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Effect of Heat Treatment on Sorption Properties and Dimensional Stability of Wood

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This research was performed in order to determine how the heating process affects sorption properties and dimensional and shape stability of oak, lime and birch wood. By subjecting specimens to 3 hours heating at 130, 160, 190 and 220 ºC temperatures, a decrease in volume, density and mass was observed in proportion to the applied temperature. It was established that when oak wood specimens underwent heating at 220 ºC temperature, the decline of mass was 1.2 times higher than in the case of birch specimens. Both heated and unheated specimens underwent moistening in air at 25 ºC ±1 ºC temperature for 3 weeks with relative humidity being 85 % ±1 % and were soaked in water at room temperature for 4 hours. It was found that after applying high temperature heating, specimens absorbed smaller amounts of moisture. It was demonstrated that during the soaking process, the volume of unheated specimens was 3 times higher than in the case of specimens heated at 220 ºC temperature. The change in the volume of unheated oak was 1.27 times smaller than in the case of lime specimens and 1.16 times larger than in the case of birch specimens, which underwent heating at 220 ºC temperature. In addition, specimens that were exposed to heat had more stable measurements and shapes. It was noticed that the heating process caused significant changes in moisture and dimensional stability of specimens, when higher temperatures ranging from 190 ºC to 220 ºC were used.

Keywords: heat-treated wood, swelling, sorption, dimensional stability.

INTRODUCTION

Wood is a natural, eco-friendly and renewable raw material, which is widely used due to simple processing and excellent physical and aesthetical properties. These properties allow incorporating wood into lightweight constructions and using it for the replacement of metal parts in separate cases. Furthermore, wood shows good thermal resistance and relationship between weight and strength. However, in addition to such advantages there are many disadvantages: moisture leads to dimensional changes in wood, wood shows poor fungus and pest resistance [1 – 2].

In order to enhance durability and dimensional stability of wood without any chemicals, a number of methods were tried out over the last decades. One of such methods is thermal treatment of wood, which involves the use of only three components: water, vapour and high temperature. Therefore, heating turns out to be an environmentally friendly method ensuring protection of wood from various factors and gaining world wide popularity [3 – 6].

Temperatures above 150 ºC cause irreversible changes in mechanical and chemical properties of wood. Heat treatment darkens the colour of the wood. It reduces the shrinkage and swelling of the wood and improves the equilibrium moisture content of the wood. The higher the heating temperature, the better biological resistance of wood, which is followed, however, by a significant deterioration in mechanical properties: wood loses rigidity and bending and tensile strength (10 % – 30 %). Exposure to heat also leads to a decrease in wood weight: the longer the heating period and the higher the temperature, the more considerable decline in weight [7 – 10].

Wood cell walls consist mainly of cellulose, hemicellulose and lignin. Each such polymer contains hydroxyl groups that play an important role in the interaction between wood and water. When wood undergoes moistening, water molecules arrange themselves between wood polymers and form hydrogen bonds between hydroxyl groups and separate water molecules. As water molecules occupy space between polymers during the moistening process, wood begins to swell. The heating process affects polymers of wood cell walls, which results in the decreased number of free OH groups and breaking of polymer chains. A reduction in the amount of free OH groups leads to the restricted interaction between wood and water. During the heating process, the number of hydrophilic hydroxyl groups begins to decline, since hydroxyl groups are replaced with hydrophilic oxygen-acetyl groups [11 – 12].

When wood is subjected to heating, property changes occur depending on the heating method, wood species and properties, initial wood moisture content, heating duration and temperature. The heating temperature has a considerably greater effect on wood properties than the heating duration. There are noticeable differences between results obtained during the heating that occurs at lower temperatures and lasts for a longer period of time and during the heating that occurs at higher temperatures and lasts for a shorter period of time [13 – 14].

The purpose of the present research is to establish how the heating process affects sorption properties and dimensional stability of oak, lime and birch wood.

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MATERIALS AND METHODOLOGY

Tests involved oak, birch and lime specimens with the following dimensions: (200×30×30) mm. Speciments were cut out using planed scantlings with measurements (1300×30×30) mm. Figure 1 shows the scheme of scantling cutting. 5 groups of specimens were prepared, each containing 20pcs. One group of specimens was not heated, meanwhile, other groups of specimens underwent 3 hour heating at 130, 160, 190 and 220 ºC temperatures, respectively, under atmospheric pressure. The weighing method was used for determining the moisture content of specimens [15].

