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Impact of high temperature drying process on beech wood containing tension wood

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Abstract: The technology of high temperature drying has a great influence on dimensional and selected physical changes in tension wood. Article is focused on the measurement properties such as moisture content, color changes and longitudinal warping. The quality of beech wood is determined based on structure and properties of wood, frequency of defects in wood material. The tension wood is considered as an important wood defect causing negative alterations in solid wood quality and limits industrial application of wood. The different values of longitudinal warping which were measured after drying were higher in tension wood than in normal wood. Impact of radial and tangential angle of growth rings is non-significant factor.

Keywords: reaction wood tension wood, normal wood, longitudinal warping, color difference

1 Introduction

Beech wood (*Fagus sylvatica* L.), is the most prevalent wood species in Slovakia and it is the most important wood material utilized for industrial processing [1–3]. Beech is wood with high frequency of defects such as red heartwood, reaction wood (tension wood), rot and so forth [4, 5]. Currently, due to the development of wood technology, it is necessary to respect the major limiting factors in manufacturing such as energy sources and sources of wood raw material. Considering the high proportion of beech wood, the way of its use is nowadays the subject of quality. Tension wood is thought of as an important wood defect because it causes negative alterations in solid wood quality and limits industrial utilization of wood [4, 18]. Findings confirmed 14–21% ratio of tension wood in beech logs [6]. Timber with content of tension wood has high longitudinal warping which affect their quality noticeably. The dominant cause of these defects is often correlated to the excessive longitudinal shrinkage of reaction wood, which is caused by the shrinkage of the G-layer in tension wood [7–9]. Tension wood affects the technological properties of wooden materials because it has got different physical, anatomical, and chemical features in comparison with normal wood. In fact, the difference in the drying rate curves of reaction and opposite wood gradually decreases when drying process progresses to the bound water domain. The analysis of both mass diffusivity and density in beech tends to prove that the diffusion of bound water is relatively easy in tension wood. This is perfectly consistent with the structure of the G-layer [10]. It was demonstrated that difference in drying rate of tension and normal wood depends on moisture content [11, 12].

The drying process of the sample is more intensive in wood with moisture content above fiber saturation point. Under these conditions the water evaporation intensity is comparable with normal wood. Therefore, the recommendation is that the direct visual detection of reaction wood should be carried out before drying at green condition. The thick cell walls of the compression wood, rich in lignin, and the presence of G-layer in the tension wood, rich in cellulose, can explain some differences observed in the colorimetric variables between the reaction wood and their corresponding parameters in the normal wood [12]. However, since the lightness of tension wood plays a key role for its visual detection, it may be adequate to only measure the lightness (L). In contrast, for the accurate detection of compression wood the a and b parameters should be also considered. The color change of the reaction wood

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may be temperature-dependent; thus, study on the effect of different drying conditions on the reaction wood color change is recommended for further research [10]. There are few reports on which color measurement was made on the wide variation of wood species using the CIELAB color system, and relations among the values of the color system [10, 13]. The aim of presented article was to analyses influence of high temperature to selected properties of beech wood with content of tension wood (*Fagus sylvatica* L.). Better understanding of tension wood in drying process or industry may have positive effect on quality of final products.

2 Materials and Methods

Beech wood (*Fagus sylvatica* L.) was used for experimental measurements. Samples were chosen from two beech logs with diameter 40 cm and length 4 m. Beech logs were selected from forests called Včelien in Kremnica Hills (450 m.a.s.l.) belonging to University Forest Enterprise of the Technical University in Zvolen, Slovakia. The choices of logs were qualified without visible defects such as red heartwood, rot, incipient fungal attack, etc., which could affect measurements noticeably. Shiny appearance is characteristic, which determines content of the tension wood in logs [14]. When using this method, it is necessary to brush surface of disks and then tension wood on the surface of lumber is more clearly visible after drying process in laboratory kiln. Based on this zone we prepared sawing pattern of samples from logs. Samples of normal (NW) and tension wood (TW) with a thickness of approximately 20 mm, width of 50 mm and length 650 mm were obtained. Tested samples of wood were divided by growth rings orientation (R -radial and T- tangential). The total number of samples in the laboratory kiln were sixteen. Measurements of moisture content were performed in the all samples. The total number of measurements was 16 for the longitudinal warping and 48 for the color changes respectively. Measurements were carried out on all the samples, before and after drying process, respectively. Selected drying mode has been used in industry. After the company contacted us, we implemented this mode into laboratory conditions. (*Selection of TW and NW samples were accurate to verify the behavior of reaction and normal wood under the drying conditions, because company had big problems in drying of different qualities of beech wood. Therefore, we used only one drying mode/drying scheme.*) The process of high temperature drying was conducted in a laboratory kiln at the Department of Wood Technology, Technical University in Zvolen, Slovakia. Electrical coils were used for the heating in the drying kiln. The flowing air, as the drying medium, was moisturized by the saturated steam. During the experimental measurements the two-stage mode of the drying process has been chosen.

