresses in the elastic range are the result of diversified elasticity modules of veneers in the direction parallel and perpendicular to the grain.

In view of the above data, these methods need to be considered when designing plywood structures, particularly in terms of loading direction. Unfortunately, the computational process is more complex in comparison to other methods. Nevertheless, it provides more detailed results, particularly at the non-axial (arbitrary) layer configuration, when shear stresses need to be considered. Such an analysis is significantly supplemented when using FEM. The consistency of numerical and experimental results shows that costly failure tests may be replaced by non-destructive computer methods. However, for the results to be fully consistent with the actual values, it is necessary to improve the model and adopt correct boundary conditions.

From the mechanical point of view, an arbitrary configuration of layer orientation, next to the type of used material, in the analysis of laminated composites is a factor determining how properties of individual layers influence properties of the entire composite material.

7 REFERENCES
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Influence of Finishing Materials on Viscous Elastic Properties of Wooden Structures

Utjecaj premaznih materijala na viskoelastična svojstva drvenih elemenata

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ABSTRACT • *In this study, the effect of finishing process on the mechanical properties of oak and pine wood elements were investigated. A special test stand was used for this purpose. Specimens were divided into subgroups, the resonance frequency of the specimens was determined (when they vibrate in mode of a theoretic isotope beam), and the modulus of elasticity (MOE) and damping coefficient were estimated. It was determined that MOE of oak and pine specimens was 8415-10570 MPa and 8220-14104 MPa, respectively, while damping coefficients were 0.014-0.019 r. u. and 0.013-0.026. Afterwards, some specimens were varnished (pentaftal varnish was used), while the specimens from others subgroups were oiled (water-based outdoor wood oil was used) and after each processing step, the viscous elastic properties of the specimen were recorded. The specimens were finished four times – first, one side was finished in two layers, and then the other side. For the determination of elastic properties of the finishing materials, films were prepared separately. The film formation was carried out by casting liquid on a smooth, siliconised surface of a test panel. The tensile test was carried out using the universal testing machine. It was established that MOE of films varied in the range of 4-7 MPa. After the varnishing process, the MOE of oak and pine elements decreased by 5 % and 7 %, respectively, while the damping coefficient decreased (in varnish case) by 60 %. The impact of oil on viscous elastic properties of the specimens was quite marginal.*

Keywords: *oak wood, pine wood, modulus of elasticity, damping coefficient, finishing materials, pentaftal varnish, wood oil*

SAŽETAK • *U radu je istraživan utjecaj procesa površinske obrade na mehanička svojstva hrastovine i borovine. Za istraživanje je pripremljeno posebno postolje. Uzorci su podijeljeni u dvije podskupine, utvrđena je njihova rezonantna frekvencija (kada vibriraju u modu teorijskog snopa izotopa) te su procijenjeni modul elastičnosti (MOE) i koeficijent prigušenja uzoraka. Utvrđeno je da je MOE uzoraka od hrastovine 8415 – 10 570 MPa, uzoraka od borovine 8220 – 14 104 MPa, a koeficijent prigušenja iznosio je 0,014 – 0,019 r. u., odnosno 0,013 – 0,026. Nakon toga dio uzoraka je lakiran (upotrijebljen je pentaftalni lak), a uzorci iz druge podskupine premazani su uljem (uljem na bazi vode za vanjsku primjenu). Nakon svakog procesa obrade uočena su viskoelastična svojstva uzoraka. Uzorci su premazani ukupno četiri puta – najprije je u dva sloja premazana jedna, a zatim druga strana uzoraka. Za određivanje elastičnih svojstava premaznih materijala posebno su pripremljeni filmovi, i to nalijevanjem premaznog materijala na glatku, silikoniziranu površinu ispitne ploče. Vlačno ispitivanje obavljeno je na*

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univerzalnom uređaju za mehanička ispitivanja. Utvrđeno je da MOE filmova varira u rasponu od 4 do 7 MPa. Nakon lakiranja MOE hrastovih elemenata smanjio se za 5 %, borovih elemenata za 7 %, a koeficijent prigušenja na lakiranim uzorcima smanjio se za 60 %. Ulja su neznatno utjecala na viskoelastična svojstva uzoraka.

