Transverse Anisotropy and Dimensional Stability of Thermal Treated Beech Red Heartwood

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Abstract: **This research is mainly focused on the impact of thermal modification on the transverse anisotropy and dimensional stability of native beech wood (Fagus sylvatica L.) and beech red heartwood. Applied to two time-temperature regimes, the first period of maximum temperature to 180° C and the second to 230° C. The factor of anisotropy in native beech wood is 1.29 and beech red heartwood is 1:24. Dimensional stability of the native beech wood is improved for 33.3% and beech red heartwood for 29.1%. The changing of the volume mass per thermal modification of 6% is too small and does not affect other properties.**

Keywords: **native beech wood, beech red heartwood, thermal modification, transverse anisotropy, dimensional stability.**

1. Introduction

The beech is typical sapwood, of diffuse porous wood species. The beech characteristic appearance is the change of the color and texture called beech red heartwood. The phenomenon is caused by interruption of the water flow in timber and reducing the vitality parenchyma tissue [1], reduction of physiological characteristics [2], decomposition of the soluble carbohydrates [3], whereby the substances are transformed into heartwood substances [4]. It is initiated the penetration of the oxygen through the building elements to central part of the older stems, where the percentage of water is small, and so the vitality is reduced [5].The oxygen in the live parenchyma tissue causes the transformation of carbohydrates into phenolic substances [6].

Anisotropy is characteristic for the wood and it is a difference of properties in different directions of the tree growing [7]. The radial shrank is usually 1.5 to 2 times less than the tangential one. It is explained by the uneven distribution of the zone of late wood in relation to the area of early tree tangential section. Dimensional anisotropy is strongly expressed in the longitudinal and transverse wood fibers in tangential and radial direction - transversal plane [8]. With high temperature treatment (160 to 240 ° C), the properties are changed. With reduction of the volume and weight, the wood decomposes which results in changes in the chemical composition of the cell wall. According to some literature data, the wood thermal modification does not affect the transverse anisotropy [9]. According to other authors, when you take into consideration the degradation of the hemicelluloses and wood material in general, the thermally modified wood has possibility for anisotropy changes [10], [11]. Specifically, after thermal modification is decreasing swelling in tangential direction, the swelling in the radial direction [12], leading to reduced anisotropy.

Dimensional stability is a constant problem with the wood products. Therefore, it is a subject of interest for many researchers. The wood dimensions change proportionally to the number of absorbed water molecules in the wood cell walls, which is associated with the free reactive OH groups. It is thought that most of the hydroxyl groups that are available for formation of hydrogen bonds are in hemicelluloses [13], [11]. Dimensional stability is in direct dependence with the mass reduction in other words the maximum values for the dimensional stability are obtained when the wood loses 20% of its

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weight [14]. The decomposition of the hemicelluloses [15], [16], [17] also results in lower wood power for water absorption, which improves the dimensional stability [18].

This research is focused on the transversal anisotropy and dimensional stability as well as the changes of these properties after treatment of the native beech wood and beech wood affected as red heartwood, with high temperature. Case study are: volume mass, volume swelling and volume shrinking, which determines anisotropy and dimensional stability before and after thermal modification 180°C and 230°C.The target of this paperwork is to contribute to the defining of the properties, the property changes and the intensity of the differences that occur in the tested samples.

2. Method of operation

2.2. Material testing

Test pieces of beech wood, grouped into six groups, three with native beech wood and three with beech wood affected by red heartwood were examined (Fagus Sylvatica L.). The material has been prepared in accordance to standard [ISO 3133:1975], with dimensions of the tested piece 20x20x300 mm, of which subsequently were extracted sample pieces with 20x20x30 mm.

The thermal modification was performed as an oxidative process. It was used as a chamber with an opening through which side products were removed (acetic acid, furfural, etc.). Two time-temperature regimes were used, the first one with period of maximum temperature of 180 °C and the second up to 230 °C. Figure 1 shows the applied regimes.

