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Dimensional stability of heat treated wood floorings

Dimenzijska stabilnost podnih obloga od pregrijanog drva

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ABSTRACT • *Heat treated wood (HTW) is successfully applied for floorings due to its better moisture resistance, increased dimensional stability, and uniform colour change to darker, brownish colours.*
The aim of this work was to define the hygroscopic range and equilibrium moisture content at ambient conditions of heat treated wood of two wood species – ash and beech. Material was treated at two temperature levels, 190 and 210 °C, and the properties were compared with native wood. The reduction in dimensional changes is expressed by volumetric shrinking and Anti Shrink Efficiency (ASE). Additionally, parquet elements were made out of such HTW, oil-impregnated and waxed, and subsequently tested for water vapour and liquid water permeability.
Shrinking gradients of HTW were not reduced in comparison with native beech wood, but the absolute reduction in water uptake resulted in cca 50 % lower EMC values and up to cca 60 % improved ASE values. Surface treatment further improved the hygroscopic properties of HTW.

Key words: *heat treated wood, parquet elements, dimensional stability, beech, ash*

SAŽETAK • *Pregrijano se drvo uspješno primjenjuje za podne obloge zahvaljujući smanjenoj higroskopnosti, boljoj dimenzijskoj stabilnosti te ravnomjernoj promjeni boje u tamnije smeđe tonove.*
Cilj je ovog rada utvrditi higroskopski raspon i ravnotežni sadržaj vode pri sobnim uvjetima za dvije vrste pregrijanog drva za parket – za jasenovinu i bukovinu. Uzorci su tretirani pri dvije temperaturne razine – 190 i 210 °C, a svojstva uspoređena s nativnim drvom. Smanjenje dimenzijskih promjena izraženo je kao poboljšanje dimenzijske stabilnosti (engl. Anti Shrink Efficiency – ASE). Nadalje, od proba pregrijanog drva načinjene su parketne daščice, tretirane parketnim uljem i voskom, te testirane na vodoupojnost i paropropusnost.
Koeficijenti utezanja pregrijanog drva nisu smanjeni u usporedbi s nativnim, ali je apsolutno smanjenje vodoupojnosti za 50% rezultiralo povećanjem dimenzijske stabilnosti za 60%. Površinska je obrada dodatno poboljšala higroskopna svojstva pregrijanog drva.

Ključne riječi: *pregrijano drvo, parketni elementi, dimenzijska stabilnost, bukovina, jasenovina*

1 INTRODUCTION
1. UVOD

Heat treated wood is a material with changed chemical composition, cell wall structure and physical properties. The process is generally conducted under the influences of heat and pressure. Temperature during thermal treatment usually ranges from 120 °C to 280 °C, treatment time spans between 15 minutes and 24 hours, depending on the type of the process, wood species, stock

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dimensions, initial moisture content, and the desired level of alteration of mechanical properties, resistance against biological deterioration, and dimensional stability of the product (Emmler and Scheiding, 2007). The presence of air or other oxidative medium can accelerate the degradation process of wood components during heat treatment and this is why the process is usually carried out in a protective gaseous medium (nitrogen, steam, CO_2) or immersed in various oils (Rep and Pohleven, 2001). Changes in cell wall chemistry cause the reduction of water uptake (Metsä-Kortelainen *et al.*, 2006) and, consequently, improvement in dimensional stability. Heat treatment of wood increases its moisture resistance, improves dimensional stability, enhances resistance against biological deterioration, and contributes to uniform colour change from original to dark brownish tones (Kollmann *et al.* 1975; Hill, 2006). This material also exhibits some shortcomings, such as reduced tensile and bending strength (which are not so relevant for flooring applications), unstable colour in exterior exposure (unless the surface is coated), appearance of surface checking and increased brittleness. From technological point of view, embrittlement results in appearance of fine irritating dust and rough, splintery edges during machining. Besides, after thermal treatment some wood species have a burnt smell for months. Heat treatment process was developed with the intention to use cheep softwoods for cladding and decking in outdoor use. At the beginning of the application of this method, the colour change was considered as a disadvantage. Nowadays, on the contrary, it is regarded as one of the main arguments for the application of this technology, because species with natural irregularities, like coloured heartwood of beech and ash, turn to aesthetically and technically valuable products when heat treated (exclusive parquet). It is especially attractive to use heat treated wood for parquet since it is possible to obtain different dark brownish colours by varying the process parameters. Furthermore, heat treated wood can be used as a substitute for tropical species (Sundquist, 2004). Better dimensional stability in variable climatic (room) conditions is an additional reason for the use of this material for parquet production.