Ključne riječi: *hrastovina, borovina, modul elastičnosti, koeficijent prigušenja, premazni materijali, pentaftalni lak, ulje za drvo*

1 INTRODUCTION
1. UVOD

The elements of wood and wood-based materials are widely used in building structures and interior products. The durability of wood for outdoor use is not only affected by climatic factors but also by mechanical properties of wood, which to a large extent depend on the finish. The complex effect of the mechanical and physical properties of wood and environmental factors determines the durability of wooden structures and other wood-based products. Depending on the purpose, wooden structures must exhibit appropriate mechanical properties, which are often subject to legislation, building regulations and standards. In some cases, the structures must be elastic and resistant to various mechanical loads, in other cases, on the contrary, they must be able to dampen vibrations and sounds, as well as have inhibitory properties (Forssén *et. al.*, 2008; Botterman *et. al.*, 2018).

The mechanical properties of these kinds of structures are determined by the mechanical properties of their individual elements and the composition method of their interconnection (Taghiyari *et al.*, 2017; Souza da Rosa *et. al.*, 2017; Albrektas and Vobolis, 2003; Albrektas and Vobolis, 2004). It is known that the modulus of elasticity (MOE) and damping coefficient of a glued wood panel depends on the properties of the glued wood scantlings (Albrektas and Vobolis, 2003; Albrektas and Vobolis, 2004). Once a scantling, which is characterised by a higher MOE, is glued to the panel, the MOE of the whole panel becomes higher, and vice versa. A lower MOE and a higher damping coefficient of the glued product than the average value of the total number of glued scantlings show that the product probably contains defects, e.g. that the seams were poorly glued together, etc.

The viscous elastic properties of the elements of wooden structures can be altered, e.g. by changing the surface area of the element (i.e. by creating grooves, notches, etc.) (Ono, 1993; Molin *et. al.*, 1984; Molin *et. al.*, 1988), by soaking them (Endo *et. al.*, 2010) and using finishing materials of different properties.

It was determined that different components of wooden composites and manufacturing technology can also have an effect on their mechanical properties (Taghiyari *et al.*, 2017).

Also, overlays have a large effect on the mechanical properties of particleboard (Vobolis and Albrektas, 2012). Depending on the orientation/direction of the overlay material (especially on sliced veneer of natural wood), the MOE of a finished particleboard can be increased or decreased in the direction concerned. This can be explained by the fact that the viscous elastic properties of natural wood can vary up to 20 times in different fibre directions.

Nowadays, the market offers various finishing materials of wood. Therefore, there is a lack of comprehensive research that evaluates the influence of finishing materials on the properties of wood-based products.

The aim of this study is to evaluate the influence of finishing materials on viscous elastic properties of wooden structures and their elements.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The research study used conditioned specimens of oak (*Quercus robur*) and pine (*Pinus sylvestris*) wood, which were stored in a climatic chamber for 336 hours at a temperature of 20 ± 1 °C, and a relative humidity of 60 ± 2 % (standard EN 408, chapter 8). The dimensions of the researched specimens were 700 mm ×100 mm ×16 mm, with moisture content ranging between 10.4 and 11.2 % (standard EN 13183-2). According to the standard EN 323, the density of the specimens was measured and the results showed that oak wood had a density ranging between 650 and 760 kg/m^3, whereas the density of pine wood ranged between 460 and 570 kg/m^3.

For finishing the specimens, two types of material were used: pentaftal varnish and water-based outdoor wood oil, based on water and natural oils. The amount of non-volatile substances of the varnish is 46 ± 3 %, whereas the amount of non-volatile substances of the oil is 21 %. The pentaftal varnish, which is based on alkyd resins, covers the wood surface with an elastic film that suppresses liquids; however, it allows steam to penetrate and it is resistant to atmospheric agents. The water-based wood oil soaks into the wood surface and serves as protection from humidity and dirt.