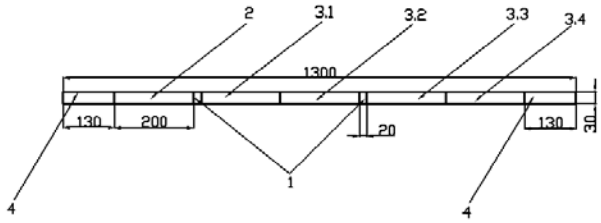

Fig. 1. Scantling cutting scheme: 1 – moisture sections; 2 – unheated specimen; 3.1, 3.2, 3.3, 3.4 – specimens heated at 130; 160; 190; 220 °C temperatures, respectively; 4 – removed ends

When specimens have an excessive MC (>10 %), wood can develop cracks during the heating process and uneven colour after the heating [16]. In order to prevent this, all the specimens were placed in the conditioning chamber before heating and kept at 25 ºC ±1 ºC temperature and under 35 % ±1 % relative humidity. When the heating process was finished, specimens underwent measurement of dimensions (length with 0.05 mm accuracy and width and thickness with 0.01 mm accuracy) and mass (with 0.01 g accuracy). In addition, heat-induced changes in mass, volume and density were evaluated. After that lime and oak wood specimens were placed in the chamber and stored at 25 ºC ±1 ºC temperature and under 85 % ±1 % relative humidity for three weeks. Measurements of moisture content were performed on a weekly basis. Subsequently, specimens were kept in air at 15 ºC temperature and 55 % relative humidity for two weeks. Afterwards, lime, oak and birch wood specimens were soaked in water for 4 hours and changes in their moisture and volume were recorded each hour. After the all experiments statistical analysis of data was performed [17].

RESULTS

Obtained results revealed that oak wood specimens proved to be the most stable ones. After exposure to 130 ºC temperature the volume of oak wood speciments decreased by 1.8 % and continued to decline by approximately 0.4 %, when the temperature kept increasing (Fig. 2).

It was found that when heating to 220 ºC temperature, the volume of oak specimens fell 4.8 %. When applying 130 ºC – 190 ºC temperature, the largest decrease in volume was observed of birch specimens. Only after reaching 220 ºC temperature, their volume declined by 5.8 %. It was determined that when applying 220 ºC temperature, the largest decrease in volume –6.5 % – was noticed of lime specimens. After exposure to 130 ºC temperature the volume of lime specimens fell an average of 2.2 %; almost the same percentage is observed of oak specimens heated at 160 ºC temperature. The volume of lime specimens was lesser by even 2.6 % under such temperature conditions. It was found that when oak specimens underwent heating at 190 ºC temperature, their volume also decreased by 2.6 %.

After exposure to 130 ºC temperature the volume of birch specimens declined in a similar way as it was observed of lime specimens heated at 190 ºC temperature (about 3 %).

It was found that during the heating process, the volume of lime specimens decreased faster than the volume of oak specimens, however, a slower rate of change in their mass and density was noticed (Figs. 3, 4).