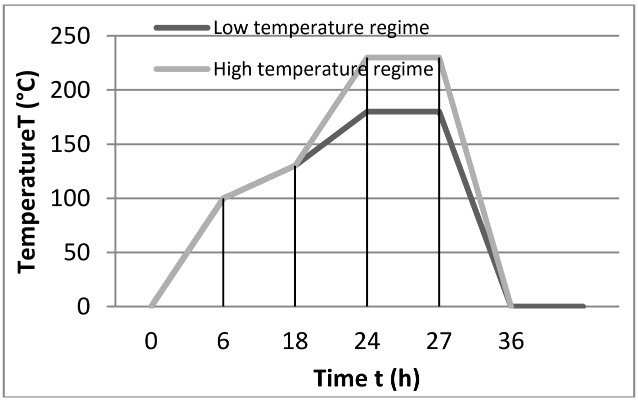

Fig. 1. Graphic mode thermal modification

The determination of the volume mass is in accordance with [ISO 3131:1975]

$$\rho_0 = \frac{m_0}{V_0} \text{ [g/cm}^3\text{]}$$

ρ_0 - volume mass in absolute dry state [g / cm3]
m_0 - mass of the sample in absolute dry condition [g]
V_0 - volume of the sample in absolute dry state [cm]

The volume shrinking and volume swelling are determined according to [ISO 4860:1982] and [ISO 4858:1982] and are calculated according to the formulas:

$$\alpha_V = \frac{V - v}{V} \cdot 100 \qquad \text{and} \qquad \beta_V = \frac{V - v}{v} \cdot 100$$

α_V - shrank volume [%]
β_V - volume of wood swelling [%]
V - volume of the sample supply [cm3]
v –volume of the sample after drying [cm3]

The transverse anisotropy (A) is defined as a ratio of tangential and radial shrinkage.

$$A = \frac{\alpha t}{\alpha r}$$

A - factor anisotropy
αt - tangential shrinkage [%]
αr - radial shrinkage [%]

The dimensional stability of the wood is expressed in percentage as improving the dimensional stability or "Anti Swelling Efficiency" - ASE (%), [19] Stamm 1964.

$$\text{ASE (\%)} = \frac{\beta vu - \beta vm}{\beta vu} \text{ x } 100 \qquad \text{where:}$$

β_{vu} -volume swelling control test piece [%]

β_{vm} - volume swelling of the treated test piece [%].

3. Results and Discussion

3.1. Volume mass in absolutely dry condition

The statistical values of the examination of the volume mass in absolutely dry conditions are shown in Table 1. The native beech wood (C) has got an identical volume mass with beech red heartwood (L). The same is the mass of the native beech wood and beech red heartwood modified by heat at 180 ° C (B180 and L180). After heat treatment at 230 ° C, the native beech wood (B230) has got a lower volume mass for 6% comparing to the wood affected by red heartwood (L230), has got significant difference.

The native beech after modification at 230 ° C (B230) has got significantly reduced volume and weight comparing to the native beech (B), while the beech with red heart after modification of 180°C and 230°C does not change the volume weight significantly (L180 and L230). This brings us to conclusion that after the thermal modification at 180°C and 230°C, the native beech wood is undergoing significant changes, which occur in the beech wood affected by red heart.

Table 1.Volume mass of the wood in absolute dry condition

No	Tested group	$\bar{x}$ (g/cm^3)	σ (g/cm^3)	Difference from the average values (g/cm^3)	Percentage difference from the average values (%)	Statistical significance t > < 2.58
1	2	3	4	5	6	7
2	B L	0.66 0.68	0.045 0.034	0.02	2.9	1.82
3	B_{180} L_{180}	0.65 0.67	0.046 0.023	0.02	2.9	2.02
4	B_{230} L_{230}	0.62 0.66	0.051 0.028	0.04	6	3.51
5	B B_{180}	0.66 0.65	0.045 0.046	0.01	1.5	0.86
6	B_{180} B_{230}	0.65 0.62	0.046 0.051	0.03	4.6	2.33
7	B B_{230}	0.66 0.62	0.045 0.051	0.04	6	3.2
8	L L_{180}	0.68 0.67	0.034 0.023	0.01	1.4	1.10
9	L_{180} L_{230}	0.67 0.66	0.023 0.028	0.01	1.4	1.26
10	L L_{230}	0.68 0.66	0.034 0.028	0.02	2.9	2.05

3.2. Volume shrinkage

According to the statistical values shown in Table 2., in the native beech wood and beech affected by red heart before and after heat treatment at 180°C and 230°C, there aren't significant difference in the shrinkage and the intensity of the shrinkage.