A special test stand (Figure 1) was used to determine the MOE and damping coefficient on the basis of non-destructive testing (transverse resonant vibrations) method, which also allowed assessing the mechanical properties of the specimens (Albrektas and Vobolis, 2003; Albrektas and Vobolis, 2004). Loudspeaker 4, controlled by the generator of electric oscillations 5, excites resonance oscillations of the specimen 1. For this purpose, the frequency of the generator's oscillations is changed. These oscillations are recorded by the sensor 6, fixed on the specimen. Their amplitude is measured using device 7. To ascertain the direction of specimen bending, the phase of oscillations is measured by a phase meter 9. The phase meter receives the signal from the measuring device and generator. For a more accurate ascertainment of the form of bending, several zones of specimen were chosen. In these zones

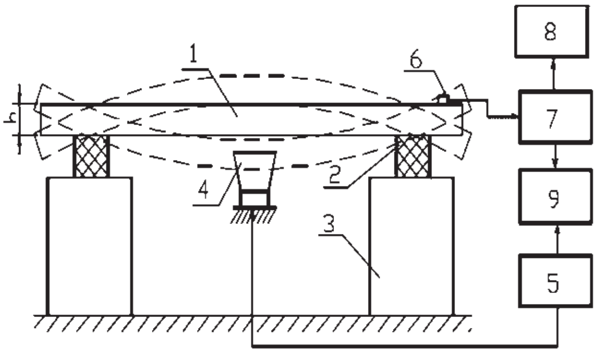


Figure 1 Scheme of test stand:1 - specimen; 2 - vibration damping material (foam rubber); 3 - massive supports; 4 - loudspeaker; 5 - vibration generator; 6 - sensor; 7 - measuring instrument; 8 - oscilloscope; 9 - phase meter
Slika 1. Shema ispitnog postolja: 1 – uzorak; 2 – materijal za prigušivanje vibracija (pjenasta guma); 3 – masivni nosači; 4 – zvučnik; 5 – generator vibracija; 6 – senzor; 7 – mjerni instrument; 8 – osciloskop; 9 – fazni mjerač

the measuring element was fixed and oscillations were recorded, i.e. their amplitude and phase were measured. By determining the corresponding (first mode) frequency, a MOE is calculated. By determining two other frequencies, when the vibrational amplitude decreases by 0.7 times, the damping coefficient is calculated. The studies were performed at a frequency of 20-2000 Hz.

The MOE was calculated by the following Eq. 1 (Timoshenko *et al*., 1985):

$$E = \frac{f_{\text{rez}}^2 \cdot 4\pi^2 \cdot \rho \cdot s \cdot l^4}{I \cdot A^2} \qquad (1)$$

Where: E – modulus of elasticity, f_{rez} – frequency of transverse vibrations, ρ – density of wood, s – cross-sectional area, l – beam length, I – cross-sectional moment of inertia, A – method of fastening represented by a coefficient.

The viscous properties of studied specimens were evaluated by damping coefficient, calculated by the following Eq. 2:

$$tg\delta \approx \frac{\Delta f}{f_{\text{rez}}} \qquad (2)$$

Where: f_{rez} – frequency of transverse vibrations, Δf – frequency bandwidth, when the amplitude of vibrations decreases by 0.7 times.

In order to evaluate the influence of finishing materials on viscous-elastic properties of wooden structures, the specimens were covered with two types of products for wooden surfaces. The finishing materials were applied to the specimens following the recommendations of the manufacturers. Prior to application, the specimens were stored at 23 ± 2 °C temperature and 50 ± 5 % relative humidity for 24 h. The surface of the specimen intended for covering was clean and free from distortion and other defects. The finishing material was applied with a brush in 2 layers (stepwise) on both sides of the specimen. After each application of the layer, the specimen was dried for 24 hours under the above temperature/humidity conditions in accordance with manufacturer's instructions without prejudice to EN 23270.

For the determination of elastic properties of finishing materials, films were prepared separately, consisting of wood varnish and oil, which were used for the study. The film was formed by casting liquid on a smooth, siliconised surface of a test panel. The casting was dried for 7 days at 23 ± 2 °C temperature and 50 ± 5 % relative air humidity. The film formation process was completed by removing it from the test surface. Afterwards, the film-coated specimens were cut to determine the modulus of elasticity. Ten specimens of varnish and the same number of oil specimens were cut for tensile test. The uniformity of film specimens was ensured by measuring the thickness, which was on average 0.30 mm in the case of varnish and 0.19 mm in the case of oil. The tensile test was carried out using the universal testing machine BTI FB-050 TN (Zwick). The gripping distance was 100 mm and the constant speed for the grips was 100 mm/min.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

