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Drago Katović[1], Andrea Katović[2], Alan Antonović[3]

Extraction Methods of Spanish Broom (*Spartium Junceum* L.)

Metode ekstrakcije brnistre ili žuke (*Spartium Junceum* L.)

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ABSTRACT • *Effects of different extraction methods of the Spanish Broom shoots were measured and compared with the purpose of obtaining composite material. The content of cellulose, lignin, pentosan and ash in the Spanish Broom fibers was determined. SEM analyses were performed.*

Keywords: *Spanish Broom fibers, fiber extraction, chemical composition, FTIR, MW*

SAŽETAK • *Mjereni su i uspoređeni učinci različitih postupaka maceracije izbojaka brnistre, radi upotrebe prirodnih vlakana u procesu dobivanja kompozitnih materijala. Uspoređeni su FTIR spektri nekih prirodnih vlakana, kao i FTIR spektri vlakana dobivenih različitim postupcima maceracije. U vlaknima brnistre određen je sadržaj celuloze, lignima, pentosana i pepela. Obavljene su SEM analize izbojka brnistre.*

Ključne riječi: *vlakna brnistre, maceracija, kemijska kompozicija, FTIR, MW*

1 INTRODUCTION
1. UVOD

The use of Spanish Broom and its diverse application has been known in the entire Mediterranean since the ancient times. Already in the ancient Rome, where Spanish Broom fields (*genestium* – or *ager* in later Latin) were cultivated as any other field, and the plant or sprouts were sown in ploughed up furrows, as the Roman agronomist Columella describes. According to Vergil, hedges of Spanish Broom were planted in addition to willow, hazel, elder and other plants. Pliny writes that the sowing and planting of Spanish Broom is crucial for peasants. Amongst other things, its branches provide excellent material for tying vine and young trees. The Greeks, Romans and Carthagians used Spanish Broom as raw material for manufacturing ropes, nets, bags, sails, clothing and for covering roofs, whilst the flower of Spanish Broom produces exquisite honey.

During the '30s of the past century, foresters widely recommended the cultivation of Spanish Broom *(Spartium junceum)* in the coastal karst areas, more precisely M. Anić Ph. D in *The Forest Journal* in 1937 and engineer Stane Benko in his booklet on Spanish Broom, published by the Ministry of Industry and Mining, in Zagreb, 1946. The member of the Institute for Forestry Research Ante Premužić explains the possibility of using Spanish Broom for economic purposes in his report *Systematic cultivation of Spanish broom in our karst areas,* published in the *Forest Journal.* He wrote that diverse biological properties could be put to

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good use for forestation of poor soil of the coastal limestone area since Spanish Broom grows on clay and limestone soil of neutral, acid and alkali reaction. Positive sides of its cultivation were highly praised, giving these studies more of a propaganda character. The use of Spanish Broom along east Adriatic was described in detail in the publications of the Faculty of Philosophy, Zagreb University (Stojanović, 1962). Notwithstanding all that, the application of Spanish Broom, as raw material, is almost forgotten today. The entire activity has been reduced to a few associations more of a tourist significance (Katović *at al*, 2011).

During the past several years the number of scientific work related to the production of Spanish Broom as raw material in the manufacture of composite materials considerably increased (Avella *et al*, 1998; Angelini *et al*, 2000; Gabriele *et al*, 2010; Cerchiara *et al*, 2010 A). The advantage of Spanish Broom over flax and hemp is that it can grow in the most unfavorable limestone soil; it is resilient to draught; and once planted it can be used during a period of up to twenty years, whilst flax and hemp demand high quality soil each year. In the past, natural fibers were not taken into account as reinforcements for polymeric materials because of certain problems associated with their use. The lack of good interfacial adhesion, low degradation temperature, properties variability depending on harvest quality, age and body of the plant, and poor resistance towards moisture make the use of natural fiber reinforced composites less attractive than the synthetic ones. However, the production of composites reinforced with synthetic fibers and matrices (glass, carbon, aramid) requires a large amount of energy, and they are impossible or hard to recycle. Moreover, in case of fire the presence of natural fibers in composites decreases the content of toxic gases resulting from combustion.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Spanish Broom – biological properties
2.1. Brnistra – biološka svojstva

Spanish Broom is a shrub like plant from the family of legumes. It is the only species in the genus *Spartium.* Spanish Broom is a shrub that grows 1–1.5 meters tall and only old examples grow into smaller trees between 4 and 5 meters tall and 15 to 20 centimeters thick. Spanish Broom produces intensively yellow flowers between May and July, and its legumes mature between August and October. Flowers have male and female organs pollinated by insects. It has many flowers, one to two centimeters in diameter that cover hills, turning into a beautiful yellow color, whilst its pleasant fragrance is especially loved by women. Spanish Broom most often grows in fresh and sufficiently moist soil, but it also grows quite well in very dry and rocky soil, stone falls and flood gravel pits. Shade does not suit it. It also has a special feature of xerophile plants. It grows small leaves on its shoots, which it discards during summer and drought and assimilates with long thin shoots, which have nuclei with chlorophyll under the cuticulum. Its roots are deep, and it binds the soil quite well. As a legume plant, it uses symbiosis to bind atmospheric nitrogen in the roots' lumps, thickening and enriching the soil (Bezić *et al*, 2003). After fiber extraction, it can be used in the production of textile fibers, just as hemp and flax. Its habitat is the Mediterranean area of the South Europe, southwest Asia and North West Africa. In Italy, in the Mediterranean area of olive groves, it climbs the altitude of 975 meters. In Turkey, Syria and Palestine, it reaches altitudes of 1,700 meters. It is regarded weed in the USA and New Zealand with a tendency to eradicate it in order to save indigenous plants.

Numerous anatomical adaptations to arid habitat can be noted in the microscopic structure of vegetative organs of Spanish Broom. The xerophytic (xerophytes – plants adapted to dry habitats) adaptation of the leaf is seen in its short life span as well as the transformation of its inner structure, with the dominating parenchyma chain. The top of the stem has taken over the leaf function, whilst the sclerenchyma fiber and conductive elements occupy most of its secondary units (Cerchiara *et al*, 2010 A).

After the maturing of seeds, between mid July and autumn, shoots of the plant are cut with scissors directly near the main tree (Kovačević *et al*, 2010).

2.2 Instruments
2.2. Instrumenti

2.2.1 FTIR (Fourier Transform Infra Red Spectrophotometer)
2.2.1. FTIR (Furierov transformirajući infracrveni spektrofotometar)

The instrument is used in infrared spectroscopy for the identification of unknown material, for determining the ratio of individual components in the sample, its quality and consistency. Infrared beams pass through the sample. Some of the beams are absorbed in the sample and others pass through it, creating a spectrum unique to each element. Perkin-Elmer FT-IR Spectrum 100 was used for the purpose of work. Before the measuring, Spanish Broom samples were turned into powder, using a grinder with an oscillating steel bowl, model MM 400, of the *Retsch* company. The measuring was performed by FTIR spectrometer using ATR technique.

2.2.2 TA (Thermal Analyzer)
2.2.2. TA (termogravimetar)

The pyrolysis characteristics of Spanish broom, hemp and flax were analyzed using a thermogravimetric analyzer PerkinElmer Pyris 1 TGA. The samples, weighing between 4 and 5 mg were stacked in an open platinum sample pan and the experiment was conducted in air atmosphere. All samples for TGA were measured from 50 °C to 800 °C at the heating rate of 10 °C /min.

2.2.3 SEM (Scanning Electron Microscope)
2.2.3. SEM (skenirajući elektronski mikroskop)

Morphological structures of Spanish Broom shoots were recorded with the FE-SEM (Field Emission-Scanning Electron Microscope) of the company

TESCAN, with a steamer and unit for EDX analysis (Energy Dispersive X-Ray Analysis). Before of the microscopic recording, samples were processed for 180 seconds in a steamer with gold and palladium, using operative voltage of 5-15 kV.

2.3 Methods
2.3. Metode istraživanja

The Spanish broom fibers were extracted from the plant branches harvested in Dalmatia (Šibenik area) which contained 35% of humidity in relation to the branches dried under standard conditions.

Fig. 1 clearly shows that Spanish Broom shoots have two basic layers: rigid and woody inner layer, porous in the middle, which makes the plant quite light; and an outer layer, or rather skin consisting of stringy fibers. Here, the lignin is a typical chemical and morphological part of the fiber, which provides rigidity and conducts fluids.

Methods for determining the content of cellulose, lignin, woody polyoses (hemicellulose), extracting substances and ash content were conducted in compliance with the regulations previously described in this journal (Antonović *et al*, 2007).

Effects of different types of the Spanish Broom shoots extraction were examined in the work in terms of quality and quantity of the obtained fibers:

A. Fiber extraction in seawater: Freshly picked Spanish Broom shoots were tied in a bundle, weighing 100 g and then soaked in water for 21 days. After resting in seawater, at the average temperature of 22 °C, the fibers were separated from the woody part by rubbing against stone plates. They were rinsed in seawater and then the fibers started to separate from the woody part. Before the examination, the fibers were dried in standard conditions. The content of the obtained fibers stood at approximately 12% of the total weight of the dry shoots.

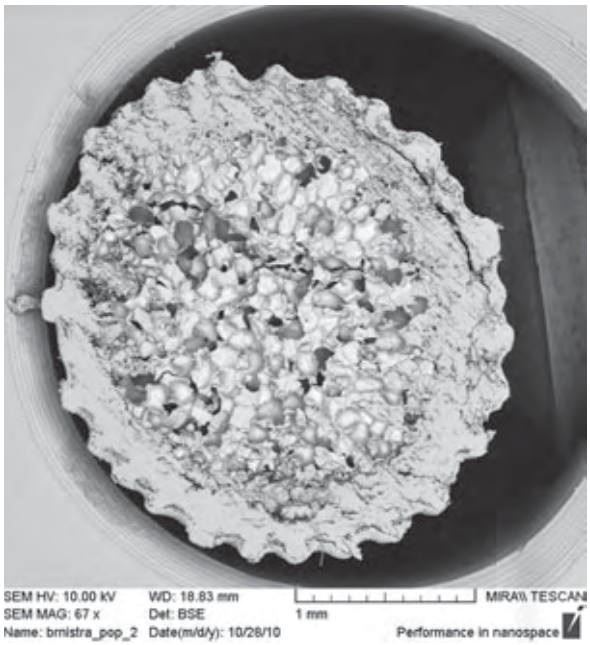

Figure 1 SEM micrograph of cross-section of Spanish Broom shoot
Slika 1. SEM slika poprečnog presjeka izbojka brnistre

B. Samples extracted in a solution of 15 g/l sodium alkali: Freshly picked Spanish Broom samples were tied in bundles (100 g) and processed during three hours at 120 °C. After the processing, the fibers easily separated from the woody part. Before the examination, the fibers were dried in standard conditions. The content of the obtained fibers stood at approximately 30% of the total weight of the dry shoots. (Cerchiara *et al*, 2010 B)

C. Samples extracted using the DiCoDe procedure: Freshly picked Spanish Broom samples were tied in bundles (100 g) and processed during 15 minutes at 100 °C. After being processed in the alkali, the fibers were rinsed in distilled water to the level of neutral, and then put in moist conditions in an autoclave at 120 °C and pressure of 10 atmospheres during three hours. Quick decompression followed. Afterwards, the fibers easily separated from the woody part. Before the examination, the fibers were dried in standard conditions. The content of the obtained fibers stood at approximately 30% of the total weight of the dry shoots.

D. Extraction by microwave application: This is a new patented extraction procedure, developed at the Institute for Textile Chemical Technology and Ecology of the Zagreb University – Faculty of Textile and Technology. For the purpose of this study, a Teflon reactor, inert to microwave activity, of the total volume of 500 ml, was constructed. 50 grams of Spanish Broom shoots and 300 ml of 15% NaOH solution were put in the Teflon reactor and then in a microwave oven set to 900 W, for a period of 10 minutes. After being processed under the influence of the microwaves, the samples were rinsed in hot and then cold distilled water. After the rinsing, the fibers easily separated from the woody part. The content of the obtained fibers stood at approximately 30% of the total weight of the dry shoots.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

The IR spectra of the fiber sample obtained after alkaline extraction was recorded on the ATR-FTIR spectrometer (Spectrum 100, Perkin Elmer), while cotton, flax and hemp fibers were taken as reference samples. From the recorded FT-IR spectra of the fiber samples, it can be seen that all fibers have peak characteristic for cellulose although they present some differences (Fig. 2.). The intensity of the signal at 1734 cm^{-1} corresponding to the C=C esther band related to pectin is higher in flax than in hemp fibers, while this band is not found in Spanish broom fiber sample. On the contrary, only a weak peak at ca. 1500 cm^{-1} corresponding to the C=C in-plane aromatic vibrations from lignin can be observed in the case of Spanish broom fibers, providing an ulterior evidence that the applied chemical treatment was adequate for the almost complete removal of the non-cellulosic compounds from the broom fibers. On the other hand, the two little sharp peaks observed over a broader peak in the area of 2850 to 2950 cm^{-1}, attributed to the CH_2 and CH groups of long alkyl chains of waxes, are present in the spectra of flax and hemp.

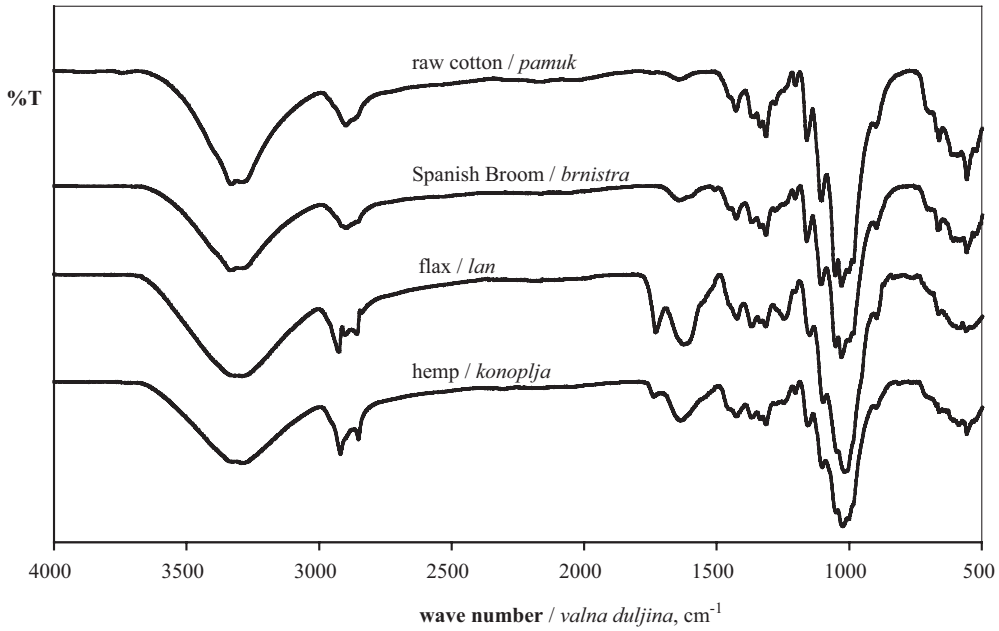

Figure 2 FTIR (Fourier Transform Infra Red) spectra of some bast fibers compared to the cotton fiber
Slika 2. FTIR (Fourier Transform Infra Red) spektri nekih stabljičnih vlakana u usporedbi s pamučnim vlaknom

Fig. 3 shows TG spectra together with the corresponding DTG curves of some bast fibers. The TG curve can be divided with respect to the three temperature ranges. A slight weight loss of the material is characteristic for temperatures under 200 °C, which is due to water loss in the form of absorbed moisture. In this area, weight loss of the examined material is under 10%. When the temperature is between 200 and 550 °C, significant weight loss is evident, which results from thermal decomposition of hemicellulose, cellulose and lignins. In this area, the weight of the examined material decreased by 70 – 80 %. When the temperature exceeds 550 °C, the weight loss is not as considerable as in the previous area. This weight loss is a consequence of thermal disintegration of other heavy components. Lignin-cellulose fiber structure can be qualitatively identified using DTG curves. In other words, hemicellulose, cellulose and lignin can be distinguished from the intensity distribution of the weight loss of the tested material. Thermal disintegration of the hemicellulose takes place at temperatures between 150 and 350 °C. The cellulose disintegrates at temperatures between 275 and 350 °C, whilst the lignin disintegrates at temperatures between 250 and 550 °C (Nekkaa *et al*, 2006; Chen *et al*, 2010).

The FTIR spectra of Spanish Broom fibers obtained after four different extraction procedures are presented in Fig. 4.

According to the previously highlighted peaks that point to the presence of pectin, lignin and/or wax, it can be seen that the procedure B resulted in the best

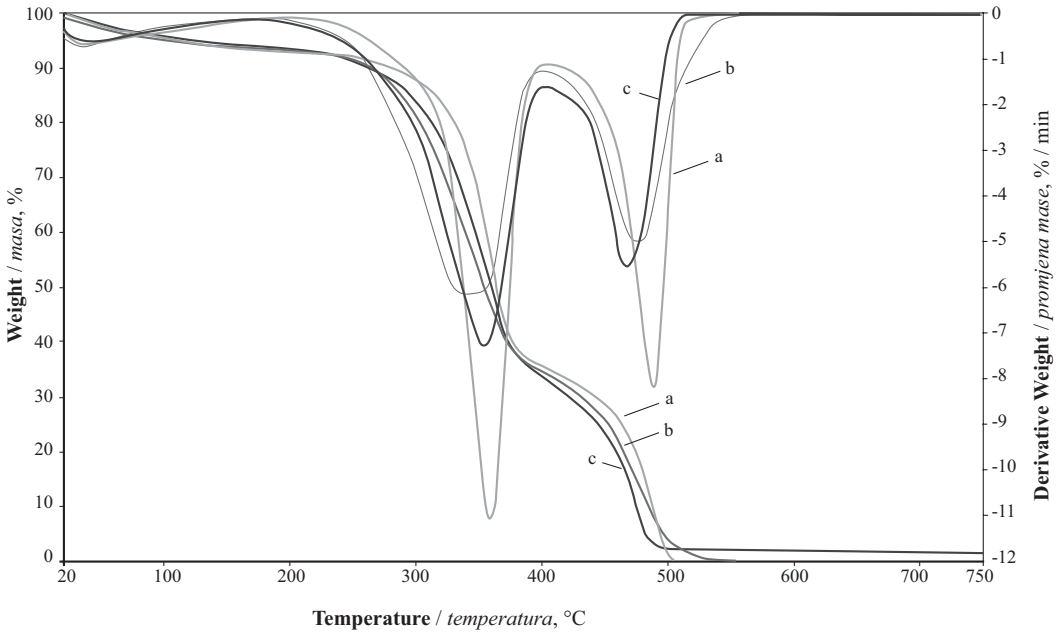

Figure 3. TG and DTG spectra of some bast fibres (a – hemp, b – Spanish Broom, c – flax)
Slika 3. TG i DTG spektri nekih stabljičnih vlakana (a – konoplja, b – brnistra, c – lan)

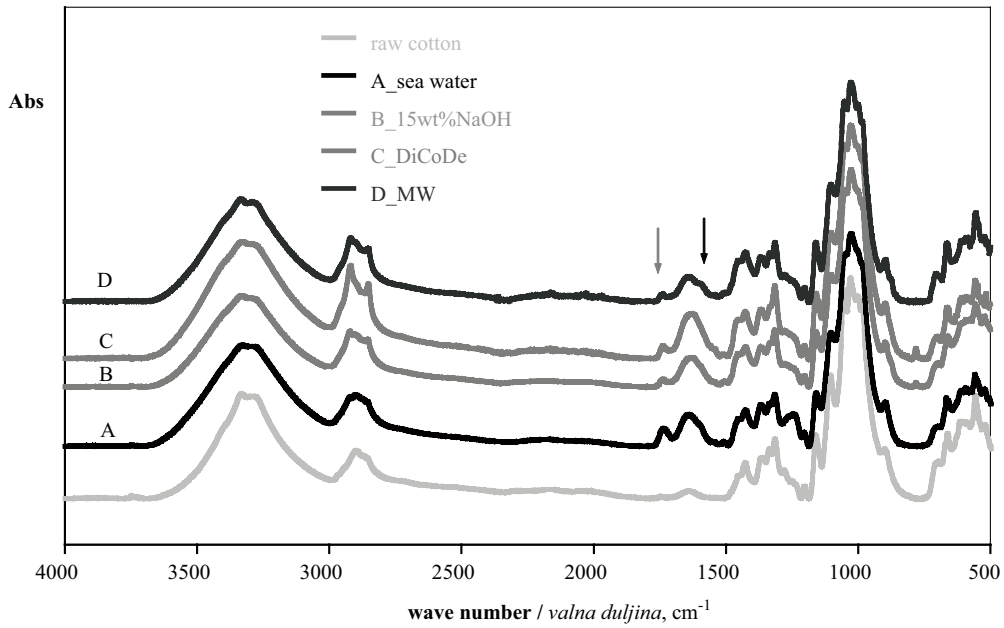

Figure 4 FTIR spectra of fibers obtained from Spanish broom plant applying four different procedures compared to the cotton fiber (A. Fiber extraction in seawater, B. Samples extracted in a solution of 15 g/l sodium alkali, C. Samples extracted using the DiCoDe procedure, D. Extraction by microwave application)
Slika 4. FTIR spektri vlakana dobivenih od brnistre različitim postupcima u usporedbi s pamučnim vlaknom (A – maceracija u morskoj vodi, B – maceracija u otopini 15 g/l natrijeve lužine, C – maceracija postupkom DiCoDe, D – maceracija primjenom mikrovalova)

removal of the non-cellulosic compounds of the fiber. Fiber treatment (B) with sodium hydroxide at 105 °C for 2 h completely removes wax and lignin, whilst a weak peak related to pectin at 1740 cm^{-1} is still visible. On the other hand, fiber treatment (D) with the same alkaline solution, but heated in a microwave oven for only 10 minutes (900 W) resulted in higher removal of pectins and maybe not total elimination of lignin as seen from the broadening of the peak at 1640 cm^{-1} (see the shoulder towards the lower wave number values). However, the latter treatment seems very promising, especially from the economical point of view.

The chemical composition of fibers extracted by different procedures is shown in Fig. 5. The only signi-

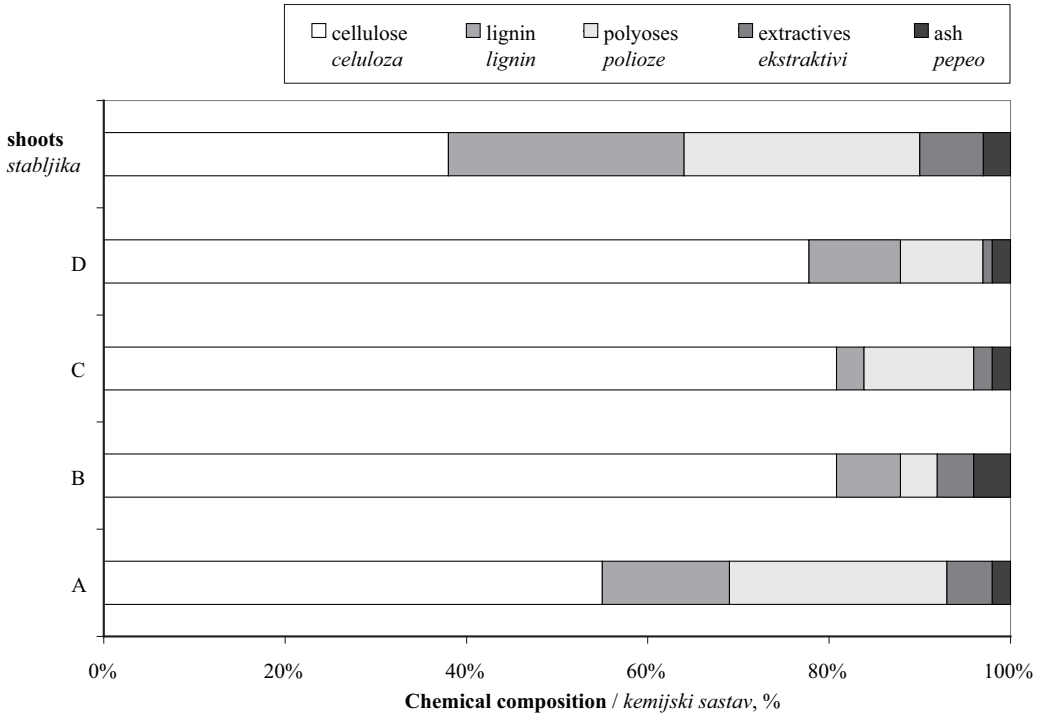

Figure 5 Chemical composition (in %) of Spanish Broom fibers obtained by four different procedures compared to the composition of shoot
Slika 5. Kemijska kompozicija (u postocima) vlakana brnistre dobivenih nakon četiri različite metode maceracije u usporedbi sa sastavom stabljike

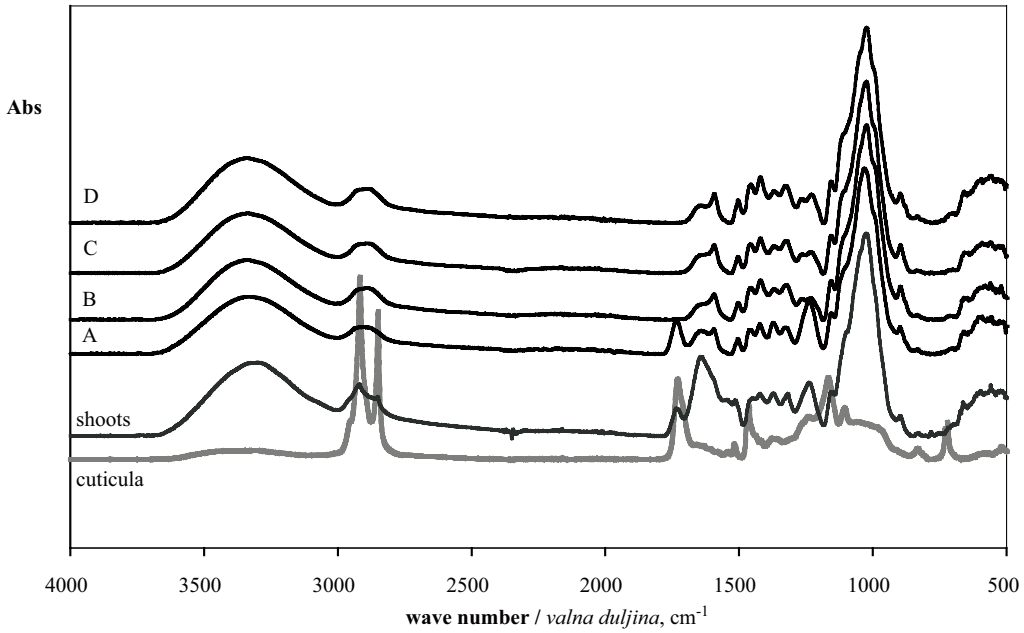

Figure 6 FTIR spectra of residues obtained after extracting fibers from Spanish Broom by four different procedures, the shoots before extraction and the cuticula.
Slika 6. FTIR spektri ostataka nakon ekstrakcije vlakana brnistre četirima različitim metodama i opne preostale nakon obrade u morskoj vodi

ficant difference is observed in the case of the procedure A for which the lowest amount of cellulose is found and the resulting high amounts of lignin, polyoses as well as extractives confirm the observation made from the FTIR spectrum of the Spanish Broom fibers obtained by sea water extraction procedure. The results of the remaining three procedures are equally good with respect to the cellulose content of the fiber, approximately 80%, whilst the content of the residuals differs from procedure to procedure. In the case of procedure B a kind of equality in the amounts of lignin, polyoses and extractives is found out, while the fibers obtained by applying the procedures C and D show different distribution among lignin, polyose and extractive amounts. In the case of the procedure C, the amounts of lignin and extractives are almost equivalent; whilst the con-

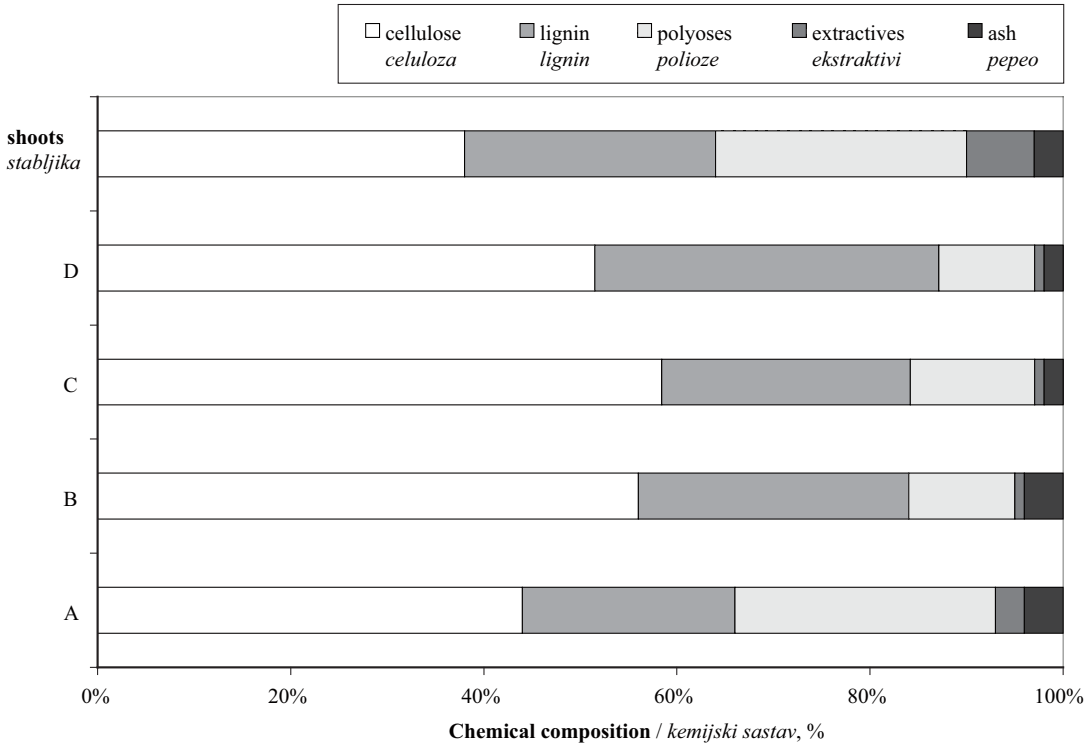

Figure 7 Chemical composition (in %) of residues left after extraction of Spanish Broom fibers obtained by four different procedures compared to the composition of shoots.
Slika 7. Kemijska kompozicija (u postocima) ostatka nakon maceracije vlakana brnistre dobivenih nakon četiri različite vrste maceracije

tent of polyoses is relatively high i.e. two times the former two components. For the microwave procedure (D), the lignin and polyoses amounts are comparable whereas the extractive content is very low.

Samples of the remaining material after the extraction of fibers from the Spanish Broom shoots were also examined.

Fig. 6 clearly shows that wax is the major component of the cuticula (vermenes membrane), i.e. two sharp peaks at 2850 and 2920 cm^{-1}, respectively. Other samples present more or less pectin and/or lignin, while the predominant part are cellulosic components having a lower degree of crystallinity as it appears from the shape of the main peak at ca. 1030 cm^{-1}, one of the C-O stretching modes characteristic of cellulose, which is smoother presenting only shoulders at ca. 1155 cm^{-1} and 1105 cm^{-1} corresponding to the C-C ring breathing and the C-O-C glycosidic ether band.

The evaluation of the FTIR spectra is confirmed by the chemical composition analyses presented in Fig. 7. The presented results are similar to those found in literature i.e. with respect to the fibre extraction procedure, the cellulose amount changes from 66.9 to 91.7% in the case of mechanical and physicochemical procedure, respectively (Cerchiara *et al*, 2010 B) or 74.1% as reported by Angelini *et al*. (2000) for mechanically obtained fibres. The same trend is valid for the lignin amount, which is always lower for the fibers extracted by non-mechanical procedures.

4 CONCLUSIONS
4. ZAKLJUČCI

The comparison between water fiber extraction and NaOH solution proved that the procedures in NaOH solution result with a significantly higher quantity of fiber bundles in relation to water fiber extraction. In all three cases of solution related processing, the quantity of fibers and the remainder after the extraction is similar. Extraction by microwaves requires the smallest amount of energy and the shortest processing period.

The structure of the Spanish Broom fibers can be qualitatively identified using DTG curves. Hemicelluloses, celluloses and lignin can be distinguished from the intensity distribution of the weight loss of the tested material since thermal decomposition of cellulose occurs at different temperatures.

FT-IR specters of the fibers cotton, hemp, flax and Spanish Broom have peak characteristic for cellulose although they present some differences.

Acknowledgments – Zahvala

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TEMATSKI PRILOZI

STRUČNI ČASOPIS

Štefan Barcík, Monika Kvietková[1], Richard Kminiak, Patrik Aláč[2]

Optimization of Cutting Process of Medium Density Fibreboards by the Abrasive Water-Jet

Optimizacija procesa rezanja ploča vlaknatica srednje gustoće abrazivnim vodenim mlazom

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ABSTRACT • *This paper deals with the process of MDF cutting by the abrasive water-jet (WJC) and shows how is kerf width influenced by process parameters. It presents the results of monitoring the kerf width related to technical and technological parameters, material parameters and cutting method. At the end of this paper, there is a detailed presentation of the possibilities of impacting kerf width by the change of the above mentioned parameters of the cutting process.*

Keywords: *feed rate, abrasive flow, water-jet cutting, sample thickness*

SAŽETAK • *U radu se opisuje proces rezanja MDF ploča abrazivnim vodenim mlazom (WJC) i analiziraju se utjecajni činitelji na širinu propiljka. Istraživan je utjecaj tehničkih i tehnoloških parametara, svojstava materijala i smjera rezanja na širinu propiljka. Rezultati rada daju detaljan prikaz mogućnosti smanjenja širine propiljka promjenom određenih parametara procesa rezanja vodenim mlazom.*

Ključne riječi: *posmak, protok abraziva, rezanje vodenim mlazom, debljina uzorka*

1 INTRODUCTION
1. UVOD

Almost any material can be cut by the application of the most used resources, water and stone. The last development makes the method of WJC very efficient. It is avery simple, clean and reliable technology and therefore it becomes an alternative to other methods in various branches. However, there are also limitations of WJC and therefore it should be monitored and its technological process improved. To this purpose we have decided to write this paper (also as a part of VEGA project under the registration number 1/0196/08 titled "Investigation of the process of wood manufacturing by Water Jet Cutting"). Our paper contains specific results from a series of experimental monitoring within the scope of the VEGA title.

WJC technology can be simply described as a process of material cutting by mechanical impact of a liquid on manufactured material. Technology of applied WJC can be divided into two basic groups – cutting by clean native water-jet and cutting by abrasive water jet. Wood processing practice knows cutting by clean native water jet as chipless cutting and abrasive water jet cutting as chip cutting (Bernd, 1993).

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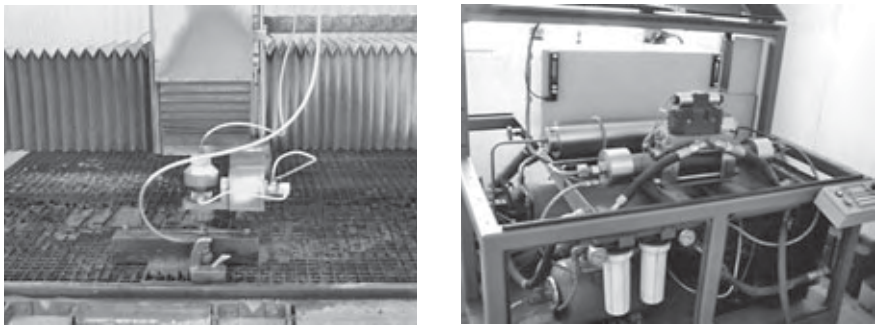


a) b)

Figure 1 Technological equipment for cutting by water-jet DEMA Ltd.: a) work-table of the equipment b) high-pressure pump (multiplier)
Slika 1. Oprema za piljenje vodenim mlazom DEMA Ltd. a) radni stol, b) visokotlačna pumpa

Technological process uses high pressure and narrow high-speed stream of water (the water pressure around 400 MPa) as a cutting tool (Maňková, 2000).

Abrasive water jet belongs to more wedges tools with undefined cutting edge (like in grinding) and also decisive mechanism for removal of machined material is similar to the above mentioned method. Cutting wedges are formed with abrasive grains randomly oriented in the beam (Barcík, 2007).

Most equipments for WJC around the world get high pressures by using the multiplier. The principle of high pressures generated by the multiplier lies in the diversity of two tightly linked pistons (Krajný, 1998).

2 MATERIAL AND METHODS
2. MATERIJALI I METODE

The methodology corresponds to the experimental pursuit (Kvietková, 2010).