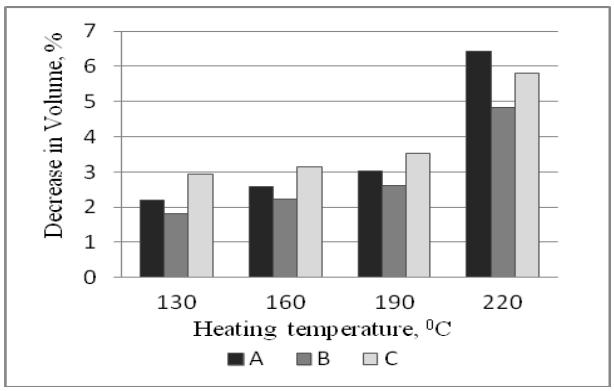

Fig. 2. Heat-induced changes in volume: A – lime; B – oak; C – birch

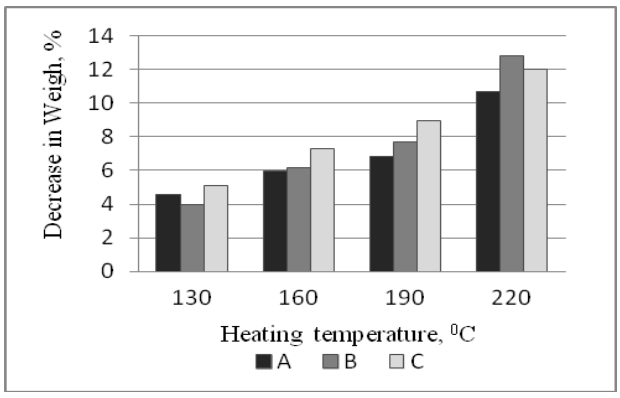

Fig. 3. Heat-induced changes in weight: A – lime; B – oak; C – birch

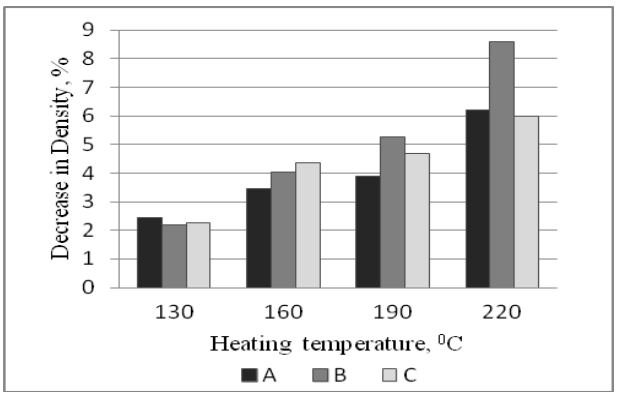

Fig. 4. Heat-induced changes in density: A – lime; B – oak; C – birch

When the lowest heating temperature was applied, there was a similar decrease in the density of birch specimens as it was observed in the case of oak specimens

(2.3 % and 2.2 %, respectively), whereas, at 160 ºC temperature the volume of birch specimens was lesser by 1.1 and 1.3 times than the one of oak and lime specimens, respectively. Considerable differences in the mass and density of specimens were noticed at 190 ºC – 220 ºC temperature. A reduction in the mass and density is mainly related to a decline in wood moisture and depolymerisation reactions of wood polymers, which occur during the heating process [18]. A considerable decrease in the density and mass of birch and oak specimens, which is caused by the rising temperature, can be explained by the fact that before heating these specimens contained more moisture than lime specimens. Furthermore, the density of oak and birch is greater than the density of lime, and wood specimens with a lesser density show more resistance to thermal decomposition, when compared to specimens with a greater density [19]. Thermal treatment affects all three components of wood: cellulose, hemicellulose and lignin. After exposure to 220 ºC temperature, the largest decrease in the mass and density was observed in the case of oak specimens, i. e.12.78 % and 8.57 %, respectively. This can be explained by the fact that oak wood contains higher amounts of hemicellulose, which is the fastest component to decompose due to its heterogeneous structure [20].

Obtained results reveal that heated specimens had the lower MC in comparison to unheated specimens after three weeks moistening (Figure 5). It was found that unheated oak and lime wood specimens had the highest MC (14.3 % and 14.8 %). There was no significant difference in the MC of lime wood specimens heated at 130 ºC – 190 ºC temperature. The heating process had a greater effect on the MC of lime wood specimens, when the heating temperature reached 220 ºC. The MC of these specimens was 1.6 times lower when compared to unheated specimens. The MC of all oak wood specimens was lower than the one of lime specimens.

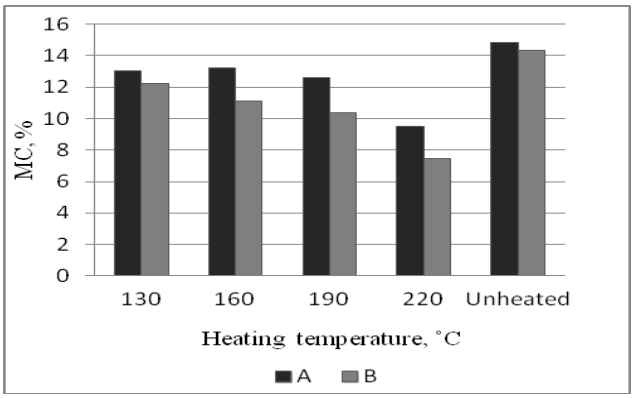

Fig. 5. MC after soaking: A – lime; B – oak

The MC of oak wood specimens heated at 190 ºC and 220 ºC temperatures was lower by approximately 4 % and 6.9 % in comparison to unheated specimens. The lower MC of oak specimens can be explained by the fact that during the heating process, specimens of this type of wood lost more mass due to thermal decomposition and that there was a significant reduction in the number of OH groups, which allows heated wood to absorb the smaller MC [21].

Subsequently, specimens were soaked in water for 4 hours and obtained data show that the volume and moisture content of specimens continued to increase each hour. It was determined that these parameters depend on the wood specie and the heating temperature. A rise in the heating temperature led to a decrease in the volume and moisture of soaked specimens. Table 1 provides obtained results. The largest increase in the volume and MC after a 4-hour soaking was observed in the case of lime wood specimens. After a 4-hour soaking the MC of unheated lime wood specimens and of lime wood specimens heated at 130 ºC temperature was almost identical: 40.7 % and 40.3 %.