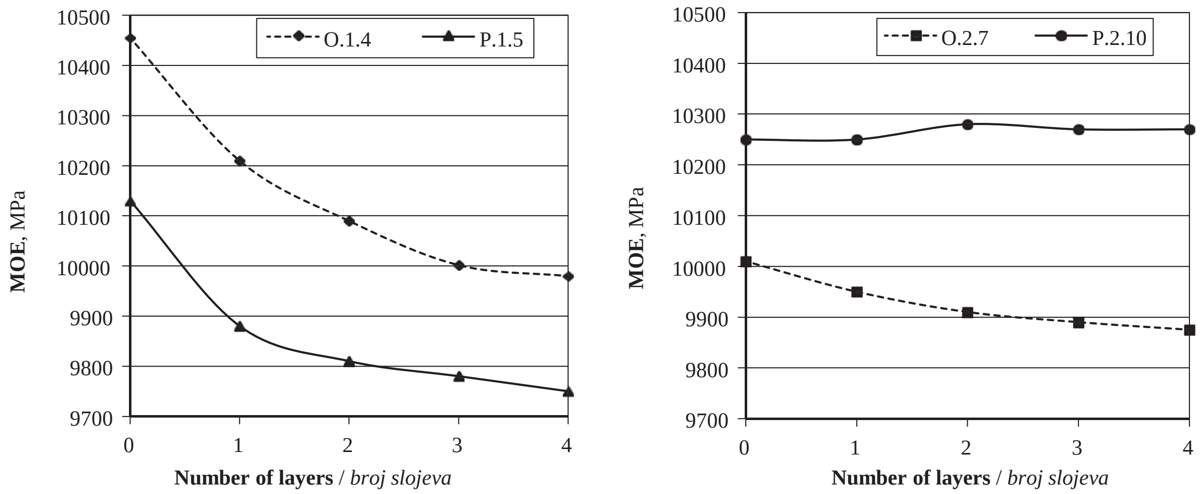
After completing the conditioning process, the specimens were divided into subgroups (oak specimens were divided into O.1 and O.2, whereas pine specimens were divided into P.1 and P.2), the resonance frequency of the specimens was determined (when they vibrate in mode of a theoretic isotope beam) (Timoshenko *et al*., 1985), and the MOE and damping coefficient were estimated. The results are displayed in Table 1.

The estimated values of the MOE and damping coefficient of wood correspond to the values that are well-known in literature (Wagenführ, 2000; Wood Handbook, 2010).

The analysis of the viscous properties of the finishing films showed that the MOE of wood varnish and oil varies in the range of 4-7 MPa with a variation of

Table 1 Values of resonance frequency, MOE and damping coefficient of specimens before finish was applied
Tablica 1. Vrijednosti rezonantne frekvencije, modula elastičnosti i koeficijenta prigušenja uzoraka prije površinske obrade

Subgroup *Podskupina*	**Resonance frequency,** Hz *Rezonantna frekvencija,* Hz		**MOE,** MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u.	
	Min	Max	Min	Max	Min	Max
O.1	114	142	8415	10570	0.014	0.031
O.2	118	130	8520	10010	0.016	0.019
P.1	132	176	8220	14104	0.013	0.026
P.2	136	159	8650	12430	0.013	0.017



a) b)

Figure 2 Variations of specimens MOE by increasing the number of layers of the finishing material: a) varnish finish; b) oil finish; these are unique identification numbers of specimens –O.1.4, P.1.5, O.2.7, P.2.10.

Slika 2. Varijacije modula elastičnosti uzoraka s povećanjem broja slojeva premaznog materijala: a) lak; b) ulje; oznake uzoraka su O.1.4, P.1.5, O.2.7, P.2.10.

10.6 %. These values correspond to the values that are well-known in literature (Mironeet *et al*., 2004; Ghaznavi *et. al*., 2013; Wawro and Kazimierczak, 2008).

