High Temperature Drying Process of Beech Wood (*Fagus sylvatica* L.) with Different Zones of Sapwood and Red False Heartwood

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This study examined the changes in the properties of beech wood (*Fagus sylvatica* L.) after intense drying. Beech wood with false red heartwood was selected as the test specimen. The test samples had dimensions of 50 mm thickness, 180 mm width, and 350 mm length. The specimens were divided into two groups, false red heartwood and sapwood. These specimens were selected with different angles of the growth rings (radial and tangential). The results showed that samples with red heartwood, in comparison to samples with sapwood content, had a remarkable effect in covering. Observation of specimens with false red heartwood and sapwood before and after drying process revealed significant differences in color changes and measured values during the covering-slicing test, but not between samples with different growth ring angles.

Keywords: Wood drying; High temperature drying; Red false heartwood; Sapwood; Color changes; Moisture gradient

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INTRODUCTION

The amount and rate of sapwood and heartwood formation vary greatly with tree species, age, rate of growth, and environmental conditions (Bamber and Fukazawa 1985). Heartwood formation in wood species usually begins at about 5 years and lasts to 100 years of growth (Dadswell and Hillis 1962). European beech (*Fagus sylvatica* L.) is an economically important tree species in forests. Beech develops discolored wood in the core of the stem, which is commonly referred to as red heart, red heartwood, facultative colored heartwood, false heartwood, or red core (Wernsdörfer *et al.* 2005). Typical red false heartwood is located in the central part of the stem. It is reddish or brownish in color, rounded, and uniform in color or of cloudy appearance in cross-section (Sachsse 1991). The color of wood is an important aesthetic matter for customers of wood products. Thus, color changes in wood during drying and heat treatment are a matter of interest (Sehlstedt-Persson 2005). The main internal defects of beech logs that are not visible on the surface and have a significant impact on its quality are reaction wood and red false heartwood. The color and homogeneity of beech false heartwood, its stability during production process, and use of the products reduces their aesthetic properties. False heartwood also significantly reduces the liquid permeability of wood (Račko and Čunderlik 2010). Differentiation of anatomical features and differences in the color of wood determine the membership of a particular species to one of three groups of trees – with tinged heartwood, with discolored heartwood, and without heartwood – which under certain circumstances may generate the so-called red false heartwood. Major difficulties during the drying of beech wood are caused by the action of other factors, which may include defects in its construction, such as false heartwood and sapwood. The color of the false heartwood depends on the tree species and the intensity of the phenomenon that caused it (*e.g*., negative temperature). False heartwood in beech wood has coloration from light-pink to red-brown; the rings of wood are often dark (Hillis 1987).

Many authors have characterized the drying behavior of beech wood (Deliiski 2005; Bajraktari 2010). Apart from the physical differences between red heartwood and normal beech wood, they have different drying characteristics (Marinescu *et al.* 2010). The drying rate has a close relationship with three parameters – permeability coefficient, diffusion coefficient, and viscoelastic behaviour. These three factors play a noticeable role in the drying behavior of wood within the free water and bound water domains (Klement and Huráková 2015).

Wood treatment at high temperature is important because it decreases the time dependent effect, however it also decreases simultaneously and significantly the mechanical resistance of the wood such as *e.g.* strength properties (Teischinger 1992; Barański *et al.* 2014). The impact of drying process in the tangential direction can induce crack process in wood material and thus decrease wood quality (Moutou Pitti *et al.* 2013). In the production of furniture, in relation to the normal beech wood, false heartwood, and sapwood contributes to increase the amount of scrap. In addition, it prevents the production of light furniture (covered with a transparent lacquer coating).

This article presents the influence of high-temperature drying process in air-steam mixture on the properties change of beech wood having defects in the form of false heartwood and sapwood. The defects in forms such as reaction wood (called also as tension wood) did not occur in dried samples. The samples of tested wood were divided by orientation of growth rings (radial and tangential).

EXPERIMENTAL

The material used in the experiment was beech wood (*Fagus sylvatica* L.). Samples from a fresh wood logs with a length of 4.0 m were cut to 350 mm × 180 mm × 50 mm dimensions (Fig. 1).