MDF boards were used for the WJC experiment. The parameters of the samples were:

- thickness of the test sample: 22 mm, 44 mm, 66 mm.
- required width of the test sample: w = 180 mm (± 2.5 mm)
- required length of the test sample: l = 500 mm (± 5 mm)
- moisture content of the test samples: w = 8% (± 2%).

Cutting of samples was done in DEMA Ltd. Zvolen. The equipment was assembled based on components of the American firm FLOW Int. by the firm PTV Ltd. Praha (Figure 1). It consists of a high-pressure pump PTV 37-60 Compact, and a work table with water-jet head WJ 20 30 D-1Z supplied by the firm PTV.

Test samples were cut according to the basic cutting plan (Figure 2). Consequently, three cuts were done for each thickness on the samples to eliminate the effect of specific properties of the given sample (Figure 3).

Technical parameters of the devices are similar to states (Barcík, 2010). The experiments were carried out with technical parameters of the equipment:

- cutting liquid pressure: 4000 bar = 400 MPa
- abrasive: Australian garnet GMA (grain size 80 MESH = 0.188 mm)
- diameter of abrasive jet nozzle: 1 mm
- diameter of water-jet: 0.013 inch = 0.33 mm
- distance of nozzle above the workpiece: 4 mm
- abrasive mass flow: m_a = 250 g·min^{-1}, m_a = 350 g·min^{-1}, m_a=450 g·min^{-1}
- feed rate: v_f = 600 mm·min^{-1}, v_f = 400 mm·min^{-1}, v_f = 200 mm·min^{-1}.

The experiments were aimed at investigating:

w_t – kerf width on the side of water-jet input into material (top kerf width): it is the kerf width created by the transfer of abrasive water-jet through material measured on the side of penetration of water-jet into material.

w_b – kerf width on the side of water-jet output from the material (bottom kerf width): it is the kerf width created by the transfer of abrasive water-jet through material measured on the side penetration of water-jet output from the material (Figure 4).

Equipment set for the evaluation:

- personal computer (COMPAQ EVO N 1020v),
- digital camera (Canon PowerShot A520),
- software for working with digital camera (Canon-Zoom Browser EX 5.0) and for comparative measuring of dimensions (AutoCAD 2007),
- reference scale (Figure 5).

Creation of digital photography of the kerf width with reference scale is illustrated in Fig. 6 and Fig. 7.

2.2 Measuring of kerf width
2.2. Mjerenje širine propiljka

Measuring of the kerf width at the output of water-jet from the material becomes more difficult due to

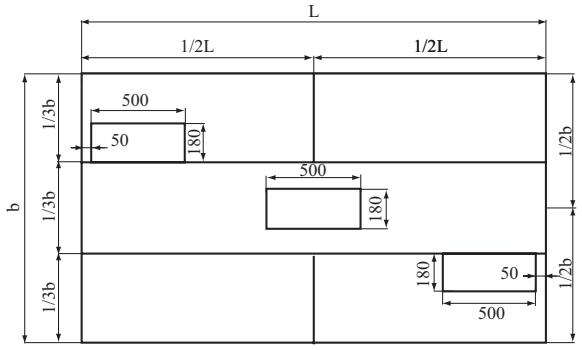


Figure 2 Preparation of test samples
Slika 2. Priprema uzoraka za istraživanje

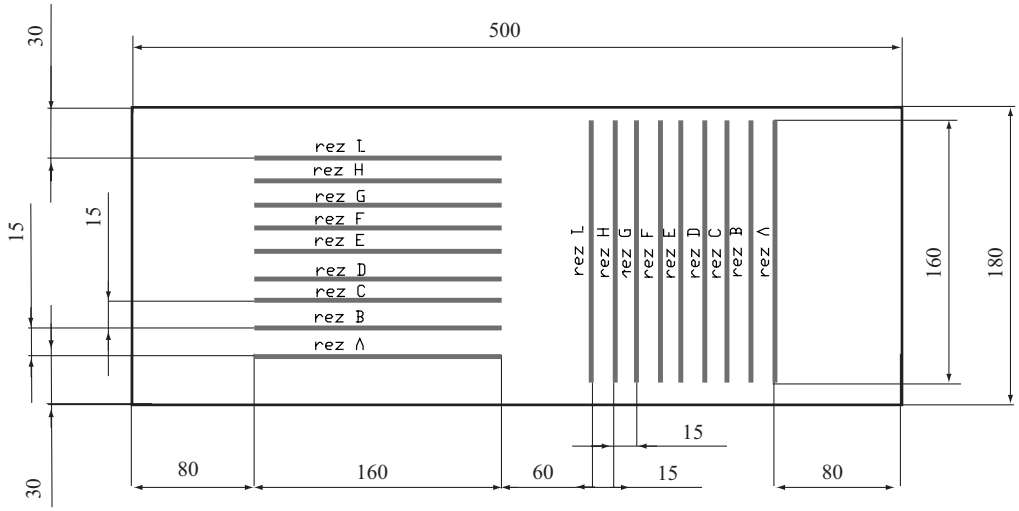


Figure 3 Cutting plan of the test sample
Slika 3. Plan rezanja uzoraka

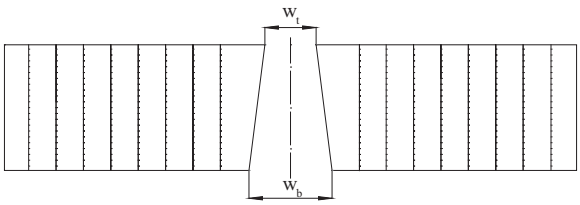


Figure 4 Illustration of the measured kerf width characteristics (w_t – top kerf width w_b– bottom kerf width)
Slika 4. Prikaz mjerenja širine propiljka (w_t – gornja širina propiljka, w_b– donja širina propiljka)

Figure 5 Apparatus for measuring the kerf width
Slika 5. Oprema za mjerenje širine propiljka

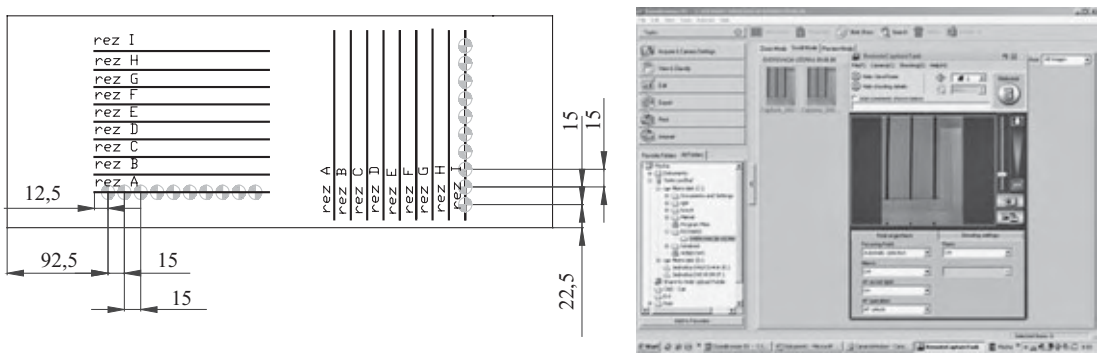
the rippled surface of the cutting edge (see Figure 7b). As for practical use it is important to determine the maximum size of the kerf (in terms of determining the possibilities of the material for further working), the kerf width is measured as the distance between the two most remote parallel tangents placed on the cutting edge, while the evaluated cutting edge length was always 15 mm.

2.3 Conversion of relative dimensions
2.3. Promjena relativnih dimenzija

Conversion of relative dimensions was done according to the relation:

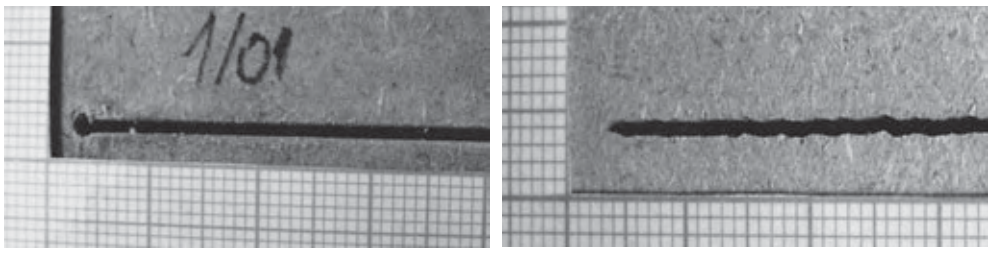
$$w_b = \frac{w_p \cdot a}{a_p} \quad (1)$$

w_b – actual size of the kerf, mm / *stvarna širina propiljka, mm*
w_p – relative size of the kerf (the size measured in AutoCAD program in digital picture) / *relativna veličina propiljka (veličina mjerena u AutoCadu na digitalnoj slici)*
a – actual size of the reference scale unit, mm / *stvarna širina propiljka u jedinicama referentne ljestvice, mm*



a) b)

Figure 6 a) Measuring points of the kerf width, b) View at the ZoomBrowser EX 5.0 program window during creation of the digital picture of kerf on the verification sample
Slika 6. a) Mjerna mjesta za određivanje širine propiljka, b) prikaz prozora programa za kreiranje digitalne slike propiljka na kontrolnom uzorku



a) b)

Figure 7 Digital picture of kerf on the MDF board verification sample a) kerf at the input of water jet into material, b) kerf at the output of water jet from the material
Slika 7. Digitalna slika propiljka na kontrolnom uzorku MDF ploče: a) propiljak na ulasku vodenog mlaza u materijal, b) propljak na izlasku vodenog mlaza iz materijala

a_p – relative size of the reference scale unit (the size measured in AutoCAd program in digital picture) (Figure 8) / *relativna veličina u jedinicama referentne ljestvice (veličina mjerena u AutoCadu na digitalnoj slici)*.

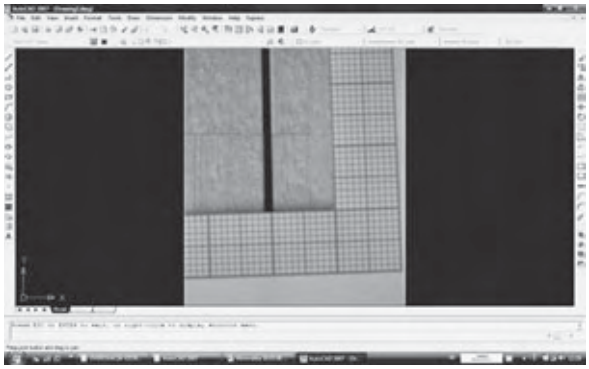


Figure 8 View at the AutoCAD program window during relative measuring of dimensions
Slika 8. Prikaz prozora AutoCaD programa primjerenju relativnih dimenzija propiljka

2.4 Statistical evaluation
2.4. Statistička obrada

Using the above procedure we have compiled the file of kerf width input and output values for all samples. Further, these values were evaluated by the software STATISTICA 7.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

On the basis of multi-factorial variance analysis, the following sequence of significance of examined factors affecting the kerf width was acquired as presented in Table 1 and 2.

Significance of input factors:	Significance of output factors:
1. cutting direction	1. sample thickness
2. sample thickness	2. feed rate
3. feed rate	3. abrasive flow
4. abrasive flow	4. cutting direction

3.1 Influence of cutting direction
3.1. Utjecaj smjera rezanja

The results of the effect of cutting direction and material flow on the kerf width are presented in Table 2 and 3.

The values of the kerf width growth at the input of water-jet into material, while changing the cutting direction from longitudinal to cross-cutting, can be explained by the orientation of particular wood elements. When the material is cut under longitudinal direction, cell elements are oriented by its length dimension identically to tool movement, and at the cross-cutting of the material there are also cells cut. By decreasing the abrasive-jet energy there is higher risk of cell rip in the material.

3.2 Influence of material thickness
3.2. Utjecaj debljine materijala

Results of the effect of material thickness on the kerf width are presented in Table 5 and 6.

The greater is the thickness, the higher amount of abrasive particles is gathered in the cut and these particles, apart from their primary effect - cutting of the material, also cause the external effect, which is the widening of the kerf due to washing-out of the material. Increased values of the kerf width in the test samples of higher thickness are significantly influenced by the lag of water-jet caused by gradual loss of its kinetic energy.

The experiment shows that the optimum material thickness is 22 mm. This thickness caused the lowest kerf width values both at the input and output.

3.3 Influence of feed rate
3.3. Utjecaj posmaka

At the input, the change of the feed rate from 200 mm/min to 400 mm/min causes values of the kerf width lower by 3%. The change of feed rate from 400 mm/min to 600 mm/min causes an increase of the kerf width by 5%.

At the output, the change in feed rate from 200 mm/min to 400 mm/min causes an increase of the kerf width by 9%, and the change of feed rate from 400 mm/min to 600 mm/min causes its increase by 4.9%.

The experiment has shown that the optimum value of the feed rate is explicitly 400 mm/min, at which the kerf width reaches the lowest dimensions both at the input and output.

3.4 Influence of abrasive flow
3.4. Utjecaj protoka abraziva

With the change of the added amount of abrasive from 250 g/min to 350 g/min, the values of the kerf width have increased by 2% at the input, and then with an increase of the abrasive amount to 450 g/min they have increased by another 2%.

Table 1 Values of multi-factorial analysis (MANOVA) at the input
Tablica 1. Rezultati višefaktorijalne analize (MANOVA) za vrijednosti širine propiljka na ulazu vodenog mlaza u materijal

Source of oscillation *Uzrok promjene*	**Sum of squares** *Zbroj kvadrata*	**Degrees of freedom** *Stupanj slobode*	**Dispersion** *Rasipanje*	**F test** *F test*	**P level of significiance** *P razina značaja*
	734.66	1.00	734.66	35417.4	0.000
sample thickness / *debljina uzorka*	2.58	2.00	1.29	623.00	0.000
cutting direction / *smjer rezanja*	1.58	1.00	1.58	762.70	0.000
feed rate / *posmak*	1.20	2.00	0.60	289.40	0.000
abrasive flow / *protok abraziva*	0.09	2.00	0.04	21.40	0.000
random factors / *slučajni faktor*	1.01	486.00	0.00		

Table 2 Values of multi-factorial analysis (MANOVA) at the output
Tablica 2. Rezultati višefaktorijalne analize (MANOVA) za vrijednosti širine propiljka na izlazu vodenog mlaza iz materijala

Source of oscillation *Uzrok promjene*	**Sum of squares** *Zbroj kvadrata*	**Degrees of freedom** *Stupanj slobode*	**Dispersion** *Rasipanje*	**F test** *F test*	**P level of significiance** *P razina značaja*
	1142.04	1.00	1142.04	10803.40	0.000
sample thickness *debljina uzorka*	190.72	2.00	95.36	902.09	0.000
cutting direction / *smjer rezanja*	0.27	1.00	0.27	2.54	0.111
feed rate / *posmak*	58.54	2.00	29.27	276.86	0.000
abrasive flow / *protok abraziva*	3.92	2.00	1.96	18.52	0.000
random factors / *slučajni faktor*	51.38	486.00	0.11		

Table 3 Values of the kerf width at the input depending on the cutting direction
Tablica 3. Vrijednosti širine propiljka na ulasku vodenog mlaza u materijal u ovisnosti o smjeru rezanja

Sample number *Broj uzorka*	**Cutting direction** *Smjer rezanja*	**Arithmetic mean** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
1	across / *poprečno*	1.12	0.01
2	along / *uzdužno*	1.22	0.01

Table 4 Values of the kerf width at the output depending on the cutting direction
Tablica 4. Vrijednosti širine propiljka na izlasku vodenog mlaza iz materijala u ovisnosti o smjeru rezanja

Sample number *Broj uzorka*	**Cutting direction** *Smjer rezanja*	**Arithmetic mean** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
1	across / *poprečno*	1.48	0.06
2	along / *uzdužno*	1.43	0.06

By changing the added amount of abrasive from 250 g/min to 350 g/min at the output of water-jet from the worked material, the kerf width values have decreased by 3%. With the change of the amount of abrasive from 350 g/min to 450 g/min, the values have decreased by 6%.

With an increase of the abrasive mass flow to 450 g/min, the kinetic energy of the particles was consumed by their mutual contact, which generated the secondary effect of washing-out of the material at the input and subsequently the narrowing of the kerf width at the output due to energy loss. However, in comparison with the uniformity of the values at both sides, the value of 450 g/min of abrasive mass flow seemed to be optimum.

Table 5 Values of the kerf width at the input depending on sample thickness
Tablica 5. Vrijednosti širine propiljka na ulasku vodenog mlaza u materijal u ovisnosti o debljini uzorka

Sample number *Broj uzorka*	**Sample thickness** *Debljina uzorka*	**Arithmetic mean** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
1	22	0.96	0.01
2	44	1.11	0.01
3	66	2.29	0.10

Table 6 Values of the kerf width at the output depending on sample thickness
Tablica 6. Vrijednosti širine propiljka na izlasku vodenog mlaza iz materijala u ovisnosti o debljini uzorka

Sample number *Broj uzorka*	**Sample thickness** *Debljina uzorka*	**Arithmetic mean** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
1	22	1.08	0.01
2	44	1.26	0.01
3	66	1.17	0.01

3.5 Economic aspects
3.5. Ekonomski aspekt

At the beginning of the cutting process, it is necessary to decide whether to use water-jet cutting (WJC) or conventional cutting methods. Water-jet cutting is an economical way to cut 2D shapes in a very wide range of materials with no tooling costs. The unique process of water-jet cutting provides reasonably good edge quality, no burrs and usually eliminates the need for secondary finishing processes. The process also generates no heat so the material edge is unaffected and there is no distortion. Water-jet cutting can cut single or multi-layer materials (Rašner, 2001).

It is very necessary to take into account the economic aspect of the whole WJC process. WJC should be compared to other cutting techniques in terms of costs and benefits. Costs of WJC assembly and the whole material flow must be monitored and quantified, including here fixed costs, then variable costs (e.g. energy consumption) and also alternative costs related to other (conventional) cutting methods. Another necesary parameter is the production (cutting) time that affects the total capacity and also productivity of an assembly within the material flow. Last but not least, the economic aspect must also take into consideration the amount of waste generated by water-jet cutting compared to conventional cutting methods (Rajnoha and Alač, 2003).

4 CONCLUSION
4. ZAKLJUČAK

The experiments have shown that the use of water-jet for cutting of agglomerated materials is a suitable method when it is used with the appropriate combination of technical and technological parameters. The most important benefit of this technology is small kerf width compared to other cutting technology. From the viewpoint of equality of kerf width on both sides of worked material, more stabile dimensions of kerf width have been observed when cutting materials in longitudinal direction. From the viewpoint of the used technological parameters, the feed rate of 400 mm/min and the abrasive flow of 350 g/min have shown to be the optimum. With a thickness exceeding 44 mm, the method becomes less efficient due to the necessary increase of additional work.

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Main Phases of Wood Formation in Chestnut (*Castanea sativa*) in Central Italy - Comparison of Seasons 2008 and 2009

Glavne faze razvoja drva pitomog kestena (*Castanea sativa*) u središnjoj Italiji – usporedba sezone 2008 i 2009

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ABSTRACT • *We present wood formation in chestnut (Castanea sativa) during the growing seasons 2008 and 2009, compare its dynamics in the two years and discuss possible effects on wood quality. To this purpose, micro-cores containing wood, cambium and phloem were collected at weekly intervals from 10 chestnut trees growing at the Cimini mountains near Viterbo, Central Italy. In 2008, the onset of wood formation started before the first sampling on 17 April 2008. Onset of lignification of the first formed vessels was observed around 23 April (day of the year DOY 113.8 ± 5.3) and the first latewood vessels were observed around 5 June 2008 (DOY 156.5 ± 7.7). Latewood formation continued until 29 September 2008 (DOY 273.9 ± 10.5) when the terminal cells of the newly formed xylem ring were fully lignified. In 2009, the main phases of wood formation generally occurred earlier than in 2008. The expansion of earlywood vessels was observed around 10 April (DOY 99.7 ± 6.1), the onset of lignification around 22 April (DOY 111.9 ± 7.4) and the first latewood vessels around 28 May 2009 (DOY 147.9 ± 4.7). Lignification of the last formed cells was completed by 26 September 2009 (DOY 273.9 ± 10.5). The average duration of tree-ring formation was 161 days in 2008 and 169 days in 2009, the average ring widths were 3296 ± 1514 µm in 2008 and 3166 ± 1073 µm in 2009, and latewood percentages comprised 76% and 74% of the 2008 and 2009 tree-rings, respectively. The small differences in timing of wood formation phases in the two study years are probably due to small variations in climatic conditions between the two years and they did not seem to have a major impact on ring widths and latewood percentages, which are two important parameters affecting wood quality in ring porous wood species.*

Key words: *Castanea sativa, sweet chestnut, Central Italy, wood formation, wood quality*

SAŽETAK • *Rad obrađuje stvaranje drva pitomog kestena (Castanea sativa) tijekom vegetacije u 2008. i 2009. godini. Uspoređuje se dinamika stvaranja drva u te dvije godine i raspravlja o mogućem utjecaju na njegovu*

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kvalitetu. Za tu su svrhu s deset stabala pitomog kestena u planinama Cimini, pokraj mjesta Viterbo u središnjoj Italiji, u tjednim intervalima skupljeni mikroizvrtci koji su sadržavali drvo, kambij i floem. Početak stvaranja drva u 2008. godini dogodio se prije uzimanja prvih uzoraka 17. travnja 2008. Početak lignifikacije prvooblikovanih traheja primijećen je oko 23. travnja (dan u godini DOY 113,8 ± 5,3), a prve traheje kasnog drva primijećene su oko 5. lipnja (DOY 156,5 ± 7,7). Stvaranje kasnog drva nastavljeno je do 29. rujna 2008. (DOY 273,9 ± 10,5), kad su završne stanice novostvorenoga goda drva bile potpuno lignificirane. U 2009. godini glavne su se faze stvaranja drva uglavnom pojavile ranije nego u 2008. godini. Širenje traheja ranog drva primijećeno je oko 10. travnja (DOY 99,7 ± 6,1), početak lignifikacije oko 22. travnja (DOY 111,9 ± 7,4), a prve traheje kasnog drva oko 28. svibnja 2009. (DOY 147,9 ± 4,7). Lignifikacija zadnjih proizvedenih stanica završena je do 26. rujna 2009. (DOY 273,9 ± 10,5). Prosječno trajanje stvaranja goda drva u 2008. godini iznosilo je 161 dan, a u 2009. godini 169 dana. Prosječne širine godova bile su 3296 ± 1514 μm u 2008. godini i 3166 ± 1073 μm u 2009. godini, a postotni udjel kasnog drva iznosio je 76 i 74% godova u 2008., odnosno u 2009. godini. Male razlike u vremenu početka pojedine faza stvaranja drva u dvjema promatranim godinama vjerojatno su posljedica malih varijacija klimatskih uvjeta između te dvije godine i čini se da nemaju velik utjecaj na širinu godova ni na postotak kasnog drva, a to su dva važna čimbenika koji utječu na kvalitetu drva prstenasto poroznih vrsta.

Ključne riječi: *Castanea sativa, pitomi kesten, središnja Italija, stvaranje drva, kvaliteta drva*

1 INTRODUCTION
1. UVOD

Sweet chestnut (*Castanea sativa* Mill.) is the only native species of the genus *Castanea* in Europe and its cultivation has a long tradition. Chestnut is valued for its wood, bark and fruit. COST action G4 "Multidisciplinary Chestnut Research" based on National Forest Inventories reported in 1997 that 2.25 million hectares of forests in Europe were dominated by chestnut, with roughly 80% cultivated for wood and 20% for fruit production. Furthermore, three types of chestnut countries have been distinguished: (i) countries with a strong chestnut tradition (e.g. Italy, France, southern Switzerland, Spain, Portugal and Greece), where the chestnut stands are cultivated with intensive and characteristic silvicultural systems (coppices and orchards); (ii) countries with only a partially developed chestnut tradition due to the country's particular geography (e.g. England) or history (e.g. Croatia, Turkey, Georgia); and (iii) countries where the chestnut only sporadically occurs (e.g. Hungary, Bulgaria, Belgium) or has been recently introduced (e.g. Slovakia, Netherlands) (Conedera *et al*, 2004).

Sweet chestnut is a very common and important tree species in Italy. It grows all over the peninsula and is characteristic of the phytoclimatic association Castanetum, which grows in the altitudinal belt from 0 to 900 m a.s.l. in the north, and from 600 to 1200 m a.s.l. in the central and southern parts of Italy. The cultivation and use of chestnut fruit and wood has a long tradition all over Central Italy and also in the Province of Viterbo (Romagnoli *et al*, 2005; Romagnoli, 2007).

In this region, chestnut wood has been used in modern and in many historical buildings (Romagnoli *et al*, 2004; Romagnoli *et al*, 2005). The species is currently cultivated for wood production using coppice silvicultural management, in which new trees (shoots) grow from the stumps. The rotation time at least 14 years.

Chestnut belongs to ring-porous hardwoods with a morphological structure similar to oak wood (Schweingruber, 1990; Nardi Berti, 2006). Ring shakes are the main wood defect, which reduces the use of chestnut wood for high-added-value products. They are considered to occur as a consequence of growth stresses (radial tensile stress) and structural weakness of portions of wood tissue (Fonti and Macchioni, 2003; Spina and Romagnoli, 2010).

Since wood quality depends on wood structure, which is defined during the process of wood formation, a detailed knowledge of wood formation processes will improve our understanding of the relationship among wood structure and properties and the end-use of wood.

We started wood formation studies in chestnut in Central Italy in 2008 and the first results on cambial activity, wood and phloem formation in five trees in 2008 have already been published (Čufar *et al*, 2011). Since considerable tree to tree and year to year variability are expected, we evaluated the results of additional five trees sampled in 2008 and continued with the experiment in 2009.

The aim of the present study was to compare the seasonal dynamics of wood formation in ten trees in 2008 and 2009 and to discuss the effect of wood formation dynamics on wood quality.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The study was carried out at a coppice chestnut (*Castanea sativa* Mill.) forest stand in the locality of the Cimini mountains, part of Comune di Soriano nel Cimino, Viterbo, Italy (approx. 42°17'N, 12°12'E, 850 m a.s.l.). The area is on volcanic soil, very close to the old beech forest described by Piovesan *et al* (2008). The climate is Mediterranean. The amount of annual precipitation in nearby Soriano nel Cimino is 1180 mm (Servizio Idrografico, 1916-2000). The precipitation maximum is recorded from October until December and the driest period occurs in summer, although there is no significant evidence of drought according to the Bagnouls-Gaussen diagram (Piovesan *et al*, 2008). The mean annual temperature is 14 °C, with a maximum in August (up to 24.2 °C) and minimum in December (6.2 °C) (Servizio idrografico 1997-2001). The daily data (minimum and

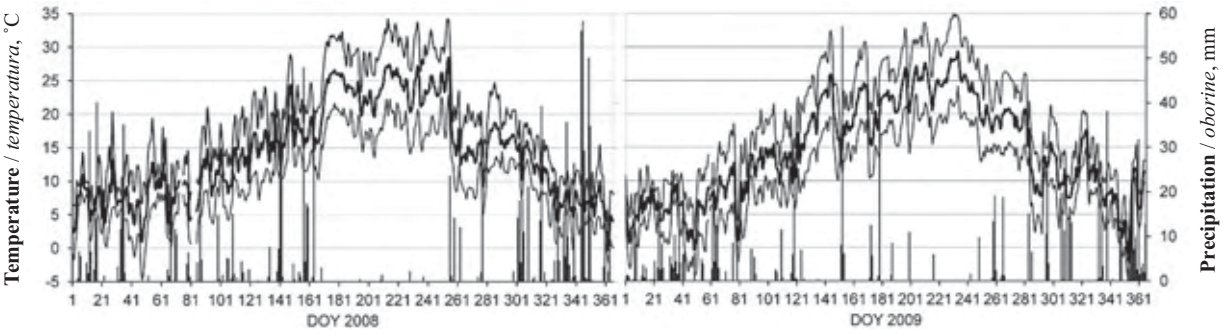

Figure 1 Daily climatic data, minimum, mean and maximum temperatures (lines), and precipitation (bars), for Soriano nel Cimino, Central Italy, in 2008 and 2009.
Slika 1 Dnevni klimatski podatci u 2008. i 2009. za Soriano nel Cimino, središnja Italija: minimalne, prosječne i maksimalne temperature (krivulje) i oborine (trake)

maximum temperature and precipitation) for 2008 and 2009 are presented in Fig. 1.

We selected ten isolated dominant healthy chestnut trees with approximate diameters of 17 cm, heights of 15 m, and ages of 30 years. The trees originate from stumps and ring shake defect was observed in some of them. Each tree represents a single shoot that had been left after cutting all other trees sprouting from the same stump, at the end of the rotation time in 2006. The sampling trees are now the standards of the site.

Samples of tissues containing the bark, cambium and the last formed wood were collected by taking micro-cores with Trephor (Rossi *et al*, 2006). The micro-cores (diameter 1.8 mm, length approx. 15 mm) were extracted from living trees, at the basal part of the stems, at weekly intervals from April until October 2008 and 2009.

Immediately after extraction from the tree, the samples were put in 70% ethanol for fixation and conservation. After the end of sampling, they were embedded in paraffin using a Leica TP 1020-1 tissue processor for dehydration in a graded series of ethanol (70%, 90%, 95% and 100%) and bio-clear (D-limonene) for paraffin infiltration (Rossi *et al*, 2006). Cross-sections of 10 μm thickness were prepared on a Leica RM 2245 rotary microtome, using disposable Feather N35H blades. For better adhesion of the sections, slides were pre-treated with albumin. Sections were dried at 70 °C for half an hour and cleaned of residual paraffin by immersing the slides in bio-clear and ethanol. Sections were finally stained for light microscopy with a mixture of safranin and astra blue (40 mg safranin and 150 mg astrablue added to a solution of 100 ml demineralized water with 2 ml acetic acid) (van der Werf *et al*, 2007) and mounted on glass slides in Euparal.

A Nikon Eclipse 800 light microscope (bright field and polarized light), Nikon digital sight DS-Fi1 video camera and the NIS elements BR 3.0 image analysis system were used for observations and semi-automatic counting and measuring of cells and tissues at various stages of their development. We also measured the width of the current increment as well as early- and latewood widths (in μm). The measurements were always done in each sample along three radial files. The boundary between earlywood and latewood was defined based on vessel dimensions; vessels smaller than 10,000 μm^2 were considered to belong to latewood (Fonti *et al*, 2007).

In the newly formed wood tissue, we could follow the development of the vessels, vasicentric tracheids around them (referred to in brief as tracheids) and tracheids or fibres apart from the vessels (fibres) (Figs. 2, 3). We recorded the following phases of cell development: post-cambial growth (PC), secondary cell wall deposition and lignification (SW) and mature cells (MT) (Fig. 3). The PC cells contained thin, non-lignified cell walls that stained blue with astra blue

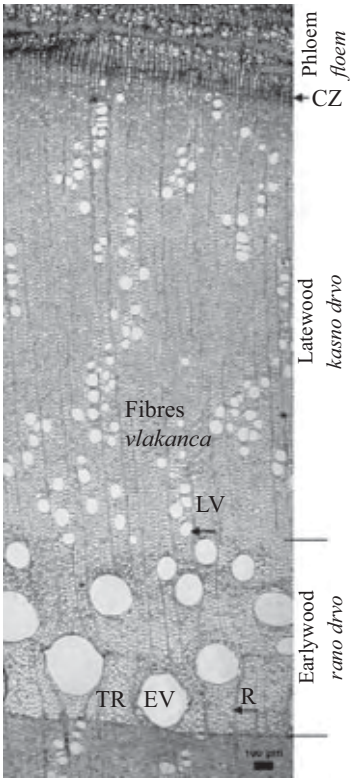

Figure 2 Cross-section of *Castanea sativa* tissues showing the last formed xylem ring divided into earlywood and latewood, cambial zone (CZ) and phloem. The cells of the wood are: earlywood vessels (EV), latewood vessels (LV), tracheids (TR) and fibres. The rays (R) are uniseriate.
Slika 2. Poprečni presjek zadnjih proizvedenih tkiva *Castanea sativa* s ranim i kasnim drvom, kambijskom zonom (CZ) i floemom. Stanice drva su traheje ranog drva (EV), traheje kasnog drva (LV), traheide (TR) i vlakanca. Traci (R) jednoredni su.

stain (Fig. 3 a) and showed no birefringence under polarized light (Fig. 3 b). In this phase, the cells enlarged in radial and tangential directions (vessels) or elongated (tracheids, fibres). The beginning of the secondary wall deposition was detected under polarized light, since the cell walls showed birefringence (Fig. 3 b). The beginning of cell wall lignification could be observed under bright-field, when red stain safranin gradually replaced the blue staining (Fig. 3 a).

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

In 2008, the onset of cambial divisions and the first earlywood vessels in the phase of expansion occurred before our first sampling on 17 April (Čufar *et al*, 2011). In 2009, the first earlywood vessels in the phase of expansion were observed around 10 April (day of the year DOY 99.7 ± 6.1) (Fig. 4), while the onset of cambial cell production was recorded on 2 April 2009 (DOY 92.0 ± 6.4).

Previous reports on wood formation in chestnut are extremely rare. In the 1940s, Ciampi (1951) sampled two chestnut trees at two sites in Tuscany in Italy: near San Giusto, at 500 m a.s.l. in the 1947 growing season, and near Vallombrosa at 1000 m a.s.l. in the 1949 growing season. It was observed that the onset of cambial activity and earlywood production differed between the two localities. In San Giusto, earlywood vessels were already formed at the beginning of April and lignification of the initial vessels was concluded by mid-May. In Vallombrosa, the onset of cambial activity occurred much later; at the end of April, but lignification was already evident at the beginning of May.

Since other reports on wood formation in chestnut are not available, we can compare our observations with those in other ring porous species, which have been conducted in various geographic areas. Gričar (2010) followed wood formation in *Quercus petraea* (sessile oak) in Ljubljana, Slovenia, at 323 m a.s.l. in 2007 and observed that the first earlywood vessels were created by mid-April. Horaček et al. (2003) presented xylem formation in *Quercus robur* (pedunculate oak) in Czech Republic. They observed that the activity of cambium started before the first sampling on 27 April 1998, when on average 6.66 radially enlarging cells were already observed. A study by Derr and Evert (1967) on young *Robinia pseudoacacia* (black locust) trees in Madison, USA, from October 1960 until October 1962, reported that the first signs of cambial cell divisions were observed on 18 April 1961 and on 7 April 1962. The first expanding vessels were observed on 27 April 1962.

Sass-Klaassen *et al.* (2011) studied vessel formation in *Quercus robur* and *Fraxinus excelsior* (pedunculate oak and ash) in relation to leaf phenology in 2008 in the Netherlands (52°23'N, 5°37'E). Vessel formation in ash started well before bud swelling and much earlier than in oak. Earlywood vessel formation in oak on average already started at the end of March and ended at the beginning of May. In ash, vessel formation started 13 days earlier than in oaks and ended around the beginning of May.

It is generally known that the first earlywood vessels develop before bud break in ring-porous trees such as *Castanea*, *Quercus*, *Fraxinus* and *Robinia*, and therefore before the resumption of photosynthetic activity. Formation of the first earlywood vessels can occur two to six weeks prior to bud break (Suzuki *et al*, 1996; Schmitt *et al*, 2000; Sass-Klaassen *et a*l. 2011). The early phases of earlywood formation thus require the mobilization of reserves stored during the previous growing season (Barbaroux and Bréda, 2002).

Fonti *et al*. (2007) tried to identify the climatic signals contained in the earlywood vessel size of *Castanea sativa* from Valle Mesolcina (46°14′N, 9°07′E, elevations 300, 600 and 900 m a.s.l.) in Switzerland and the physiological processes involved in the underlying mechanisms. They reported that the first vessels appeared in late April to early May. They hypothesised that April temperatures are related to tree activation, whereby new hormone production fosters vessel expansion.

Deposition of the secondary wall layers and lignification of first formed vessels and surrounding fibres/fibre tracheids started at almost the same time, around 23 April 2008 (DOY 113.8 ± 5.3) and around 22 April 2009 (DOY 111.9 ± 7.4) (Fig. 4). The onset of deposition was recognized due to birefringence of vessels and fibres observed under polarized light (Fig. 3b), whereas lignification was characterized by red staining of the cell walls observed in bright-field (Fig. 3a).