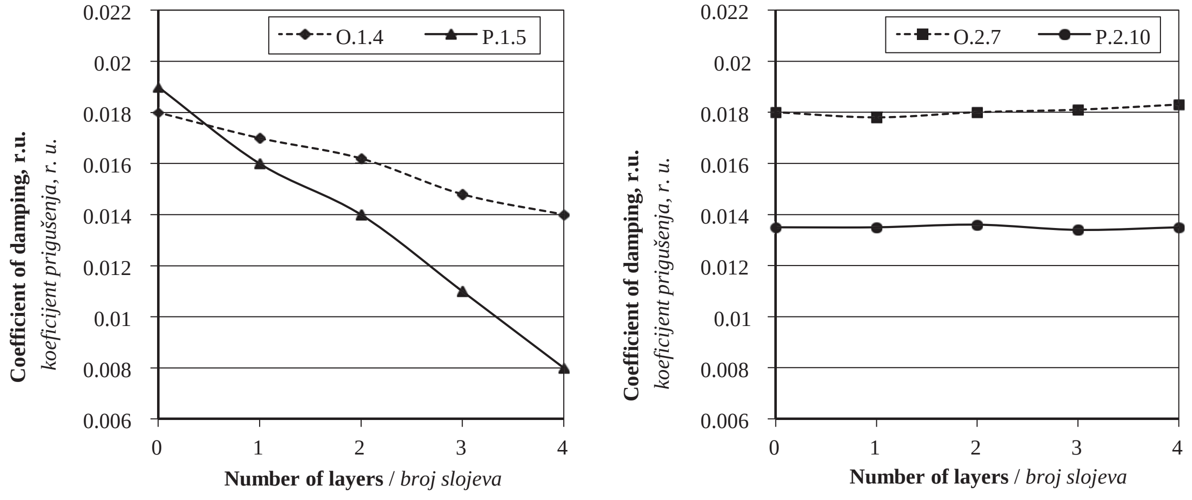
Afterwards, the specimens from subgroups O.1 and P.1 were varnished, while the specimens from subgroups O.2 and P.2 were oiled using the test finishing materials, and after each processing step, the viscous elastic properties of the specimen were recorded. Each subgroup is appropriately represented by the variation of the MOE and damping coefficient of the specimens in Figures 2 and 3.

The values of the mechanical properties of all the specimens before and after the finishing treatment are provided in Tables 2 and 3.

According to these results (Table 2), it was estimated that between the minimum and maximum value in the same group of specimens, the MOE of oak wood specimens before and after varnish finish can vary up to 23 %, whereas the results before and after oil finish show that the difference between the maximum and minimum value is no larger than 15 %. Before using the varnish finish on oak wood specimens, the values of the damping coefficient in the same group can vary more than 50 %. After using the varnish finish, the difference between the minimum and maximum damping coefficient was reduced to 37 %. The use of this finishing treatment reveals that the damping coefficient of the specimens was reduced in all cases. The outcome was a little different in the group that was treated with oil finish. After applying the oil finish, the damping ratio was practically left unchanged, and in some cases, the results showed a slight increase or decrease.

The equivalent results were retrieved by analysing the tests results of pine wood specimens. The use of oil finish on pine wood specimens proved to have no effect on the damping coefficient, since in nine out of ten cases, after applying the oil finish, the damping coefficient of the specimens remained unchanged.

It was determined that, after the varnishing process, the mass of oak wood specimens increased by 9-14



a) b)

Figure 3 Variations of damping coefficient of specimens by increasing the number of layers of the finishing material: a) varnish finish; b) oil finish

Slika 3. Varijacije koeficijenta prigušenja uzoraka s povećanjem broja slojeva premaznog materijala: a) lak; b) ulje

Table 2 Mechanical properties of oak wood specimens before and after the finishing treatment
Tablica 2. Mehanička svojstva uzoraka hrastovine prije i nakon površinske obrade

Specimen No. *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u.		**Speci-men No.** *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u	
	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*		Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*	Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*
O.1.1	9733	9380	0.031	0.017	O.2.1	9505	9215	0.018	0.019
O.1.2	8655	8390	0.030	0.017	O.2.2	8945	8610	0.017	0.018
O.1.3	10010	9720	0.023	0.012	O.2.3	9775	9420	0.017	0.018
O.1.4	10455	9980	0.023	0.019	O.2.4	8652	8550	0.018	0.018
O.1.5	9352	8883	0.018	0.014	O.2.5	9595	9230	0.019	0.020
O.1.6	8415	8002	0.017	0.014	O.2.6	8883	8790	0.018	0.018
O.1.7	10570	10357	0.014	0.012	O.2.7	10010	9875	0.018	0.018
O.1.8	8942	8758	0.025	0.017	O.2.8	8995	8850	0.018	0.018
O.1.9	10251	10040	0.015	0.012	O.2.9	8520	8350	0.019	0.018
O.1.10	9522	9320	0.016	0.014	O.2.10	8811	8720	0.016	0.017