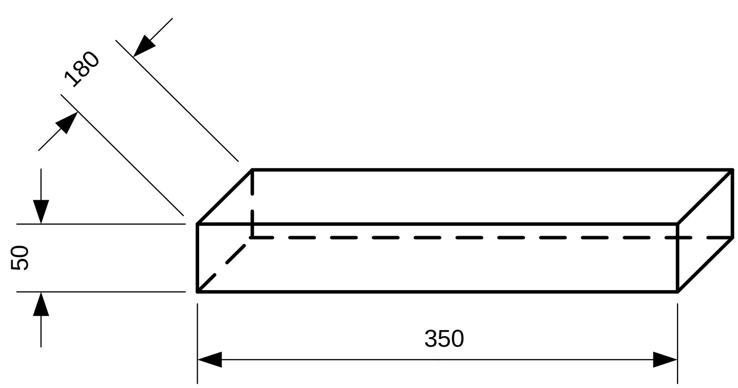

Fig. 1. The dimensions of sample prepared for drying

Samples were selected from forests called Včelien in Kremnica Hills (450 m.a.s.l.) belonging to the University forest holdings of the Technical University in Zvolen, Slovakia.

The drying experiments were performed in a laboratory convection drying kiln with a 1.1 m^3 load capacity. The superheated steam was produced by steam generator, which maintained a constant temperature and relative humidity inside the drying kiln. Steam circulation inside the experimental chamber was forced by fan. The speed of the drying medium could be changed up to 1.5 m/s. The temperature inside the drying chamber during experiments was changed from 100 °C to 120 °C. The system, which controls the drying process, is located outside the drying kiln. It contains six thermocouples to measure respectively temperature inside the kiln and temperature inside drying wood samples in three chosen locations. It consists also of the psychrometer, which is based on two thermometers with dry and wet bulbs. The temperature difference between these thermometers is used to determine the humidity inside the drying kiln during experiments.

The gravimetric method was used to determine moisture content. The specimens (Fig. 2) were taken from the middle of the drying samples. This method is more accurate than commonly used methods with moisture content sensors based on resistance. The experimental rig consisted of a balance to measure the weight of the sample during drying. Mass measurements were made with precision to 0.01 g. The drying of specimens to an absolute dry condition was done in the laboratory kiln at 103 ± 2 °C. Moisture content was calculated using Eq. 1,

$$MC\ (\%) = \frac{m_w - m_o}{m_o} \times 100 \tag{1}$$

where m_w is the weight of moisture specimen (g) and m_o is the weight of absolute dry specimen (g).

The moisture content of the wood samples was determined before and after drying. Figure 2 shows the method of moisture content measurements from the sample of tested wood, while Fig. 3 presents the view of the specimen, which was prepared for moisture gradients measurements.

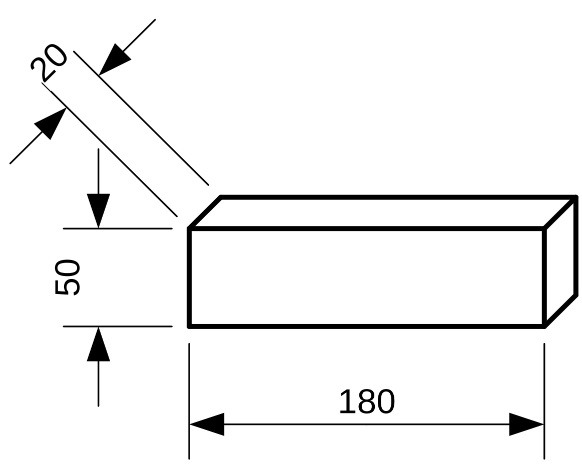

Fig. 2. Moisture content measurements using the gravimetric method

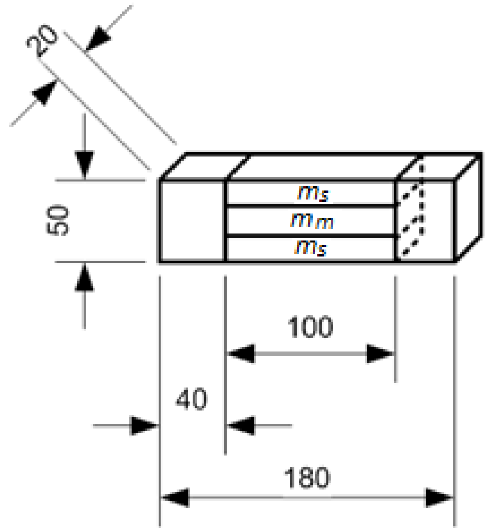

Fig. 3. The view of moisture gradients measuring scheme in wood sample before and after drying by using the gravimetric method

This sample was taken from the middle of drying samples and machined into three parts, two outer surface parts and one middle part. The moisture gradient (w) was calculated by Eq. 2,

$$w\ (\%) = m_m - m_s \tag{2}$$

where m_m is the moisture of middle layers (%) and m_s is the moisture of the surface layer (%).