As reported by several studies, both secondary wall formation and lignification start first in the vessels and in the cells that are in contact with the vessels (Murakami *et al*, 1999; Terashima 2000; Grünwald *et al*, 2002; Marion *et al*, 2007; Prislan *et al*, 2009). Since

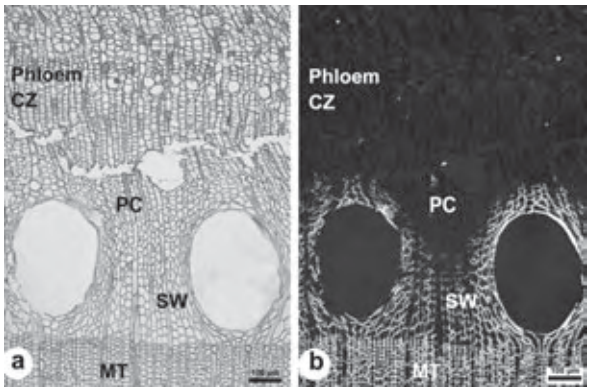

Figure 3 Cells in different phases of formation observed under a light microscope: (a) bright field and (b) polarized light. Phases of cell formation: post-cambial growth (PC), secondary cell wall deposition and lignification (SW) and mature cells (MT) formed in the season.
Slika 3. Stanice u različitim fazama razvoja promatrane svjetlosnim mikroskopom: (a) u svijetlom polju i (b) u polariziranoj svjetlosti. Faze razvoja stanica obuhvaćaju: postkambijski rast (PC), odlaganje sekundarnog sloja stijenke i lignifikacija (SW) te odrasle stanice (MT) proizvedene u sezoni.

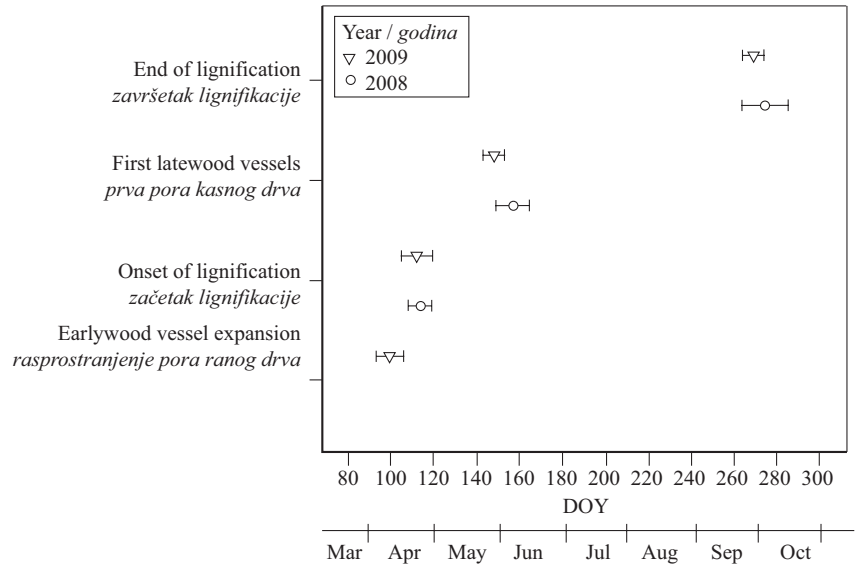

Figure 4 Milestones of wood formation in 2008 and 2009 shown for days of the year (DOY) and calendar dates, with variation (± standard deviation).
Slika 4. Prekretnice u stvaranju drva u 2008. i 2009. godini prikazane za dane u godini (DOY) i kalendarske datume, s varijacijom (± standardna devijacija)

ring-porous species mainly transport water through the wide early-wood vessels of the current growth ring (Suzuki *et al*, 1999), early establishment of water conducting pathways is particularly important (Sass, 1993).

Earlywood formation was completed and the first newly formed late-wood vessels were observed around 5 June (DOY 156.5 ± 7.7) in 2008 and around 28 May (DOY 147.9 ± 4.7) in 2009 (Fig. 4).

Gričar (2010) observed a transition from early- to latewood in *Quercus petraea* slightly earlier; i.e., in the third week of May 2008. Derr and Evert (1967) observed that the period of greatest cambial activity coincided with earlywood formation in *Robinia pseudoacacia*. Furthermore, Schmitt *et al*. (2000), who investigated wood production in *Robinia pseudoacacia* near Hamburg, Germany reported that wood formation started around 3 May, and about 70% of wood was already formed by 5 July.

Xylem growth ring formation in chestnut was completed when the last formed xylem cells were completely lignified. In both years, this was observed at approximately the same time, i.e., around 29 September 2008 (DOY 273.9 ± 10.5) and around 26 September 2009 (DOY 269.1 ± 4.7) (Fig. 4).

Ciampi (1951) observed that lignification of the terminal xylem cells in *Castanea sativa* concluded in October. Schmitt *et al*. (2000) noted the end of wood formation in *Robinia pseudoacacia* in the second week of September. Derr and Evert (1967) reported that cambial activity in *Robinia pseudoacacia* ended in early September; however, xylem differentiation did not end until October. Termination of cambial activity, when no wood increment was noticed, occurred from the end of September to October in *Quercus robur* in Czech Republic (Horaček *et al*, 2003).

According to the presented data the xylem growth ring formation in the studied chestnuts lasted on average 160.7 ± 13.0 days in 2008 and slightly more, 169.4 ± 8.0 days, in 2009. The duration slightly varied from tree to tree and the differences were larger in 2008 (RSD = 10%) than in 2009 (RSD = 4%).

The duration of earlywood formation was on average 43.9 ± 8.9 days in 2008 and 48.2 ± 6.4 days in 2009. The formation of latewood lasted on average 108.7 ± 18.8 days in 2008 and 110.7 ± 7.9 days in 2009 (Table 1). Early wood was thus formed in a period that lasted less than one third of the growing season.

Xylem ring in 2008 was on average 3296 ± 1514 μm wide and slightly narrower in 2009, with 3166 ± 1073 μm, although the growth season was about one week longer in 2009 (Table 1). Earlywood width on average comprised 702 ± 430 μm in 2008 and 781 ± 209 μm in 2009 and its proportion was similar in both years, with 24 ±11% in 2008 and 26 ±5% in 2009. Consequently, the largest part of the xylem growth ring in both years consisted of latewood, the proportion of which was 76 ±12% in 2008 and 74 ±5% in 2009 (Table 1). The variation in earlywood proportion among

Table 1 Main characteristics of wood formation in 2008 and 2009
Tablica 1. Glavna obilježja stvaranja drva u 2008. i 2009.

Measured parameter / *Mjereni parametar*	**2008**	**2009**
Duration of wood formation, days / *trajanje stvaranja drva, dani*	160.7 ± 13.0	169.4 ± 8.0
Duration of earlywood formation, days / *trajanje stvaranja ranog drva, dani*	43.4 ± 9.3	48.2 ± 6.4
Duration of latewood formation, days / *trajanje stvaranja kasnog drva, dani*	117.2 ± 10.1	121.2 ± 5.0
Total tree-ring width, μm / *širina cijeloga goda, μm*	3295.6 ± 1513.6	3166.1 ± 1072.8
Proportion of latewood, % / *udjel kasnog drva, %*	75.7 ± 11.2	74.4 ± 4.7

the trees was much higher in 2008 (RSD = 46%) than in 2009 (RSD = 18%).

We observed small differences in the timing of wood formation phases and duration of wood production between 2008 and 2009, and a comparable average width of tree-rings formed in the two years. The observed similarity in ring width and earlywood/latewood proportions are also expected to be reflected in a similar wood density.

The morphology of cells and the structure of the xylem growth ring are determined during wood formation. All this crucially affects wood properties. Chestnut is a typical representative of ring-porous wood species, with large earlywood vessels (mean diameters around 250 μm, range 150-300 μm), a more or less abrupt transition from early- to latewood, and small latewood vessels (mean diameters around 65 μm, range 36-125 μm) (Wagenführ, 1996). The morphological cell structure of chestnut is comparable to that of oak (e.g., *Quercus petraea* and *Quercus robur*). Chestnut and oak can be differentiated on the basis of the size of rays, which are exclusively uniseriate in chestnut and of two sizes, uniseriate and over 10 cells wide ones, in oaks (Schweingruber, 1990; Nardi Berti, 2006). The oven-dry density of chestnut wood is 530-590 kg/m^3 (Wagenführ, 1996) and in ring porous wood species it mainly depends on the proportion of earlywood and latewood and increases with increasing ring width (Kollmann and Cote, 1968).

The observed differences in the wood formation dynamics in chestnut in 2008 and 2009 did not seem to have a major impact on wood quality as characterized by tree-ring widths and latewood percentages.

The climatic situation in the two years seemed to be similar (Fig. 1). However, to evaluate the effect of climate on wood formation and quality, we would need to explore in detail the climate-wood formation relationships with specific models, taking into account the climatic parameters that could affect each step of wood formation. A longer time series of wood formation would be necessary for this purpose.

4 CONCLUSIONS
4. ZAKLJUČCI

The expansion of first formed earlywood vessels, the onset of cell wall development and lignification that first occurs in vessels and in tissues around them, the occurrence of the first latewood vessels and end of lignification of terminal xylem cells are crucial phases of wood formation in *Castanea sativa*. They helped us to link the dynamics of wood formation and its effect on wood structure. The variation in dynamics between the two years, 2008 and 2009, was generally smaller than the variation among the 10 study trees. Wood formation on average lasted about six months in both studied years and average tree ring widths were above 3 mm. Earlywood on average formed about one quarter and latewood about three quarters of xylem rings in both years. The recorded differences in timing of wood formation phases did not seem to have a major impact on wood structure as characterized by tree-ring widths and earlywood/latewood percentages.

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Kontrola i određivanje sadržaja vode u drvu standardnim i nestandardnim metodama

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Projektiranje i razvoj klasičnih i nekonvencionalnih načina sušenja

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Izrada i modifikacija režima sušenja drva

Savjetovanje u odabiru tehnologije sušenja

Provođenje standarda kvalitete sušenja

Odabir parametara savijanja drva

Detekcija pogrešaka u hidrotermičkoj obradi drva i sprečavanje njihovog nastanka

Skraćivanje postupka sušenja drva

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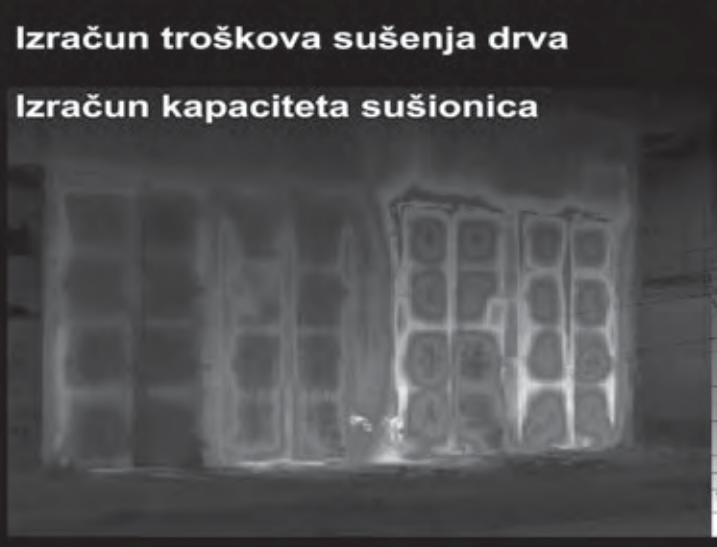

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Accelerated Weathering of Coated and Uncoated Beech Wood Modified with Citric Acid

Ubrzano izlaganje vanjskim uvjetima bukovine modificirane limunskom kiselinom, neobrađene i obrađene lazurama

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ABSTRACT • *Chemical modification of wood can minimize wood drawbacks in exterior application, such as moisture absorption, swelling and shrinkage, susceptibility to photodegradation and microbial attack. We modified a beech wood with 7.0 % water solution of citric acid and 6.5 % sodium-hypophosphite monohydrate (SHP) as a catalyst and investigated the color stability and weathering performance of coated and uncoated wood under accelerated weathering conditions. The modified and unmodified beech wood samples were coated with transparent water-borne stain and transparent solvent-borne stain, and with reference stain. The accelerated outdoor exposure was conducted in a QUV weathering tester (Q-Panel Company) equipped with UVA-340 florescent lamps for 56 days (1344 hours). The surface of samples was examined for color and gloss changes, adhesion and appearance of flaking, cracking, blistering and chalking. The overall color change (ΔE*) of coated beech wood samples at the end of exposure was smaller in unmodified wood samples. The trend of gloss changes of modified and unmodified wood samples was very similar during the exposure. At the end of exposure unmodified beech wood samples exhibited better weathering performance than modified beech wood samples. In order to achieve the optimal protection of wood modified with citric acid the new type of finishes should be developed.*

Key words: *chemical modification, citric acid, QUV weathering, wood stain, beech wood*

SAŽETAK • *Kemijskom modifikacijom mogu se smanjiti nedostaci drva pri vanjskoj uporabi, kao što su upijanje vlage, bubrenje i utezanje, podložnost razgradnji pod utjecajem svjetlosti te pri napadu mikroorganizama. U ovom je istraživanju bukovina modificirana 7,0 %-tnom vodenom otopinom limunske kiseline uz dodatak 6,5% natrijhidrofosfita monohidrata (SHP) kao katalizatora i istraživana stabilnost boje i postojanost pri ubrzanom izlaganju vanjskim utjecajima tako modificiranoga drva, neobrađenoga i obrađenog lazurama. Uzorci su površinski obrađeni transparentnom vodenom lazurom i transparentnom otapalnom lazurom, te referentnom lazurom. Ubrzano izlaganje vanjskim uvjetima bilo je provedeno u QUV uređaju (tvrtke Q-Panel), opremljenome s UVA-340 fluorescentnim svjetiljkama, u trajanju 56 dana (1344 sati). Na površini uzoraka mjerila se promjena boje i sjaja, određivala adhezija i provjeravala pojava ljuštenja, pukotina, mjehuranja i kredanja. Ukupna promjena boje (ΔE*) obrađenih bukovih uzoraka na kraju izlaganja bila je manja od promjene na nemodificiranim uzorcima.*

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Trend promjene sjaja modificiranih i nemodificiranih uzoraka bio je vrlo sličan tijekom izlaganja. Na kraju ubrzanog izlaganja vanjskim uvjetima nemodificirani su bukovi uzorci bili postojaniji nego modificirani. Kako bi se povećala površinska zaštita modificiranog drva, potrebno je posebno razviti novi tip premaza za drvo modificirano limunskom kiselinom.

Ključne riječi: *kemijska modifikacija, limunska kiselina, QUV izlaganje vanjskim uvjetima, lazura za drvo, bukovina*

1 INTRODUCTION
1. UVOD

In exterior application wood is susceptible to weathering and attack by microorganisms. Weathering is the general term used to define the slow degradation of materials exposed to the weather (Williams, 2005). The weathering process often results in discoloration, a physical deterioration of the wood surface, and loss of paint-retaining properties. Sunlight (especially UV and visible light) and water play a major role in weathering of wood.

The UV light causes photochemical degradation mainly in lignin polymer in the cell wall. As the lignin is degraded, water leaches out degradation products and washes away loosened surface cellulose fibers, causing a rough surface. Water also causes the wood to swell, and upon drying, checks and cracks develop that expose new material to UV degradation (Feist et al. 1991). Wood can be chemically modified to minimize specific problems such as moisture absorption, swelling and shrinkage, as well as susceptibility to photodegradation and microbial attack. It has been established that chemical modification of wood can also influence the behavior of wood under weathering and improve the performance of coatings (Plackett *et al*, 1992; Beckers *et al*, 1998; Evans *et al*, 2000; Xie *et al*, 2005, 2006, 2008; Tomažič *et al*, 2004; Temiz *et al*, 2007). Modification of fir and beech wood with citric acid has been shown to improve the dimensional stability and biological durability (Bischof Vukušić *et al*, 2006; Despot *et al*, 2008; Šefc *et al*, 2009). The citric acid crosslink with wood and enhance dimensional stability of the modified wood, which might help to improve the coating performance because the coating should be less stressed by movements of the substrate. However, the modification of wood may have an impact on wood wettability and adhesion of coatings (Podgorski *et al*, 2000; Hakkou *et al*, 2004; Petrič *et al*, 2007). The aim of this preliminary research was to investigate the color stability and weathering resistance of coated and uncoated wood modified with citric acid under accelerated weathering conditions.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

This study examined chemically modified (mark: M) and unmodified (mark: U) beech wood (*Fagus sylvatica* L.). Chemical modification was performed with 7.0 % water solution of citric acid and 6.5 % sodium-hypophosphite monohydrate (*SHP*) as a catalyst. Beech wood panels with radial surfaces and with dimensions of (500x110x21) mm^3 were conditioned at 20 °C and 65 % RH and then modified. The chemical modification consisted of impregnation followed by thermal process. The impregnation process was started with initial vacuum of 2 kPa without solution (1h). The vacuum vessel was then filled with the solution followed by pressure of 200 kPa (17h), vacuum of 2 kPa (3h), pressure of 200 kPa (2h), and at the end by vacuum of 2 kPa of samples without solution (0.5h). After impregnation the samples were gradually heated from 50 °C to 200 °C. The curing of the samples was carried out as follows: 50 °C (24 h), 75 °C (24 h), 100 °C (96 h), 110 °C (25 min), 120 °C (25 min), 130 °C (20 min), 140 °C (15 min), 150 °C (10 min), 160 °C (10 min), 170 °C (5 min), 180 °C (5 min), 190 °C (5 min) and 200 °C (5 min). The wood panels were planed and sawed to dimensions of (150x74x18) mm^3 and then conditioned at 20 °C and 65 % RH. The average weight percentage grain (WPG) of sixteen modified samples was 5.8 %.

The samples were coated with two commercial wood stains: transparent water-borne stain (mark: W) and transparent solvent-borne stain (mark: S), and with reference stain (mark: R) according to HRN EN 927-3 provided by Belinka Belles d.o.o. All coatings were applied on wood manually by brush in three layers with a 24 hour drying time between layers. The amount of applied water-borne stain was 90 g/m^2 per layer and of solvent-borne and referent stains 50 g/m^2 per layer. The average dry film thickness was 50 μm for the water-borne and referent system, and 60 μm for the solvent-borne system. The dry film thickness was measured at five positions on two samples for each coating.

The accelerated outdoor exposure was conducted in a QUV weathering tester (Q-Panel Company) equipped with UVA-340 florescent lamps. Seven panels of each type of coated samples and two panels of uncoated chemically modified and unmodified samples were exposed to UV light directly at the distance of 5 cm for 56 days (1344 hours). The exposure cycle consisted of 24 h condensation period at (45±3) °C followed by 2.5 h UV irradiation period of 0.77 $W/m^2/nm$ at (60±3)°C and by 0.5 h water spray period of 6-7 l/min without irradiation. The periods of UV irradiation and water spray were alternately repeated 48 times. It took a whole week to complete the cycle (168 h).

The surface of samples was examined for color and gloss changes, adhesion and appearance of flaking, cracking, blistering and chalking before and after 2, 4, 7, 14, 28, 42 and 56 days of exposure.

Color changes were measured with a portable spectrophotometer Microflash 100d produced by Datacolor (d/8° measuring geometry, 10° standard observer, D65 standard illuminate, xenon flash lamp source)

always on the same eight locations. The overall color change ΔE* was measured using the CIE *L*a*b** color measuring system by the following equation:

$$\Delta E^* = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2} \quad (1)$$

where ΔL^*, Δa^* and Δb^* are the differences between the initial and final values (before and after UV irradiation) of L^*, a^* and b^*, respectively.

Gloss changes were measured with a portable glossmeter produced by Erichsen, model 507. The measurements were made at the angle of 60° on the three locations parallel to the wood grain.

The examination of wood samples for appearance of cracking, blistering, flaking and chalking was performed according to HRN EN ISO 4628-2, 4, 5 and 6.

The adhesion of coatings was determined by cross-cut test according to HRN EN ISO 2409 at two positions on the samples.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of color and gloss changes are presented in Figure 1 and 2. As could be expected, the most prominent color changes were in uncoated wood samples. Modified uncoated wood changed the color more than unmodified uncoated wood during accelerated exposure. This could be expected because modification of wood with citric acid modifies cellulose not lignin, which is susceptible to photodegradation.

At the end of exposure the overall color change (ΔE^*) of coated wood samples was smaller in unmodified wood samples. After 56 days of exposure the samples coated with referent stain exhibited the smallest color change, followed by samples coated with solvent-borne stain, and samples coated with water-born stain. Referent stain shows the best color stability because it contains pigments that protect wood from UV light. Table 1 shows the initial values of color parameter for all the samples. They were apparently different for modified and unmodified wood, and for coated and uncoated wood. After modification with citric acid, wood changed color due to the high temperature during thermocondensation and the decomposition of citric acid at high temperatures (Katović *et al*, 2005).

The trend of gloss changes of modified and unmodified wood samples was very similar during the exposure as can be seen in Figure 2. The gloss of uncoated modified and unmodified wood samples was basically unchanged during the exposure (Figure 2d).

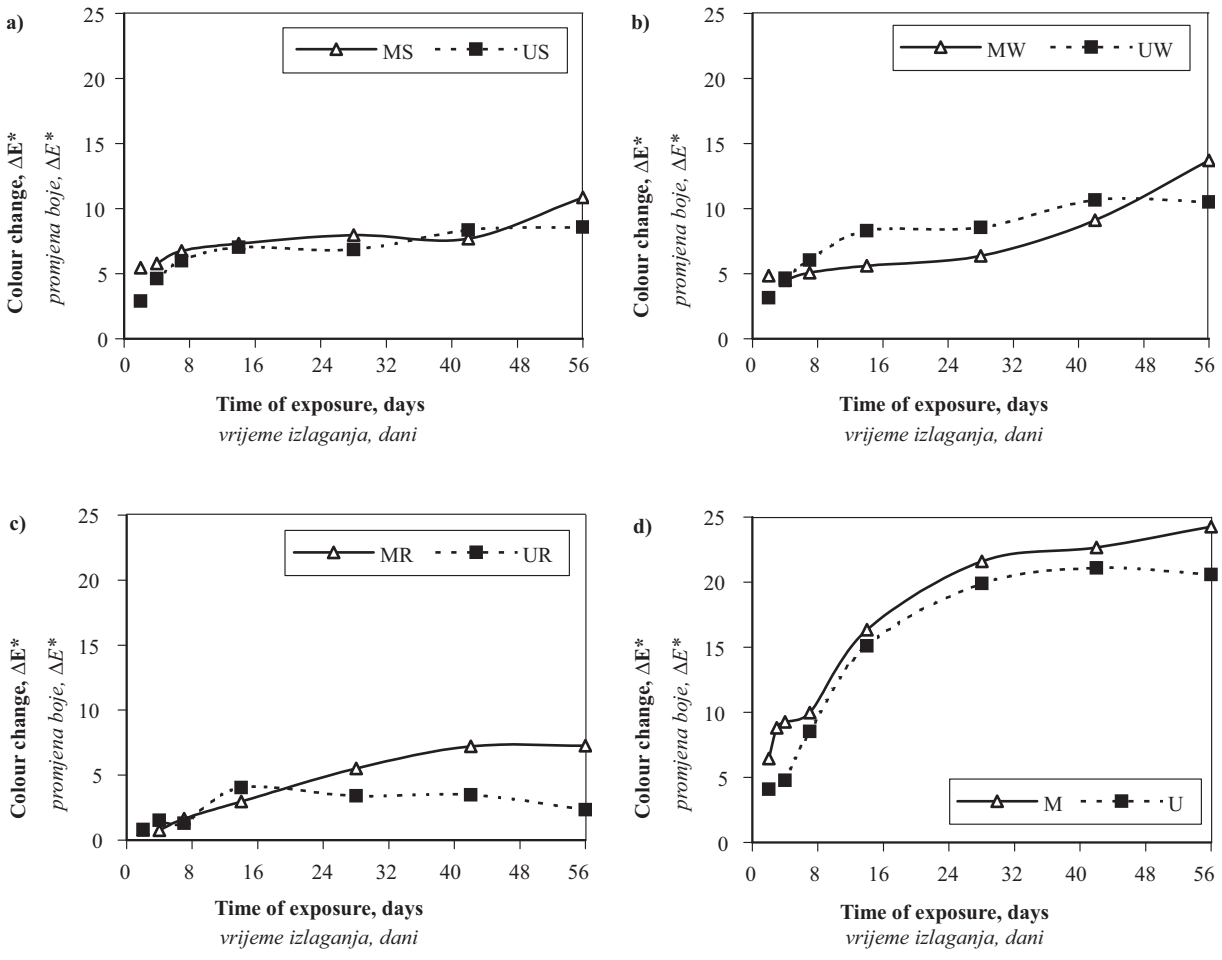

Figure 1 Color changes of beech wood modified with citric acid and coated with solvent-borne stain (a), water-borne stain (b), referent satin (c) and of unmodified and uncoated beech wood (d) during accelerated weathering
Slika 1. Promjene boje bukovine modificirane limunskom kiselinom i obrađene otapalnom lazurom (a), vodenom lazurom (b), referentnom lazurom (c), te nemodificirane, neobrađene bukovine (d)

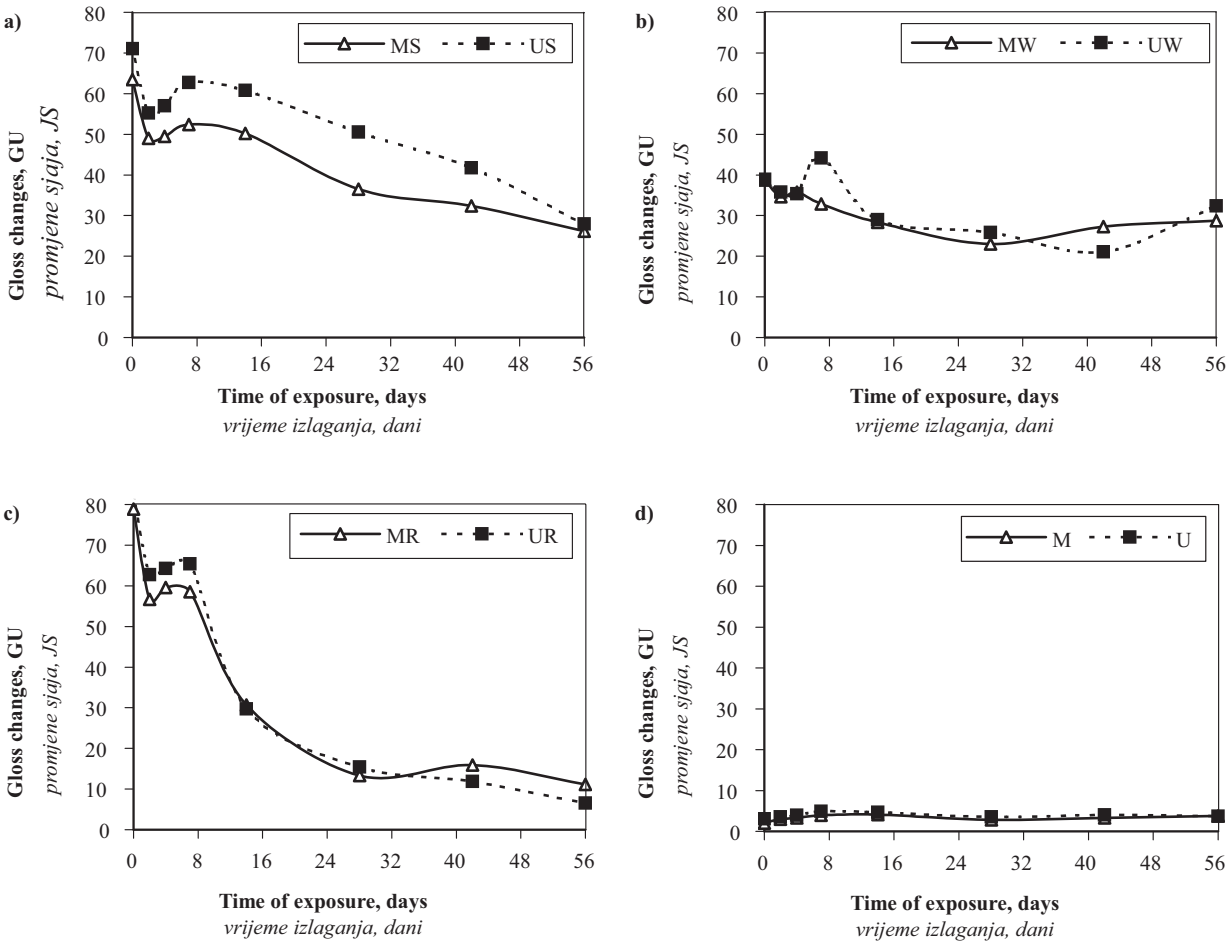

Figure 2 Gloss changes of beech wood modified with citric acid and coated with solvent-borne stain (a), water-borne stain (b), referent satin (c) and of unmodified uncoated beech wood (d) during accelerated weathering
Slika 2. Promjene sjaja bukovine modificirane limunskom kiselinom i obrađene otapalnom lazurom (a), vodenom lazurom (b), referentnom lazurom (c), te nemodificirane, neobrađene bukovine (d)

The referent stain exhibited the most prominent gloss change during the exposure (Figure 2c), followed by solvent-borne stain (Fig 2a) and water- borne stain (Figure 2b). The solvent-borne stain exhibited higher gloss changes between unmodified and modified wood samples than other stains.

The results of adhesion and visual assessment of surface properties after accelerated exposure are presented in Table 2.

According to the results presented in Table 2, it can be concluded that unmodified coated beech wood samples exhibited better weathering resistance than

Table 1 Color CIE*L*a*b** parameters for beech wood samples before accelerated weathering
Tablica 1. Parametri boje CIE*L*a*b** uzoraka bukovine prije ubrzanog izlaganja vanjskim uvjetima

Type of sample / *Vrsta uzorka*	**Color parameters** / *Parametri boje* [a]		
	*L**	*a**	*b**
Uncoated / *Neobrađen*			
unmodified / *nemodificiran*	73.10 (3,72)	9.05 (1.82)	20.08 (2.44)
modified / *modificiran*	55.86 (5.35)	11.25 (0.78)	24.17 (2.10)
Coated with water-borne stain / *Obrađen transparentnom vodenom lazurom*			
unmodified / *nemodificiran*	73.69 (1.73)	7.05 (1.01)	22.20 (0.33)
modified / *modificiran*	59.30 (4.04)	8.32 (0.61)	14.07 (2.78)
Coated with solvent-borne stain / *Obrađen transparentnom otapalnom lazurom*			
unmodified / *nemodificiran*	70.00 (5.34)	9.80 (2.72)	26.78 (1.84)
modified / *modificiran*	47.12 (6.78)	14.22 (1.47)	16.39 (7.99)
Coated with referent stain / *Obrađen referentnom lazurom*			
unmodified / *nemodificiran*	37.73 (1.17)	29.02 (2.20)	18.97 (2.00)
modified / *modificiran*	34.91 (1.16)	21.41 (3.40)	14.20 (2.06)

[a] Values in parenthesis are standard deviations. / *Vrijednosti u zagradama standardne su devijacije.*

Table 2 Determination of adhesion before and after 52-day accelerated weathering and visual assessment of surface properties after 52-day accelerated weathering
Tablica 2. Određivanje adhezije prije i nakon 52 dana ubrzanog izlaganja te vizualna procjena površine nakon 52 dana ubrzanog izlaganja

Type of sample / *Vrsta uzorka*	**Class** / *Ocjena*[a]					
	Before weathering *Prije izlaganja*	**After 52-day weathering** / *Nakon 52 dana izlaganja*				
	Adhesion *Adhezija*	Adhesion *Adhezija*	Cracking *Pucanje*	Chalking *Kredanje*	Flaking *Ljuštenje*	Blistering *Mjehuranje*
Uncoated / *Neobrađen*						
unmodified / *nemodificiran*	-	-	5	-	-	-
modified / *modificiran*	-	-	5	-	-	-
Coated with water-borne stain / *Obrađen transparentnom vodenom lazurom*						
unmodified / *nemodificiran*	2	3	3	1	3	2
modified / *modificiran*	3	4	5	2	3	3
Coated with solvent-borne stain / *Obrađen transparentnom otapalnom lazurom*						
unmodified / *nemodificiran*	1	1	4	2	2	2
modified / *modificiran*	2	3	4	1	0	2
Coated with referent stain / *Obrađen referentnom lazurom*						
unmodified / *nemodificiran*	2	1	3	1	1	1
modified / *modificiran*	1	2	5	1	1	2

[a] Class 0 – no changes, class 5 – the greatest changes. / *Ocjena 0 – bez promjene, 5 – najveća promjena.*

modified coated beech wood samples. During accelerated weathering, the cracking behavior of uncoated modified and unmodified wood samples was very similar. These results suggested that cross-linking reaction between cellulose and citric acid was not sufficient to stop the effects of weathering. At the end of the accelerated exposure the most prominent changes were the changes in adhesion and cracking. Of all tested stains, at the end of accelerated weathering the referent stain showed the best performance, followed by the solvent-borne stain and the water-borne stain. These results are opposite to majority of literature data concerning the weathering of chemically modified wood but there are also results that indicate that some methods of modification do not improve the weathering performance of wood. For example Evans (1998) established that esterification of wood with dicarboxylic acid anhydrides did not increase the resistance of wood to weathering. Podgorski and Roux (1998) showed that acetylation treatment did not improve the coating behavior during artificial weathering. Feist and Rowell (1982) also found that butylenes oxide- or butyl isocyanate-modified southern pine wood performed no better than untreated controls during accelerated outdoor weathering. Unfortunately there is no literature data regarding the coatability of wood modified with citric acid. Modification is generally expected to diminish adhesion by making the wood surface less polar and less porous resulting in worse coating wetting of wood and fewer chemical bonds between the two surfaces (Hunt *et al*, 2007). Trajković *et al*. (2007) established the decrease of pH value, increase of wettability with water and decrease of total surface free energy after modification of beech wood with citric acid, but which of these properties contributed mostly to change adhesion should be further investigated.

4 CONCLUSIONS
4. ZAKLJUČCI

The modification of beech wood with citric acid did not improve the color stability of neither uncoated nor coated samples during accelerated weathering.

These preliminary results show that wood modification with citric acid and sodium-hypophosphite monohydrate (*SHP*) as catalyst negatively affects the performances of tested commercial water-borne and solvent-borne wood stains. This indicates that in future research the wood modified with citric acid should require the novel type of finishes developed especially for this type of substrate.

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Usporedba fizikalnih svojstava neobrađene i toplinski obrađene bukovine i grabovine

Comparison of Physical Properties of Untreated and Heat Treated Beech and Hornbeam

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SAŽETAK • *Istraživanjem fizikalnih svojstava toplinski obrađene bukovine i grabovine utvrđeno je da je njihova srednja vrijednost manja i signifikantno se razlikuje od srednjih vrijednosti fizikalnih svojstava neobrađene bukovine i grabovine. Srednja vrijednost gustoće u apsolutno suhom stanju toplinski obrađene bukovine manja je za 8,5 % od neobrađene, a za grabovinu je ona manja za 7,5 %. Smanjenje srednjih vrijednosti maksimalnih utezanja toplinski obrađene bukovine i grabovine u odnosu prema neobrađenoj još je veće. Maksimalno radijalno utezanje toplinski obrađene bukovine manje je za 7 %, maksimalno tangencijalno utezanje za 23,5 %, a maksimalno volumno utezanje za 19,3 % od istih fizikalnih svojstava neobrađene bukovine. Toplinski obrađena grabovina ima srednju vrijednost maksimalnoga radijalnog utezanja za 123 %, maksimalnoga tangencijalnog utezanja za 86 % i maksimalnoga volumnog utezanja za 99,5 % manju od istih fizikalnih svojstava neobrađene grabovine.*
Takvim smanjenjem maksimalnih utezanja u radijalnome i tangencijalnom smjeru toplinskom obradom grabovina postaje znatno prihvatljivija za izradu proizvoda za koje je važna dimenzionalna stabilnost.

Ključne riječi: *fizikalna svojstva, toplinski obrađeno drvo, bukovina, grabovina*

ABSTRACT • *The investigation of physical properties of heat treated beech wood and hornbeam wood found that their average value is lower and significantly different from average values of physical properties of untreated beech wood and hornbeam wood. The average value of density in absolutely dry condition of heat treated beech wood is smaller by 8.5% from the untreated, and the hornbeam wood is smaller by 7.5%. Reduction of average values of maximum shrinkage of heat treated beech wood and hornbeam wood is even bigger in relation to the untreated wood. Maximum radial shrinkage of heat treated beech wood is smaller by 7%, maximum tangential shrinkage by 23.5% and maximum volumetric shrinkage by 19.3% compared to the same physical properties of untreated beech wood. Heat treated hornbeam wood has an average value of maximum radial shrinkage smaller by 123%, maximum tangential shrinkage by 86% and maximum volume shrinkage by 99.5% compared to the same physical properties of untreated hornbeam wood.*
With such reduction in the maximum shrinkage in radial and tangential direction using heat treatment, hornbeam becomes particulary suitable for making products where dimensional stability is important.