Equilibrium moisture content of heat treated specimens after 3 years of natural exposure was 40 – 60 % lower compared to untreated wood, regardless of surface protection system, which indicates permanent improvement in dimensional stability (Jämsä and Viitaniemi, 2001). However, Arnold (2007) showed that the improvement in dimensional stability does not correlate well with the form stability of HTW elements. In other words, although HTW parquet will shrink and swell considerably less, it will still cup and twist due to the same ratios of radial to tangential properties as would native wood do. Heat treated wood is an excellent substrate for finishing as it is dry and free of resin which run out during heating. At temperatures above 180 °C oils and waxes are extracted from sapwood and later they cause no problems with adhesion (Jämsä and Viitaniemi, 2004).

The aim of this work was to define the hygroscopic range (determine the fibre saturation point, FSP) and equilibrium moisture content of heat treated wood prepared for parquet elements out of two wood species – ash and beech, heated at two temperature levels, 190 and 210 °C. The reduction in dimensional changes of heat treated wood compared to untreated wood was expressed by volumetric shrinking. Additionally, parquet elements were made out of such HTW, oil-impregnated and waxed, and subsequently tested for water vapour and liquid water permeability.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Specimen preparation
2.1. Priprema uzoraka

For the experimental purposes 10 replicates were prepared to form a sample of each of the following variables: wood species, ring orientation (structure), and treatment level, according to Table 1. Material for testing was commercially heat treated wood for two local parquet manufacturers at two temperature levels – *mild* at 190°C, and *intensive* at 210°C in water vapour atmosphere.

Laboratory tests implied weight measurements, along with length and width measurements in three pre-defined positions on every sample, using electronic

Table 1 Specimen preparation scheme
Tablica 1. Shema pripreme uzoraka

		Mark *oznaka*	Texture *tekstura*
Ash *jasenovina*	Native *prirodna*	A.N	radial *radijalna*
			tangential *tangentna*
	Heat treated - mild / *blago pregrijana*	A.HM	radial *radijalna*
			tangential *tangentna*
	Heat treated - intensive *jako pregrijana*	A.HI	radial *radijalna*
			tangential *tangentna*
Beech *bukovina*	Native *prirodna*	B.N	radial *radijalna*
			tangential *tangentna*
	Heat treated - mild *blago pregrijana*	B.HM	radial *radijalna*
			tangential *tangentna*
	Heat treated - intensive *jako pregrijana*	B.HI	radial *radijalna*
			tangential *tangentna*

calliper with the resolution of 1/100 mm. Separate panels of tangential and radial structure were used for measurements of dimensional changes over their width.

Since water uptake properties of HTW were unknown (no indication as to the time needed for specimen to achieve the fibre saturation point), the preliminary test with vertically immersed specimens was conducted during several days. Initially the specimens were vertically immersed (their end grain facing down) up to cca 1/3 of their height, the next day up to 2/3, and third day completely covered with water. The purpose of such procedure was to enable efficient capillary draw and a uniform, complete saturation. To avoid their floating, the specimens were loaded with weights. After seven days the HTW blocks still exhibited tendency to float, but since their dimensions stopped changing, it was concluded that the cell walls were fully saturated at that point. All the panels in the main test were subsequently water-saturated following such procedure. After complete water-logging, the specimens were taken out from the water and stored in a climate chamber (50 ± 5 % r.h. / 23 ± 2 °C) to dry. Their dimensions and weight were measured after 2, 4 and 7 days. Finally, the panels were oven-dried at 103 ± 2 °C to constant mass (48 hrs) and ultimately measured in dry condition. The values in absolute dry condition were used as references for determination of equilibrium MC levels during conditioning.