Before the experiments, the value of fibre saturation point (FSP) and shrinkage coefficients of analyzed beech wood (*Fagus sylvatica* L.) were not measured. Only the initial moisture content and main dimensions of wood sample were measured.

For covering measure, the slicing test was applied. The measurements were performed before and after experiments for all specimens taken from sixteen samples. The size of these specimens was 180 mm x 50 mm x 20 mm. The covering was measured as a maximum space between two slices of the wood sample (Fig. 4).

In order to measure a change of color, the places of defect were determined and marked on the samples (Fig. 5). The changes of color were obtained as comparison of measured values of the parameters respectively L, a, and b before and after drying. The color difference was calculated using Eq. 3 (norm: STN EN 01 1718),

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \tag{3}$$

where L_1, a_1, and b_1 are the values of color spectra before drying process, and L_2, a_2, and b_2 are the values of color spectra after the drying process or milling process.

The parameters L, a, and b are coordinates of colorimetric space. The color change criteria are presented below,

$\Delta E < 0.2$: invisible color change
$2 > \Delta E > 0.2$: slight change of color
$3 > \Delta E > 2$: color change visible in high filter
$6 > \Delta E > 3$: a color change visible with the average quality of the filter,
$12 > \Delta E > 6$: high color change
$\Delta E > 12$: different color

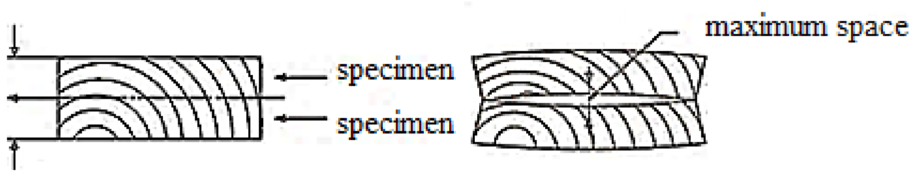

Fig. 4. The view of the samples of covering measure – slicing test (Cup test)

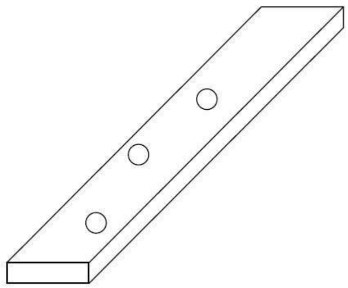

Fig. 5. The explanatory figure of the samples used to measuring color changes

RESULTS AND DISCUSSION

In general, the 16 samples of beech wood (*Fagus sylvatica* L.) were dried in four replicates. Half the number of dried samples had the defect of false red heartwood, respectively: four of them exhibited tangential growth rings, the rest of them exhibited radial growth rings. In the second part of the samples (also eight wood planks), the zone of sapwood and growth rings was the same as in the wood with false red heartwood. Changes in temperature, the wet and dry bulb thermometer variability, and the moisture content changes of wood during the experiment were determined (Fig. 6).