Key words: *physical properties, heat treated wood, beech wood, hornbeam wood*

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1. UVOD
1 INTRODUCTION

Celuloza, hemiceluloze i lignin (Kollmann i Cote, 1968) tri su makromolekularne komponente od kojih je izgrađeno drvo. Reaktivne hidroksilne grupe u polimerima stijenki gradbenih stanica drva utječu na većinu kemijskih i fizikalnih svojstava drva. Iznosi utezanja koji utječu na stabilnost drva jedni su od njegovih bitnih fizikalnih svojstava. Toplinskom obradom drva smanjuje se utjecaj reaktivnih hidroksilnih grupa. U proteklim desetljećima mnogi su istraživači proveli istraživanja na tom području (Stamm, 1946, 1956; Stamm, 1964; Hillis, 1984; Rowell, 1983; Rowell, 1984; Kumar, 1994; Militz *et al*, 1997). Tjeerdsma *et al*. (1998) i Kotilainen (2000) također su proučavali utjecaj temperatura viših od 180 ºC na kemijska svojstva drva. Na temelju promjene kemijskih svojstava dolazi, među ostalim, do smanjenja mase i higroskopnosti drva odnosno do povećanja stabilnosti dimenzija drva (Tjeerdsma *et al*, 1998; Kotilainen, 2000; Yildiz, 2002; Rousset *et al*, 2004). Uz te pozitivne učinke toplinske obrade drva nastaju i negativni koji se očituju smanjenjem mehaničkih svojstava drva (Yildiz *et al*, 2002). Veličina slabljenja mehaničkih svojstava drva ovisi o vrsti drva, maksimalnoj temperaturi i vremenu izloženosti drva visokoj temperaturi (Vernois, 2001). Navedena istraživanja pridonijela su mogućnosti široke industrijske primjene toplinske obrade drva (Bourgois, 1989; Rapp, 2001).

Bukva (*Fagus sylvatica* L.) je najzastupljenija vrsta drva u Hrvatskoj pa je zato potrebno proučiti fizikalna svojstva bitna za njezinu uporabu. Toplinska obrada bukovine, uz poboljšanje fizikalnih svojstava, omogućuje i ujednačivanje boje, doduše većinom smeđe, za dijelove bukovih stabala koji sadržavaju nepravu srž odnosno crveno srce. Time se povećava i iskoristivost sirovine.

Grab (*Carpinus betulus)* je zbog nekih svojih fizikalnih svojstava slabo cijenjena vrsta difuzno poroznih listača. Uobičajena je sličnost fizikalnih svojstava grabovine sa svojstvima bukovine, uz još veće iznose utezanja nego u bukovine. S takvim fizikalnim svojstvima grabovina je slabo iskorištena iako posjeduje specifična estetska svojstva. Toplinsk je obrada proces koji bi trebao omogućiti veću primjenjivost grabovine, uz gubitak specifičnih estetskih svojstava. Mogućnost šire primjene grabovine u drvnoj industriji i manja cijena grabovine kao sirovine mogli bi se povećati primjenom toplinske obrade.

2. MATERIJAL I METODE
2 MATERIAL AND METHODS

Istraživanje je provedeno na bukovini i grabovini. Od svake vrste drva uzeta je po jedna srednjača dužine dva metra, a sredina te piljenice nalazila se na prsnoj visini. Srednjače su izrađene od stabala s područja Papuka i iz iste gospodarske jedinice, što znači da su stabla imala i jednake uvjete rasta. Srednjača je u poprečnoj ravnini prepiljena na pola i dio ispod prsne visine uzet je za izradu uzoraka recentne bukovine i grabovine. Dio piljenica iznad prsne visine toplinski je obrađen na temperaturi 200 ºC, uz ukupno vrijeme trajanja procesa od 72 sata od početka zagrijavanja do hlađenja industrijske komore. Vremensko razdoblje u kojemu je drvo bilo na 200 ºC iznosilo je 48 sati.

Nakon završetka procesa toplinske obrade od piljenica su izrađeni uzorci za ispitivanje fizikalnih svojstava drva. Uzorci su izrađivani od piljenica s mjesta od prsne visine prema žilištu i krošnji kako bi položaj uzoraka u piljenicama odnosno deblu bio što sličniji za obje grupe uzoraka. U trenutku ispitivanja fizikalnih svojstava sadržaj vode u uzorcima neobrađene bukovine i grabovine iznosio je 11 %, a u uzorcima toplinski obrađene bukovine i grabovine 4 %.

Ispitivanja fizikalnih svojstava – gustoće nakon potapanja, sadržaja vode nakon potapanja, gustoće u apsolutno suhom stanju, maksimalnih utezanja u radijalnome i tangencijalnom smjeru te maksimalnoga volumnog utezanja – provedena su prema važećim Europskim normama.

Statistička obrada i testiranje signifikantnosti razlike srednjih vrijednosti uspoređivanih svojstava neobrađene i toplinski obrađene bukovine i grabovine obavljeno je Mann-Whitneyevim testom, uz pomoć računalnoga statističkog programa Statistica.

3. REZULTATI I DISKUSIJA
3 RESULTS AND DISCUSSION

Statističke vrijednosti rezultata istraživanja fizikalnih svojstava neobrađene i toplinski obrađene bukovine prikazane su u tablici 1.

Srednja vrijednost gustoće nakon potapanja neobrađene bukovine, kao i sadržaja vode nakon potapanja, veća je od gustoće nakon potapanja i sadržaja vode nakon potapanja toplinski obrađene bukovine. Srednje vrijednosti obaju svojstava neobrađene bukovine signifikantno su veće od srednjih vrijednosti toplinski obrađene bukovine prema Mann-Whitneyevu testu.

Srednja vrijednost sadržaja vode nakon potapanja neobrađene bukovine veća je za 15,4 % od srednje vrijednosti sadržaja vode nakon potapanja toplinski obrađene bukovine. To je posljedica smanjenog potencijala upijanja vode nakon toplinske obrade drva.

Slična tendencija smanjenja fizikalnih svojstava i signifikantnost razlike srednjih vrijednosti pokazuje se za gustoću u apsolutno suhom stanju te za maksimalno radijalno, tangencijalno i volumno utezanje. Srednja vrijednost gustoće u apsolutno suhom stanju neobrađene bukovine veća je za 8,5 % od srednje vrijednosti gustoće u apsolutno suhom stanju toplinski obrađene bukovine. Srednja vrijednost maksimalnoga radijalnog utezanja neobrađene bukovine veća je za 7 % od srednje vrijednosti maksimalnoga radijalnog utezanja toplinski obrađene bukovine i signifikantno se razlikuju. Sličan odnos pokazuje maksimalno tangencijalno utezanje, s tim da je srednja vrijednost maksimalnoga tangencijalnog utezanja neobrađene bukovine za 23,5 % veća od srednje vrijednosti maksimalnoga tangencijalnog ute-

Tablica 1. Prikaz statističkih vrijednosti fizikalnih svojstava neobrađene i toplinski obrađene bukovine.
Table 1. Survey of statistical values for physical properties of untreated and heat treated beech

Neobrađena bukovina – *Untreated beech*							**Toplinski obrađena bukovina** – *Heat treated beech*					
ρ_w	ρ_o	W	β_r maks.	β_t maks.	β_v maks.		β_v maks.	β_t maks.	β_r maks.	W	ρ_o	ρ_w
g/cm^3	g/cm^3	%	%	%	%		%	%	%	%	g/cm^3	g/cm^3
49	49	49	49	49	49	N	65	65	65	65	65	65
1,094	0,636	88	4,44	11,6	16,2	MIN	11,7	5	3,3	72	0,546	1,01
1,144	0,680	105	5,78	12,6	17,9	AVE	15	10,2	5,4	91	0,627	1,084
1,201	0,752	117	6,94	13,5	19,1	MAX	17	11,7	8,1	119	0,739	1,141
0,0247	0,0347	8,9	0,62	0,43	0,65	SD	1,54	1,18	0,94	12,7	0,06	0,028
0,0006	0,0012	79,7	0,38	0,19	0,43	VAR	2,36	1,4	0,88	160	0,004	0,0008

Legenda: ρ_w – gustoća nakon 14-dnevnog potapanja u vodi, ρ_o – gustoća u apsolutno suhom stanju, W – sadržaj vode nakon 14-dnevnog potapanja, β_r maks. – totalno radijalno utezanje, β_t maks. – totalno tangencijalno utezanje i β_v maks. – totalno volumno utezanje

Key: ρ_w – density after a fortnight of water soaking, ρ_o – density in absolutely dry condition, W – water content after a fortnight of soaking, β_r max – total radial shrinkage, β_t max – total tangential shrinkage and β_v max – total volume shrinkage

zanja toplinski obrađene bukovine. Srednja vrijednost maksimalnoga volumnog utezanja neobrađene bukovine veća je za 19,3 % nego toplinski obrađene bukovine.

Sve navedene vrijednosti pokazuju da toplinski obrađena bukovina slabije upija vodu, ima manju gustoću i manja maksimalna utezanja od neobrađene. Toplinska obrada bukovine opravdava svoju svrhu jer su toplinskom obradom neobrađene bukovine njezina relativno nepovoljna maksimalna utezanja poboljšana, tj. znatno smanjena.

Na slikama 1. i 2. prikazan je odnos maksimalnoga radiajalnog utezanja te gustoće u apsolutno suhom stanju za neobrađenu i toplinski obrađenu bukovinu.

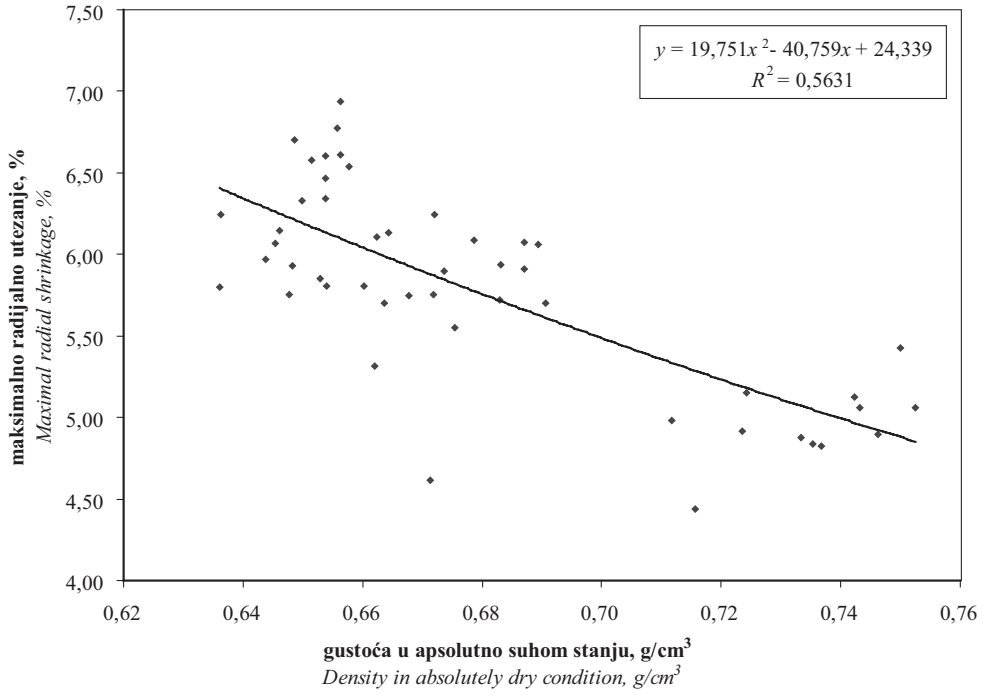
Na slikama 1. i 2. vidljivo je da se s porastom gustoće u apsolutno suhom stanju neobrađene bukovine maksimalno radijalno utezanje smanjuje, uz zadovoljavajući koeficijent korelacije za drvo. Nasuprot tome, s porastom gustoće u apsolutno suhom stanju toplinski obrađene bukovine maksimalno radijalno utezanje raste, uz zadovoljavajući koeficijent korelacije za drvo.

Slične zakonitosti vidljive su i za maksimalno volumno utezanje neobrađene i toplinski obrađene bukovine na slikama 3. i 4.

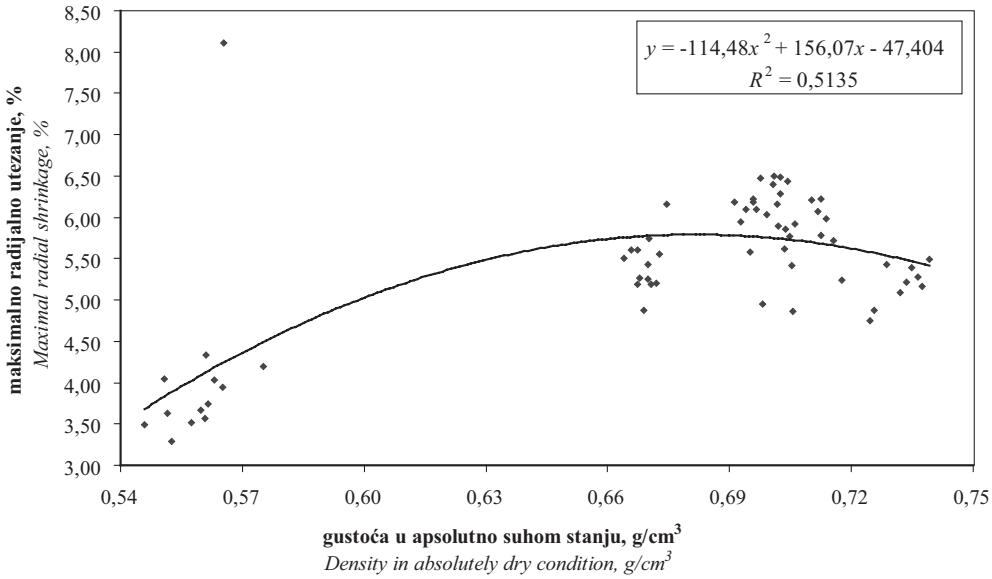
Statističke vrijednosti rezultata istraživanja fizikalnih svojstava neobrađene i toplinski obrađene grabovine prikazane su u tablici 2.

Prema Mann-Whitneyevu testu, srednje vrijednosti gustoće i sadržaja vode nakon potapanja neobrađene grabovine signifikantno su veće od srednjih vrijednosti gustoće i sadržaja vode nakon potapanja toplinski obrađene grabovine.

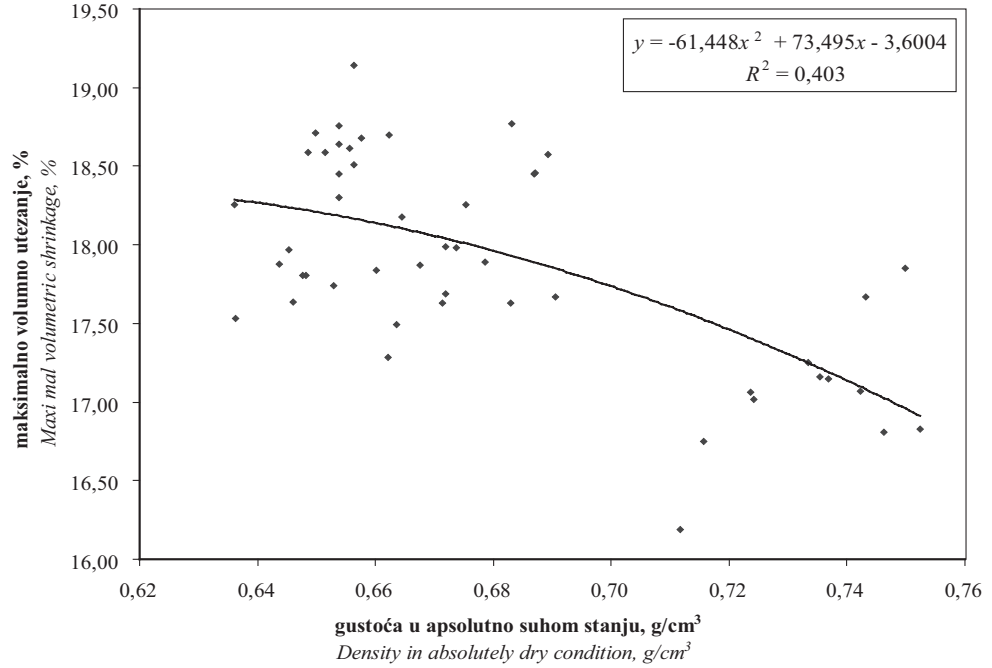
Srednja vrijednost sadržaja vode nakon potapanja neobrađene grabovine veća je za 12,5 % od srednje vrijednosti sadržaja vode nakon potapanja toplinski obrađene grabovine. To je posljedica smanjenog potencijala upijanja vode nakon toplinske obrade drva.



Slika 1. Odnos gustoće u apsolutno suhom stanju i maksimalnoga radijalnog utezanja neobrađene bukovine
Figure 1 Relationship between density in absolutely dry condition and maximum radial shrinkage for untreated beech wood



Slika 2. Odnos gustoće u apsolutno suhom stanju i maksimalnoga radijalnog utezanja toplinski obrađene bukovine
Figure 2 Relationship between density in absolutely dry condition and maximum radial shrinkage for heat treated beech



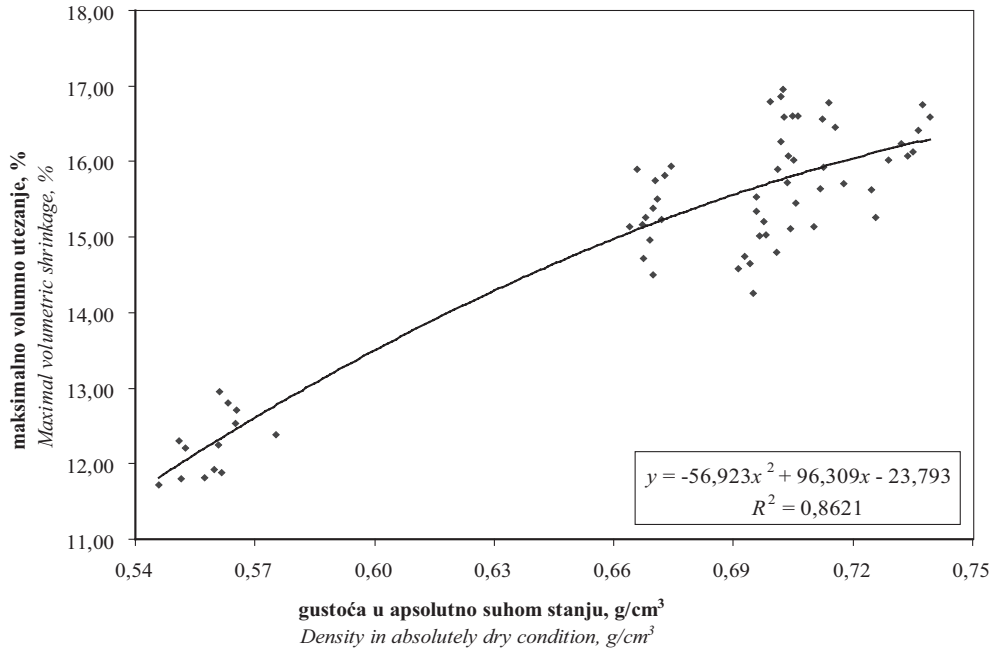
Slika 3. Odnos gustoće u apsolutno suhom stanju i maksimalnoga volumnog utezanja neobrađene bukovine
Figure 3 Relationship between density in absolutely dry condition and maximum volume shrinkage for untreated beech wood

Tablica 2. Prikaz statističkih vrijednosti za fizikalna svojstva neobrađene i toplinski obrađene grabovine
Table 2 Survey of statistical values for physical properties of untreated and heat treated hornbeam wood

Neobrađena grabovina *Untreated hornbeam*							**Toplinski obrađena grabovina** *Heat treated hornbeam*					
ρ_w	ρ_o	W	β_r maks.	β_t maks.	β_v maks.		β_v maks.	β_t maks.	β_r maks.	W	ρ_o	ρ_w
g/cm³	g/cm³	%	%	%	%		%	%	%	%	g/cm³	g/cm³
59	59	59	59	59	59	N	30	30	30	30	30	30
1,103	0,683	84	6,34	8,3	15,5	MIN	7,53	4	3,1	66	0,620	1,049
1,125	0,716	90	8,02	9,86	17,1	AVE	8,57	5,3	3,6	80	0,666	1,092
1,154	0,735	94	9,54	11,1	19,3	MAX	9,99	8,6	4,4	92	0,711	1,124
0,01	0,0123	2,43	0,84	0,64	0,92	SD	0,65	0,92	0,31	6,38	0,03	0,02
0,0001	0,0002	5,92	0,71	0,41	0,85	VAR	0,42	0,84	0,1	40,6	0,0009	0,0004

Legenda: ρ_w - gustoća nakon 14-dnevnog potapanja u vodi, ρ_o - gustoća u apsolutno suhom stanju, W - sadržaj vode nakon 14-dnevnog potapanja, βr maks. - totalno radijalno utezanje, βt maks. - totalno tangencijalno utezanje i βv maks. - totalno volumno utezanje

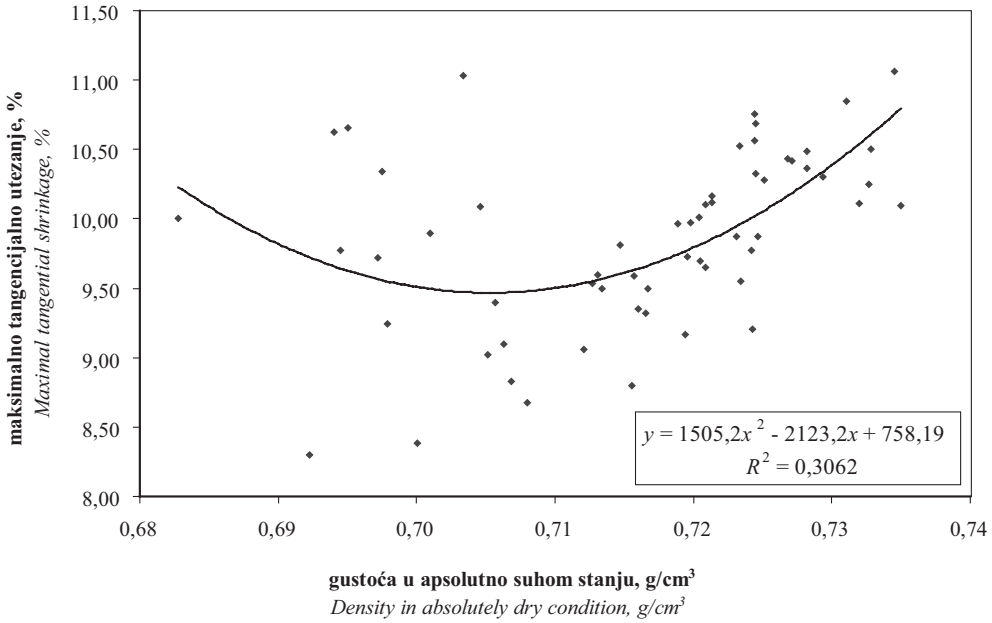
Key: ρ_w - density after a fortnight of water soaking, ρ_o - density in absolutely dry condition, W – water content after a fortnight of soaking, βr max - total radial shrinkage, βt max - total tangential shrinkage and βv max - total volume shrinkage



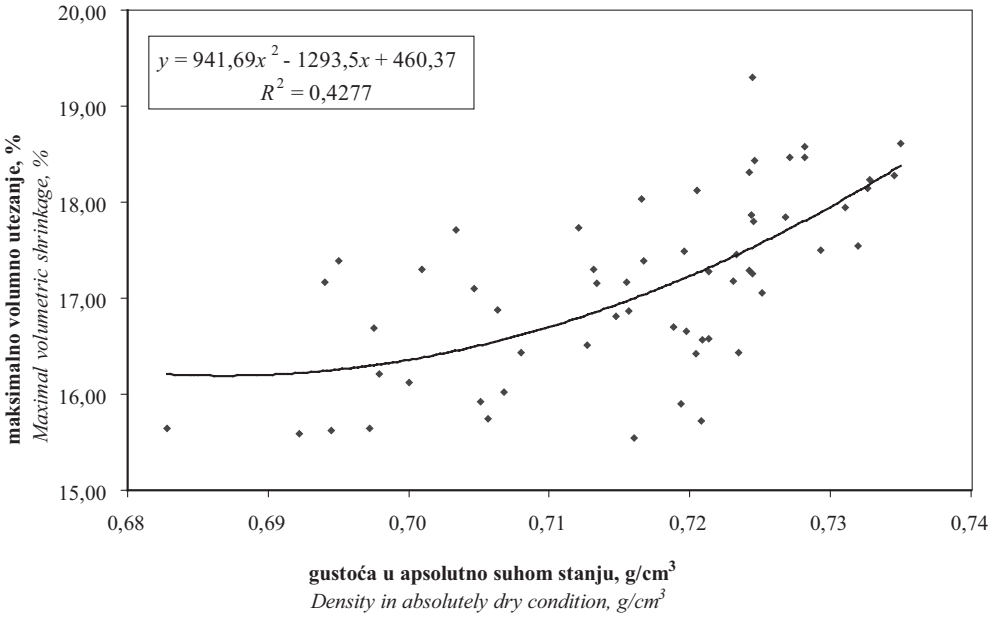
Slika 4. Odnos gustoće u apsolutno suhom stanju i maksimalnoga volumnog utezanja toplinski obrađene bukovine
Figure 4 Relationship between density in absolutely dry condition and maximum volume shrinkage for heat treated beech wood

Slična tendencija smanjenja fizikalnih svojstava i signifikantnost razlike srednjih vrijednosti pokazuje se za gustoću u apsolutno suhom stanju te za maksimalno radijalno, tangencijalno i volumno utezanje. Srednja vrijednost gustoće u apsolutno suhom stanju neobrađene grabovine veća je za 7,5 % od srednje vrijednosti toplinski obrađene grabovine. Srednja vrijednost maksimalnoga radijalnog utezanja neobrađene grabovine veća je za 123 % od srednje vrijednosti maksimalnoga radijalnog utezanja toplinski obrađene grabovine i signifikantno se razlikuju. Sličan odnos pokazuje tangencijalno utezanje, s tim da je srednja vrijednost maksimalnoga tangencijalnog utezanja neobrađene grabovine za 86 % veća od paralelne srednje vrijednosti toplinski obrađene grabovine. Srednja vrijednost maksimalnoga volumnog utezanja neobrađene grabovine veća je za 99,5 % od paralelne srednje vrijednosti toplinski obrađene grabovine.

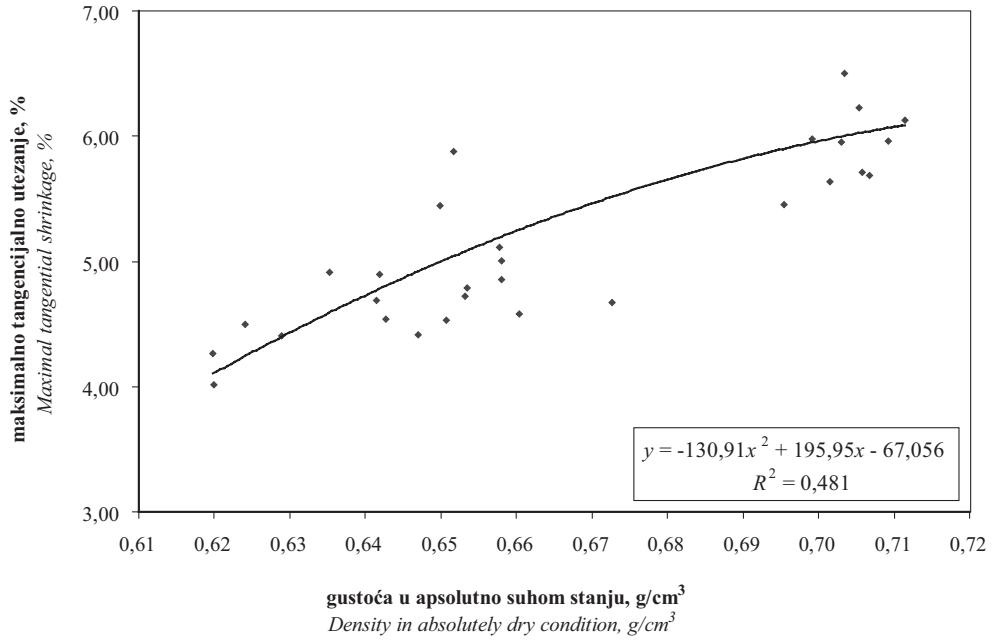
Navedene vrijednosti pokazuju da toplinski obrađena grabovina slabije upija vodu, ima manju gustoću u apsolutno suhom stanju i manja maksimalna utezanja od neobrađene grabovine. Toplinska obrada grabovine opravdava svoju svrhu jer su toplinskom obradom neobrađene grabovine njezina izrazito nepovoljna maksimalna utezanja znatno poboljšana, tj. uvelike smanje-



Slika 5. Odnos gustoće u apsolutno suhom stanju i maksimalnoga tangencijalnog utezanja neobrađene grabovine
Figure 5 Relationship between density in absolutely dry condition and maximum tangential shrinkage for hornbeam wood



Slika 6. Odnos gustoće u apsolutno suhom stanju i maksimalnoga volumnog utezanja neobrađene grabovine
Figure 6 Relationship between density in absolutely dry condition and maximum volume shrinkage for hornbeam wood



Slika 7. Odnos gustoće u apsolutno suhom stanju i maksimalnoga tangencijalnog utezanja toplinski obrađene grabovine
Figure 7 Relationship between density in absolutely dry condition and maximum tangential shrinkage for heat treated hornbeam wood

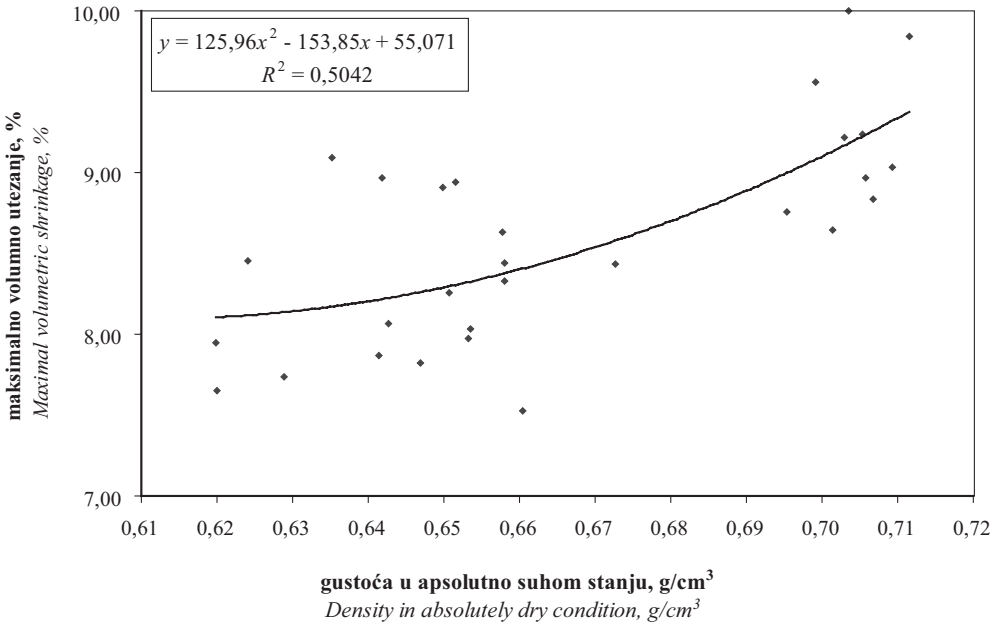
na. Na slikama 5. i 6. prikazan je odnos maksimalnoga tangencijalnog i volumnog utezanja te gustoće u apsolutno suhom stanju za neobrađenu grabovinu.

Na slikama 5 – 8. vidljivo je da se s porastom gustoće u apsolutno suhom stanju povećavaju maksimalna utezanja u tangencijalnom smjeru i volumna utezanja neobrađene i toplinski obrađene grabovine. Koeficijenti korelacije podataka, s krivuljama koje pokazuju trend, također su zadovoljavajući za drvo. Takav opći trend nije u potpunosti jednak za sve prikazane odnose fizikalnih svojstava. Na slici 5. za odnos gustoće u apsolutno suhom stanju i maksimalnoga tangencijalnog utezanja neobrađene grabovine pri nižim je gustoćama zamjetan pad vrijednosti, nakon čega dolazi njegova porasta.

4. ZAKLJUČCI
4 CONCLUSIONS

Toplinskom obradm bukovine postignuto je očekivano smanjenje maksimalnih utezanja po smjerovima, kao i maksimalno volumno utezanje. Iznosi smanjenja srednjih vrijednosti maksimalnih utezanja toplinski obrađene bukovine u usporedbi s neobrađenom kreću se od 19,3 % za maksimalno volumno utezanje i 23,5 % za maksimalno tangencijalno utezanje do 7 % za maksimalno radijalno utezanje.

Srednje vrijednosti maksimalnih utezanja neobrađene bukovine signifikantno se razlikuju od srednjih vrijednosti maksimalnih utezanja toplinski obrađene bukovine. Neobrađenoj je bukovini toplinskom obra-



Slika 8. Odnos gustoće u apsolutno suhom stanju i maksimalnoga volumnog utezanja toplinski obrađene grabovine
Figure 8 Relationship between density in absolutely dry condition and maximum volume shrinkage for heat treated hornbeam wood

dom također smanjena gustoća u apsolutno suhom stanju. Srednja vrijednost gustoće u apsolutno suhom stanju neobrađene bukovine veća je za 8,5 % od srednje vrijednosti gustoće u apsolutno suhom stanju toplinski obrađene bukovine i te se vrijednosti signifikantno razlikuju. Srednja vrijednost gustoće nakon potapanja neobrađene bukovine veća je od iste vrijednosti toplinski obrađene bukovine, što vrijedi i za srednju vrijednost sadržaja vode, koji je nakon potapanja neobrađene bukovine za 15,4 % veći nego u toplinski obrađene bukovine. Iz rezultata istraživanja vidljivo je da s porastom gustoće maksimalno radijalno utezanje u apsolutno suhom stanju u neobrađene bukovine pada. U toplinski obrađene bukovine s porastom gustoće u apsolutno suhom stanju maksimalno radijano utezanje raste. Ista je pojava uočena i za maksimalno volumno utezanje.

Neobrađena grabovina ima 12,5 % veću srednju vrijednost sadržaja vode nakon potapanja nego toplinski obrađena grabovina, kao i veću srednju vrijednost gustoće u apsolutno suhom stanju, i to za 7,5 %. Srednja vrijednost maksimalnog utezanja u radijalnom smjeru čak je za 123 % veća za neobrađenu grabovinu nego za toplinski obrađenu grabovinu. Srednje vrijednosti maksimalnoga tangencijalnog utezanja neobrađene grabovine veće su za 86 %, a srednje vrijednosti maksimalnoga volumnog utezanja veće su za 99,5 % nego u toplinski obrađene grabovine. Sve srednje vrijednosti istraživanih svojstava neobrađene i toplinski obrađene grabovine signifikantno se razlikuju. Odnos gustoće u apsolutno suhom stanju i maksimalnih utezanja u tangencijalnom smjeru te maksimalnoga volumnog utezanja pokazuje da s porastom gustoće u apsolutno suhom stanju rastu i maksimalna utezanja u tangencijalnom smjeru i volumno.

Iz provedenog je istraživanja vidljivo da toplinski obrađena bukovina i grabovina imaju manje iznose srednjih vrijednosti maksimalnih utezanja u radijalnome i tangencijalnom smjeru, kao i volumno utezanje u usporedbi s neobrađenim drvom. Toplinskom je obradom tih dviju vrsta drva, a posebno grabovine, smanjen negativan faktor maksimalnih utezanja kao prepreka za primjenu u proizvodima od drva za koje je stabilnost dimenzija presudna.