■ – the maximum group value / *najveća vrijednost skupine,* □ – the minimum group value / *najmanja vrijednost skupine*

Table 3 Mechanical properties of pine wood specimens before and after finishing
Tablica 3. Mehanička svojstva uzoraka borovine prije i nakon površinske obrade

Speci-men No. *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u.		**Specimen No.** *Broj uzorka*	**MOE**, MPa		**Damping coefficient, r. u.** *Koeficijent prigušenja,* r. u	
	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*	Before varnish finish *Prije lakiranja*	After varnish finish *Nakon lakiranja*		Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*	Before oil finish *Prije uljenja*	After oil finish *Nakon uljenja*
P.1.1	14104	13790	0.017	0.011	P.2.1	9320	9305	0.014	0.014
P.1.2	11810	11500	0.019	0.013	P.2.2	12430	12425	0.013	0.022
P.1.3	13260	12950	0.019	0.013	P.2.3	9290	9305	0.014	0.014
P.1.4	12720	12450	0.015	0.010	P.2.4	8880	8830	0.016	0.016
P.1.5	10130	9750	0.019	0.008	P.2.5	8725	8705	0.014	0.014
P.1.6	9082	8450	0.013	0.007	P.2.6	12210	12190	0.015	0.015
P.1.7	13070	12130	0.013	0.009	P.2.7	11510	11480	0.013	0.013
P.1.8	9687	9315	0.026	0.019	P.2.8	8950	8915	0.015	0.015
P.1.9	8220	8045	0.015	0.011	P.2.9	8650	8625	0.017	0.017
P.1.10	15050	14210	0.024	0.012	P.2.10	10250	10270	0.014	0.014

■ – the maximum group value / *najveća vrijednost skupine,* □ – the minimum group value / *najmanja vrijednost skupine*

g (on average approximately 1.5 % of the specimen mass). In all cases, the MOE decreased by 1-5 %, whereas the damping coefficient decreased by 15-50 %.

The results show that the mass of the varnished pine wood specimens increased by 13-21 g (on average approximately 3.3 % of the specimen mass). A higher mass change also implied a change in the mechanical properties of the specimens – the MOE decreased by 2-7 %, while the damping coefficient decreased by 30-60 %. Pine wood could absorb more varnish, since it has a lower density and its capillary system can encompass a higher relative volume of the whole specimen.

It was established that the mass of the oiled oak wood specimens increased by 7 g, while in the case of pine, it increased by only 4 g, i.e. it altered less than 1 % of the specimen mass. It can be assumed that the impact of oil on the viscous elastic properties of the specimens was quite marginal. The MOE of oak specimens decreased by 1-4 %, the damping coefficient increased by 5 %, whereas the MOE and damping coefficient of pine specimens were ultimately left unchanged – the values varied within a 1 % range.

A clear reliance of the impact of the finishing material on a varied density of the same type of specimens was not determined. Also, there is no evidence of a linear relationship between the amount of finishing material for the specimen finishing procedure and the change of the viscous elastic properties. Moreover, there was also the influence of other factors, such as the uniformity of coating thickness of the finish, the depth of penetration, etc.

The decrease of the MOE of the finished specimens can be explained by taking into account that the

MOE of the finishing materials is significantly lower (4-7 MPa) than that of natural wood (8220-14104 MPa) (Table 1). Furthermore, the finishing materials, especially varnish, can improve the acoustic properties of wood elements (Ono, 1993).

4 CONCLUSIONS
4. ZAKLJUČAK

It was established that the finishing materials can alter the viscous elastic properties of wooden structure elements. Moreover, this effect is proportional to the amount of used material but not directly depend on the mass of the finishing materials. When the varnish formed 2 % (oak) - 5 % (pine) of sample mass, the MOE decreased by 5-7 percent, respectively. The damping coefficient in these cases decreased to 30-60 percent. The oil formed a smaller part of the specimen and its influence on mechanical properties was lower.

It was estimated that the finishing material (oil and varnish) amounted to a considerable fraction of the total mass of the finished specimen (at least 1.5 %), and in all cases, its modulus of elasticity and damping coefficient decreased. This can be explained by the fact that the modulus of elasticity of finishing material is lower in relation to wood lengthwise fibre.

It was determined that a substantial amount of the finishing material (varnish) can improve the acoustic properties of a wooden element. An unvarnished wooden structure can dampen the sound more effectively than a varnished one.