Water – vapour and liquid water permeability were determined on native and heat treated ash specimens. The samples were prepared as uncoated panels and panels treated with commercial flooring oil and wax. All surfaces of the panels but the faces were coated with two coats of extremely impermeable 2K epoxy paint. Faces of the specimens were amply treated with flooring oil (Lobasol HS Akzent 100 Oil) for 30 minutes, when the excess liquid was removed with a soft cloth. After 24 hours' drying, the samples were treated with flooring wax (Lobasol HS Akzent 100 Wax). Thin wax was gently applied and rubbed in the wood until the surface remained dry and polished. After further 24 hours, the tests were performed according to EN 927-4 and EN 927-5. They generally consist of weighing the panels before and after exposure to liquid water (for 72 hrs) or high air humidity (for two weeks) to establish the amount of absorbed water through the panel face.

2.2 Calculation
2.2. Izračun

Fibre saturation point (FSP) was estimated in such specimen condition when their dimensions reached their maximum after soaking. After complete saturation and through gradual drying period, to final oven-drying, the relation was determined between the moisture content and corresponding dimensions in various stages of the hygroscopic range. In this way five points were obtained on a straight line of the MC-dimension diagram. A point where the straight MC - dimension line intercepts the value of maximal dimensions (D_{max}, MC_{max} parallel with abscissa in Figure 1) defines the estimated fibre saturation point (FSP).

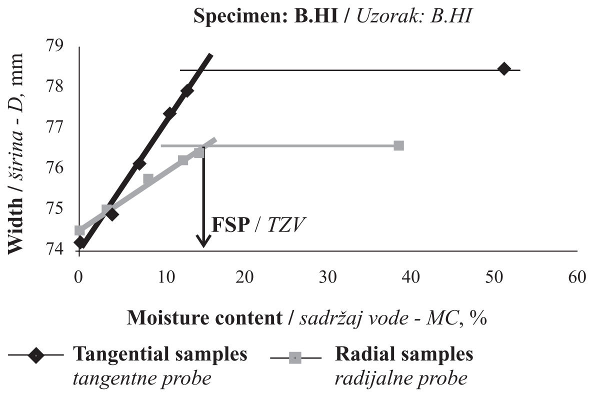

Figure 1 Estimation of fibre saturation point
Slika 1. Određivanje procijenjene tokče zasiećnosti vlakanaca

The value of shrinking β represents the ratio of the difference between the dimensions of fully saturated wood (D_v) and those of absolutely dried wood (D_0) compared to fully saturated D_v wood, and it was calculated according to equation

$$\beta(\%) = \frac{D_v - D_0}{D_v} \cdot 100 \qquad (1)$$

Volume shrinking (β_v) was calculated as a product of linear dimensional changes on separate radial and tangential texture samples, since it allowed to get more precise dimension measurements over the width of the specimens. It was calculated according to the equation

$$\beta_v = \beta_r + \beta_t + \beta_l - \beta_t \cdot \beta_r \qquad (2)$$

Anti-Shrink Efficiency (ASE) (Rowell, 2005) was calculated on the basis of shrinkage of native (β_o) and heat treated wood (β_p).

$$ASE(\%) = \left(1 - \frac{\beta_p}{\beta_0}\right) \cdot 100 \qquad (3)$$

Linear shrinking gradients (shrinking in radial or tangential direction per 1 % moisture decrease) were calculated according to the formula (Kollmann and Cote, 1968):

$$\beta_c(\%/\%) = \frac{\Delta\beta}{\Delta MC}$$

Where β_c – linear shrinking gradients
$\Delta\beta$ – difference of shrinking
ΔMC – difference of moisture content

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

Figure 2 shows that the estimated fibre saturation point (FSP) values are somewhat higher than those quoted in the reference literature for samples of native wood. These values are higher for ca 10% MC and 4% MC for beech and ash, respectively). FSP of mild heat treated beech samples is about 50% lower compared to native wood, and intensive heat treated wood shows about 70% lower FSP value. Mild heat treated ash exhibits for about 35% lower FSP, and intensively treated about 40%. This

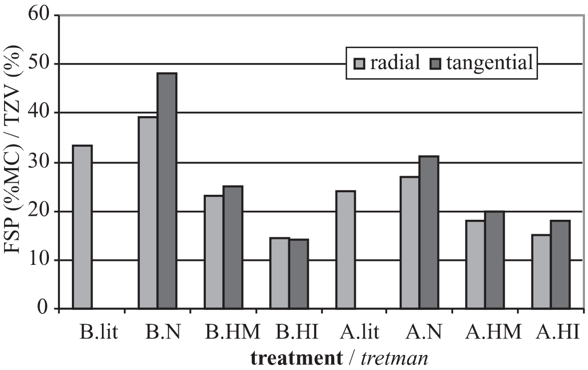

Figure 2. Fibre saturation point (FSP) for beech and ash for two treatment intensities (Marks on abscissa listed in Table 1, *lit* mark refers to literature values (Horvat and Krpan 1967))
Slika 2. Točka zasićenosti vlakanaca (TZV) bukovine i jasenovine za dva stupnja pregrijavanja (oznake na apscisi objašnjene su u tablici 1, osim oznake lit, koja predočuje vrijednost iz literature (Horvat i Krpan, 1967)