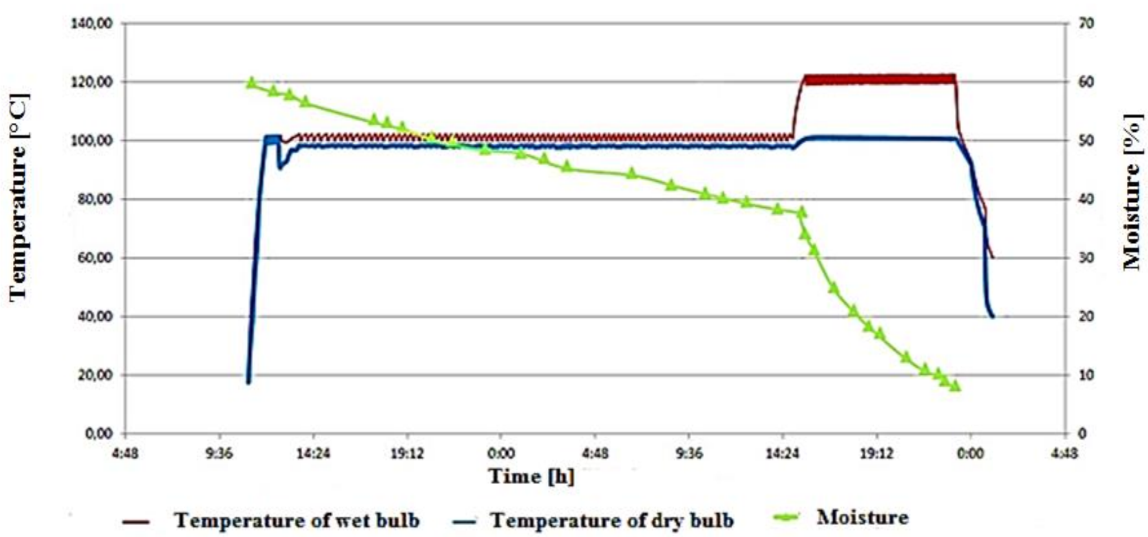

Fig. 6. Variable changes during high temperature drying

The drying time in the superheated steam at 100 °C was approximately 24 h at approximately 100% relative humidity. The samples were dried for 8 h in the air-steam mixture at 120 °C, and the relative humidity of the drying medium was 48%.

To analyze the quality of dried wood, the wood moisture content before and after drying was compared (Table 1). Figure 7 shows the result of the measurements of the covering before and after drying. The higher level of covering in the dried species that contained red heartwood may have resulted from the greater value of shrinkage in this kind of wood.

Table 1. Values of Wood Moisture Content in Different Zones of Wood

	Radial Red Heartwood	Tangential Red Heartwood	Radial Zone Sapwood	Tangential Zone Sapwood	Mean Moisture Content of Samples
Moisture content before drying	56.35%	53.2%	63.86%	70.96%	59.94%
Moisture content after drying	7.29%	17.58%	9.67%	11.84%	7.17%

Before and after drying experiments, the moisture gradient and quality degree for radial and tangential samples with red heartwood and with zone of sapwood of tested material were measured. Table 2 shows these values. Table 3 presents the values of covering-slicing test for the same type of beech samples. It shows the quality of the dried wood in terms of deformation.

Table 2. Values of Moisture Gradients

	Radial Red Heartwood	Tangential Red Heartwood	Radial Zone of Sapwood	Tangential Zone of Sapwood
Before drying	0.33 %	2.07 %	0.76 %	2.63 %
Quality degree	1	2	1	2
After drying	7.8 %	12.96 %	11.71 %	13.25 %
Quality degree	3	3	3	3