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Tarrietia utilis (Sprague) Sprague

NAZIVI

Tarrietia utilis (Sprague) Sprague naziv je drva botaničke vrste iz porodice *Malvaceae*. Trgovački su nazivi te vrste također: niangon (Francuska, Nizozemska, Njemačka, Šri Lanka, Velika Britanija); wismore, wishmore (Nigerija, Liberija, Velika Britanija), kekosi, kouanda, yangon (Šri Lanka); attabini, niankuma, nyankom (Gana); ogoué, engongkom (Gabon); yawi (Siera Leone).

NALAZIŠTE

Stabla *Tarrietia utilis* nalazimo u zapadnoj Africi, i to od Siera Leonea, preko Liberije, Obale Bjelokosti i Gane do Gabona. Rastu u tropskim nizinskim prašumama. Mogu se naći i na sušnijim i močvarnim mjestima.

STABLO

Visina stabla doseže 20 – 30 (40) metara. Čisto deblo dugo je 10 (18) m, a prsni mu je promjer od 0,5 do 0,9 m. Debla su valjkastog oblika. Kora drva je ispucana, bjelosiva ili smećkasta. U mladih je stabala ružičasta, a sa starenjem potamni. Debljina kore je 1 – 2 cm.

DRVO

Makroskopska obilježja

Drvo je rastresito porozno. Bjeljika je bjelkasta do crvenkastosiva, a široka je oko 6 cm. Srž drva je svjetlocrvenkastosmeđa do tamnocrvenkastosmeđa, narančastih promjenjivih tonova. Granica goda je uočljiva. Pore i drvni traci vidljivi su povećalom.

Mikroskopska obilježja

Traheje su pretežito pojedinačno raspoređene, ali mogu biti i u paru ili u skupinama. Promjer traheja je 215...260...320 mikrometara, gustoća im je do 3 traheje na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi oko 13 %. Traheje su često ispunjene tamnosmeđim sržnim tvarima. Aksijalni parenhim drva apotrahealno je rastresit, apotrahealno koncentričan, paratrahealno vazicentričan, katno raspoređen. Volumni je udio aksijalnog parenhima oko 14 %. Staničje drvnih trakova je heterogeno. Drvni su traci nepravilno katno raspoređeni. Pojedini su visoki 450...900...1300 mikrometara, a širina im je 24...90...150 mikrometara, odnosno 1...5...10 stanica. Gustoća drvnih trakova je 3...5...6 na 1 mm. Njihov volumni udio iznosi oko 17 %. Stanice drvnih trakova ispunjene su dobro vidljivim tamnim sadržajem. Drvna su vlakanca libriformska, a katkad su to i vlaknaste traheide. Dugačka su 500...1100...2050 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 1,8...2,6...4,1 mikrometara, a promjeri njihova lumena su 8,0...14,0...26,0 mikrometara. Volumni je udio vlakanaca oko 56 %.

Fizička svojstva

Gustoća apsolutno suhog drva, ρ_o	570...600 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	630...720 kg/m^3
Gustoća sirovog drva, ρ_s	900...950 kg/m^3
Poroznost	oko 60 %
Radijalno utezanje, β_r	2,9...3,7...4,5 %
Tangentno utezanje, β_t	7,6...8,5...9,2 %
Volumno utezanje, β_v	10,0...12,9...14,0 %

Mehanička svojstva

Čvrstoća na tlak	50...60...68 MPa
Čvrstoća na vlak, paralelno s vlakancima	oko 130 MPa
Čvrstoća na vlak, okomito na vlakanca	1,9...2,2...2,7 MPa
Čvrstoća na savijanje	87...109...140 MPa
Tvrdoća prema Brinellu, paralelno s vlakancima	38 do 50 MPa
Modul elastičnosti	9,6...11,9...13,2 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro pili, lijepi, buši, brusi i polira. Meržne tvari pri obradi drva mogu zatupljivati alate i otežati površinsku i finalnu obradu.

Sušenje

Drvo se normalno suši, ali ima veliku sklonost promjeni oblika i malu sklonosti raspucavanju.