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Scientific-Research Cluster as a form of Knowledge Transfer

Znanstvenoistraživački klaster kao oblik prijenosa znanja

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ABSTRACT • *The issue of knowledge transfer within organizations acting in the economic sphere is high on the agenda at this time. The reason is that on the one hand, considerable public funds are spent for different forms of research, but on the other hand, the effectiveness of these resources within the industry is comparatively low. Developing an efficient technology transfer is along-term activity. The concept of technology transfer is a narrowed concept. The wider concept is the transfer of intellectual property. The suggested model would contain substantive, structural, and relationship functional definition of a scientific-research cluster as a new form of knowledge transfer in the industrial sphere. The stated issue is solved within the project of the 7th EU Framework Programme, where the author of the paper participates as a co-project manager. The proposed scientific-research cluster is to serve as a model for countries of Central and Eastern Europe.*

Key words: *knowledge transfer, economic sphere, technology transfer*

SAŽETAK • *Pitanje prijenosa znanja u organizacije na području gospodarstva trenutačno je visoko na prioritetnoj listi. Razlog je ponajprije to što se znatna sredstva ulažu u različite oblike istraživanja, no unatoč tome učinkovitost rezultata tih istraživanja u industriji je relativno niska. Povećanje učinkovitosti prijenosa znanja dugotrajna je aktivnost. Koncept transfera tehnologija je uzak. Transfer intelektualnog vlasništva mnogo je širi koncept. Predloženi model sadržava značenjske definicije, strukturne definicije i definicije funkcionalnih odnosa znanstvenoistraživačkog klastera kao novog oblika prijenosa znanja u industrijsko okruženje. Promatrani problem rješava se unutar projekta 7. EU Okvirnog programa, u kojemu autorica rada sudjeluje kao koprojekt menadžer. Opisani znanstvenoistraživački klaster predložen je kao model za zemlje srednje i istočne Europe.*

Ključne riječi: *prijenos znanja, gospodarsko okruženje, prijenos tehnologije*

1 INTRODUCTION
1. UVOD

One of the fundamental problems of increasing the effectiveness of organizations today includes the issues concerning the knowledge transfer into organizations operating in the economic sphere. On the one hand, at present considerable resources are spent both from the public resources and from the funds of economic organizations for the various forms of research, on the other hand, the effectiveness of these funds is low. The experience of advanced industrialized countries shows that it often takes several years prior to building an effective technology transfer function (Figure 1). The concept of technology transfer is a narrow concept, and actually the wider concept includes the tran-

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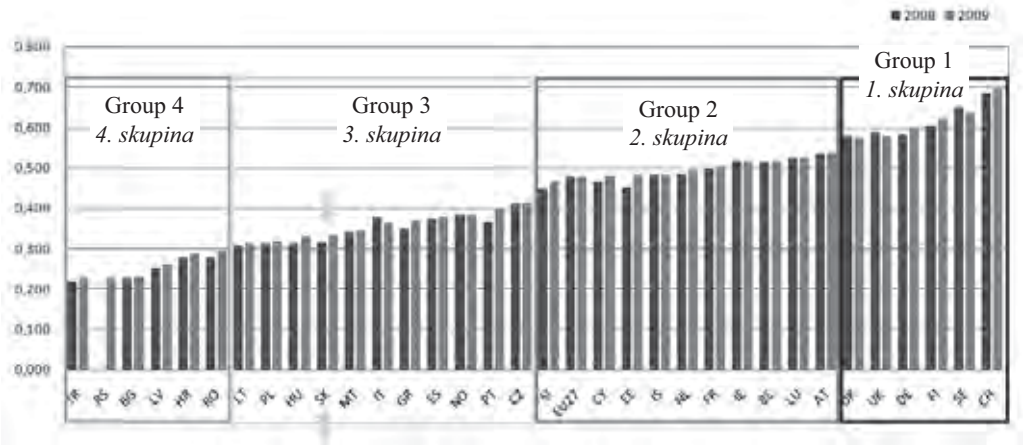

Figure 1 European Innovation Scoreboard 2009, Published 2010, www.proinno-europe.eu, Note: The SII
Slika 1. Europska tablica inovacija 2009, izdanje 2010, www.proinno-europe.eu, Note: The SII

sfer of intellectual and industrial property. This transfer (besides technology it relates to other forms of intellectual and industrial property, particularly to materialization of intellectual and industrial property in developing new products, etc.) should be an effective implementation of aproactive management system of the intellectual and industrial property.

This requirement has recently been underestimated.

At present, however, the main challenge is to:
- provide activities of knowledge transfer (particularly in research organizations, regardless of their funding, a clear commitment of the top management of these organizations);
- provide management of the ownership regimes of such knowledge, particularly the results of development and research in order to clearly determine the entity responsible for the use of intellectual and industrial property;
- be involved in the implementation of this commitment of scientists and researchers to develop a structure that is, from the professional point of view, prepared for the maintenance of effective relations of research and development organizations of all parties involved (stakeholders).

Regardless of the ownership, legal and organizational form of research and development organizations, at present an effective form of resolving the above issues is considered to be the establishment of so-called „knowledge transfer offices" (Knowledge Transfer Office-KTO). These organizations have a different legal and organizational form, but the role that is performed in the course of their activities is common. Formulating the mission of these organizations, their structures and networking is preceded by several key assumptions, which apply to all these organizations.

Transfer of knowledge is an important function, which requires the Professional management. This function must be adequately secured by resources, by a long-termcommitment of providing an access to the necessary funds and expertise.

KTO increases the effectiveness of research organizations in the transfer of knowledge to maximize the benefits of these organizations for the society.

The most effective approach to the transfer of knowledge lies in creating a solid link among KTO, research organizations, as well as the researchers themselves.

Acquiring the knowledge, tools and techniques in the field of knowledge transfer can take several years and it is therefore important to allow the exchange of the best experience and practices not only between individual KTO, research organizations, but also with the industrial practice.

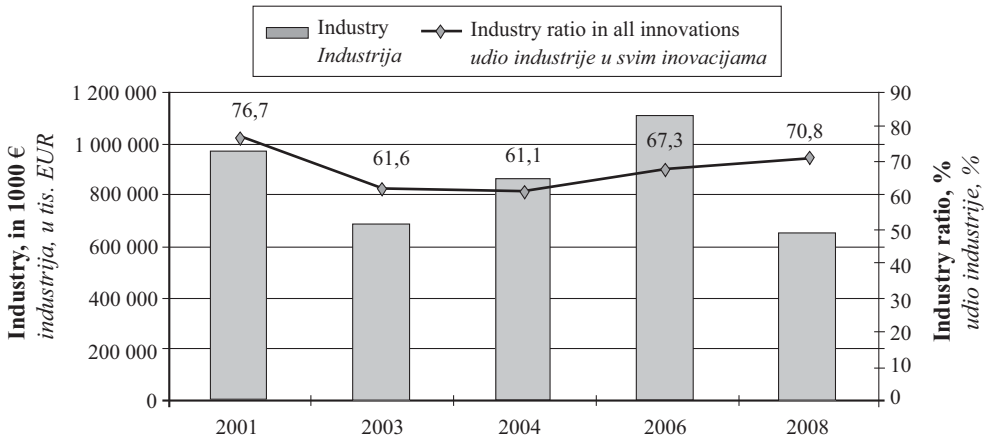

Figure 2 Trend of investments to industry in Slovakia (in 000 €). Source: ŠÚ SR
Slika 2. Trend investicijskih ulaganja u industriju Slovačke (u tis.EUR). Izvor: ŠU SR

1.1 Research problem
1.1. Problematika istraživanja

The knowledge transfer office (KTO) includes different organizations that operate in the active transfer of knowledge from research and development organizations, financed from public sources, such as universities, academy of science and others, but also from the research organizations receiving contributions from the state budget, etc. The organizational forms of these organizations are diverse, ranging from e.g. centers established at particular universities up to different half-autonomous organizations and profit organizations.

Before taking a decision on what type of KTO this refers to, it will be necessary for a KTO founder to formulate its mission, which would include the objectives of the respective founder. The mission must be formulated so as to be understood and adopted by the following entities: the management and employees of the future KTO, the management of the respective founder (e.g. a university or a research institute), by the investigators, who are expected to be involved in the respective innovation process, industrial enterprises that should manufacture new products and introduce them to the market, by state administration bodies and local self-government authorities (especially regional ones), which are responsible for defining the public policy and which will often be in charge of providing financial subsidies to KTO. This mission is not always understood by the representatives of several involved parties, since the involved parties may include employees of the Academy of Science, employees of universities, departments of these organizations, but also students, government bodies (national and international), employees in the service sector e.g. experts in the field of patents, lawyers, national and multinational industrial companies, small and medium enterprises, financial institutions, risk capital owners and others. The problem does not lie in the fact that these entities do not understand the importance of KTO, but in the fact that each of these entities has its own interests and the creation of KTO may limit the interests of such involved parties.

Therefore, the formulation of the mission is rather difficult.

Although the detailed formulation of the mission may be differentiated depending on specific conditions, whether the local or other ones, the central idea of each KTO mission may be formulated as follows:

The central mission of knowledge transfer offices is to ensure the increase in the efficiency of the transfer of research and development results so as to achieve a maximum benefit for the society.

In formulating the mission in a particular case, various aspects may be taken into account and the key aspect should be determined so as to play the most important role in the KTO activities. Such aspects maybe:

- providing the transfer of results of the publicly-funded research into new products and services for the public use and nation wide benefits;
- promoting regional economic development and increasing the employment rate;
- for universities - promoting the development, maintaining the faculties and increasing the level of educational process;
- creating new or improving the existing relations with industry;
- generating new sources of funding for universities or research institutes based on the sponsored research, increasing the consultancy and expertise opportunities for universities and research institutes, obtaining either financial or non-financial ones (in the form of equipping these institutions with necessary facilities);
- serving as a service centre for the protection and exploitation of intellectual and industrial property;
- acting actively in order to facilitate the creation of spin-out businesses, scientific and technological parks, incubators and others;
- generating the network of income for KTO;
- creating conditions for effective implementation of the knowledge transfer, innovations, technologies and the results of development and research activities from universities, the Slovak Academy of Science and departmental development and research institutions to the economic practice (small and medium-sized companies and large companies in theregion);
- creating a marketing platform of development and research institutions to support obtaining financial resources – both the public and private ones;
- implementing lobbying of development and research institutions towards national institutions and European governmental institutions for achieving the objectives of KTO.

Regardless of the formulation of particular aspects of the KTO mission, it would be needed to incorporate an aspect to the KTO mission as mentioned in the above list, since this aspect creates a basis for managing the intellectual property, particularly in the organizations financed from the public sources.

2 RESEARCH METHOD
2. METODA ISTRAŽIVANJA

2.1 Analysis of the current situation and establishment of structure of research and development cluster (RDC)
2.1. Analiza trenutačne situacije i uspostavljanje strukture klastera za istraživanje i razvoj (RDC)

Primary tasks that must be determined in connection with the establishment of the Knowledge Transfer Office shall include:

- determining the nature of the office being established (legal and organizational type of the office)
- determining the amount of resources needed for fulfilling the task of the office and
- deciding how resources are to be used and created.

In advanced industrialized countries various organizational structures are established for the performance of tasks and missions of knowledge transfer offices. In general, they may be divided into three basic groups:

- offices that provide services of this nature only for one research organization, and they are generally a part of the development and research organization;

- offices that are created as legally and organizationally separate entities that ensure transfer of knowledge of several scientific and research organizations and customers are considerably differentiated;
- offices that have come into existence and operate as profit-making-orientedentities and their organizational structure generally corresponds to the structure of economic organizations.

Based on the approved task of the 7th Framework Programme, under which the transfer of knowledge is to be made, the RDC is an organization that can be included to the second group of organizations described in the above structuring. Based on this fact, the RDC will be aimed at promoting knowledge transfer to a larger number of research organizations, meaning on the other hand that it will operate separately (geographically and organizationally) from research organizations and, of course, from the researchers of these organizations, where the number of these researchers will be considerable and also the results of their research activities will be differentiated.

In this context, it should be noted that this form of organization requires close relations with the inventors and researchers, and the opportunities of knowledge transfer are so difficult that they can often lead to unfulfilled expectations which are typical for the establishment of RDC. On the other hand, this form of organization that represents acertain form of centralization of resources may finally be effective. It should be emphasized that the model for the knowledge transfer office is clearly conditioned by the formulation of mission and tasks of the RDC.

In connection with the establishment of such R & D cluster, it is necessary to fulfill the following basic tasks:
- formulate a cluster mission;
- determine its organizational and legal model;
- define the method of acquiring resources for the cluster operation;
- define the relationship with research organizations and researchers;
- define the relationship with industry;
- define the relationship with government organizations and
- define the relationship with regional organizations in the area of the cluster acting.

2.2 Cluster mission
2.2. Misija klastera

In formulating the cluster mission, it is necessary to determine the cluster fundamental role and its additional tasks. The basic role of the RDC can be defined as follows:

Create the conditions and ensure the implementation of the transfer of knowledge and the results of scientific research activity from the area of the research funded by public sources, as well as sources of economic profit organizations and own resources of R & D centers into the economic practice and thereby contribute to increasing the competitiveness of economic organizations. The target beneficiaries of such knowledge should mostly be small and medium-sized enterprises, which do not have the resources for both basic and extensive applied research.

Additional tasks and functions of RDC shall include:
- assisting in the planning of research tasks of scientific research organizations;
- ensuring that the results of scientific research tasks are placed to the international databases;
- creating the conditions for participation in the marketing survey in the area of ascertaining requirements of industrial practice for solving the urgent requirements and for the transfer of these requirements to R & D centers;
- assisting in placing the results of scientific research activities into the implementation phase;
- co-participating in the transfer of knowledge to the economic practice and social development of a respective region;
- co-participating in the protection and exploitation of intellectual and industrial property by consulting and teaching activities, especially for small and medium-sized enterprises;
- advisory activities by which they will co-act in building spin-out businesses, incubators and scientific and technological parks in a respective region.

2.3. Organizational and legal model of the research and development cluster
2.3. Organizacijski i pravni model klastera za istraživanje i razvoj

A research and development cluster should be an economically and legally independent nonprofit organization focusing on the tasks referred to in the RDC mission. Organizational structure of the RDC will be flexible. However, in principal, the RDC should be an organization with few employees, whose organizational structure should be tailored to the tasks in 3 key areas:
- cluster management area, which would be necessary to solve the issues of the management of the cluster activity, economic problems of the cluster, the area of marketing and relationships with government and regional authorities, assistance insolving the problems of protection and exploitation of industrial and intellectual property in research organizations (the issue of ownership of the tasks being solved, legal issues relating to patents and others);
- the area of relations to scientific-research organizations; in this field this should refer primarily to the assistance to scientific research organizations in the planning of tasks, providing information on obtaining grants, placement of the results of research to international and national databases, ensuring that the results of scientific research activity will be transferred to the industrial practice;
- the area of industrial relations practice (small and medium-sized enterprises and big companies) as the main beneficiaries of the knowledge transfer. In this area the main activities of the RDC would be aimed primarily at identifying and influencing prospective plans of small and medium-sized enterprises with regard to the possibility of using the results of scientific research

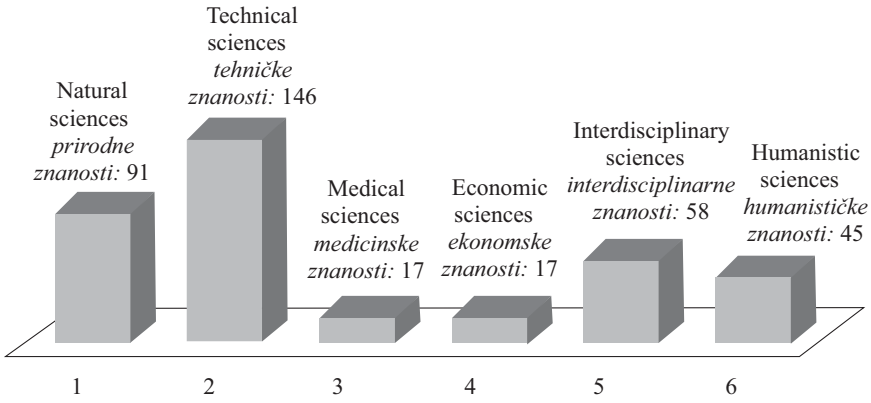

Figure 3 Number of investments in research and development in particular fields in the period 2006-2008 in Slovakia. Source: ŠÚ SR
Slika 3. Broj investicija u istraživanje i razvoj na pojedinim poljima znanosti u razdoblju 2006-2008.u Slovačkoj. Izvor: ŠU SR

tasks solved by the scientific research base of a respective region.

2.4 Provision of sources for the cluster activity
2.4. Pribavljanje sredstava za aktivnosti klastera

Experience from the advanced industrialized countries shows that the period until the office forknowledge transfer obtains sufficient funds to cover its activities lasts up to 10 years. On the other hand, it is necessary to take into account that the economic organizations in our country are at present focused mainly on short-term profits (Figure 2). These two assumptions result in problems with financing the activity of a research and development cluster. Especially in the initial period it is required, in the area of the RDC activities, to rely on a massive support from the structural funds, the support from government and regional authorities. E.g. in Canada the amount representing 7% of the budget funds for science and research is determined to support knowledge transfer offices. The support of knowledge transfer is the main tool of using outputs from scientific research activities in a respective country (Figure 3). This means that in the initial period of the cluster activity, such activity should be financed mainly from the structural funds and the national budget. The second main source of cluster financing is the support of the regional authorities. The cluster activity within a respective region is a major tool for increasing the business competitiveness of a certain region (Figure 4) and thereby not only for improving the living standard of the respective region, but through the tax and levy policy, it is also the tool for increasing the region income. The third source of financing the cluster activities are members' contributions of individual members of the cluster.

Although it is probable that this should be the main source of revenues for the cluster, it is necessary to note that at present the formation of clusters has become popular and that each cluster expects contributions from its members. On the other hand, the impacts of the contribution of individual clusters on the economic results of thecluster members are minimal and consequently problems may be expected in this area already during the cluster establishment. From a long-term perspective, the cluster activity should be financed by a share of profits reached by the transfer of knowledge (whether in thefield of technology, new products and services, the share of profits of potential spin-out businesses, licenses, contracts with the industrial practice, or other forms of the transfer of know-how).

In this respect the position of the cluster, as an organization to ensure cooperation with a number of economic or scientific research organizations, is far more complex than the position of the organization (or

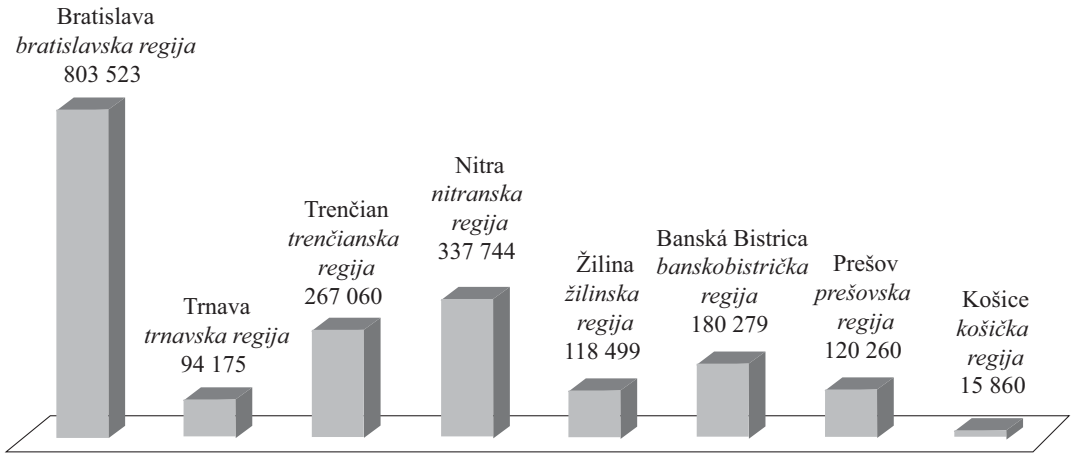

Figure 4 Investments in innovations for particular regions in Slovakia (in 1000 €). Source: ŠÚ SR
Slika 4. Investicije u inovacije za pojedine regije u Slovačkoj (u tis. EUR). Izvor: ŠU SR

the centre of technology transfer, etc.) operating as an organizational unit of a particular organization (e.g., university, etc.). Identification of resources and obtaining funds for the RDC is a task that in no case can be underestimated. In the first years of cluster operation, this task is regarded as the most complicated and most important task.

3 RESEARCH RESULTS
3. REZULTATI ISTRAŽIVANJA

3.1 The basic precondition for the cluster success – maintaining strategic cluster relationships
3.1. Osnovni preduvjeti za uspjeh klastera – održavanje strateških odnosa klastera

In connection with the mission of R&D cluster and its organizational structure, focus was placed on the issues of relations with major entities, with which the RDC has to maintain relations as a precondition for the success of the cluster. The main strategic relationships are the relationships with the following entities:

- relationships with scientific research institutes and centers, regardless of the sources of their funding and in this respect a non negligible role is played by researchers and inventors. In the effective transfer of knowledge into the business practice the RDC must professionally and methodically assist in solving the relations of the parties involved;
- relations with the private sector, which is a major suggested customer of outputs from scientific research activities;
- relations with the state administration bodies and local government bodies (Figure 5).

3.1.1 Relations with scientific-research centers
3.1.1. Odnosi sa znanstvenoistraživačkim centrima

The relationship with scientific research centers in terms of meeting the cluster mission is the most important. Without the cooperation with these centers, where inventions, new technologies, designs of new products and knowledge are created, the transfer of knowledge to the industry would be impossible. Although it is not obvious at first sight, since the success and effectiveness of R&D centers depend on the work of inventor sand researchers, the aspect of influence (even the indirect one) cannot be marginal for the successful operation of the cluster. Therefore it is necessary to highlight the problems and the role of inventors and researchers and this will result in the possibility of cluster acting in this area.

This group of researchers is of such importance that without their active support and involvement in the tasks being solved it would be difficult to achieve any measurable result in this activity. In this context it is necessary for them to be interested in the achieved results and they should be provided with the help in the process of licensing and patenting and enabled to have personal contact with potential candidates for the license. It is also necessary to prove them that know-how and show-how are an essential precondition for potential commercialization of the results of research activities. Since they are very busy individuals, it would be necessary to simplify the process of inventions and to provide them access to the senior staff of a research centre and contact with the cluster. This brief survey of the tasks that must be organized mostly by the management of a respective institution, also points out at the necessary technical and methodological assistance that should be provided to research organizations (the cluster members). The cluster should also help research organizations to create such relationships with the industry that would enable the flow of benefits from the industry to research institutes. These are mostly benefits such as sponsorship of research tasks, subsidies for equipment and facilities for the task being solved and others. The other aspect, not to be neglected, includes issues of the

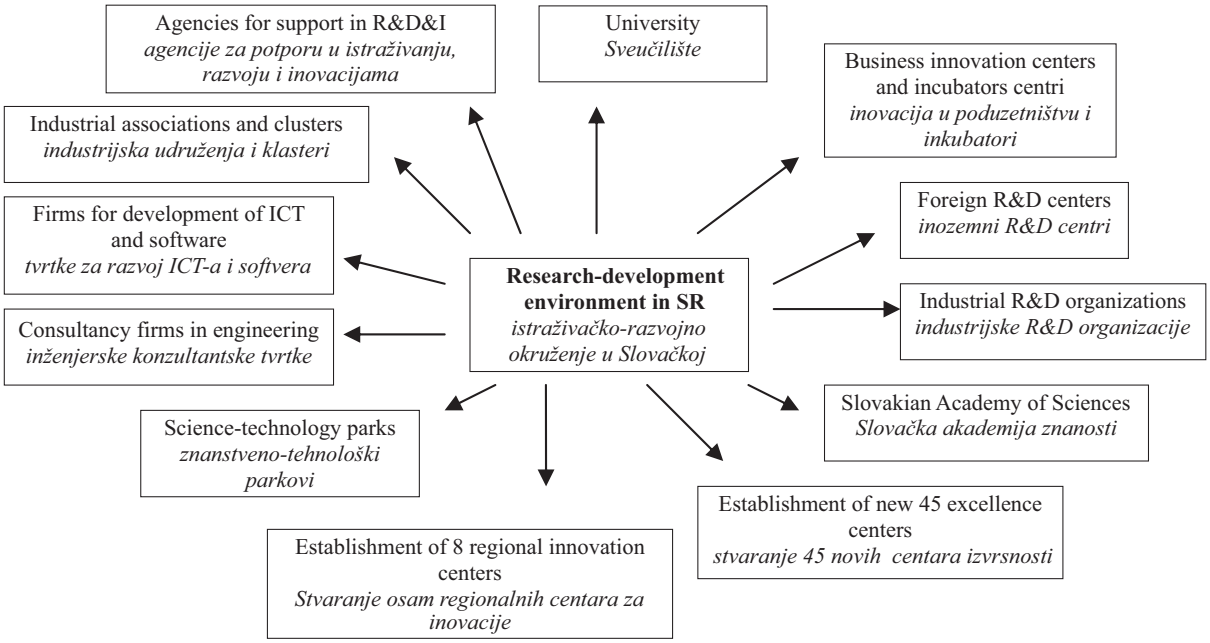

Figure 5 Structure of Slovakian research-development environment. Source: Kováč and Švač (2010)
Slika 5. Struktura slovačkoga istraživačko-razvojnog prostora. Izvor: Kováč i Švač (2010)

protection of intellectual property, shares in the profits from licenses and other forms of incentives for researchers. In this sense the cluster should be in a position to provide advisory and educational activities in the respective fields. Examples of other possible cluster cooperation with research institutes include:

- help to provide background research for the patent in the planning stage of research or any other forms of protecting of already solved research tasks. The aim of this cooperation should lie in avoiding a duplicate solution of research tasks, since the experience shows that often up to 30% of the time spent on research is spent inefficiently due to the reason of duplicity.
- in relation to the protection of intellectual property, assistance in applying confidential or secret procedures in the tasks that lead to potential outcomes that may be commercialized;
- judge the outputs of scientific research works with regard to their possible licensing or patenting;
- assist in evaluation of outputs in terms of ownership of inventions and outputs of scientific research tasks;
- provide technical assistance in the field of patent procedure.

The above mentioned tasks are focused more on aid that the cluster should provide to the management of the research centre in relation to the researchers. However, the cluster has a key role in maintaining the relationship between the cluster and research centers in the following areas:

- participating in the provision of information on perspective areas of research in the sphere of acting of a respective scientific research institute;
- assisting the scientific-research organizations (cluster member) in commercialization of the outcomes of scientific-research activities of a respective organization;
- assisting members of the cluster in searching contacts with small and medium-sized businesses as the future users of the outcomes of scientific-research activities;
- placing information on the outcomes of scientific-research activities of members of the cluster to international databases;
- assisting members of the cluster in establishing contacts and concluding contracts with foreign partners;
- provide counseling to members of the cluster on the protection and exploitation of intellectual and industrial property;
- organize educational activities for members of the cluster in the area of protection and exploitation of intellectual and industrial property with regard to EU legislation in this area.

3.1.2 Relations with the private sector
3.1.2. Odnosi sprivatnim sektorom

Relations in this area belong to the most important preconditions for the success of both R&D cluster and knowledge transfer to the economic sphere. Industrial enterprises, whether large, medium-sized or small, are or should be the customers of the outcomes of scientific-research activities. The main focus of relationships with the industrial sector may be defined in the following way:

- searching for fields of common interest of the industrial sector and R&D cluster in the implementation of the outcomes of scientific-research activities to the industrial practice, identifying demands of the industrial sector for scientific-research activity or mapping the areas of possible cooperation with the R&D cluster;
- entering into long-term cooperation contracts in the exploitation of outcomes of scientific-research activities with large enterprises and their parent companies;
- actively participating in the conclusion of licensing agreements between the members of the cluster and the industrial sector, taking into account EU legislation in this area;
- provide marketing activities in informing small and medium-sized enterprises about the outcomes of scientific-research activities and co-participating in any potential licensing negotiations;
- co-acting in establishing spin-out businesses in the research institutions financed from the public resources, particularly in universities, this still being the weakest point of knowledge transfer to the industrial use in our conditions.

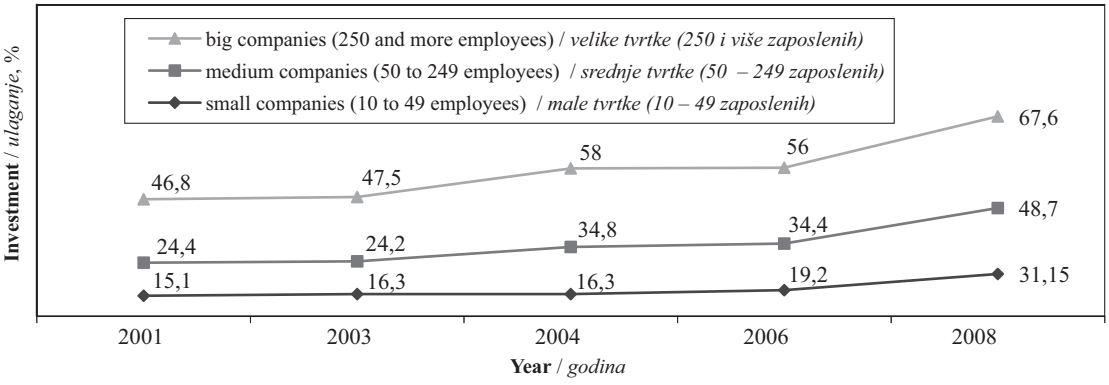

Figure 6 Trends of investments in research and development to companies for the period 2006-2008. Source: ŠU SR
Slika 6. Trend ulaganja u istraživanje i razvoj u poduzećima za razdoblje 2006 – 2008. Izvor: ŠU SR

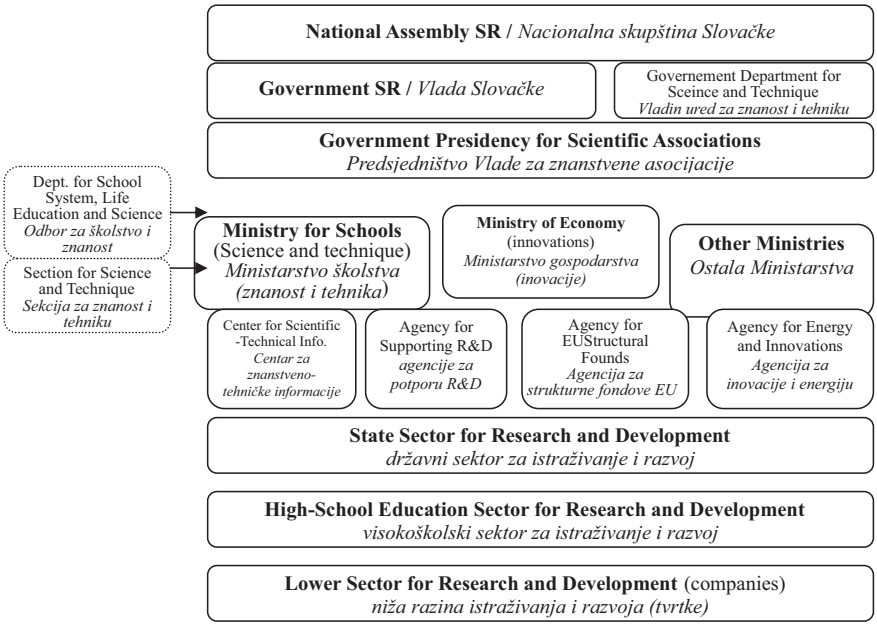

Figure 7 Management of state scientific-technical and innovation policy in Slovakia
Slika 7. Upravljanje državnom znanstveno-tehničkom i inovacijskom politikom u Slovačkoj

3.1.3 Relations with government authorities and public administration bodies
3.1.3. Odnosi sdržavnim tijelima i tijelima javne uprave

As mentioned in the introductory part, especially in the first phase of activity of R&D cluster it is necessary to organize the operation of this cluster by providing the funds whether from the structural funds or from the state budget as well as from the funds of public administration bodies. On the other hand, it should be emphasized that the successful operation of the cluster results in increasing the competitiveness of industrial organizations in a respective region, as well as in the whole national economy, which will be also reflected in the growth of taxes and levies. For these reasons, the establishment of close and mutually beneficial relations between the cluster and the state and public administration bodies is one of the preconditions for the successful operation of the cluster. Specific relationship with the state authorities is the relationship with the Industrial Property Office of the Slovak Republic, which covers the whole area of intellectual property protection from the protection of inventions, substantive patent law, utility models, industrial designs and protection of commercial symbols. In this context, for the functioning of the cluster, it is necessary to achieve the position granting that:

- at least in the first 5 years, the cluster operation is also covered by the resources of these bodies (Figure 6);

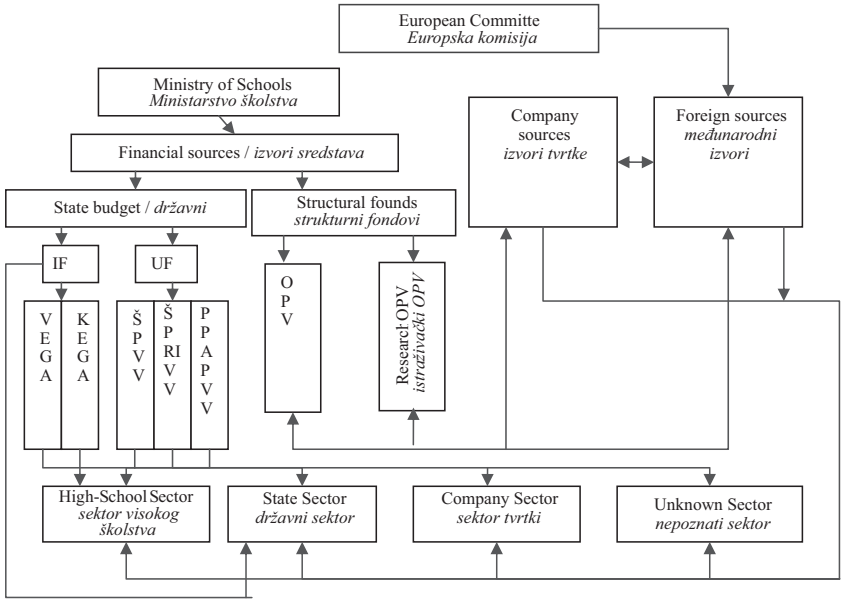

Figure 8 Scheme of financing science and research in Slovakia – Long-term plan of state scientific and technical policy until 2015
Slika 8. Shema financiranja znanosti i istraživanja u Slovačkoj – dugoročni plan državne politike za znanost i tehniku do 2015. godine

Table1 Preview of expences for cluster implementation in the first 3 years
Tablica 1. Pregled troškova uvođenja klastera u prve tri godine

Cluster costs /*Troškovi klastera*				**€ per year** / *EUR u godini*		
				2012	2013	2014
Fix costs / *Fiksni troškovi*				234 550	217230	227 933
Main planned costs (rough plan) / *osnovni planirani troškovi (grubi plan)*	Months *Mjeseci*	Persons *Osoba*	€/month *EUR/mjesec*			
Manager / *menadžer (direktor)*	12	1	3500	42000	44 100	46305
Project manager / *projektni menadžer* (3 persons / *3 osobe*)	12	3	8700	104 400	109 620	115 101
Market-technical manager / *trgovinsko-tehnički menadžer*	12	1	2900	34 800	36540	38 364
Assistant / *asistent*	12	1	1200	14400	15120	15 876
Other / *ostalo*						
Services purchesed on the market / *usluge nabavljene na tržištu*						
Professional services / *stručne usluge*	12			2500	2650	2800
Other needed services / *druge potrebne usluge*	12			3000	3150	3307
Other main costs / *ostali osnovni troškovi*						
- Assurance / *osiguranje*				200	200	200
- Tests and controls / *testovi i kontrole*				300	300	300
- Invoice audit / *pregled računa*				500	500	500
- Taxes and expences / *porezi i nameti*				0	0	0
Production overhead costs / *proizvodna režija*						
- Stationery and office supplies / *potrebni materijal i kancelarijski materijal*				1000	1100	1200
Managers overhead costs / *upravna režija*						
- Hygiene and cleaning supplies / *materijal za čišćenje i higijenu*				150	150	180
- Travel expences / *putni troškovi*				1000	1000	1000
- Telecommunication costs / *telekomunikacijski troškovi (internet, ISDN, SIM)*				1800	1800	1800
Rent for the offices / *najam prostorija*				15000	15300	15606
Purchase of techinque / *nabavka tehničke opreme*				4000	0	0
Purchase of furniture / *nabavka namještaja*				3500	0	0
Purchase of vehicle / *nabavka vozila*				20 000	0	0
Variable costs / *varijabilni troškovi*				2450	2700	2950
Electric energy / *električna energija*				1000	1100	1200
Water / *voda*				150	160	170
Heating / *grijanje*				1000	1100	1200
Waste disposal / *odvoz otpada*				200	220	250
Hygiene and cleaning supplies / *potrepštine za higijenu i čišćenje*				100	120	130
Total costs per year / *ukupni godišnji troškovi*				237 000	219 930	230 883
Fix costs / *fiksni troškovi*				234550	217230	227933
Variable costs / *varijabilni troškovi*				2450	2700	2950

- such conditions are created that the respective public administration departments (departments of government and regional bodies) could be actively involved in the activities of the cluster as well as in the cluster bodies;
- operation of the cluster is transparent, both in the area of intentions and achievements;
- a regular and effective dialogue is maintained with public administration authorities on the operation of the cluster, the results of operations of the cluster, as well as the problems of implementing the cluster mission (Figure 7, Figure 8).

3.2 Procedures and personnel hiring for the cluster activity
3.2. Postupcii upošljavanje osoblja za aktivnosti klastera

The operation of the cluster assumes mastering of all managerial functions, including protection of intellectual and industrial property. Achieving this objective entails the elaboration of major procedures for the cluster operation, as well as mastering of these procedures not only by internal but also external personnel involved in the cluster tasks. This is also a prerequisite for successful cooperation with all parties involved (sakeholders), especially with the public administration bodies and individual members of the cluster.