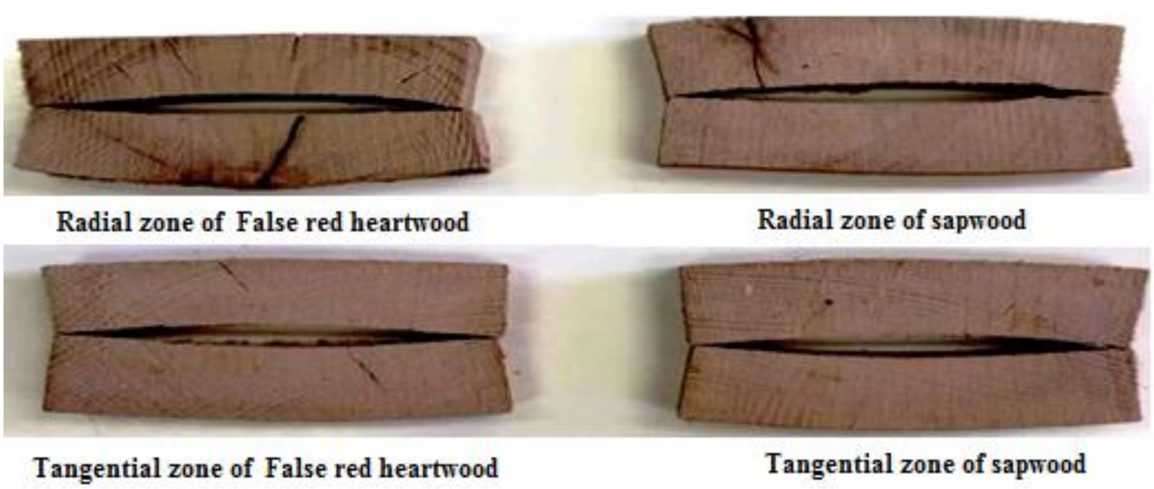

Fig. 7. Photos of the covering-slicing test after drying

Table 3. The Values of Covering – Slicing Test

	Radial Red Heartwood	Tangential Red Heartwood	Radial Zone of Sapwood	Tangential Zone of Sapwood
Before drying	1.06 mm	1.05 mm	0 mm	0 mm
Quality degree	2	2	1	1
After drying	8.58 mm	9.09 mm	9.13 mm	9.2 mm
Quality degree	-	-	-	-

Based on the results of this test, it can be stated that the drying process under high temperature conditions influences the internal stress of wood. The value of the gap dimension in the covering-slicing test was notable, and small differences between samples were apparent. The values of covering differed for sapwood zones and for red heartwood zones by only 0.62 mm. This means that after the high temperature drying process, the sapwood had higher internal stress than red heartwood.

Tables 4, 5, 6, and 7 show coordinates of color for specimens with different angle of growth rings and red false heartwood and sapwood content. The samples with content of red false heartwood exhibited important color changes in tangential samples, which were compared before and after drying. Color changes were more noticeable in sapwood than in red heartwood samples. This is because sapwood zone is much lighter than the heartwood zone and thus the color change of the red heartwood samples was weak after the high temperature drying process.

Table 4. The Color Difference (ΔE^*) of the Radial Red Heartwood of Dried Samples

Position	Before – After Drying	Before Drying – After Drying and Milling	After Drying – After Drying and Milling
1	12.4	9.0	3.6
2	13.9	5.4	8.5
3	13.8	9.4	4.7
Average of Positions 1-3	13.4	7.9	5.6

Table 5. The Color Difference (ΔE^*) of the Tangential Red Heartwood of Dried Samples

Position	Before – After Drying	Before Drying – After Drying and Milling	After Drying – After Drying and Milling
1	6.9	5.0	3.1
2	13.0	9.9	3.6
3	22.5	10.4	12.8
Average of Positions 1-3	14.1	8.4	6.5

Table 6. The Color Difference (Δ*E*) of the Radial Sapwood of Dried Samples

Position	Before – After Drying	Before Drying – After Drying and Milling	After Drying – After Drying and Milling
1	12.7	7.8	18.6
2	23.3	8.4	16.5
3	13.4	4.1	10.8
Average of Positions 1-3	16.5	6.8	15.3

Table 7. The Color Difference (Δ*E*) of the Tangential Sapwood of Dried Samples

Position	Before – After Drying	Before Drying – After Drying and Milling	After Drying – After Drying and Milling
1	12.2	13.9	16.7
2	16.6	14.5	17.3
3	15.9	10.5	17.5
Average of Positions 1-3	14.9	13.0	17.2

It is planned to conduct the experimental studies of drying process of the beech wood to examine the viscoelastic effects and the application of the method to other types of wood, as the spruce and the pine.

CONCLUSIONS

The more remarkable changes between the red heartwood and the sapwood can be explained by a different structure on the microscopic and submicroscopic level. The red heartwood has a higher content of cells with tyloses. These tyloses have remarkable influence on the final quality of dried timber, because they slow the drying process by lowering permeability of the red heartwood.

In this study, beech wood was dried for 36 h to a final moisture content of 8%. The temperature was evaluated on the cross section, and the final differences between the surface and the center of samples were uniform. The final value of the moisture gradient was pronounced after the drying process, and the specimens were passed to the third grade of quality. The measured values of the slicing test for heartwood and sapwood were identical, and the final results were passed to the third grade of quality. The higher occurrence of covering in the dried samples that contained red heartwood may have resulted from the higher amount of shrinkage in this kind of wood. Color changes were more noticeable in sapwood than in red heartwood. In all measurements, sapwood showed a larger color difference value than red heartwood.

Based on these findings it can be concluded that:

- The evaluated covering was more important in the red heartwood sample. The results are influenced by the structure of red heartwood.
- Color changes were not influenced by the thickness of samples. The color changes were more noticeable in sapwood samples that in red heartwood samples. The color changes can eliminated (removed) by milling process surface layer.

- The high temperature drying process did not result in reportable effects for samples containing red heartwood.

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