The temperature of dry bulb (t_d) was set at 100°C and maintained in the first phase of drying process until the moisture content in the samples did not decrease below the fiber saturation point. In turn temperature of wet bulb (t_w) was set at 98 ± 0.5°C.

After decreasing the moisture content below the fiber saturation point (FSP) the temperature of dry bulb was increased up to 120°C without regulation of t_w.

The average final moisture content was 8–9%. The last stage of the drying process was cooling of wood. The air velocity was set at 3 ± 0.3 m·s^{-1}.

The moisture content was measured using gravimetric method according to STN EN 49 0103 [**?**]. Moisture content was calculated using equation (1):

$$MC = \frac{m_w - m_0}{m_0} \cdot 100 \qquad (1)$$

where: m_w is the weight of the wet sample (g) and m_0 is the weight of the absolutely dry sample (g).

The longitudinal warping was evaluated by measuring the maximum space distance between the analyzed samples (Figure 1).

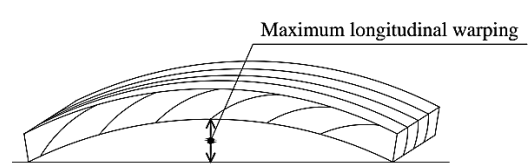

Figure 1: Method of measure longitudinal warping

The color space of the dried material was determined using Konica Minolta Color Reader type CR10. It describes the output coordinates *L, a, b* by the color change in the color space (Figure **??**) using the equation (2). The color changes were obtained as comparison of measured values of the parameters respectively *L, a, b* before and after drying, and 3 mm under the surface after drying process.

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

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

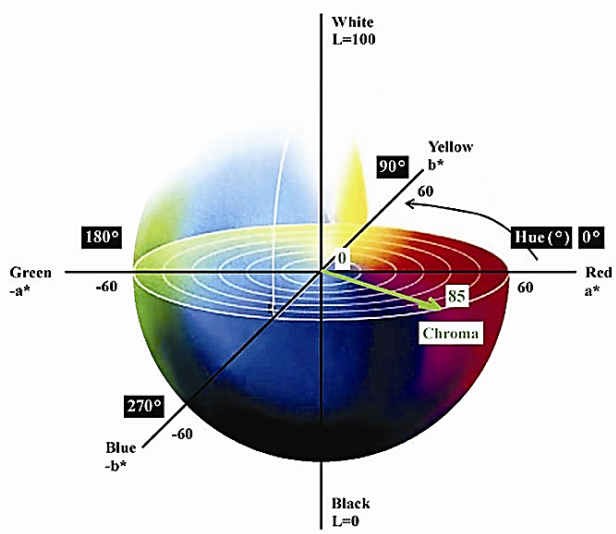

Figure 2: The color expressed in the picture consists of color coordinates [16]

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For the purpose of this were used color change criteria Δ**E** < **0.2** - *invisible color change*; **2** > Δ**E** > **0.2** - *slight change of color*; **3** > Δ**E** > **2** - *color change visible in high filter*; **6** > Δ**E** > **3** - *color changes visible with the average quality of the filter*; **12** > Δ**E** > **6** - *high color change*; Δ**E** > **12** - *different color* (Cividini *et al.* 2007).

3 Results and Discusion

The courses of temperature and MC changes are shown in the Figure 3. In the first stage of process, temperature of the drying air was maintained at approximately 100°C until the moisture content of the samples did not decrease below the fiber saturation point (FSP) this time was about 20 hours. Then, the temperature (t_d) was increased to the maximum value of 120°C. The final moisture content was 10% after achieving this step. The last stage of process was cooling, which lasted for 3 hours. The total drying time was 28 hours.

The average values of initial and final moisture content, drying time and longitudinal warping are shown in Table 1. The differences of initial moisture content in the radial and tangential samples containing tension and normal wood could be caused by different structure of samples and sample location in a wood log during machining too. The values of initial moisture in the radial and tangential samples were higher in the samples with content of the tension wood, which is in agreement with the results of authors [11]. Subsequently, it can be said that the drying processes of samples with tension and normal wood content were balanced and have not been influenced by variability of initial moisture and angle of growth rings as well.