The practices that appear necessary for the operation of the cluster include:

- management of the ownership of inventions, patents and the outcomes of scientific-research activities;
- solving the issues of distributing the profit among individual parties involved;
- judgment and evaluation of proposed inventions and patents;
- rules for concluding the contracts between the clusters and its members, between the clusters and the enterprises to which the transfer of knowledge is headed;

- portfolio management of inventions, patents and the outcomes of scientific-research activities;
- marketing activities both in terms of entry into the cluster, as well as in the area of products offered;
- obtaining and providing information for the members of the cluster about disposable risk capital;
- management of conflicts in the interest of parties involved and others.

The portfolio of critical roles in the effective management of intellectual and industrial property and its transfer into the economic sphere is very extensive. Performance of the tasksin this area assumes 5 basic forms of expertise:

- good and effective management of all aspects of intellectual and industrial property, inventorship and patent activities, but especially the transfer of such knowledge into industrial practice;
- effective handling of basic problems of such area of the science in which the cluster has the main line of its activities;
- correct understanding of the problems of individual sectors and building of new enterprises (spin-out businesses);
- excellent project management and mastering the tools and techniques of research management;
- managing of interpersonal management tools and methods in critical situations.

4 CONCLUSIONS
4. ZAKLJUČAK

This article is the result of solving the seventh EU Framework Programme „Emergence of Research Driven Cluster in Central Europe“. The main objective was to create a research cluster focusing on knowledge transfer form research to SMEs.

The methodology for building such a cluster is to serve as a model for other countries in Central Europe. The main objective of the grant task was fulfilled. This was confirmed by the commission of the EU and problem solving has been approved.

The outputs of the project are interesting in this context in the area of wood industry.

Concerning the organizational structure of the cluster, it was pointed out that an easy organizational structure was suggested. The internal staff of the cluster will probably not be able to solve all the tasks mentioned in the section above. It is therefore necessary, when establishing the cluster bodies, to take into account the fact that the cluster bodies will not be able to assess and influence the activity of the cluster all by themselves, but they will also have to consider the engagement of external executive fellow workers. The last but not least, it should be noted that the cluster will need highly skilled employees for its work, but it will not be able to reward them in the manner of the organizations that reach very high profit. Therefore, it will also be necessary to take into account the forms of motivation of the cluster employees.

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Nencho Deliiski[1]

Evaluation of Wood Sorption Models and Creation of Precision Diagrams for the Equilibrium Moisture Content

Ocjena sorpcijskih modela drva i izrada preciznih dijagrama za ravnotežni sadržaj vode u drvu

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ABSTRACT • *Precision has been evaluated of the 10 most often used wood sorption models, available in literature, for the calculation of the equilibrium moisture content of wood given a change in temperature within the range from 0 °C to 200 °C and in the relative humidity of the surrounding air environment from 0% to 100%. Based on the results of the critical analysis, an argumentative selection has been done of the models that can be purposefully used for the computer determination of wood equilibrium moisture content in contemporary systems for model-based or model predictive automatic control of different processes of hydrothermal treatment of wood and wood materials. With the help of these models, diagrams have been created for precise determination of wood equilibrium moisture content. The established high precision of both the Simpson and Ray et al. models and the Garsía model, which we have refined, makes them user friendly for model-based or predictive automatic systems and other engineering applications in the respective temperature ranges specified in the paper.*

Keywords: *wood sorption models, mathematical description, equilibrium moisture content, temperature, relative humidity, model-based control*

SAŽETAK • *U radu se ocjenjuje točnost deset u literaturi najčešće primjenjivanih sorpcijskih modela za izračun ravnotežnog sadržaja vode u drvu za raspon temperature od 0 do 200 °C i relativne vlažnosti okolnog zraka od 0 do 100%. Na temelju kritičke analize napravljena je selekcija modela koji se mogu upotrijebiti za računalno određivanje ravnotežnog sadržaja vode u drvu u sklopu suvremenih sustava za automatsku kontrolu procesa hidrotermičke obrade drva i drvnih materijala. Uz pomoć odabranih modela napravljeni su dijagrami za prezicno određivanje ravnotežnog sadržaja vode u drvu. Dokazana visoka točnost Simpsonova i Rayeva te Garsíjeva modela, uz napravljene dorade modela, čine te modele jednostavnima za primjenu u automatskim sustavima za upravljanje i druge inženjerske primjene u rasponu temperatura specificiranih u radu.*

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Ključne riječi: *sorpcijski modeli drva, matematički opis, ravnotežni sadržaj vode, temperatura, relativna vlažnost, upravljanje na temelju modela*

1 INTRODUCTION
1. UVOD

In practice the most widely used method for the control of various processes of hydrothermal treatment of wood materials is based on ensuring scientifically based change during the time of wood equilibrium moisture content in a function of temperature t and relative humidity φ of the processing medium. In any combination of values t and φ after a certain time the wood reaches a state of stability and thus its moisture content is constant and it either receives, or emits moisture, i.e. it is in equilibrium with the surrounding environment. This moisture is defined as wood equilibrium moisture content U_{EMC}.

The instructions for exploitation of the systems for automatic control of the processes of convective drying and other kinds of hydrothermal treatment of wood materials, as a rule consist of empirical tables and/or diagrams for the dependency of U_{EMC} on t and φ. The implementation of modern control of technological processes with the help of programmable controllers or computers allows for the determination of U_{EMC} with the help of software. For this purpose, it is necessary to have a precise mathematical description of U_{EMC} depending on t and φ.

The effective control of U_{EMC} can ensure a significant reduction of the duration and specific energy expenses of the processes of hydro-thermal treatment of wood, as well as deviations in the final moisture content in the separated materials, subjected to such treatment.

The aim of the present paper is to analyze the precision of wood sorption models, found in reference literature and most often used, and to provide an argumentative choice of those most suitable for use as mathematical description of U_{EMC} in the systems of model-based and model predictive automatic control of various processes of hydrothermal treatment of wood and wood-composite materials (Deliiski, 2009b; Shubin, 1990; Trebula and Klement, 2002; Videlov, 2003).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

In the reference literature we found 10 most often used mathematical models of the sorption behavior of wood, with the help of which U_{EMC} can be calculated depending on temperature and relative humidity of the air. Chronologically, these models are published in the following way:

Model 1: Brunauer, Emmett, and Teller (1938);
Model 2: Hailwood and Horrobin (1946) – one hydrate model;
Model 3: Hailwood and Horrobin (1946) – two hydrate model;
Model 4: Malmquist (1958);
Model 5: King (1960);
Model 6: Day and Nelson (1965);
Model 7: Kaplan (1972);
Model 8: Simpson (1991);
Model 9: Garsía (2002);
Model 10: Ray *et al*. (2007).

Vidal and Cloutier (2005) make a relative assessment of the precision of the models 1, 2, 3, 4, 5, 6 and 9 in relation to experimental data published in the literature for U_{EMC} at five different values of relative humidity: 40, 52, 65, 75 and 85% for the temperature ranging between 0 °C and 160 °C. The authors determine, and our calculations also prove, that the models 1, 2 and 5 give the least accuracy. Because of this fact, these models are not evaluated below, and the calculations in the present paper at $0\% \le \varphi \le 100\%$ are limited to assessing the precision of the models 3, 4, 6, 7, 8, 9 and 10 within the range $0\ ^{o}C \le t \le 100\ ^{o}C$ and of the model 3, 4, 6, 7 and 9 within the range $100\ ^{o}C \le t \le 200\ ^{o}C$. The models 8 and 10 represent regression equations, which indicate the change in U_{EMC} depending on t and φ only within the range from 0 °C to 100 °C and are not applicable in the range$100\ ^{o}C \le t \le 200\ ^{o}C$ (Deliiski *et al*, 2009a).

In the equations of the models below φ is labeled as the relative vapor pressure, which is the result of division by 100 so as to get the relative air humidity expressed in percentages. In the models 3, 4 and 6 thermo-dynamical temperature T (in K) is taken into account and in the models 7, 8, 9 and 10 – the temperature t (in °C).

The calculated values of wood equilibrium moisture content U_{EMC} of the models 3, 6, 7, 8 and 10 are expressed with dimension percentages, and in the models 5 (Malmquist, 1958) and 9 (Garsía, 2002) U_{EMC} is expressed in kg·kg^{-1} and in order to express this in percentage terms, the obtained results have to be multiplied by 100.

The models 3, 4, 6, 7, 8, 9 and 10 are presented through the following equations:

Model 3: Hailwood and Horrobin (1946) – two hydrate model

$$U_{EMC} = \frac{1800}{M_p}\left(\frac{K\varphi}{1-K\varphi} + \frac{K_1K\varphi + 2K_1K_2K^2\varphi^2}{1+K_1K\varphi+K_1K_2K^2\varphi^2}\right) \quad (1)$$

where 1800 is the molecular weight of water x 100, g·mol^{-1}; M_p - molecular weight of a polymer unit that forms a hydrate, g·mol^{-1}.

As a result of the parameterization procedure Vidal and Cloutier (2005) deduct the following equations for the calculation of the coefficients on the right side of equation (1):

$$M_p = -330.03 + 2.3468T + 0.00028368T^2, \quad (2)$$

$$K = 0.68405 + 0.00047238T - 3.3289.10^{-8}T^2, \quad (3)$$

$$K_1 = 19.641 - 0.0587818T + 4.05.10^{-5}T^2, \quad (4)$$

$$K_2 = 2.6172 + 0.0016795T - 0.000006414T^2. \quad (5)$$

Model 4: Malmquist (1958)

$$U_{EMC} = \frac{K_1}{1 + K_2\left(\frac{1}{\varphi} - 1\right)^{\frac{K}{3}}}, \quad (6)$$

where, according to the author

$$K = 2.2885 - 0.0016742T + 2.0637.10^{-6}T^2. \quad (7)$$

$$K_1 = 0.40221 - 0.00009736T - 5.8964.10^{-7}T^2, \quad (8)$$

$$K_2 = 2.6939 + 0.018552T - 2.1825.10T^2. \quad (9)$$

Model 6: Day and Nelson (1965)

$$U_{EMC} = \frac{K_1}{1 + K_2\left(\frac{1}{\varphi} - 1\right)^{\frac{K}{3}}}, \quad (10)$$

where K_1, K_2, K_3, K_4 are constants, for which Avramidis (1989) has determined the following values:

$K_1 = -3.4.10^{-17}$; $K_2 = 9.98$; $K_3 = 300$ and $K_4 = -0.93$.

Model 7: Kaplan (1972)

$$U_{EMC} = 10{,}6^{\varphi}(3.27 - 0.015t), \quad (11)$$

Model 8: Simpson (1991)

$$U_{EMC} = \frac{1800}{M_p}\left(\frac{K_1\varphi}{1 - K_1\varphi} + \frac{K_2K_1\varphi + 2K_3K_2K_1^2\varphi^2}{1 + K_2K_1\varphi + K_3K_2K_1^2\varphi^2}\right) \quad (12)$$

where, according to the author:

$$M_p = 349 + 1.29t + 1.35.10^{-2}t^2, \quad (13)$$

$$K_1 = 0.805 + 7.36.10^{-4}t - 2.73.10^{-6}t^2, \quad (14)$$

$$K_2 = 6.27 - 9.38.10^{-3}t - 3.03.10^{-4}t^2, \quad (15)$$

$$K_3 = 1.91 + 4.07.10^{-2}t - 2.93.10^{-4}t^2. \quad (16)$$

Model 9: García (2002)

$$U_{EMC} = K\left[\left(\frac{K_5}{\varphi}\right)^{K_7} - 1\right]^{-\frac{1}{K_6}}, \quad (17)$$

where, according to the author:

$$K = K_1 \exp\left[-\left(\frac{t + K_2}{K_3}\right)^{K_4}\right], \quad (18)$$

$K_1 = 1865.75.10^{-4}$; $K_2 = 1025$; $K_3 = 1163.31$; $K_4 = 12.7441$; $K_5 = 1.09603$; $K_6 = 2.36069$ and $K_7 = 1.84447$.

Model 10: Ray et al. (2007)

In 2007 Ray et al. (2007) published their results of research on the precision of the calculation of U_{EMC} with the help of the Simpson model, i.e. using the equations (12) ÷ (16). They came to the conclusion that the average square error, when determining U_{EMC} by these equations in the range 0 °C ≤ t ≤ 44 °C, is equal to ±0.5%, but in the range 44 °C < t ≤ 100 °C it increases to ±1.5%.

This inspired the authors to propose their regression equation for the computation of U_{EMC} depending on φ and t in the range 44 °C < t ≤ 100 °C. Ray *et al* (2007) present the equation for the determination of U_{EMC} depending on φ and on temperature t expressed in degrees Fahrenheit. After substituting t in the known relation from degrees Fahrenheit to degrees Celsius, namely: t[°F] = 1,8t [°C]+32 , we obtained the following equation for determining U_{EMC} for the range 0% ≤ φ ≤ 100% and 44 °C < t ≤ 100 °C:

$$U_{EMC} = \begin{pmatrix} 7.30548 + 11.64339\varphi_c - 0.00792t_c \\ -0.37436K_1 - 0.39562K_3 + 0.06902K_2^2 \\ +0.00518K_3^2 + 0.00129K_1K_4 \\ -0.00048153K_2K_4 + 0.61135K_5 \end{pmatrix}^2 \quad (19)$$

where:

$$K_1 = 0.0001 + 0.0025t_c + 0.0007t_c^2, \quad (20)$$

$$K_2 = 0.2 + 0.06t_c - 0.00004t_c^2, \quad (21)$$

$$K_3 = 14.0 + 35.5\varphi_c + 20.7\varphi_c^2, \quad (22)$$

$$K_4 = 1.0 + 0.01\varphi_c t_c + 0.1\varphi_c^2 t_c^2, \quad (23)$$

$$K_5 = \frac{1 + K_2 + K_3}{K_1^2 + K_3^2}, \quad (24)$$

$t_c = 1.8t - 125.5$ - centered (named by the authors) value of t, °C (Ray *et al*, 2007),
$\varphi_c = \varphi - 0.58537037$ - centered value of φ, (Ray *et al*, 2007).

The authors (Ray *et al*, 2007) prove that the error of the results obtained from the equations (19) ÷ (24), for the ranges 0% ≤ φ ≤ 100% and 44 °C < t ≤ 100 °C, is smaller by 44% than the error of the results obtained from the equations (12) ÷ (16).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

For the solution of the models 3, 4, 6, 7, 8, 9 and 10, which include the equations (1) ÷ (24), we created a program in the computing environment of VISUAL FORTRAN PROFESSIONAL supported by Windows.

With the help of the program, we calculated the values of U_{EMC} when t changes from 0 °C to 200 °C in steps of 0.1 °C and φ from 0% to 100% in steps of 0.1%. The results are compared with the corresponding experimental data from the literature (FPL 1999) and (Kubojima *et al*, 2003) related to the change of U_{EMC} depending on t and φ (Table 1, 2 and 3).

During the analysis of the results obtained, we did not take into consideration the sorption hysteresis,

possible variations of the sorption isotherms due to different species of wood used for the determination of the sorption isotherms taken from the literature, and variations due to internal structures such as heartwood and sapwood (Ball *et al*, 2001; Pervan, 2000).

As the experimental data in FPL (1999) are temperatures expressed in degrees Fahrenheit, in the very first column of both Table 1 and 2, the values of t are given in degrees Celsius, which were assigned to t during the experiments. Since the experiments are conducted using different values of φ, not always corresponding to φ values in Table 1, 2 and 3, in the very last column of the tables the exact experimental values of U_{EMC} (when the experimental and computed values of φ coincide) are not marked with an asterix sign (*), while the interpolated experimental values of U_{EMC} (when the experimental and computed values of φ do not coincide) are shown with an asterix sign (*).

3.1 Change of U_{EMC} in the range $0 \le t \le 100$ °C

3.1. Promjena U_{EMC} u rasponu temperature $0 \le t \le 100$ °C

The computed values of U_{EMC} according to the models 3, 4, 6, 7, 8, 9 and 10 and their corresponding experimental values from FPL (1999) are given in Table 1 (for the range $0\% \le \varphi \le 50\%$) and in Table 2 (for the range $60\% \le \varphi \le 94\%$).

The analysis of the data from Table 1 and 2, and also of the others not given in these tables, shows that the experimentally established change in U_{EMC} depending on φ is described most accurately by the Simpson model within the range 0 °C ≤ t ≤ 50 °C and by the model of Ray et al. within the range 50 °C < t ≤ 100 °C. The absolute error of U_{EMC}, which is obtained from these models in the given temperature ranges, is within the limits of ±0.4% at $0\% \le \varphi \le 50\%$ and ±0.7% at $60\% \le \varphi$ φ ≤ 94%. Figure 1 shows the isotherms of U_{EMC} derived using these two models when t = 0, 20, 40, 60, 80 and 100 °C with the change of φ from 0 to 100%.

The next most accurate model is that of Garsía with the absolute error within the limits of ± 0.7% at $0\% \le \varphi \le 50\%$ and 0.9% at $60\% \le \varphi \le 94\%$. The models of Hailwood and Horrobin–2 and of Malmquist give very close results with the absolute error within the limits of ±0.7% at $0\% \le \varphi \le 50\%$ and ±1.2% at $60\% \le \varphi \le 94\%$. The biggest inaccuracy is observed in the models of Day & Nelson and of Kaplan – they give the results of U_{EMC} higher than the experimental ones within the limits of 3.3%.

It should be noted that all of the examined models reflect very well the complicated character of change in U_{EMC} depending on t and φ as shown in Fig. 1. The indicated limits of change of the absolute error in determining U_{EMC} based on all the models refer to the relatively high values of φ. With smaller values of φ, the absolute error, as a rule, significantly decreases. Only for Kaplan's model the opposite dependency can be observed – the more the value of φ decreases, the more the absolute error increases and reaches +3.3% at t = 0 °C and φ = 0%.

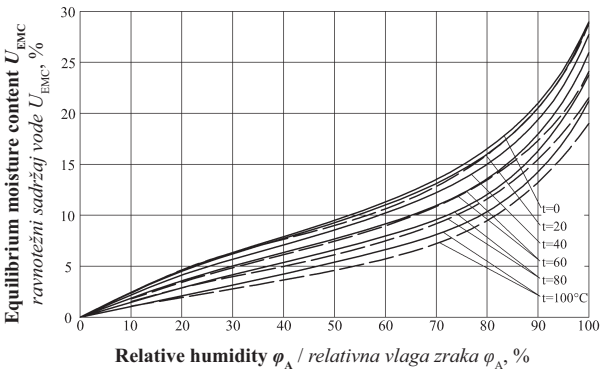

Figure 1 Isotherms of the change of U_{EMC} calculated based on the Simpson model (full lines), and based on a combination of both Simpson model – at t = 0, 20 and 40 °C and Ray *et al.* model – at t = 60, 80 and 100 °C (dotted lines)
Slika 1. Izoterme promjene ravnotežnog sadržaja vode izračunane na temelju Simpsonova modela (pune linije), i na temelju kombinacije Simpsonova modela za temperature t = 0, 20 i 40 °C te Rayeva modela za temperature t = 60, 80 i 100 °C (iscrtkane linije)

Figure 2 shows a precise diagram of the change of U_{EMC} depending on φ and t within the range $0\% \le \varphi \le 100\%$ and 0 °C < t ≤ 100 °C. The diagram curves are built based on the results obtained by the Simpson model at 0 °C ≤ t ≤ 50 °C, and with the help of Ray *et al*. model when 50 °C < t ≤ 100 °C. This diagram shows the experimentally established relations of U_{EMC} depending on t and φ with a higher precision in comparison with analogous diagrams, usually referred to in the literature (Shubin, 1990; Trebula and Klement, 2002; Videlov, 2003).

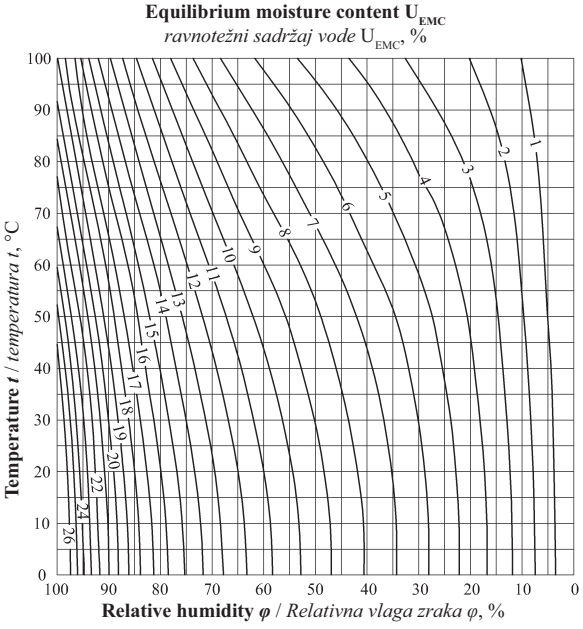

Figure 2 Change in U_{EMC} depending on φ and t, calculated according to the Simpson model at 0 °C ≤ t ≤ 50 °C and according the Ray et al. model at 50 °C < t ≤ 100 °C
Slika 2. Promjene ravnotežnog sadržaja vode u ovisnosti o temperaturi i vlažnosti zraka, izračunane na temelju Simpsonova modela za temperature 0 °C ≤ t ≤ 50 °C i Rayeva modela za temperature 50 °C < t ≤ 100 °C

Table 1 Change of the calculated and their corresponding experimentally established values of U_{EMC} depending on t and φ within the range $0 \le t \le 100$ °C and $0 \le \varphi \le 50\%$
Tablica 1. Razlike između izračunane i odgovarajuće eksperimentalno dobivene vrijednosti ravnotežnog sadržaja vode u ovisnosti o temperaturi i vlažnosti zraka u rasponu $0 \le t \le 100$ °C i $0 \le \varphi \le 50$ %

Temperature *Temperatura* t, °C	**Computed values of U_{EMC}, % /** *Izračunana vrijednost U_{EMC}, %*							**Experimental values** *Eksperimentalna vrijednost U_{EMC}*, %
	H & H-2 (1946)	M (1958)	D & N (1965)	K (1972)	S (1991)	G (2002)	R *et al.* (2007)	
	Relative air humidity φ = 0% / *Relativna vlažnost zraka φ = 0 %*							
0	0.0	0.0	0.0	3.27	0.0	0.0	126.2	0.0
25	0.0	0.0	0.0	2.89	0.0	0.0	7.23	0.0
50	0.0	0.0	0.0	2.52	0.0	0.0	0.02	0.0
100	0.0	0.0	0.0	1.77	0.0	0.0	0.33	0.0
Relative air humidity φ = 10% / *Relativna vlažnost zraka φ = 10 %*								
15.6	2.6	2.8	3.2	3.8	2.5	2.3	19.0	2.5*
26.7	2.3	2.6	2.8	3.6	2.4	2.2	7.0	2.4
35.0	2.1	2.4	2.6	3.5	2.3	2.1	3.6	2.3
48.9	1.9	2.2	2.3	3.2	2.1	2.0	2.1	2.3
65.6	1.6	2.0	1.9	2.9	1.8	1.9	2.6	2.2*
Relative air humidity φ = 20% / *Relativna vlažnost zraka φ = 20 %*								
26.7	4.2	4.2	4.7	4.6	4.4	3.8	8.0	4.5
35.0	3.9	4.0	4.4	4.4	4.2	3.7	5.5	4.0
46.1	3.6	3.7	4.0	4.1	4.0	3.6	4.0	3.9
60.0	3.2	3.4	3.5	3.8	3.6	3.3	3.4	3.5*
71.1	3.0	3.2	3.1	3.5	3.2	3.2	3.1	3.1*
Relative air humidity φ = 30% / *Relativna vlažnost zraka φ = 30 %*								
29.4	5.7	5.6	6.3	5.7	6.0	5.3	8.1	6.0
35.0	5.5	5.4	6.1	5.6	5.9	5.2	7.0	5.7
43.3	5.2	5.1	5.7	5.3	5.6	5.0	5.9	5.4
60.0	4.6	4.6	4.9	4.8	5.0	4.7	4.8	4.8
87.8	3.8	3.9	3.8	4.0	3.8	4.0	3.4	3.3
Relative air humidity φ = 40% / *Relativna vlažnost zraka φ = 40 %*								
35.0	6.9	6.8	7.8	7.1	7.3	6.7	8.2	7.2*
43.3	6.5	6.4	7.3	6.7	7.0	6.5	7.3	6.8
48.9	6.3	6.2	7.0	6.5	6.8	6.4	6.8	6.6
60.0	5.9	5.8	6.4	6.1	6.3	6.0	6.1	6.0
82.2	5.1	5.1	5.3	5.2	5.2	5.3	4.8	4.8
Relative air humidity φ = 50% / *Relativna vlažnost zraka φ = 50 %*								
40.6	8.0	8.0	9.2	8.7	8.6	8.2	9.0	8.7
46.1	7.8	7.8	8.9	8.4	8.3	8.0	8.5	8.2
60.0	7.2	7.2	8.0	7.7	7.7	7.5	7.5	7.5*
82.2	6.3	6.3	6.8	6.6	6.5	6.6	6.0	6.0
98.9	5.8	5.8	5.9	5.8	5.4	5.8	4.7	5.1

3.2 Change of U_{EMC} within the range $100 \le t \le 200$ °C

3.2. Promjene U_{EMC} u rasponu temperatura $100 \le t \le 200$ °C

The values of U_{EMC} calculated using the models 3, 4, 6, 7 and 9 and their corresponding experimental values from FPL (1999) and Kubojima *et al*. (2003) are given in Table 3 within the range 100 °C $\le t \le$ 150 °C and $10\% \le \varphi \le 85\%$.

The comparison of the calculated and experimental results, partly presented in Table 3, shows that the experimentally established change of U_{EMC} depending on t and φ is most accurately described by the Garsía model. Fig. 3 shows the isotherms of U_{EMC} built using this model when t = 100, 120, 140, 160, 180 and 200 °C with the change of φ ranging from 0% to 100%.

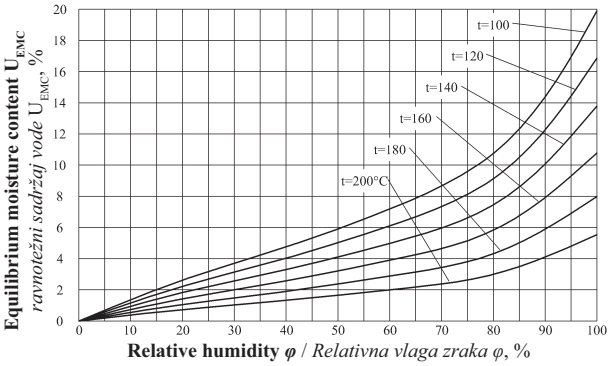

Figure 3 Change in U_{EMC} depending on φ and t, calculated based on Garsía model
Slika 3. Promjene ravnotežnog sadržaja vode u ovisnosti o temperaturi i vlažnosti zraka, izračunane na temelju Garsíjeva modela za temperature 0 °C $\le t \le$ 50 °C

Table 2 Change of the calculated values and their corresponding experimentally established values of U_{EMC} depending on t and φ within the ranges $0 \le t \le 100$°C and $60 \le \varphi \le 94$%
Tablica 2. Razlike između izračunane i odgovarajuće eksperimentalno dobivene vrijednosti ravnotežnog sadržaja vode u ovisnosti o temperaturi i vlažnosti zraka u rasponu $0 \le t \le 100$ °C i $60 \le \varphi \le 94$ %

Temperature *Temperatura* t, °C	**Computed values of U_{EMC}, % /** *Izračunana vrijednost U_{EMC}, %*							**Experimental values** *Eksperimentalna vrijednost U_{EMC}, %*
	H & H-2 (1946)	M (1958)	D & N (1965)	K (1972)	S (1991)	G (2002)	R *et al.* (2007)	
	Relative air humidity φ = 60% / *Relativna vlažnost zraka φ = 60 %*							
12.8	11.5	11.4	13.1	12.7	11.2	10.9	14.5	11.0
40.6	9.6	9.7	11.2	11.0	10.2	10.0	10.6	10.3
54.4	8.9	9.0	10.3	10.1	9.5	9.4	9.4	9.4
71.1	8.1	8.2	9.1	9.1	8.5	8.6	8.1	8.2
87.8	7.4	7.5	8.0	8.0	7.5	7.8	6.8	7.0
98.9	7.0	7.1	7.4	7.4	6.7	7.2	5.9	6.3
110.0	6.7	6.7	6.7	6.7	5.8	6.6	4.7	5.7
Relative air humidity φ = 70% / *Relativna vlažnost zraka φ = 70 %*								
12.8	13.7	13.6	15.6	16.1	13.4	13.3	18.3	13.4
37.8	11.7	11.9	13.8	14.1	12.3	12.2	13.0	12.4
43.3	11.4	11.6	13.4	13.7	12.0	12.0	12.4	12.0
51.7	10.9	11.1	12.7	13.0	11.5	11.6	11.5	11.5
65.6	10.1	10.3	11.7	11.9	10.6	10.8	10.3	10.3
82.2	9.4	9.5	10.4	10.6	9.5	9.8	9.0	9.0
98.9	8.7	8.8	9.2	9.3	8.3	8.8	7.4	8.0
Relative air humidity φ = 80% / *Relativna vlažnost zraka φ = 80 %*								
10.0	17.0	16.8	19.0	20.6	16.4	16.6	28.0	16.3
37.8	14.4	14.6	16.9	17.9	15.1	15.0	16.3	15.0
48.9	13.6	13.9	15.9	16.8	14.4	14.4	14.6	14.1
65.6	12.6	12.8	14.5	15.1	13.1	13.3	12.9	13.0
87.8	11.5	11.6	12.6	12.9	11.4	11.7	10.8	10.9
98.9	11.0	11.0	11.7	11.8	10.4	10.8	9.6	10.3*
101.7	10.9	10.9	11.5	11.5	10.2	10.6	9.3	9.8
Relative air humidity φ = 90% / *Relativna vlažnost zraka φ = 90 %*								
43.3	18.2	18.4	21.1	21.9	19.1	18.9	20.1	19.0
51.7	17.6	17.8	20.3	20.9	18.4	18.2	18.6	18.3*
65.6	16.6	16.8	19.0	19.1	17.2	17.1	17.0	16.6
87.8	15.3	15.4	16.8	16.4	15.1	15.0	14.5	14.2
98.9	14.8	14.7	15.7	15.0	14.0	13.9	13.2	13.8
101.7	14.7	14.5	15.4	14.6	13.7	13.6	12.9	13.5
Relative air humidity φ = 94% / *Relativna vlažnost zraka φ = 94 %*								
48.9	20.3	20.6	23.8	23.3	21.2	20.9	21.4	21.3
54.4	19.9	20.2	23.2	22.6	20.7	20.4	20.5	21.0
82.2	18.0	18.3	20.3	18.7	18.0	17.6	17.2	17.3
87.8	17.8	17.9	19.7	18.0	17.4	17.0	16.5	16.9
92.3	17.5	17.6	19.2	17.4	17.0	16.5	16.0	16.4
98.9	17.2	17.2	18.5	16.4	16.2	15.7	15.3	16.0

In the contemporary model-based and model predictive systems for automatic control of high temperature processes for wood hydrothermal treatment (e.g. veneer drying), it is required to compute continuously the set values of U_{EMC} in the temperature range from 0 °C to 200 °C. For ensuring this requirement, the evaluation of the validity of the models has been extrapolated to 200°C in Fig. 3.

The comparison of the results calculated based on the Garsía model at t = 100 °C as shown in Table 3, with the precisely analogous results in Fig. 2 having the same temperature obtained based on the Ray *et al*. model, show that the Garsía model gives higher values of U_{EMC} within the whole range of change of φ. Table 3 clearly shows that the calculated values of U_{EMC} based on the Garsía model are higher than their corresponding values of U_{EMC} in all the examined values of $t \ge 100$ °C.

In order to increase the precision of the Garsía model and for a better qualitative and quantitative coordination of the calculated values of U_{EMC} when $t \ge 100$ °C with the values of U_{EMC} based on the Ray *et al*. model within the range 50 °C < $t \le 100$ °C, we suggest adding a power coefficient of 1.33 to the denominator on the right side of the equation (17). Then the equation (17) becomes:

$$U_{EMC} = K\left[\left(\frac{K_5}{\varphi^{1.33}}\right)^{K_7} - 1\right]^{-\frac{1}{K_6}} \qquad (25)$$

Table 3 Change of the calculated values and their corresponding experimentally established values of U_{EMC} depending on t and φ within the range 100 °C ≤ t ≤ 150 °C and 0% ≤ φ ≤ 85%
Tablica 3. Razlike između izračunane i odgovarajuće eksperimentalno dobivene vrijednosti ravnotežnog sadržaja vode u ovisnosti o temperaturi i vlažnosti zraka u rasponu 100 °C ≤ t ≤ 150 °C i 0% ≤ φ ≤ 85%

Temperature *Temperatura* t, °C	**Computed values of U_{EMC}, % /** *Izračunana vrijednost U_{EMC}, %*						**Experimental values** *Eksperimentalna vrijednost U_{EMC}, %*
	Hailwood& Horrobin-2 (1946	Malmquist (1958)	Day&Nelson (1965)	Kaplan (1972)	Garsía (2002)	Garsía-Deliiski	
Relative air humidity φ = 10% / *Relativna vlažnost zraka φ = 10 %*							
100	1.21	1.63	1.23	2.24	1.50	0.83	1.0*
110	1.10	1.54	1.09	2.05	1.39	0.77	0.9*
120	1.01	1.45	0.95	1.86	1.28	0.70	0.8*
130	0.92	1.37	0.83	1.67	1.16	0.64	-
140	0.83	1.30	0.73	1.48	1.04	0.57	-
150	0.75	1.22	0.63	1.29	0.93	0.51	-
Relative air humidity φ = 20% / *Relativna vlažnost zraka φ = 20 %*							
100	2.4	2.7	2.3	2.8	2.6	1.7	2.3*
110	2.2	2.5	2.1	2.6	2.4	1.6	2.0*
120	2.1	2.4	1.8	2.4	2.2	1.4	1.7*
130	1.9	2.2	1.6	2.1	2.0	1.3	1.5*
140	1.7	2.1	1.4	1.9	1.8	1.2	-
150	1.6	2.0	1.3	1.6	1.6	1.1	-
Relative air humidity φ = 40% / *Relativna vlažnost zraka φ = 40 %*							
100	4.6	4.7	4.5	4.5	4.8	3.6	4.2*
110	4.3	4.4	4.1	4.2	4.4	3.4	3.6*
120	4.1	4.2	3.7	3.8	4.0	3.1	3.2*
130	3.8	4.0	3.4	3.4	3.7	2.8	2.9*
140	3.6	3.7	3.0	3.0	3.3	2.5	-
150	3.4	3.5	2.7	2.6	2.9	2.2	-
Relative air humidity φ = 60% / *Relativna vlažnost zraka φ = 60 %*							
100	7.0	7.1	7.3	7.3	7.2	6.0	6.3*
110	6.7	6.7	6.7	6.7	6.7	5.5	5.7*
120	6.4	6.4	6.2	6.1	6.1	5.1	-
130	6.1	6.1	5.6	5.4	5.5	4.6	-
140	5.8	5.8	5.1	4.8	5.0	4.1	-
150	5.5	5.5	4.7	4.2	4.4	3.7	-
Relative air humidity φ = 85% / *Relativna vlažnost zraka φ = 85 %*							
100	12.6	12.5	13.3	13.2	12.1	10.9	11.7*
110	12.1	12.0	12.4	12.1	11.2	10.1	9.9
120	11.7	11.5	11.5	10.9	10.3	9.2	7.8
125	11.5	11.2	11.1	11.5	9.8	8.8	7.5
130	11.3	11.0	10.7	9.8	9.3	8.4	6.9
135	11.2	10.7	10.3	9.3	8.8	8.0	5.9
140	11.0	10.5	9.9	8.7	8.4	7.5	5.2
145	10.8	10.3	9.5	8.1	7.9	7.1	4.5
150	10.7	10.1	9.1	7.6	7.5	6.7	4.4

The column before the last one in Table 3 presents the obtained results of the change of U_{EMC} based on the so-called Garsía–Deliiski model, which consists of both equations (25) and (18). The comparison of these results with the experimental data, presented on the right in Table 3, shows a significant reduction of the absolute errors of U_{EMC} when U_{EMC} is calculated according to the absolute errors obtained by Garsía model (17) and (18).

Fig. 4 shows isotherms of the change of U_{EMC}, with full lines, obtained based on the Garsía model, and their analogues, calculated based on the Garsía-Deliiski model, shown with dotted lines. In the present paper the proposed Garsía-Deliiski model, which consists of equation (25) and (18), precisely reflects qualitatively and quantitatively the relation of U_{EMC} depending on φ and t within the range from 100 °C to 200 °C. A future clarification of this model should be made when having extensive experimental data for the change in U_{EMC} depending on t and φ within this temperature range.