means that the intensity of the treatment (level of temperature, duration and other parameters) influences the intensity of changes, but that different species do not react equally to the regime parameters.

Measured equilibrium moisture content (EMC) (Figure 3) at room conditions (23±2 °C and 50±5% relative humidity, RH) amounts to 8% for native beech, and 10% for ash, while the reference literature value is 9% (Kollmann and Côté, 1968). Mild treated beech exhibits 15% lower EMC, mild treated ash 35%, while both intensive treated species attain nearly 50% lower EMC than native wood (EMC value for beech is reduced to 3.5%, and for ash to 5%). This means that in the same ambient conditions the heat treated wood absorbs almost 50% less water which, of course, affects the reduction in dimensional changes, but also aggravates the reliable measurements with electrical moisture meter. It is interesting to see that the EMC, established on tangential panels, exhibits a fraction higher values than those determined on radial samples, although both sets of panels were conditioned to constant mass. This behaviour and its delicate measurement will form an additional experimental work.

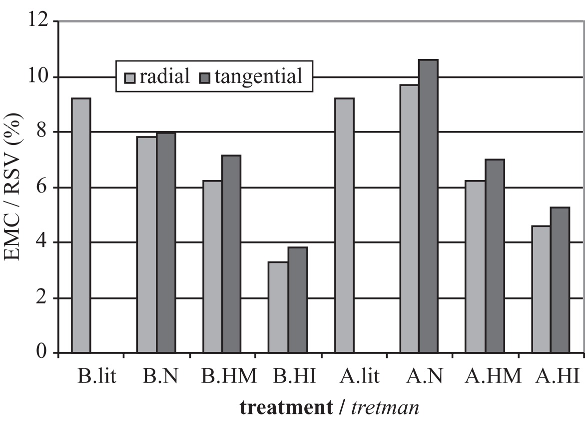

Figure 3 Equilibrium moisture content (EMC) at ambient conditions for beech and ash, for two levels of treatment intensities
Slika 3. Ravnotežni sadržaj vode (RSV) pri sobnim uvjetima za bukovinu i jasenovinu uz dva stupnja pregrijavanja

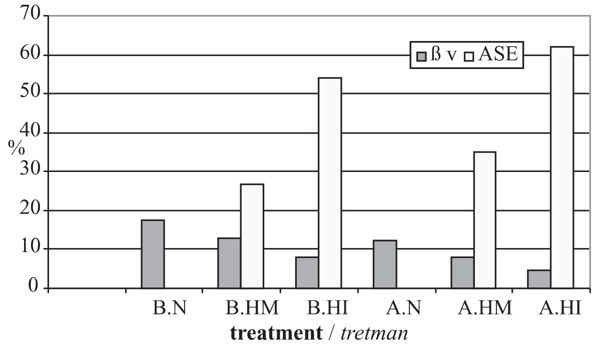

Figure 4 Volume swelling (β_v) and anti-shrink efficiency (ASE)
Slika 4. Volumno bubrenje (β_v) i poboljšanje dimenzijske stabilnosti (ASE)

Reduction in shrinking (Figure 4) results in better dimensional stability of heat treated wood, expressed as Anti-Shrink Efficiency (ASE). Heat treating at lower temperature (190 °C) resulted in improvement of dimensional stability of 27% for beech and of 35% for ash, while treatment on higher temperature (210 °C) resulted in better dimensional stability of 54% for beech and even 62% for ash samples.