Table 1. Soaking-induced changes in MC and volume

MC, %				Volume increase Δ, %		
Meas.	Oak	Lime	Birch	Oak	Lime	Birch
Unheated						
Before moistening	12.91	13.69	9.79	–	–	–
After 1 h	16.28	25.05	18.53	0.55	1.12	1.17
After 2 h	17.69	31.85	23.04	0.85	2.46	1.85
After 3 h	18.51	36.74	26.48	1.07	3.45	2.49
After 4 h	19.18	40.75	29.36	1.37	4.23	3.19
130 °C						
Before moistening	11.88	13.21	9.90	–	–	–
After 1 h	15.19	26.43	14.82	0.54	1.38	0.98
After 2 h	16.51	31.41	19.61	0.95	2.18	1.76
After 3 h	17.35	36.36	22.45	1.18	3.13	2.37
After 4 h	17.96	40.26	24.80	1.41	3.83	2.69
160 °C						
Before moistening	11.57	13.43	9.58	–	–	–
After 1 h	14.69	24.44	12.32	0.48	1.09	0.82
After 2 h	16.08	29.88	17.14	0.91	1.76	1.37
After 3 h	16.87	33.88	20.11	1.02	2.52	2.03
After 4 h	17.53	37.22	22.08	1.24	3.14	2.35
190 °C						
Before moistening	10.89	12.06	9.23	–	–	–
After 1 h	13.85	23.48	11.45	0.50	1.14	0.75
After 2 h	15.07	27.11	16.45	0.82	1.82	1.29
After 3 h	15.84	30.56	19.08	1.01	2.35	1.82
After 4 h	16.39	33.19	21.52	1.25	2.82	2.18
220 °C						
Before moistening	8.13	9.17	8.28	–	–	–
After 1 h	10.09	18.99	13.07	0.33	0.86	0.48
After 2 h	10.89	21.77	14.45	0.56	1.16	0.92
After 3 h	11.37	23.95	15.55	0.67	1.50	0.94
After 4 h	11.76	25.80	16.69	0.76	1.74	1.16

The heating process had a greater effect on the MC of lime wood specimens, when the heating temperature continued to rise, and when it reached 220 ºC, the MC of lime wood specimens was 25.8 %: virtually the same percentage was observed in the case of birch wood specimens heated at 130 ºC temperature (24.8 %). After 4-hour soaking the MC of birch wood specimens heated at 160 ºC – 190 ºC temperature was almost the same (22.1 % and 21.5 %), and the MC of birch wood specimens heated

at 220 ºC temperature (16.7 %) was almost identical to the MC of oak wood specimens heated at 190 ºC temperature (16.4 %). It was found that oak wood specimens had the smallest increase in the MC and density. After a 4-hour soak the volume of unheated oak wood specimens and of oak specimens heated at 220 ºC temperature increased by 1.4 % and only 0.8 %, respectively. Meanwhile, the volume of lime and oak wood specimens heated at 220 ºC temperature increased by 1.7 % and 1.2 % and there was a 4.2 % and 3.2 % increase in the volume of unheated lime and oak wood specimens.

After all experiments statistical analysis of all data was performed. It was found out that after 4-hour soak the coefficient of variance of oak specimens was from 2 % – 5 % (unheated and heated at 130 ºC – 190 ºC) to 15 % (heated at 220 ºC). Lime wood specimens – from 11 % to 17 %, birch – from 9 % to 16 %. Similar results were obtained after moistening in air: the coefficient of variance of oak wood specimens was from 3 % to 16 %, lime specimens – from 5 % to 15 %.

CONCLUSIONS

1. It was demonstrated that a decrease in the volume, density and mass of heated specimens is proportional to the heating temperature: higher temperatures lead to significant changes.

2. It was established that after exposure to 220 ºC temperature the largest decrease in the mass was observed in the case of oak specimens, whereas, the smallest one was noticed in the case of birch specimens. The difference reached the number of 1.2 times.

3. It was found that a decline in the density of oak, birch and lime specimens heated at 220 ºC temperature was larger by 3.9, 2.5 and 2.6 times, respectively, than in the case of specimens heated at 130 ºC temperature.

4. It was shown that when kept in humid air, unheated specimens absorbed the highest MC, meanwhile, specimens exposed to the highest temperature (220 ºC) reached the lowest MC.

5. It was determined that when soaked in water, unheated specimens absorbed the highest MC, whereas, specimens heated at 220 ºC temperature absorbed the lowest MC. After a 4-hour soak the difference reached 15 % on average.

6. It was found that during the soaking process, an increase in the volume of unheated specimens was 3 times higher than in the case of specimens heated at 220 ºC temperature. The volume change of unheated oak specimens was 1.27 times smaller than the one of lime specimens and 1.16 times larger than the one of birch specimens heated at 220 ºC temperature.

7. It was demonstrated that heating is a proper method for reducing wood hygroscopicity and enhancing dimensional and shape stability.

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