Fig. 5 shows for the first time the summarized diagram of the change in U_{EMC} depending on φ and t within the range 0% ≤ φ ≤ 100% and 0 °C < t ≤ 200 °C. The curves are built based on the results obtained by the Simpson model at temperatures 0 °C ≤ t ≤ 50 °C, by the Ray *et al*. model at 50 °C < t ≤ 100 °C and by the Garsía-Deliiski model at 100 °C < t ≤ 200 °C.

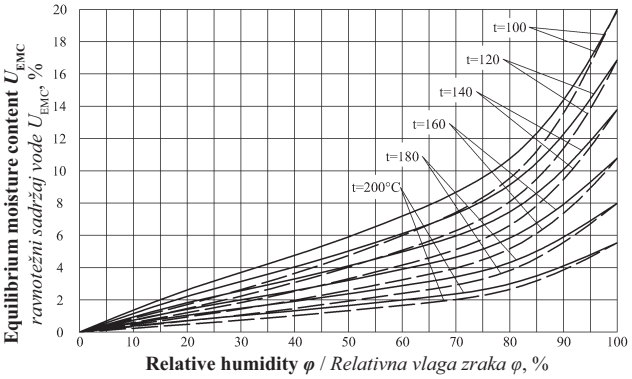

Figure 4 Change in U_{EMC} depending on both φ and t, calculated using the Garsía model – full lines, and using the Garsía-Deliiski model - dotted lines

Slika 4. Promjene ravnotežnog sadržaja vode u ovisnosti o temperaturi i vlažnosti zraka, izračunane na temelju Garsíjeva modela (pune linije) i Garsía-Deliiskijeva modela (iscrtkane linije)

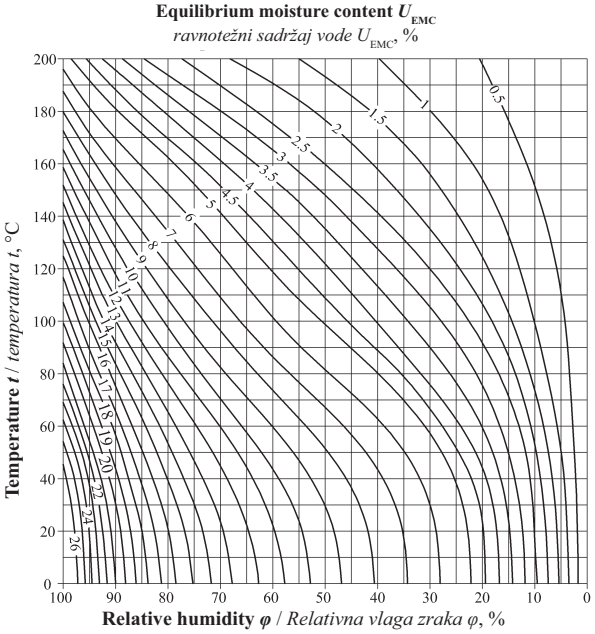

Figure 5 Change in U_{EMC} depending on φ and t, calculated by the Simpson model at 0 °C ≤ t ≤ 50 °C, by the Ray *et al*. model at 50 °C < t ≤ 100 °C and by the Garsía-Deliiski model at 100 °C < t ≤ 200 °C

Slika 5. Promjene ravnotežnog sadržaja vode u ovisnosti o temperaturi i vlažnosti zraka, izračunane na temelju Simpsonova modela za temperature 0 °C ≤ t ≤ 50 °C, Rayeva modela za temperature 50 °C < t ≤ 100 °C i Garsía-Deliiskijeva modela za temperature 100 °C < t ≤ 200 °C

4 CONCLUSIONS
4. ZAKLJUČCI

The present paper describes the evaluation of the precision of the 10 most often used wood sorption models, available in the literature, for the calculation of wood equilibrium moisture content U_{EMC} given a change in temperature within the range from 0 °C to 200 °C and in relative humidity φ of the surrounding air environment from 0% to 100%. The calculated results were compared to corresponding precise experimental data from the literature.

The obtained results show that the Simpson model gave the best fit to experimental data for the range 0 °C ≤ t ≤ 50 °C. The best precision within the range 50 °C < t ≤ 100 °C was provided by the Ray *et al*. model and within the range 100 °C < t ≤ 150 °C by the Garsía model.

In order to increase the precision of the Garsía model and for better qualitative and quantitative coordination of the calculated values, with the help of U_{EMC} at t ≥ 100 °C, with values of U_{EMC} based on the Ray *et al*. model within the range 50 °C < t ≤ 100 °C, we suggest the clarification of the Garsía model. The clarification means introduction of a power coefficient, equaling 1.33, to the denominator on the right side of the equation of the Garsía model.

With the results calculated from the Simpson and Ray et al. models, a diagram has been built for the change in U_{EMC} depending on φ and t within the ranges 0% ≤ φ ≤ 100% and 0 °C ≤ t ≤ 100 °C. This diagram reflects the experimentally established dependency of U_{EMC} on φ and t with better precision in comparison to analogous diagrams, usually found in the literature.

Using the results obtained by both the Simpson and Ray et al. models and the Garsía model, which we have refined, a summary diagram of the change in U_{EMC}, depending on φ and t within the range 0% ≤ φ ≤ 100% and 0 °C ≤ t ≤ 200 °C, has been created for the first time. This diagram can be used for the precise determination of U_{EMC} when having different temperature-humidity impacts on the wood.

The established high precision of both the Simpson and Ray et al. models and the Garsía model, which we have refined, makes them user friendly for contemporary systems for model-based and model predictive automatic control (Hadjiyski, 2003) of different processes of hydrothermal treatment of wood and wood materials. This way, for example, we have input the Simpson model into the software of the microprocessor programmable controller in order to control the temperature conditioning process of dried lumber (Fig. 6).

The long use of the implemented automated installation in the conditioning storage house (Deliiski, 2009b) confirmed completely the validity of the calculating and controlling algorithm used in the controller. It proved its high energy efficiency, reliable functioning and suitability to assure the temperature-humidity parameters of the air, corresponding completely to the U_{EMC} of the wood, required by the user.

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Figure 6 Automated storage house for dried wood materials (on the left) and programmable controller for automatic computation and model-based control of its conditioning process (on the right)
Slika 6. Automatizirano skladište osušenoga drvnog materijala (lijevo) i programabilni kontroler za automatsko izračunavanje parametara i na modelu utemeljeno upravljanje procesom kondicioniranja u skladištu

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Alexander Pfriem[1]

Alteration of Water Absorption Coefficient of Spruce (*Picea abies* (L.) Karst.) due to Thermal Modification

Promjena koeficijenta upijanja vode smrekovine (*Picea abies* (L.) Karst.) zbog njezine termičke modifikacije

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ABSTRACT • *The aim of the investigations was to evaluate the influence of a thermal modification on the water absorption behaviour of spruce (Picea abies (L.) Karst.). After recording the water uptake of wood samples by partial immersion, a water absorption coefficient of the material could be determined according to EN ISO 15148:2002. The thermal modification results in an alteration of the water absorption behaviour in dependence on the sectional area. In radial and tangential direction the water absorption decreases with the modification. In contrast, in longitudinal direction the water uptake increases.*

Key words: *anisotropy, thermal modification, water absorption coefficient*

SAŽETAK • *Cilj istraživanja bio je procijeniti utjecaj termičke modifikacije smrekovine (Picea abies (L.) Karst.) na svojstvo upijanja vode. Bilježenjem količine vode što ju upiju drvni uzorci nakon njihova djelomičnog uranjanja može se, prema normi EN ISO 15148:2002, odrediti koeficijent upijanja vode. Termičkom modifikacijom drva mijenja se svojstvo upijanja vode u ovisnosti o površini presjeka drva. U radijalnome i tangencijalnom smjeru upijanje vode se smanjuje u modificiranog drva. Suprotno tomu, u uzdužnom se smjeru upijanje vode povećava.*

Ključne riječi: *anizotropnost, termička modifikacija, koeficijent upijanja vode*

1 INTRODUCTION
1. UVOD

Moisture movement in a hygroscopic capillary-porous material is a combination of moisture vapor and liquid transport. These are related to the pressure, temperature and moisture gradients and the properties of the materials in a complex interrelationship.

The steady-state (e.g. Popper *et al*, 2005) and the unsteady-state (e.g. Pfriem *et al*, 2007; Pfriem *et al*, 2010) sorption behavior of thermally modified wood is well studied. Thermal degradation of hemicelluloses

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leads to a reduction of hydroxyl groups and to a reduced number of intra- and intermolecular hydrogen bonds (Pfriem, 2006; Boonstra and Tjeerdsma, 2006; Windeisen *et al*, 2007). For this reason, the equilibrium wood moisture of thermally modified wood is lower and the sorption isotherms show a reduction of the sorption capacity (Popper *et al*, 2005). Metsä-Kortelainen *et al*. (2006) determined the alteration of water absorption of sapwood and heartwood of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) due to thermal modification in a floating test. They found that the higher the modification temperature, the lower the amount of absorbed moisture.

The aim of the present investigation was to evaluate the intensity of the absorption of water due to capillary forces and their alteration due to thermal modification.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Spruce (*Picea abies* (L.) Karst.) was analyzed. The thermal modification was performed in a single stage dry process – patented by the company Mühlböck (Austria) – at 180 °C in a commercial plant at Mitteramskogler GmbH in Gaflenz (Austria). In this process, the exhaust volatile gases and remaining oxygen are removed from the reaction chamber and burnt off externally. The treatment duration was 4 h (Pfriem 2006).

The dimension of the specimens was 100 mm x 100 mm (parallel and tangential to the axis) and 20 mm (radial). The modified and unmodified specimens were conditioned at 23 °C and RH 60%. Water absorption tests were performed according to EN ISO 15148:2002 by partial immersion for short periods of time and without temperature gradient in dependence on the main cutting direction cross-section, tangential and radial section. It is used to assess the intensity of water absorption via the wood capillary system. To restrict moisture transport to one direction the non-tested surfaces of the specimens were sealed with epoxy resin and aluminum foil. For the study of capillary water absorption the non-sealed surface of a specimen was partially immersed in water. Therefore, the samples have been placed in a water basin. The water level was kept constant at 10 mm above the bottom of the sample. The test lasts 24 hours, with at least three specimens.

The specimens are periodically removed, the surfaces are wiped, the specimens are weighed, and again partially immersed in the water. The mass of water absorbed per unit area of specimen surface is plotted against the square root of time. In accordance to EN ISO 15148:2002 the water absorption coefficient A_w describes the time-dependent water absorption of the material. The first derivative of the change in mass plotted against the square root of time is used for the calculation of A_w.

3 RESULTS, DISCUSSION AND CONCLUSIONS
3. REZULTATI, DISKUSIJA I ZAKLJUČCI

The rate of liquid water absorption in wood depends on several factors. There are clear differences in water absorption coefficient in the three main directions (Table 1). Due to the capillary action of the cells, the rate of absorption is most rapid in longitudinal direction. In radial direction the water uptake may be partly taking place about the rays, resulting in higher water absorption than in tangential direction.

In radial and tangential direction, thermally modified samples show a reduction in the capillary water absorption compared to the native specimens. As the wood becomes more hydrophobic, its wettability by water decreases as shown by contact angle measurements by Kocaefe *et al*. (2008) or Metsä-Kortelainen and Viitanen (2011).

It is remarkable that the thermal modification increases the capillary water uptake in longitudinal direction. This is partly in contradiction to the work of Bächele *et al*. (2004) or Krause and Militz (2004).

One explanation for this abnormal behavior is the increase of porosity of the wood by the thermal modification. Our own studies using helium pycnometry and mercury intrusion porosimetry have shown that there are quantitative differences in the true density and pore structure depending on wood species and intensity of the thermal modification (Pfriem *et al*, 2009).

The determined parameters can contribute to describe the ability of the capillary water transport in wood. The effect of increased water uptake must be considered particularly in the use of thermally modified wood in structures, if the cross-sectional areas are exposed to water.

Table1 Water absorption coefficient of thermally modified and unmodified spruce (standard deviation in brackets)
Tablica 1. Koeficijent upijanja vode termički modificirane i nemodificirane smrekovine (standard devijacije u zagradama)

Wood section *Presjek drva*	**Water absorption coefficient A_w in kg/(m²·h$^{1/2}$)** *Koeficijent upijanja vode A_w u kg/(m²·h$^{1/2}$)*		
	Spruce, unmodified *Nemodificirana smrekovina*	Spruce, thermally modified *Termički modificirana smrekovina*	Alteration *Promjena*
Cross-section / *poprečni presjek*	0.615 (0.004)	0.808 (0.006)	31%
Tangential section / *tangencijalni presjek*	0.088 (0.006)	0.058 (0.002)	-34%
Radial section / *radijalni presjek*	0.108 (0.015)	0.099 (0.004)	-8%

Additionally, it has to be stated that the determined values do not contain information about the water content profiles that occur during the sorption process.

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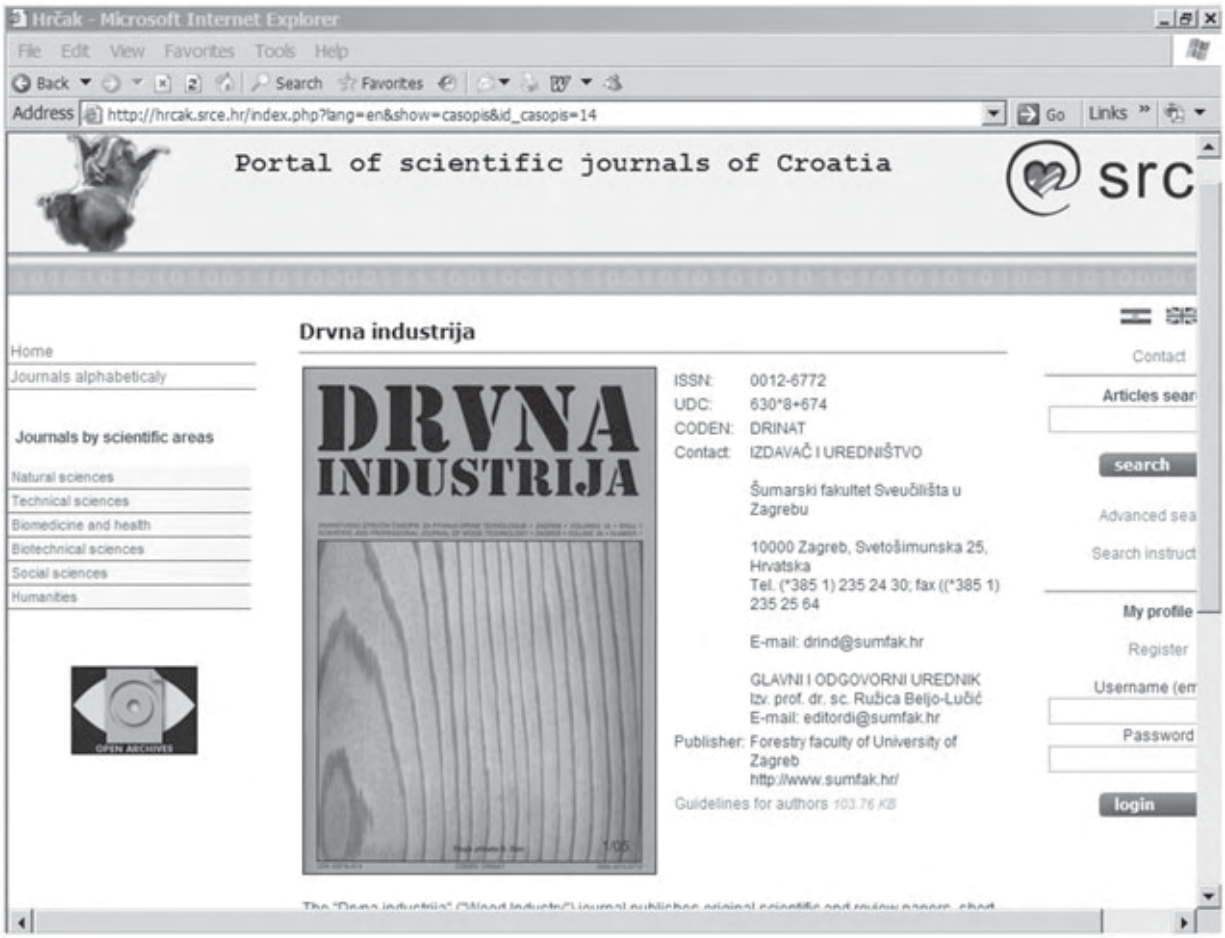

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Laboratorij za ispitivanje namještaja i dijelova za namještaj – novoakreditirani laboratorij Šumarskog fakulteta Sveučilišta u Zagrebu

Uvod

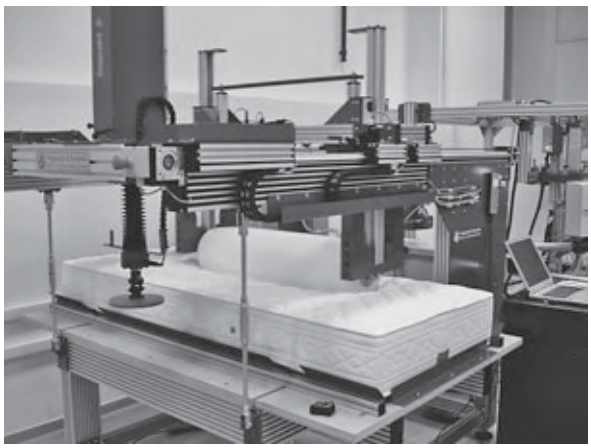
Laboratorij za ispitivanje namještaja i dijelova za namještaj u sastavu Zavoda za namještaj i drvne proizvode Šumarskog fakulteta Sveučilišta u Zagrebu dobio je 17. listopada 2011. od Hrvatske akreditacijske agencije potvrdu o akreditaciji kojom se utvrđuje da je, prema zahtjevima norme HRN EN ISO/IEC 17025, osposobljen za ispitivanje namještaja i određenih svojstava boja i lakova. Prema HRN EN-u, akreditirano je 28 normi/metoda sa širokog područja, a obuhvaćaju ispitivanja ili određivanja izdržljivosti, trajnosti, stabilnosti i dimenzija različitih vrsta namještaja (kreveta, ležaja-madraca, uredskih, školskih i drugih vrsta stolica, ormara, uredskih i kućnih stolova i dr.) te ispitivanje otpornosti i sjaja površine namještaja. Ističemo da je Laboratorij za ispitivanje namještaja i dijelova za namještaj prvi akreditirani laboratorij za procjenu zapaljivosti ojastučenog namještaja i ležaja-madraca, a osim akreditiranih metoda, Laboratorij je sposoban provoditi i ispitivanja prema dosad važećim normama, kao i prema većini HRN EN koje se odnose na ispitivanja namještaja i dijelova za namještaj. Usto, Laboratorij obavlja znanstvenoistraživačku i stručnu djelatnost s ciljem poboljšanja i unapređenja kvalitete namještaja.

Osnivanje i razvoj

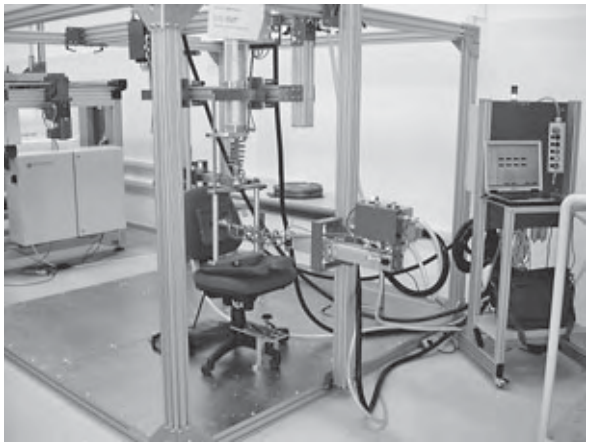
Laboratorij za ispitivanje namještaja i dijelova za namještaj (LIN) osnovan je davne 1976. g. pri Institutu za drvo u Zagrebu, suradnjom Šumarskog fakulteta, Instituta za drvo i Udruženja drvne industrije. Krajem iste godine Laboratorij je od nadležnih institucija (Privredne komore, Tržne inspekcije i Zavoda za standardizaciju) ovlašten za ispitivanje namještaja u skladu s postojećim normama i sustavom ispitivanja preuzetim iz Švedske. Nakon prestanka rada Instituta za drvo 1990. g., Laboratorij i njegove aktivnosti prenose se na Šumarski fakultet, u Zavod za finalnu obradu drva, koji danas nosi naziv Zavod za namještaj i drvne proizvode. Od 1995. Laboratorij (tj. Šumarski fakultet) ovlašten je za ispitivanje namještaja u skladu s Pravilnikom za obvezno ispitivanje namještaja i dijelova za namještaj (NN 63/95). Laboratorij je ovlašten za ispitivanja prema tada važećih 40 normi i propisa. Usporedno s tim laboratorijem, na Šumarskom se fakultetu razvijao i Laboratorij za ispitivanje namještaja za ležanje (1980. g.), koji je kasnije uklopljen u Laboratorij za ispitivanje namještaja i dijelova za namještaj. Od samih početaka voditelj Laboratorija bio je prof. dr. sc. Boris Ljuljka, a 2002. g. na mjestu voditelja naslijedio ga je prof. dr. sc. Ivica Grbac, koji i danas obavlja tu funkciju. Novo ovlaštenje, koje vrijedi i danas, Laboratorij je dobio 25. siječnja 2002. godine od Državnog zavoda za normizaciju i mjeriteljstvo, čime je potvrđen dobar rad i potreba za takvom vrstom kontrolnog mehanizma na tržištu koje je postajalo sve konkurentnije svojim cijenama, ali, nažalost, i sve slabijom kvalitetom ponuđenog namještaja i opreme.

Nevezano za ovlaštenja i ulogu u razvoju gospodarstva, u LIN-u se u sklopu znanstvenoistraživačkog rada i rada sa studentima provode istraživanja namještaja prema znanstvenim i stručnim metodama te se razvijaju nove konstrukcije namještaja. Budućim se inženjerima drvnoprerađivačke struke na primjerima rada Laboratorija i rada u njemu (tijekom izrade diplomskih radova) približava problematika struke putem perspektive kvalitete namještaja i razvija se svijest o potrebi takvoga načina razmišljanja i shvaćanja važnosti problema kvalitete proizvoda uopće. Na taj način Laboratorij, uz bitnu funkciju u znanstvenoistraživačkome i stručnom radu, dugoročno postaje oslonac cjelokupnome drvnom sektoru, počevši od dizajna pa sve do valorizacije kvalitete u nas izrađenih, odnosno uvezenih proizvoda.

U proteklih nekoliko godina u LIN su uložena znatna sredstva za opremanje i nabavu opreme. Ispitivanja prema akreditiranim metodama provode se na suvremenim, računalom upravljanim i kontroliranim uređajima koji u potpunosti zadovoljavaju zahtjeve što ih nameće HRN EN. Intenzivno se radilo na modernizaciji opreme, što je rezultiralo nabavom četiriju multifunkcionalnih uređaja za ispitivanje različitih vrsta namještaja. Specifičnost uređaja jest njihova fleksibilnost i mogućnost programiranja za svaku traženu metodu unutar fizičkih mogućnosti uređaja. Za potpuno zadovoljavanje zahtjeva pripreme uzoraka za ispiti-



Uređaj za ispitivanje madraca valjanjem i određivanje elastičnih svojstava

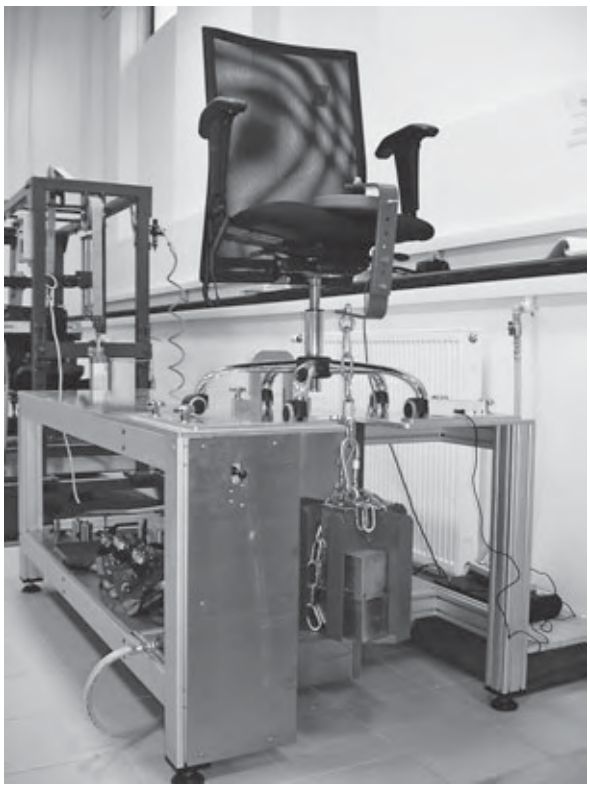


Uređaj za ispitivanje uredskih i drugih vrsta stolica, stolova i korpusa

vanje i provedbu ispitivanja laboratorij raspolaže klima-prostorijom za pripremu uzoraka te potpuno klimatiziranim i automatiziranim laboratorijem za provedbu ispitivanja površinske obrade, boja i lakova te ljepila i lijepljenja.

Ljudski potencijali i članstvo

Posebno treba istaknuti da su djelatnici Laboratorija visokoobrazovane i stručne osobe koje se svakodnevno bave spomenutom problematikom u sklopu nastavnoga, znanstvenoga i stručnog rada. Među šesnaest stručnih djelatnika LIN-a osam je doktora znanosti s područja konstruiranja i oblikovanja proizvoda od drva i drvnotehnoloških procesa te tri diplomirana inženjera drvne tehnologije. Tijekom dugogodišnje zastupljenosti na tržištu LIN i njegovi djelatnici postali su članovi mnogih domaćih i međunarodnih stručnih i znanstvenih udruženja. Osim članstva u Hrvatskoj komori inženjera šumarstva i drvne tehnologije i tehničkim odborima HZN-a, djelatnici su članovi brojnih domaćih i međunarodnih udruga koje se bave problemima istraživanja i ispitivanja kvalitete namještaja te su sudjelovanjem na mnogim stručnim i znanstvenim seminarima i usavršavanjima osposobljeni za navedenu djelatnost, što je nužno za rad akreditiranog laboratorija i konkurentnost na tržištu EU.



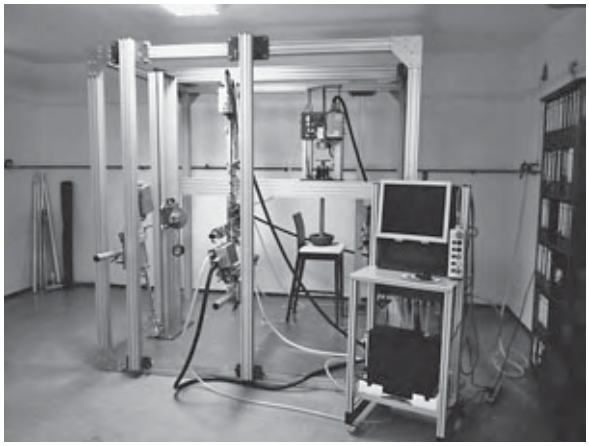
Stol za ispitivanje stabilnosti uredskih, školskih i drugih vrsta stolica

Laboratorij je 1996. g. postao članom međunarodne europske udruge institucija koje se bave ispitivanjem i istraživanjem kvalitete namještaja EURIFI, čime je stekao pravo na ravnopravnu suradnju u ispitivanju i istraživanju kvalitete namještaja za sve zemlje članice. Šumarski fakultet, s predstavnikom prof. dr. sc.

Uređaj za određivanje dimenzija uredskih i drugih vrsta stolica

Pogled na dio laboratorija

Dio laboratorija za površinsku obradu



Uređaj za ispitivanje dječjih visokih i barskih stolica, dječjih krevetića i ormara

Abrazer

Ivicom Grbcem, od 2001. g. član je udruženja INNOVAWOOD, krovne organizacije kojoj je cilj pridonijeti poslovnim uspjesima u šumarstvu, drvnoj industriji i industriji namještaja, s naglaskom na povećanju konkurentnosti europske industrije. Laboratorij održava suradnju s nekoliko institucija poput španjolske AIDIMA-e iz Valencije, njemačkog IHD-a (EPH-a) iz Dresdena, talijanskih COSMOB-a iz Pesara i CATAS-a iz Udina, Biotehničke fakultete Univerze u Ljubljani, Šumarskog fakulteta iz Beograda te Euroinspekta-drvokontrole d. o.o. iz Zagreba, a posebno razvijenu suradnju ima s njemačkim institutom za ispitivanje kvalitete tehničkih proizvoda LGA iz Nürnberga. Ta je suradnja 2006. g. potvrđena i ugovorom o međusobnom pomaganju i potpori pri ispitivanjima namještaja. Laboratorij je član udruge hrvatskih laboratorija CROLAB, čiji je cilj udruživanje hrvatskih ispitnih, mjeriteljskih i analitičkih laboratorija radi unapređenja sustava kvalitete laboratorija te lakšeg pridruživanja europskom tržištu iskorištavanjem zajedničkih potencijala.

Akreditacija prema normi HRN EN ISO/IEC 17025

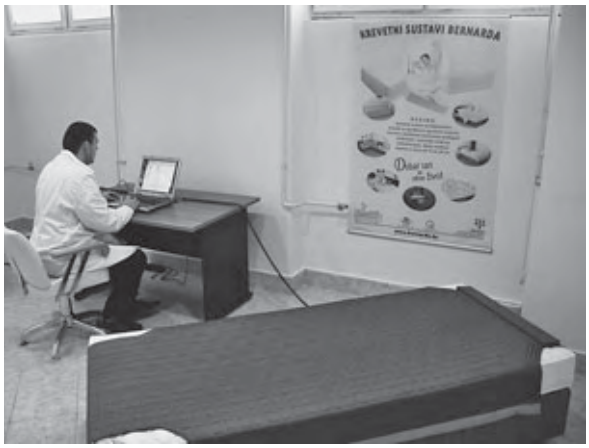
Hrvatska akreditacijska agencija (HAA), koja na temelju Zakona o akreditaciji (NN 158/03 i 75/09) obavlja poslove nacionalnoga akreditacijskog tijela, provela je, sukladno prijavi od 14. srpnja 2010. g., ocjenu osposobljenosti Šumarskog fakulteta, Laboratorija za ispitivanje namještaja i dijelova za namještaj, Svetošimunska 25, HR-10000 Zagreb, za provedbu ispitivanja namještaja i odabranih svojstava boja i lakova, i to prema zahtjevima norme HRN EN ISO/IEC 17025:2007: *Opći zahtjevi za osposobljenost ispitnih i umjernih laboratorija*.

Akreditirane su metode na području ispitivanja otpornosti površine prema tekućinama, toplini i habanju te ocjenjivanje stupnja sjaja površine. Kad je riječ o bojama i lakovima, metode se odnose na određivanje otpornosti na habanje te na ispitivanje mrežice zarezivanjem. LIN je prvi laboratorij u zemlji koji ima akreditiranu sposobnost procjene zapaljivosti

Uređaj za mjerenje sjaja

Laboratorij za ergonomiju – mjerne prostirke ErgoCheck Chair i Classic

Mjerenje raspodjele i veličine tlakova pri sjedenju – EC Chair



Mjerna prostirka EC Classic – za mjerenja na ležaju-madracu

ojastučenog namještaja i ležaja-madraca uz tinjajuću cigaretu i plamen šibice kao izvore zapaljenja. Na području namještaja za sjedenje i stolova za kućnu uporabu, akreditirane su metode za određivanje stabilnosti, čvrstoće i trajnosti, na području ispitivanja stolica i stolova za obrazovne ustanove – metode mjerenja dimenzija, a na području uredskih radnih stolica i stolova te stolica za posjetitelje – metode za određivanje dimenzija, ispitivanje stabilnosti i mehaničke čvrstoće strukture. Metode za krevete i ležaje-madrace obuhvaćaju mjerenja dimenzija, ispitivanje stabilnosti, trajnosti i mehaničke čvrstoće strukture.

Važno je naglasiti da LIN ispituje namještaj i izvan akreditiranog područja, što obuhvaća ispitivanja prema starim normama – HRN-u, te prema ostalim HRN EN na području namještaja, dijelova za namještaj, površinske obrade, boja i lakova, ljepila i lijepljenih spojeva, dječjih igrališta, dječje opreme i dr.

Budućnost

Šumarski fakultet na svom Drvnotehnološkom odsjeku, u svojim zavodima i laboratorijima, unapređuje i razvija nove metode individualnog određivanja svojstava i udobnosti namještaja za sjedenje i ležanje te ergonomskih svojstava namještaja, čime želi biti svojevrsna potpora hrvatskome sektoru proizvodnje "zdravog namještaja". Laboratorij za ispitivanje namještaja i dijelova za namještaj dugoročno će nastaviti svoj razvoj u smislu proširenja akreditiranih metoda, s ciljem obuhvaćanja što većeg područja namještaja i opremanja unutarnjih i vanjskih prostora, ergonomije i antropometrije namještaja za sjedenje i ležanje, udobnosti, sigurnosti svih vrsta namještaja u uporabi, termofizioloških svojstava i ostalih obilježja namještaja.

dr. sc. Zoran Vlaović
prof. dr. sc. Ivica Grbac

Predstavljanje fakulteta i strukovnih škola na Ambienti 2011

Od 19. do 23. listopada 2011. na Zagrebačkom je velesajmu održan 38. međunarodni sajam namještaja, unutarnjeg uređenja i prateće industrije Ambienta 2011. Iako je ove godine izložba održana na manjem prostoru, s manje izlagača i manje posjetitelja nego prijašnjih godina, ovogodišnju manifestaciju ne treba promatrati kao neuspjelu. Prostor su ove godine velikim dijelom oplemenile nastavne ustanove za izobrazbu stručnjaka s područja dizajna i proizvodnje namještaja i unutarnjeg opremanja.

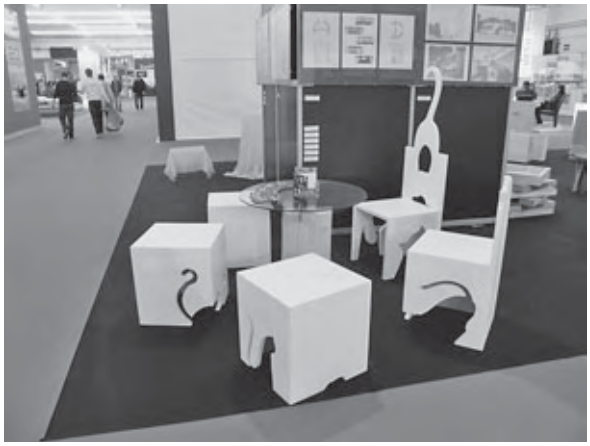
Najveći prostor do sada, koji je bio posvećen obrazovnim ustanovama Hrvatske obilovao je novim idejama učenika i studenata koji su uz pomoć nastavnika predstavili svoja idejna rješenja i proizvode ostvarene u suradnji s hrvatskim proizvođačima.

Izložene radove izradili su učenici i studenti iz strukovnih škola RH, učenici Škole primijenjene umjetnosti i dizajna, Kiparskog odjela te Odjela unutrašnje arhitekture, studenti Šumarskog fakulteta te Studija dizajna.

Uz mentorstvo prof. Filipa Pintarića i Milana Vučića, Škola primijenjene umjetnosti i dizajna predstavila je radove učenika Odjela unutrašnje arhitekture - njihova inventivna dizajnerska rješenja stolova, stolica, ležaljki i klupa. Izloženi su predmeti konačan proizvod, utemeljen na vrsnom poznavanju arhitekture interijera, drvnih konstrukcija, tehnologije materijala, skiciranja i tehničkog crtanja, povijesti umjetnosti, teorije oblikovanja, i naravno, vještine stolarskog obrta. Izvrsno izrađen popratni katalog svjedoči o inovativnom pristupu izradi i prezentaciji proizvoda.

Izložbom *Park u parku* predstavljene su drvene skulpture koje su izradili učenici Kiparskoga i Arhitektonskog odjela Škole primijenjene umjetnosti i dizajna iz Zagreba, pod mentorstvom prof. Filipa Pintarića, dipl. ing. arh., Bernarde Cesar, aps. arh. i prof. Miroslava Sabolića, akademskog kipara. Izložba je dio projekta koji se ostvaruje i provodi suradnjom Škole primijenjene umjetnosti i dizajna Parka prirode Žumberak - Samoborsko gorje, te u partnerstvu s projektom *Drvo je prvo* čiji su nositelji Hrvatska gospodarska komora, Ministarstvo regionalnog razvoja šumarstva i vodnoga gospodarstva te Hrvatske šume.