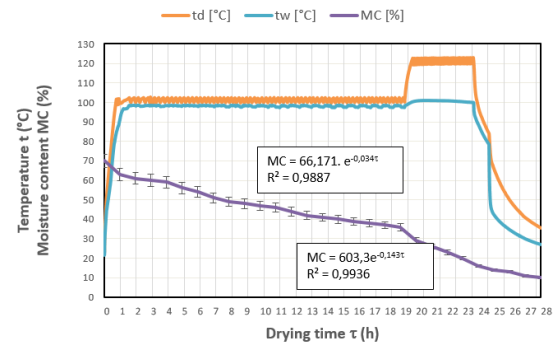

Figure 3: Temperatures and MC in drying process

Table 1: Moisture content and drying time tension and normal samples

Samples		Moisture content (%)		Drying Time (h)	Longitudinal warping (mm)	
		Before drying	After drying		Before drying	After drying
TW	Radial	74.49	8.78	28	**1.14**	**6.87**
	Tangential	76.88	8.85		**1.78**	**4.54**
NW	Radial	61.01	9.01		0.66	2.95
	Tangential	73.2	8.76		0.65	2.34

Based on the work of [15] results shown that bound water diffusion is relatively easy in G-layer of tension wood. The first explanation of it could be chemical composition of this layer, which consists mostly of cellulose.

Another possible explanation would involve the nanostructure of the G-layer, which contains mesopores producing an easy way for bound water migration [17].

The final moisture content confirmed presented results that the variability of initial moisture content does not influence on the final moisture, even when using high temperature drying process.

The values of longitudinal warping before and after drying process are shown in Table 1. The values of longitudinal warping between tension and normal wood are less noticeable. The different values of longitudinal warping which were measured after drying were higher in tension wood than in normal wood. The final values of longitudinal warping between tension and normal wood are not considered noticeable in industry and all of these samples can be processed. The present observations are consistent with those of Sujan *et al.* 2015 [15]. tension wood, when was kiln-dried, is likely to deform hugely, which is probably

caused by a gelatinous layer of the gelatinous fiber. This fact can be explained by the value of longitudinal warping tension wood has greater values of shrinkage in longitudinal direction. The analysis of the physical properties confirmed that the main impact of deformation with content of tension wood has 6 times higher longitudinal shrinkage than normal wood [12]. Figures 4 and 5 show color coordinates for samples with different angle of growth rings. Differences were calculated by colorimetric coordinates respectively *L*, *a*, and *b* before/after drying and before drying/ after milling process.

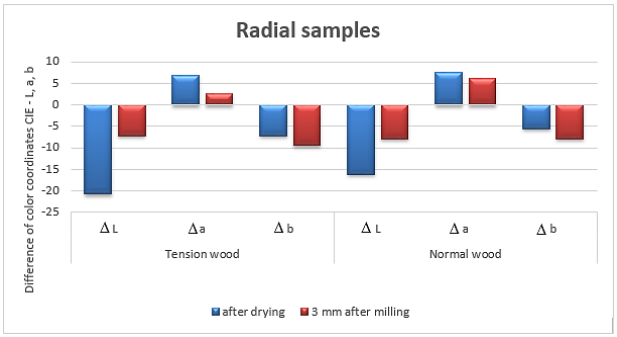

Figure 4: Difference of color coordinates *L*, *a*, *b* of the radial test samples

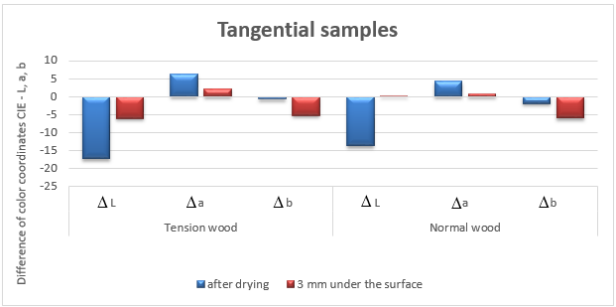

Figure 5: Difference of color coordinates *L*, *a*, *b* of the tangential test samples

These colorimetric coordinates indicate differences between tension and normal wood. Differences were calculated from the value of 0, which in this case is the coordinate value before the drying process. Considerable changes occurred in the *L* colorimetric coordinate, which measures lightness.