After the thermal treatment at 180°C shrinkage at the native beech was reduced to 17.7%, and 16.2% with the red heart. By raising the temperature to 230 ° C, the tendency of shrinkage reducing continued, with the native beech for 27.4% and with the red heartwood for 24.8%.

Generally, after the thermal treatment of the native beech wood and the one affected by red heart, there is shrinkage decrease. The decrease of the wood shrinkage with the same heat treatment regime was significantly greater with the red heart than with the native beech wood. The trend of the obtained results matches, but the values are smaller than those from the reference data [20] and other authors, according to which the shrinkage is reduced from 30% to 80 %.

Table 2. Volume shrinkage of the wood (α_v)

No	Tasted group	$\bar{x}$ (%)	σ (%)	Difference from the average values (%)	Percentage difference from the average values (%)	Statistical significance t > < 2.58
1	2	3	4	5	6	7
2	B L	19.7 19.7	2.28 2.15	0	0	0
3	B_{180} L_{180}	16.2 16.5	3.39 1.75	0.3	1.8	0.54
4	B_{230} L_{230}	14.3 14.8	4.06 3.52	0.5	3.3	0.41
5	B B_{180}	19.7 16.2	2.28 3.39	3.5	17.7	4.64
6	B_{180} B_{230}	16.2 14.3	3.39 4.06	1.9	11.7	1.83
7	B B_{230}	19.7 14.3	2.28 4.06	5.4	27.4	5.82
8	L L_{180}	19.7 16.5	2.15 1.75	3.2	16.2	5.08
9	L_{180} L_{230}	16.5 14.8	1.75 3.52	1.7	10.3	1.77
10	L L_{230}	19.7 14.8	2.15 3.52	4.9	24.8	4.86

3.3. Volume swelling

According to the values shown in Table 3, the swelling volume of native beech wood and the wood affected by red heart is equally undergoing the same intensity of changes after heat treatment at 180°C and 230°C.

The thermal modification of native beech and the beech affected by red heart has got the same impact on the swelling volume. The swelling is significantly reduced after treatment at 180°C, with the native beech at 22.7% and with the red heartwood of 19.8%. Also, by treating at a temperature of 230°C, there is no significant difference in the intensity reduction of the native beech and the beech affected by red heart swelling and for the native beech it is 33.3%, and for the red heartwood it is 29.1%.

According to the literature [21], [22] the swelling of the beech wood is reduced by 50% to 80%, and according to [20], the wood swelling is reduced by 30% to 80%. The results from these researchers are with decreasing trend, but with lower intensity than quoted.

Table 3. Volume swelling of the wood (β_v)

No	Tasted group	$\bar{x}$ (%)	σ (%)	Difference from the average values (%)	Percentage difference from the average values (%)	Statistical significance t > < 2.58
1	2	3	4	5	6	7
2	B L	24,6 24,7	3,80 3,35	0,1	0	0,10
3	B_{180} L_{180}	19,0 19,8	4,01 2,49	0,8	4	0,86
4	B_{230} L_{230}	16,4 17,5	4,93 4,83	1,1	6,3	0,69
5	B B_{180}	24,6 19,0	3,80 4,01	5,6	22,7	5,54
6	B_{180} B_{230}	19,0 16,4	4,01 4,93	2,6	13,7	2,05
7	B B_{230}	24,6 16,4	3,80 4,93	8,2	33,3	6,65
8	L L_{180}	24,7 19,8	3,35 2,49	4,9	19,8	5,16
9	L_{180} L_{230}	19,8 17,5	2,49 4,83	2,3	11,6	1,73
10	L L_{230}	24,7 17,5	3,35 4,83	7,2	29,1	5,03

3.4. Transverse anisotropy

Anisotropy factors are shown in Table 5. If we compare the factors in native beech and beech affected by red heart, the anisotropy is higher in native beech. However, after heat treatment at 180 ° C and 230 ° C, the anisotropy factor in native beech is more intensively reduced and is lower than the red heartwood. The differences in transverse anisotropy in native beech wood and red heartwood before and after modification are negligible and it can be concluded that the thermal modification reduces anisotropy.