Tanje piljenice s nepravilnom žicom drva izrazito su sklone promjeni oblika. Prije stavljanja u sušionice drvo je preporučljivo prirodno prosušiti.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva *Tarrietia utilis* (Sprague) Sprague slabo je otporna na gljive uzročnice truleži (razred otpornosti 3) i slabo otporna na termite (razred otpornosti M). Srž je slabo permeabilna (razred 4). Po trajnosti pripada razredu 2 i stoga se može koristiti u interijeru. Za upotrebu na otvorenim prostorima drvo je potrebnoprethodno zaštititi._

Uporaba

Drvo se upotrebljava kao furnirsko drvo, služi za izradu kvalitetnog namještaja, vanjske i unutarnje stolarije, kao prednja i stražnja strana uslojenog drva, za izradu podova, stuba (u zatvorenim prostorima) te za unutarnje i vanjske obloge.

Sirovina

Drvo se isporučuje u obliku trupaca dužine 4,0 do 8,0 m, najčešće srednjeg promjera 50 – 80 centimetara.

Napomena

Drvo niangona slično je mahagonijevini i prema tehničkim svojstvima usporedivo je s drvom bukve, iroka, tole, tamnocrvenog merantija ili sipa. Zasada se ne nalazi na popisu ugroženih vrsta međunarodne organizacije CITES, niti na popisu međunarodne organizacije IUCN.

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BIBLIOGRAFIJA ČLANAKA, STRUČNIH INFORMACIJA I IZVJEŠTAJA OBJAVLJENIH U *DRVNOJ INDUSTRIJI*, U VOLUMENU 69 (2018), UDK I ODK

UDK: 630*79 Ekonomska i organizacijska pitanja drvne industrije

doi:10.5552/drind.2018.1711
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UDK: 630*81 Drvo, kora i svojstva

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UDK: 630*812.11 Optička svojstva; 630*812.76 Čvrstoća na vlak

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UDK: 630*812.122 Apsorpcija; 630*812.71 Savijanje; 630*861.15 Smole; 630*863.312 Ploče vlaknatice srednje gustoće

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UDK: 630*812.222 Adsorpcija i desorpcija vode; 630*824.328 Urea smole; 630*824.43 Svojstva ljepljivosti zaštitnog sredstva, usporivača gorenja i dr.

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UDK: 630*812.463 Termička obrada; 630*812.7 Svojstva čvrstoće: općenito (spojevi, konstrukcije, sanduci i dr., međusobno vezani)

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UDK: 630*812.582 Zapaljivost; 674.032.13 *Picea abies* Karst.

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UDK: 630*812.7 Svojstva čvrstoće: općenito; 630*812.1 Optička, akustična, magnetična, frikcijska, termička i električna svojstva

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UDK: 630*812.71 Savijanje; 630*861.232 Ploče iverice

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UDK: 630*813.111 Prirodni lignin; 630*824.328 Urea smole; 630*863.312 MDF ploče

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UDK: 630*812.71 Savijanje; 630*832.282 Uslojeno drvo; 630*847.3 Sušenje s pomoću vakuuma
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UDK: 630*812.791 Čvrstoća držanja čavala i vijaka; 630*863.312 Ploče vlaknatice srednje gustoće

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UDK: 630*813.4 Kemijsko djelovanje topline. Kemija termičkog raspada; 630*874.1 Smole i esencijalna ulja, uključujući terpentin, kolofonij i talino ulje; 674.032.475.4 *Pinus brutia* Ten

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UDK: 630*814.111 Prirodna trajnost. Staro drvo. Fosilno drvo. Utjecaj Sunčevih zraka; 630*829.5 Metode testiranja

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UDK: 630*824.21 Čavli; 630*824.23 Vijci; 630*833.01 Drvo u zgradama i građevinskim konstrukcijama (proizvodnja i upotreba)

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Tony Leiva-Leiva T.; Moya, R.; Navarro-Mora, A.: Kalibracija modela montažnih drvenih zidnih okvira izrađenih od drva *Hieronyma alchorneoides* i *Gmelina arborea* uz pomoć čavala i vijaka, br. 1, str. 3-12.

UDK: 630*832.11 Planiranje i projektiranje. Energetika. Strojevi

doi:10.5552/drind.2018.1736
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UDK: 630*832.28 Proizvodi; 630*812.7 Mehanička svojstva: općenito

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UDK: 630*836.1 Pokućstvo i umjetna stolarija

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UDK: 630*841.5 Zaštita i procesi

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Primjer

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Primjeri

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Ostale publikacije (brošure, studije itd.)

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Web stranice

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

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