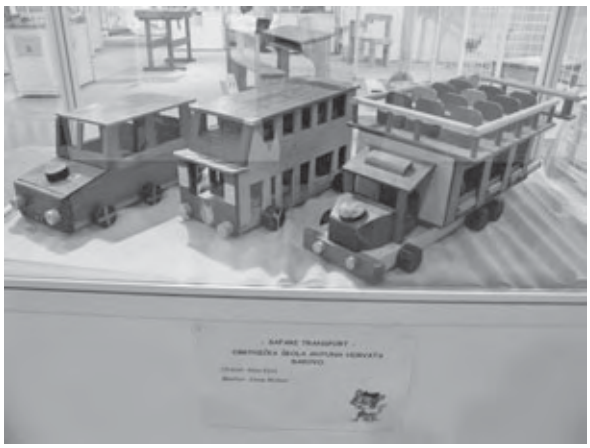
Kao i prethodnih godina, učenici srednjih strukovnih škola ove su godine prikazali svoje radove u obliku tematske izložbe. U organizaciji Agencije za strukovno obrazovanje i obrazovanje odraslih, ove je godine održana izložba s naslovom *Drvene dječje igračke*. Pod mentorstvom svojih nastavnika, učenici devet srednjih drvodjeljskih škola iz cijele Hrvatske osmislili su, dokumentacijom potkrijepili i izradili



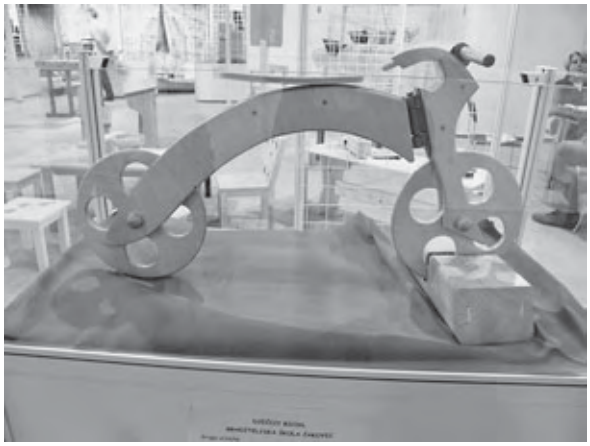
Slika 2. Namještaj za sjedenje *Mijau-vau* rad grupe učenika Škole primijenjene umjetnosti i dizajna

Slika 1. Izložbeni prostor Odjela unutrašnje arhitekture Škole primijenjene umjetnosti i dizajna

Slika 3. *Jedan u dva*, rad učenika Dejana Solića iz Obrtničke škole Nova Gradiška



Slika 4. *Safari transport*, rad učenika Alena Kelića iz Obrtničke škole Antuna Horvata u Đakovu



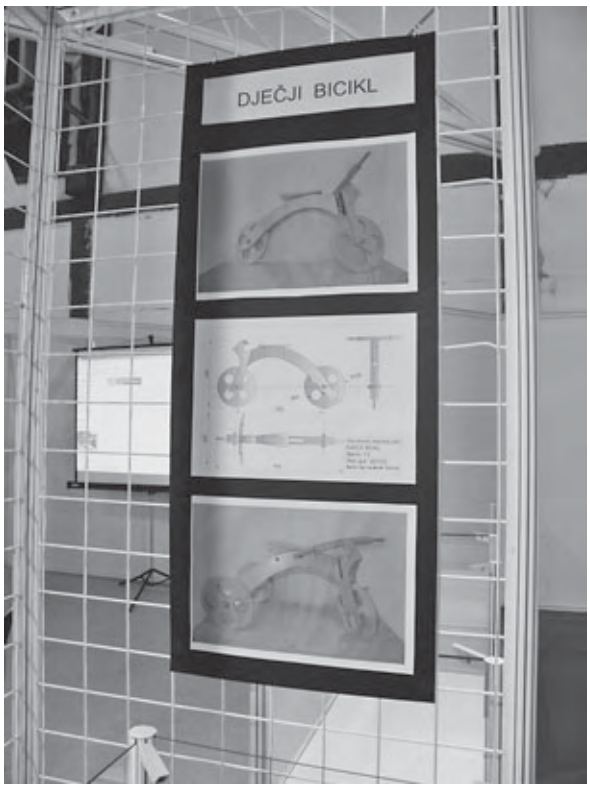
Slika 5. Dječji bicikl, rad grupe učenika Graditeljske škole iz Čakovca

igračke. Odabrani predmeti najbolji su radovi s ovogodišnjega državnog natjecanja učenika, održanoga u travnju 2011. u Novoj Gradiški.

Studenti Studija dizajna predstavili su svoj rad izložbom prototipova stolica i plakata s idejnim rješenjima proizvoda. Drugu cjelinu činila je izložba *Šest pogleda na sobu*, a predstavila je projekt *Soba s pogledom*, čiji je voditelj Mladen Orešić. Projekt je orijentiran na stvaranje novih vrijednosti i održivi razvoj. Uz izložbu plakata s vizualizacijama svih šest soba, u Kineskom su paviljonu bile postavljene sobe s opremom - rasvjetom, sagovima, zavjesama i posteljinom te namještajem koji su izradile domaće tvrtke iz klastera Hrvatski interijeri. Posebna vrijednost projekta je povezivanje sektora turizma, proizvođača namještaja i akademske zajednice.

Izložba je obuhvatila i računalne prezentacije s opisom svih šest soba različite namjene i cjenovnih razreda.

Studenti, uz mentorstvo nastavnika, analizom su zaključili da domaće hotelske sobe izgledaju gotovo jednako, u kojem god se hrvatskom gradu nalazile. Najčešće su opremljene jednolikim namještajem bez identiteta, ne govore gotovo ništa o određenom gradu ili kraju, a na turiste ne ostavljaju poticajan početni dojam. Ta je spoznaja iznjedrila više idejnih rješenja, od kojih je odabrano šest i prema njima je proizveden namještaj



Slika 6. Vizualna prezentacija dječjeg bicikla

te su sobe izložene na sajmu. Njihova izvedba govori i o cjelokupnoj kvaliteti kojom se odlikuje idejno oblikovan proizvod, usklađen s odabranim materijalom traženoga cjenovnog razreda te optimalnom konstrukcijom.

Ishod je vrijedan divljenja: šest atraktivnih soba fleksibilnoga dizajna prilagođavat će se obilježjima određenoga podneblja i novčanim mogućnostima ulagača.

Studenti i nastavnici Šumarskog fakulteta ove su se godine predstavili izlažući znanstvene i stručne radove na međunarodnom savjetovanju *Drvo je prvo – izazovi sektora pred ulaskom u EU*, studentskim prezentacijama završnih i diplomskih radova te izložbenim prostorom štanda na kojemu su bili izloženi udžbenici te ostale publikacije nastavnika, kao i radovi studenata, a sadržajem su predstavljali idejnu i proizvodnu doku-

Slika 7. Izloženi radovi studenata Studija dizajna

Slika 8. Autori dizajnerskog rješenja hotelske soba za zdravstveni i wellness turizam Ika Perić, Luka Jelaska i Sanja Tušek s voditeljicom grupe Sanjom Bencetić

Slika 9. Vedran Erceg, jedan od autora dizajnerskog rješenja hotelske sobe za ekološki turizam

Slika 10. Pogled 1 – dizajn
Autorice: Marija Tizaj, Anamaria Sever, Mia Vučić i Kristina Mirošević
Voditelj grupe: Neven Kovačić

Slika 11. Pogled 2 – sustavi namještaja za hostele
Autorice: Sandra Maglov, Ena Priselec, Kristina Crnek Vidović
Voditelj grupe: Vedran Kasap

Slika 12. Pogled 3 – luksuzna hotelska soba
Autori: Vlatka Leskovar, Filip Havranek, Marija Ružić
Voditelj grupe: Zlatko Kapetanović

Slika 13. Pogled 4 – hotelska soba Small & friendly meetings
Autori: Nera Nejašmić, Luka Gobin
Suradnik: Ruđer Novak Mikulić
Voditeljica grupe: Ivana Fabrio

Slika 14. Pogled 5 - hotelska soba za ekološki turizam
Autori: Livija Filipčić, Marta Anić-Kaliger, Vedran Erceg
Voditelji grupe: Marijan Orešić, Mladen Orešić

mentaciju razvoja proizvoda. Prototip školske radne stolice asistentice dr. sc. Danijele Domljan bio je rezultat njezina istraživanja obavljenoga u sklopu izrade nedavno objavljene doktorske disertacije.

Prezentacijama završnih i diplomskih radova studenti Šumarskog fakulteta potvrdili su da su primjenom znanja stečenih na studiju osposobljeni za rješavanje realnih zadataka u struci. Ovo je već treća go dina prezentiranja studentskih radova koja mladim stručnjacima omogućuje njihovo predstavljanje i uvo-

Slika 15. Pogled 6 - hotelska soba za zdravstveni i wellness turizam
Autori: Ika Perаić, Luka Jelaska, Sanja Tušek
Voditelji grupe: Sanja Bencetić, Mladen Orešić

Slika 16. Izložbeni prostor Šumarskog fakulteta s radovima studenata i nastavnika Drvnotehnološkog odsjeka

đenje na tržište rada. Neke od tema odabrane su na temelju posebne zainteresiranosti studenata predavanjima nastavnika i odlaskom na terensku nastvu, a neka kao stvaran problem i izazov za njegovo rješavanje. Ukupno je prezentirano 13 tema s područja šumarstva i drvne tehnologije, a izlaganja su održali ovi studenti:
Gordana Popović
Skladišta i stovarišta u drvnoj industriji
Lana Glad
Modifikacija drva s usporivačima gorenja
Marina Jajčinović
Prirodna ulja i voskovi u završnoj obradi drva
Magdalena Ađić
Američke furnirske ploče u krovnim konstrukcijama
Petar Škoda
Optimiranje potrošnje energije zračnih konvejera
Krunoslav Đerek
Dječji krevetić
Karlo Halužan
Drveni opločnici
Juraj Škarica
Biološka postojanost modificiranog drva
Jelena Kranjec
Povijest motorne pile - tehnološki razvoj i utjecaj na pridobivanje drva
Iskra Kolarić
Fiziološki mehanizmi obrane biljaka na stres izazvan sušom
Mateja Gelemanović
Analiza oštećenosti ploda bukve s područja Šumarije Pakrac
Pero Jerčić Martinčić
Grafički i matematički modeli izmjere širine piljenica 80 mm debljine
Martin Gmaz
Grafički i matematički modeli izmjere širine piljenica 70 mm debljine

Iz naslova referata vidljiv je velik raspon područje znanja što ih studenti usvajaju tijekom studija, no on je svakako i mnogo većeg obujma što će vjerojatno potvrditi odabir radova koji će biti prezentirani na sljedećoj Ambienti.

Učenici strukovnih škola, kao i studenti i nastavnici Šumarskog fakulteta i Fakulteta dizajna, su svojim idejnim rješenjima i proizvodima pokazali da recesija i ekonomska kriza ne utječu na njihov rad već ih na neki način potiču na stvaranje bolje budućnosti. Izradom trodimenzionalnih renderiranih vizualnih prezentacija, kataloga s opisom ideja te izradom predstavljenog dijela proizvodne dokumentacije dokazali su svoj temeljiti pristup razvoju novog proizvoda. Ne treba zaboraviti ni izvrsnu suradnju s proizvođačima namještaja, koji su idejna rješenja pretvorili u proizvod. Ovogodišnja je Ambienta dobar primjer udruživanja nastavnih ustanova i proizvođača i pokazuje kako se radom dolazi do uspjeha.

doc. dr. sc. Silvana Prekrat

INSPIRACIJA, INOVACIJA, INTERZUM - 2011

INTERZUM AWARD

Liječnici u ležaju-madracu i banane na podu!

Tim naslovom samo nastavljamo sinergijski niz u dizajnu i tehnologiji. Graditi „čardake ni na nebu ni na zemlji“ postao je sve neprihvatljiviji zadatak u dizajniranju i oblikovanju tehničkih i estetskih rješenja. Od dizajnera se sve više traže pragmatična rješenja. Poliamidne tkanine definitivno su „out“, a „in“ su materijali od prirodnih vlakana, npr. kokosova vlakna. Možda u budućnosti umjetne materijale nećemo u potpunosti zamijeniti prirodnima, ali ćemo spavati na madracima koji će nam mjeriti tlak i kontrolirati rad srca.

Interzum award: inteligent material & design (nagrada Interzuma: *Inteligentni materijali i dizajn*), pod tom su temom ove godine dodijeljene nagrade za inovaciju i dizajn, a dobitnici su ponudili uistinu pametna rješenja.

INTERZUM NAGRADE

Ojastučenje i tekstil

Smart Wrap, proizvođač: Bekaert Textiles NV, Waregem, Belgija, dizajn: Koen Bodyn, www.bekaert-textiles.com

Inovacija predstavlja novu generaciju „inteligentnih“ presvlaka za ležajeve-madrace. Sadržava integrirane infracrvene optičke vodove i čitače koji prate vaše tjelesne funkcije prilikom spavanja, te pronalazi primjenu u mnogim područjima uporabe, posebice u bolničkim sustavima. Program koji prikuplja informacije putem senzora u svojoj je primjeni ograničen samo maštom i sposobnošću programera. Praćenje životnih funkcija pacijenata, znanstvena istraživanja, praćenje razvoja djece - sve su to područja u kojima možemo primijeniti takav proizvod.

Najvažnija odlika tog sustava jest da nije utemeljen na protoku električne struje i elektriciteta, pa stoga ne utječe na ljudsko tijelo.

Ukrasne površine i materijali

Naturalia, proizvođač: ARPA INDUSTRIALE S.p.A., Bra, Italija, www.arpaindustriale.com

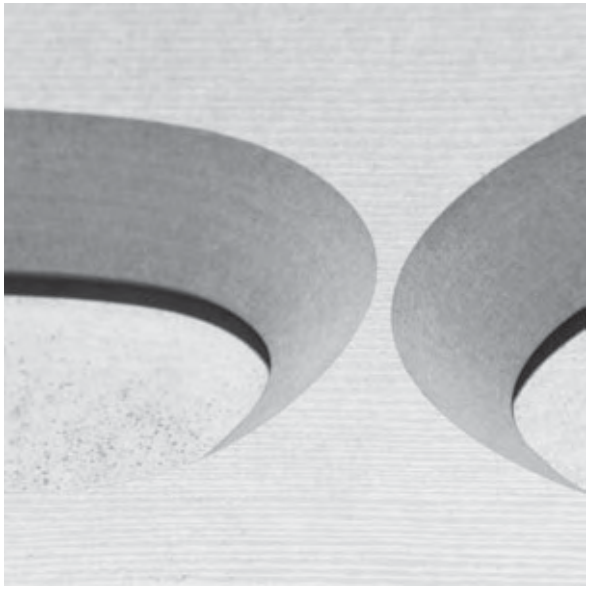
Taj ekološki prihvatljiv materijal objedinjuje izuzetna estetska i funkcionalna obilježja. Može se oblikovati i izrezivati u gotovo sve forme. Time se otvaraju i nove mogućnosti prilikom dizajna namještaja i interijera. Jednako se kvalitetno ponaša u kuhinji, kao i u obliku pregradnih stijena ili namještaja u bolnici. Ističe se njegova uporabljivost u izradi kuhinjskih radnih površina, dizajnerskog namještaja, ormarića i kućišta za različite uređaje.

Zbog svojstava koja pokazuju da je materijal izuzetno otporan na habanje i utjecaj vode i vlage nalazi primjenu u svim situacijama i uvjetima u praksi. Dapače, njegova osnovna primjena ograničena je samo kreativnošću pojedinaca koji ga rabe i primjenjuju.

Taj novi ekološki proizvod može poprimati oblike, boje i teksture prirodnih materijala, a reflektira ih u obliku ekološki održivog proizvoda načinjenoga od drvnih vlakana. *Naturalia* je i certificirana *Greenguard* certifikatom.

Slika 1. *Interzum award: inteligent material & design* (nagrada Interzuma: *Inteligentni materijali i dizajn*)

Slika 2. *Smart Wrap* presvlaka za ležaj-madrac



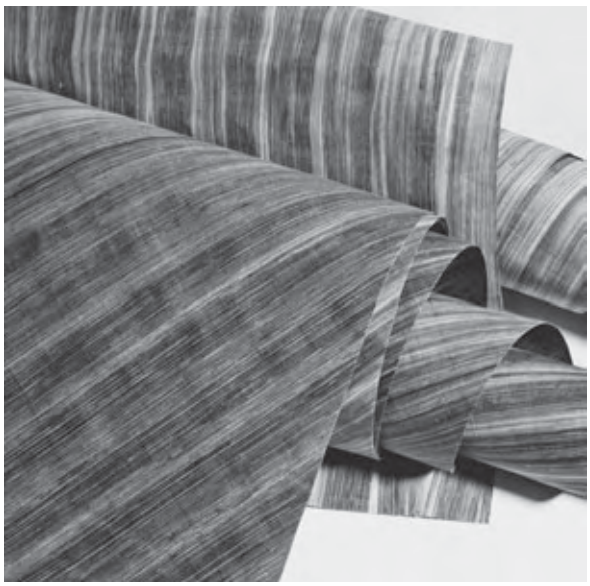
Slika 3. *Naturalia,* drvnokompozitna ploča

Furniri i dekori

Furnir od vlakanaca kore (plašta) banane, proizvođač: Beleaf Veneers, Beleaf s.a.m., Monaco, dizajn: Marco Cassin, glavni projektant, www.beleaf.mc

Taj novi proizvod tvrtke Beleaf nudi širok spektar primjene. Pri tome se pozornost usmjerava na proizvodnu, ali i na kreativnu komponentu. Velika savitljivost listova furnira izrađenih od vlakanaca otvara dizajneru nove mogućnosti prilikom oblikovanja namještaja i dizajniranja interijera. Proizvod se primjenjuje i pri oblikovanju eksterijera i namještaja koji je izložen vanjskim utjecajima.

Glavna odlika tog proizvoda jest ekologičnost, koja je na prvome mjestu. Naime, prilikom plantažnog uzgoja banana, u procesu berbe, velike su količine biomase i ostataka koji se dosad nisu mogli komercijalno iskoristiti ostajale na plantažama i trunule. U tom se procesu oslobađala velika količina CO^2. Na ovaj novi način, tvrdi proizvođač, preradom vlakanaca, ta je emisija smanjena.



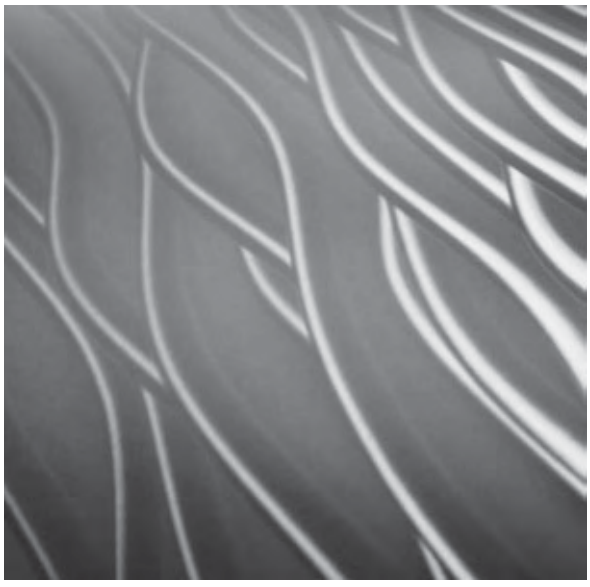
Slika 4. Furnir od vlakanaca kore (plašta) banane

Estetske odlike stavljaju taj proizvod u sam vrh trendova i time još jedanput potvrđuju uspješnost tog ulaganja i razvoja proizvoda.

Inovacije u dekorima

High pressure laminate HPL, proizvođač: Duropal GmbH, Arnsberg, Njemačka, dizajn tvrtke, www.duropal.com

Duropal iznenađuje još jednom u nizu HPL ploča. Inovativna površina lukavom optičkom varkom stvara dojam trodimenzionalnosti i „apsurda u escherovskoj maniri“. Unatoč dojmu da je riječ o površini punoj neravnina i brazda, pred sobom imamo materijal savršene glatkoće. Čak i kada se frontalno pomno zagledamo u površinu, ne možemo bez dodira zaključiti je li riječ o stvarnim valovima ili ne. Kombinacija tiska, 3D folija, završnih transparentnih lakova i tehnologije koju proizvođač još nije otkrio javnosti dobivamo uistinu jedinstven doživljaj.



Slika 5. *Duropal HPL* nove generacije

Dizajneri i arhitekti ocijenili su taj proizvod odličnim, a različite boje i dezeni kao da su stvoreni da male prostore učine velikima a velikim prostorima podare grandioznost. Njime se ostvaruju fronte, korpusi i pregradne stijene, u zatvorenome i na otvorenome prostoru.

Okovi

LEGRABOX pure, Box system, proizvođač: Julius Blum GmbH, Höchst, Austrija, dizajn tvrtke, www.blum.com

Legrabox, kako kažu u Blumu, limuzina je među boks sustavima ladica. Taj koncept odlikuje minimalizam, lakoća i jednostavnost, a što je najvažnije - elegancija tankih i jednostavnih oblika. Potpuno izmijenjen klizni mehanizam napravljen od dvije nazubljene letve koje klize preko sustava minizupčanika. Dimenzije vodilica najmanje su do sada, tako da maksimalno povećavaju prostor za odlaganje unutar ladice i smanjuju prostor zazora između ladice i stranice korpusa. Materijali od kojih je *Legra* napravljena unificirani su bojom i materijalom tako da dodatno naglašavaju eleganciju.

Slika 6. *Legrabox* sustav kliznih vodilica

Dekori i materijali za oblaganje

RE-Y-STONE®, proizvođač: Resopal GmbH, Groß-Umstadt, Njemačka, DEKODUR GmbH & Co. KG, Hirschhorn, Njemačka, dizajn tvrtke, www.resopal.de

Proizvođač promovira kamen kao vječni materijal u oblikovanju interijera, namještaja i okruženja. Ocjenjivački žiri ocijenio je taj materijal bezvremenskim. Što to u praksi znači? Njime se koristimo svugdje i u svakoj prilici. On pristaje uz gotovo sve, a trendovi kao da ga s poštovanjem obilaze. Je li uistinu tako, procijenite sami.

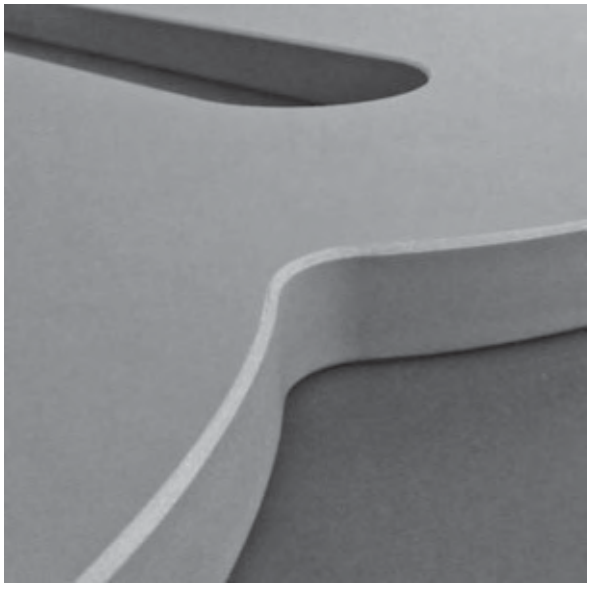
S tehnološkoga gledišta, to je u svakom smislu vrlo jednostavan i nezahtjevan materijal. Proizveden je od celuloze i recikliranog papira s dodatkom adheziva prirodnog podrijetla. Sva su otapala na bazi vode, a kada se proces izrade završi, to postaje materijalom neosjetljivim na vlagu i vodu. Prema specifikacijama proizvođača, taj materijal ima emisiju plinova 0, a površina mu je vrlo otporna na habanje.

Slika 7. *RE-Y-STONE*® dekorativne obloge

Trake i materijali za oblaganje rubova

WO Linoleum rubna traka, proizvođač: WO Interior A/S, Randers SØ, Danska, dizajn: Niels Flemming Troelsen, www.wo.dk

S pojavom organskih formi u dizajnu namještaja klasična primjena rubnih traka postala je neodgovarajuća. Tvrtka WO Interior godinama je radila na razvoju tehnologije koja će doskočiti problemima s kojima se proizvođači susreću. Linoleum se u malo poboljšanome strukturnom i kemijskom obliku pokazao idealnim za rješavanje tih problema. Wo Linoleum daje izvrsne rezultate aplikacijom u sklopu CNC tehnologije, a radijusi koji se mogu strojno oblagati svedeni su na 10 mm. Ovisno o debljini materijala koji



Slika 8. WO Linoleum rubna traka

Slika 9. *UNICLIC* nova tehnologija za izradu namještaja

oblažemo, i trake se prilagođuju potrebama. One se, uz primjenu minimalne topline pri prvom postavljanju, zaista mogu prilagoditi bilo kojem obliku.

Tehnologija za izradu namještaja

UNICLIC, proizvođač: Unilin bvba, Wielsbeke, Belgium, *In-house* dizajn: Luc Maertens, Mark Cappelle, Bernard Thiers, www.unilin.com, www.uniclic.com

Bilo 90°, bilo 180°, *Uniclic* jednim klikom može svladati oboje. Razvijan ponajprije za tehnologije pri sklapanju namještaja od masivnog drva, *Uniclic* je svoje mjesto konačno pronašao među ivericama. Mnogi se pitaju hoće li taj koncept u masovnoj proizvodnji istisnuti mnoge vezne elemente? Mišljenja su oprečna i različita, ali kako god bilo *Uniclic* je podigao mnogo prašine na ovogodišnjem Interzumu.

Stranice namještaja ujedno sudjeluju u međusobnom povezivanju tako da mnogi dodatni dijelovi više nisu potrebni. Tehnologija se može uspješno primijeniti na iverice i MDF ploče. Proizvođači kažu da je sve vrlo jasno i da proizvod govori sam za sebe, pa pogledajmo!

prof. dr. sc. Ivica Grbac
Ivan Littvay, dipl. ing.
dr. sc. Danijela Domljan

AFRIČKI MAHAGONIJ

NAZIVI

Drvo botaničkog roda *Khaya* iz porodice *Meliaceae* u trgovinu najčešće dolazi kao afrički mahagonij. Pod time se uglavnom podrazumijeva drvo *K. ivorensis* A. Chev., *K. anthotheca* C.DC., *K. grandifoliola* C. DC., *K. nyasica* Stapf i *K. senegalensis* A. Juss.

K. ivorensis poznata je i kao Benin, lagos, nigerijski i degema mahagonij, lagoswood i ogwango (Nigerija) te ngollon (Kamerun). *K. anthotheca* dolazi u trgovinu i kao krala (Obala Bjelokosti), mangona (Kamerun), munyama (Uganda). *Khaya grandifoliola* C. DC. poznata je kao eninwood, Benin mahogany (Nigerija), grandifoliola (Velika Britanija). *Khaya nyasica* Stapf. na tržištu se pojavljuje kao Mozambique mahogany, mbaua, umbaua (Mozambik), mbawa (Malavi), mkangazi (Tanzanija).

Khaya senegalensis (Desr.) A. Juss. poznata je kao bissilom (Port Guinea) i Guinea mahogany (Velika Britanija).

NALAZIŠTE

K. ivorensis raste u kišnim šumama zapadne Afrike, od Obale Bjelokosti do Kameruna i Gabona, uključujući Ganu i Nigeriju. *K. anthotheca* raste u zapadnoj Africi, u područjima s manjom količinom kiše nego što ih zahtijeva *K. ivorensis* i ne nalazimo je na obalnom području. U istočnoj Africi raste samo na području Ugande i Tanzanije. *K. grandifoliola* raste u zapadnoj Africi, udaljena od obalnog pojasa, u područjima s relativno malo kiše. *K. nyasica* nalazimo u istočnoj i središnjoj Africi, osobito u Ugandi i Tanzaniji. *K. senegalensis* raste na zapadu, od Senegala do Konga, te u Sudanu i Ugandi.

STABLO

Stabla roda *Khaya* obično su visoka oko 30 m ili su viša od toga, s promjerom debla oko sto i više centimetara. Imaju jako žilište, visoko i preko 2,5 m, iznad kojega se uzdiže ravno i čisto deblo do visine od 12 do 24 m.

DRVO

Makroskopska obilježja

Drvo afričkog mahagonija difuzno je porozno. Granice godova su neuočljive ili ih nema. Bjeljika je uska, kremasto bijela do žućkasta. Svježa srž je ružičastosmeđa, a sa starenjem drva potamni do crvenkastosmeđe. Vrlo je rijetko žućkastosmeđa do zlatnosmeđa, kao američki mahagonij (*Swietenia macrophylla* King). Pore su na svim presjecima vidljive običnim okom. Granice godova mjestimično su vidljive po gušće raspoređenim sitnim porama. Žica je često dvostruko usukana, što radijalnim površinama daje privlačan prugasti izgled. Sjaj drva afričkog mahagonija visok je, a tekstura mu je najčešće srednje gruba.

Mikroskopska obilježja

Traheje drva raspoređene su rastresito, pojedinačno, u parovima i u radijalnim skupinama. Promjeri im se kreću od 35...145...do 230 mikrometara. Gustoća traheja iznosi od 2 do 9 odnosno do 24 na 1 mm^2 poprečnog presjeka. Udio traheja je od 10,0 do 17,7 odnosno do 29,0 %. Traheje su često ispunjene tamnim sržnim tvarima.

Drvni traci široki su 1 do 5 odnosno do 7 stanica, heterocelularni su, s kvadratnim ili uspravnim stanicama na rubnim dijelovima traka. Širina trakova je 28 ... 65 ... 170 mikrometara, visoki su 300 ... 520 ... 100 mikrometara, a gustoća im je 3 ... 5 ... 9 na 1 mm. Volumni udio trakova u građi drva iznosi 14 ... 20,8 ... 28,2 %.

Vlakanca su libriformska, septirana i neseptirana. Na poprečnom su presjeku pravilno radijalno raspoređena. Dvostruka debljina staničnih stijenki iznosi 3,3 ... 5,2 ... 9,7 mikrometara, a promjer lumena 4,6 ... 15,5 ... 26,3 mikrometara. Duljina vlakanaca kreće se od 500 do 1280 odnosno do 2000 mikrometara. Udio vlakanaca je 47,2 ... 57,2 ... 72,4 %. Vlakanca su ravna, dvostruko usukana i valovita.

Uzdužni parenhim je paratrahealan, vazicentričan i unilateralan, rijedak. Udio mu je od 2 do 4,3 odnosno do 8,2 %.

U rubnim stanicama trakova i aksijalnom parenhimu nalaze se pojedinačni kristali. Pokatkad se (rijetko) mogu naći aksijalni traumatski međustanični kanali.

Fizikalna svojstva

Gustoća standardno suhog drva ρ_o	420 ... 490 ... 570 kg/m^3
Gustoća prosušenog drva $\rho_{12\text{-}15}$	440 ... 510 ... 590 kg/m^3,
Gustoća sirovog drva ρ_s	650 – 800 kg/m^3
Poroznost	oko 68 %
Radijalno utezanje β_r	2,4 ... 3,2 ... 4,1 %
Tangentno utezanje β_t	5,1 ... 5,7 ... 6,2 %
Volumno utezanje β_v	7,5 ... 9,1 ... 10,7 %

Mehanička svojstva

Čvrstoća na tlak	36 ... 46 ... 58,5 MPa

Čvrstoća na vlak, paralelno s vlakancima	32,5 ... 61,5 ... 101 MPa
Čvrstoća na vlak, okomito na vlakanca	1,7 ... 2,3 MPa
Čvrstoća na savijanje	36 ... 87 ... 126 MPa
Čvrstoća na smik	6 ... 8 ... 9,5 MPa
Tvrdoća (prema Brinellu), paralelno s vlakancima	oko 33 MPa
Tvrdoća (prema Brinellu), okomito na vlakanca	oko 14 MPa
Modul elastičnosti	oko 10 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo afričkog mahagonija općenito se dobro obrađuje strojnim i ručnim alatima. Izuzetak je tenzijsko drvo te drvo izrazito dvostruko usukane žice, koje se pri ručnoj obradi često trga. Da bi se to spriječilo, pri blanjanju se preporučuje smanjiti kut rezanja od 20 stupnjeva. Pri piljenju nema posebnih zahtjeva glede alata, a alat se tupi umjereno. Tokarenje, glodanje, bušenje i brušenje afričkog mahagonija zadovoljavajući su, uz već spomenute izuzetke. Drvo se dade dobro lijepiti i površinski obrađivati. Čavle i vijke drži dobro, uz napomenu da drvo u dodiru sa željezom u vlažnim uvjetima potamni. Savijanje uz pomoć pare nije preporučljivo jer se, unatoč upotrebi trake s vlačne strane luka, s unutrašnje tlačne strane luka stvaraju bore od zgnječenih vlakanaca.

Sušenje

Drvo afričkog mahagonija suši se dobro i brzo, uz izuzetak dijelova s tenzijskim drvom, koje za vrijeme sušenja može prouzročiti jako vitoperenje i krivljenje. Nakon sušenja drvo je prilično stabilnih dimenzija u upotrebi.

Trajnost

Afrički mahagonij pripada srednje trajnom drvu (razred 3 prema EN-u). Srž je otporna na tercijarne insekte, dok je bjeljika osjetljiva na njih. Srž i bjeljika podložne su napadu termita. Srž je vrlo nepermeabilna i teško se impregnira (razred 4 prema EN-u), a bjeljika je srednje permeabilna. Prema

EN-u, afrički je mahagonij prikladan za upotrebu u unutrašnjim ili natkrivenim prostorima, s visokom relativnom vlagom zraka. Na otvorenome, nezaklonjenom prostoru u kojemu je vlaženje često ne preporučuje se upotreba afričkog mahagonija bez zaštite.

Uporaba

Zbog boje, teksture i sjaja afrički se mahagonij upotrebljava za izradu pokućstva, za unutarnje uređenje stambenih i poslovnih prostora, brodskih salona i sl. (obloge, stolarija), za unutarnje konstrukcije, stolarske ploče i furnire.

Napomena

Afrički se mahagonij često upotrebljava kao zamjena za američki mahagonij (*Swietenia macrophylla* King) jer je jeftiniji i dostupniji, a može se primijeniti za iste svrhe. Ta je zamjena osobito česta nakon 2003. godine, kad je američki mahagonij službeno proglašen vrstom kojoj prijeti nestanak te je uvršten na popis CITES (Convention on International Trade in Endangered Species). Vrijednosti mehaničkih svojstava drva *K. ivorensis* nalaze se između vrijednosti drva obeche (*Triplochiton scleroxylon* K. Schum.) i obične bukve (*Fagus sylvatica* L.).

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Šumarski fakultet Sveučilišta u Zagrebu
Svetošimunska 25, HR – 10000 Zagreb
E-mail: drind@sumfak.hr

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Predani rukopisi smiju sadržavati najviše 15 jednostrano pisanih DIN A4 listova s dvostrukim proredom (30 redaka na stranici), uključivši i tablice, slike i popis literature, dodatke i ostale priloge. Dulje članke je preporučljivo podijeliti u dva ili više nastavaka.

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Latinska imena pisana kosim slovima trebaju biti podcrtana.

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

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

Rezultati trebaju obuhvatiti samo materijal koji se izravno odnosi na predmet. Obvezatna je primjena metričkog sustava. Preporučuju se SI jedinice. Rjeđe rabljene fizikalne vrijednosti, simboli i jedinice trebaju biti objašnjeni pri prvom spominjanju u tekstu. Za pisanje formula koristiti Equation Editor (program za pisanje formula unutar MS Worda). Jedinice se pišu normalnim (uspravnim) slovima, a fizikalni simboli i faktori kosim slovima. Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.

Broj slika mora biti ograničen na samo one koje su prijeko potrebne za pojašnjenje teksta. Isti podaci ne smiju biti navedeni u tablici i na slici. Slike i tablice trebaju biti zasebno obrojčene arapskim brojkama, a u tekstu se na njih upućuje jasnim naznakama ("tablica 1" ili "slika 1"). Naznaka željenog položaja tablice ili slike u tekstu treba biti navedena na margini. Svaka tablica i slika treba biti prikazana na zasebnom listu, a njihovi naslovi moraju biti tiskani na posebnim listovima, i to redoslijedom. Naslovi, zaglavlja, legende i sav ostali tekst u slikama i tablicama treba biti pisan hrvatskim i engleskim ili hrvatskim i njemačkim jezikom.

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

Ostale publikacije (brošure, studije itd.):
Müller, D. 1977: Beitrag zür Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanstalt für Forst- und Holzvvirtschaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

Web stranice:
****1997: "Guide to Punctuation" (online), University of Sussex, www.informatics.sussex.ac.uk/department/docs/punctuation/node 00.html. First published 1997 (Pristupljeno 27. siječnja 2010).*

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

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