Both sets of beech radial samples (mild and intensive treated) exhibit about 10% greater radial shrinking gradients than the native wood (Figure 5). In tangential direction the difference is greater, and heat treated wood exhibit significantly (up to 50 %) greater gradients. This means that shrinking at one percent change in moisture content is even greater with HTW than with genuine beech wood. On the other side, mild treated ash samples exhibit ca 40% reduction, and intensive treated about 60% reduction of partial shrinking gradients compared to untreated wood. Therefore, the shrinking gradient proves to be an irregular and not realistic parameter for the expression of dimensional properties and stability of HTW. Apparently, shrinking gradients were not much altered by heating treatment, but since the absolute values of water uptake and dimensional changes are much smaller than with native wood, overall dimensional stability of HTW is improved.

An additional aspect of dimensional changes, noted previously by Arnold (2007), about the ratio of radial to tangential properties being nearly the same as with the native wood, has been noticed here as well (Figure 5). It has some importance for the use of HTW for

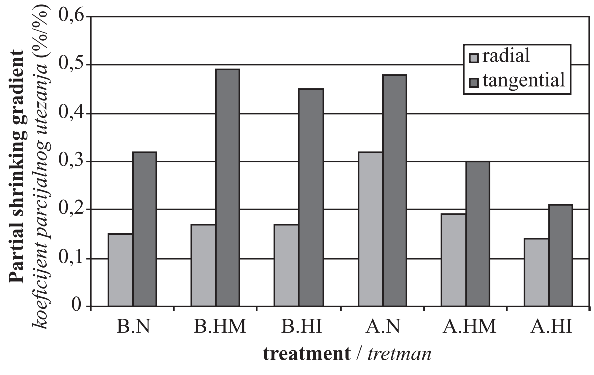

Figure 5 Partial shrinking gradient
Slika 5. Koeficijent parcijalnog utezanja

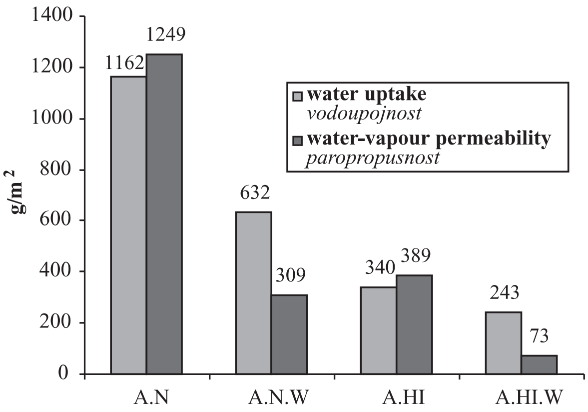

Figure 6. Liquid water and water-vapour permeability of ash wood according to EN 927-5 and EN 927-4 (W means waxed)
Slika 6. Vodoupojnost i paropropusnost javorovine prema EN 927-5 i EN 927-4 (W znači voštano)

flooring, indicating that although the dimensional changes of HTW may be much smaller, the distortions of elements due to the R/T ratio will be similar as with the native wood. Therefore the flooring elements of HTW may exhibit better dimensional stability than native wood elements, but not better shape stability in conditions of changing humidity.

Oiling and waxing significantly affects the hygroscopic properties of parquet elements, reducing the vapour uptake to approximately 25% of that of genuine wood (Figure 6). The effect is even better pronounced with HTW than with native wood, where the vapour uptake during 14 days in humid (>98% r.h.) conditions amounted to only about 70 g/m^2 or 20% of the value of genuine wood. Liquid water uptake was not affected to that level by heat treatment, but the comparison of Figures 3 and 6 shows that the reduction of absolute water uptake is substantially greater than could be concluded by the reduction of EMC values when surfacing is applied on HTW.

4 CONCLUSION
4. ZAKLJUČAK

The results of laboratory test show that the heat treated wood, when compared to genuine wood, exhibits a significant reduction of fibre saturation point (up to 15% in average), lower equilibrium moisture content in room conditions (3.5 to 5%), and improvements in dimensional stability (up to 60%) expressed as ASE. This applies to both wood species, but it should be mentioned that better effects were achieved with ash than with beech samples. Higher level of treatment temperatures yielded proportionally greater stabilization effects. Water vapour and liquid water uptake can be reduced by 70%, and simple oiling and waxing of parquet surfaces further contributes to better performance of HTW in humid conditions. Although the flooring elements of HTW may exhibit better dimensional stability than native wood elements, the ratio of radial to tangential properties remains nearly the same. Therefore, the distortions of HTW elements due to the R/T ratio will be similar as with the native wood, exhibiting similar shape stability as native flooring elements in conditions of changing humidity.

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