Differences are visible after the drying process and 3 mm under the surface as well. Darker color was more noticeable in tension wood than in normal wood. Other color coordinates *a* and *b* have not noticeable changes between tension and normal wood and radial and tangential either. Heterogenity in the wood anatomical structure may effect on its color. One of these heterogeneities is tension wood [9].

However, many researchers have also indicated that the tension wood has a shiny appearance and its color is much lighter than normal wood. The higher lightness of tension wood can be explained by the presence of gelatinous layer (G-layer), which is rich on cellulose [10].

Table 2: Values of the color difference *Δ*E

Samples		ΔE (-)			
		Before/ after drying	Color change criteria	Before drying/ after milling	Color change criteria
TW	Radial	23.00	Different color	12.25	High color change
	Tangential	18.40		8.38	High color change
NW	Radial	18.76		12.77	High color change
	Tangential	14.46		6.00	Color changes visible with the average quality of the filter

On the other hand, the greatest difference was found in the *Δ*E (Table 2). Color difference was higher before drying process, where was more pronounced in tension wood. Subsequently, color differences 3 mm under the surface were lower values in a both test samples, tension and normal wood. However, in all measurements the color difference *Δ*E was > 12, which means high color change in the all samples. Expect one tangential normal sample, which has 6 > *Δ*E > 3. It means color changes visible with the average quality of the filter.

These differences between TW and NW samples with varying inclinations of annual circles may be due to the drawing of annual circles on the measured area. Table 3 shows average values and basic statistical characteristics of color parameters *L*, *a*, *b* before/ after drying and before/ after milling process (3 mm). The calculated values of the standard deviation and sample variance confirm the small variance of the measured values of the coordinates of the color space from the average value. For each sample, 30 measurements of coordinates *L*, *a*, *b* were made.

Based on the article Klement *et al.* [19] overall, the differences in the colorimetric variables between the reaction wood and the NW were less remarkable under the dry condition. Drying may interfere with the accurate visual differentiation of the reaction wood from the NW. These findings are relevant with our research.

Table 3: Basic statistical characteristic of color coordinates

Samples		Color coordinates	Before drying			After drying			After milling			Count
			Mean	Standard Deviation	Sample Variance	Mean	Standard Deviation	Sample Variance	Mean	Standard Deviation	Sample Variance	
TW	R	*L*	**68.7**	1.503	2.259	**48.0**	3.277	1.737	**61.5**	0.230	0.053	30
		a	**9.4**	0.747	0.558	**16.3**	0.610	0.372	**12.0**	0.223	0.050	30
		b	**28.3**	0.361	0.130	**21.1**	0.946	0.896	**18.8**	0.425	0.180	30
	T	*L*	**67.7**	1.842	3.393	**50.4**	0.587	0.344	**61.6**	0.569	0.324	30
		a	**9.7**	0.669	0.448	**16.0**	0.541	0.293	**12.0**	0.348	0.121	30
		b	**23.1**	1.129	1.275	**22.4**	0.158	0.025	**17.8**	0.149	0.022	30
NW	R	*L*	**69.6**	0.533	0.284	**53.4**	1.373	1.886	**61.7**	1.306	1.705	30
		a	**5.9**	0.507	0.257	**13.5**	0.567	0.322	**12.2**	0.562	0.316	30
		b	**26.7**	0.706	0.498	**21.1**	0.083	0.007	**18.8**	0.074	0.006	30
	T	*L*	**65.2**	0.816	0.666	**51.5**	1.202	1.444	**65.5**	0.117	0.014	30
		a	**10.7**	0.422	0.178	**15.0**	0.446	0.199	**11.6**	0.126	0.016	30
		b	**24.6**	0.501	0.251	**22.6**	0.620	0.385	**18.7**	0.117	0.014	30

4 Conclusions

The quality of beech wood is determined based on structure and properties of wood, frequency of defects in this material. Based on the experimental measurements, we can conclude:

- Variability of initial moisture of tension wood was not conspicuous and therefore, has got not remarkable impact on the final drying time of the process.
- The different values of longitudinal warping which were measured after drying were higher in tension wood than in normal wood. The final values of longitudinal warping between tension and normal wood are not considered noticeable in industry and all of these samples can be processed. Impact of radial and tangential angle of growth rings is non-significant factor
- Color difference was higher before drying process, where was more pronounced in tension wood. Color change, which occurred in comparison between tension and normal samples, was always higher on tension samples. The most important color change occurred in the coordinate of the color space *L*.
- Finally, it can be said that the properties of the samples with content of the tension wood are depended on the distribution and ratio in materials.

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Norms:

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