The obtained results do not match some of the quoted authors according to whom the wood thermal modification does not affect the transverse anisotropy [9]. In this experimental study the anisotropy percentage reduction is 38%, which leads to the conclusion that the thermal modification reduces the wood anisotropy. In addition, it is the literature data that after the thermal modification there is decreasing of the swelling in tangential direction comparing to the one in radial direction [12], that leads to anisotropy reduction.

Transverse anisotropy is inversely proportional to the volume mass of the wood type [23], in other words, wood types with small volume mass have a higher anisotropy factor. In this study, with increasing of the heat treatment temperature,there is reduction of the wood volume mass and at the same time there is anisotropy reduction which is stronger in native beech wood.

Table 4: Transversal anisotropy (A)

No	Tasted group	Radial shrinkage - α_r (%)	Tangential shrinkage - α_t(%)	Transversal anisotropy – A
1	2	3	4	5
2	B	8.64	11.17	1.29
3	B_{180}	8.28	8.11	0.98
4	B_{230}	7.69	6.16	0.80
5	L	8.81	10.95	1.24
6	L_{180}	7.90	8.77	1.11
7	L_{230}	7.39	6.51	0.88

3.5. Dimensional wood stability

The percentage improvement of the dimensional wood stability is shown in graphic 2. After thermal treatment at 180 °C and 230 °C, the improvement of the dimensional native beech wood stability is 22.7% and 33.3%, while in the red heartwood it is 19.8% and 29.1%. The improvement of the dimensional stability is more intensive in the native beech than in the one with red heart, after treatment at 180 ° C of 6.4% after the treatment at 230 ° C of 4.2%.

The dimensional wood stability according to other authors [14], [24], [25], ranges from about 35% to 50%, which is greater improvement than the obtained in this research.

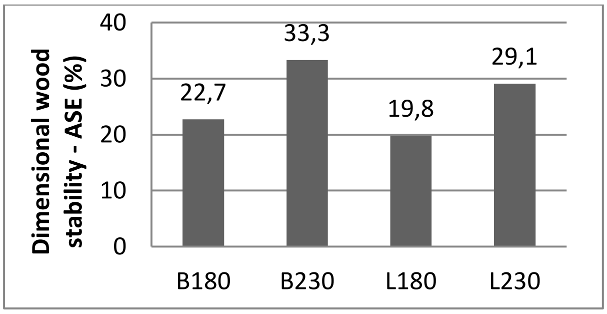

Fig 2. Graphical display of dimensional wood stability

4. Conclusions

Based on the presented results of the studies on the impact of thermal modification on some physical properties, transverse anisotropy and dimensional native beech wood stability and wood affected by red heartwood, the following conclusions can be stated:

- The thermal treatment at 180 °C does not cause significant changes of the volumetric mass, and after 230 ° C, the native beech wood volumetric mass is reduced by 6% in relation to the initial in terms of thermal treated beech red heartwood. This difference in the volumetric mass is significant, but it is small compared to the results in other properties' differences.
- The thermal treatment has got significant impact on collection and the native beech wood swelling and the beech red hat wood. The shrinkage and the swelling are significantly reduced after the treatment at 180 ° C for about 20%, and after the treatment at 230 ° C for about 30%. The decreasing trend coincides with the reference data, but the values are smaller than the reference data.
- Transverse anisotropy after the thermal treatment decreases with equal intensity in both native beech wood and the one affected by red heart. After the treatment at 230 °C, the transverse anisotropy is reduced by 38%.
- It's reached a percentage improvement of the dimensional stability which is greater in native beech than in the one with red heart. The improvement of the dimensional stability after the thermal treatment of the beech wood is smaller than the reference data.

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