

Research Article

## The Effect of Heating Temperature on Static Hardness of Beech (*Fagus Sylvatica* L.) Wood

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### Abstract

A study was carried out to evaluate the effects of heating treatment on static hardness of beech (*Fagus sylvatica* L.) wood of Albanian origin. The heat treatment was conducted at temperatures 180, 200 and 220°C for 2 hours, at atmospheric pressure. Samples were produced from logs sapwood of origin from central Albania. Before treatment the oven dried density was calculated. The weight loss after treatment resulted from the lowest to the highest temperature respectively 3.57, 5.33 and 9.46%. It was noted a small decrease of hardness for temperatures up to 200°C, while for higher temperature the hardness decreased considerably, up to 20%. Decrease of hardness in tangential section was lower than in radial one. From the perspective of utilisation it seems that Albanian beech wood treated at temperatures up to 200°C presents a suitable choice for indoor and outdoor stairs, floor tiles and parquet.

**Keywords:** wood, beech, heat, treatment, hardness

### 1. Introduction

Thermal treatment aims at improving the performance of wood during its use in certain conditions. It has been recognized decades ago as useful modify method to improve the dimensional stability of wood and its decay resistance (Kollman, *et al*, 1975). Thanks to its eco-friendly approach, it is nowadays the most advanced commercially method (Hill, 2006). During last two decades several industrial application are developed in Europe, such as Thermowood in Finland, Rectification and Bois Perdure in France, Platowood in Netherland, Oil-heat treated wood in Germany and Thermo-vacuum wood in Italy. The main differences between these applications are in treatment conditions, such as use of steam or water spray or oils, application of oxygen or nitrogen or vacuum, as well as different treatment stages (Militz, 2002; Ferrari, *et al*, 2012). Anyway, heat treatment has positive impact mainly on physical properties of wood and its biological durability, while on mechanical ones negative consequences are evident (Epmeier, *et al*, 2003; Esteves and Pereira, 2009; Unsal, *et al*, 2009). From the perspective of wood utilization this fact means that for proper performance during application, the limiting conditions have to be taken into account.

Because of high temperature during heat treatment the wood chemical structure is modified, causing

permanently changes of its properties. Changes start appears at about 150°C and become more evident as the temperature becomes higher (Hill, 2006). Hemicellulose, which constitutes 25-35% of wood, has high oxygen content and degrades faster than cellulose and lignin and at lower temperatures (Fengel and Wegener, 1984; Esteves and Pereira, 2009). During this process methanol, acetic acid and various volatile heterocyclic compounds are produced. The exact temperature for the onset of hemicelluloses degradation varies on the mode of treatment and ranges from 90-150°C. When steam is used acetic acid starts to be formed from hemicelluloses at 120°C, by hydrolysis.

This acid serves as catalyst in the hydrolysis of hemicelluloses to soluble sugars, causing a reduction of hemicelluloses amount in wood. With degrading of the hemicelluloses, the concentration of water-absorbing hydroxyl groups decreases. As consequence, the equilibrium moisture is reduced; dimensional stability, biological durability and weather resistance are improved (Kotilainen, 2000). By the other hand cellulose which constitutes 40-50% of wood consists in chains joined by bonds between hydroxyl groups. At high temperatures cellulose starts decomposition, eliminating water and increasing crystallinity as well as dimensions of crystals. As consequence, the equilibrium moisture content is reduced and the toughness of wood is changed. Lignin varies from 20-30% of wood and has the best ability to withstand heat.

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Lignin's mass start to decrease above 200°C, because of its chemical bonds start to break. The assessment of lignin content in wood was based on valuation of non-hydrolysable residues (Hill, 2006). It affects biological durability, strength and paintability of heat treated wood (FTA, 2003).

There are several variables which effect on heat treatment, such as time and temperature of treatment (Esteves and Pereira, 2009), wood species (Militz, 2002; Ibach, 2010), treatment atmosphere and sample dimensions (Hill, 2006), initial moisture content (Gaff and Gasparik, 2013), maturity of wood (Bal and Bektas, 2012; 2013), use of catalysts (Fengel and Wegener, 1989) as well as wet and dry systems (Burmester, 1981).

Beech (*Fagus sylvatica L.*) is one of the most important European hardwoods. In Albania it occupies around 60% of total forests volume and is used for tiles and parquet, desks and chairs, solid wood panels, doors, stairs etc. It has high density and presents good physical and mechanical properties, but his biological durability leaves much to be desired. Improvement of its properties always has been a primary interest.

Czech researchers studied the impact of heat treatment on the elastic and strength properties of European beech (*Fagus sylvatica L.*) applying two different values of temperature, 165 and 210°C. They improvised based on the Finish technology, using sprinkling instead of steam. It was found that impact toughness of wood treated in 210°C was decreased by about 81%, meanwhile the static bending strength decreased 59%. Higher temperatures of heat treatment correlated with lower elastic and strength properties (Boruvka, et al, 2018).

A study was carried out to analyse the effect of heat treatment under atmospheric pressure on some of physical and mechanical properties of Turkish beech (*Fagus orientalis Lipsky*). Samples were treated at 150°C, 175°C and 200°C for 1, 3 and 5 hours. The results showed an increase of weight loss, density loss and dimensional stabilization. Also, the compression strength parallel to grain was increased, except for the treatment at 200°C for 5 hours. It was noted that treatments no longer than 3 hours, at low temperature, did not influence negatively on mechanical strength, meanwhile higher temperatures and duration decreased noticeably wood strength (Percin, et al, 2016).

Regarding to the heat treatment, a study was carried out to evaluate the influence of heat temperature on static hardness of European beech (*Fagus sylvatica L.*) of Albanian origin. The results should give suitable information regarding to utilization of heat treated beech for a proper application as tiles and parquet.

## 2. Materials and method

The study was based on comparative laboratory method, cause-consequence. Method consists in

quantity evaluation of a specific phenomena caused by a provocative factor and after, in evaluation of the same phenomena in situation of the factor's absence. In our case, the phenomenon is Brinell hardness and the provocative factor is heating temperature.

Laboratory tests consisted in preparation of samples, treatment (heating), weighing of samples and measurements of their dimensions, tests of hardness. The study was carried out at the Faculty of Forestry Sciences of Tirana, during the period February 2019.

As raw material for production of samples were used air dried beech boards (*Fagus sylvatica L.*), selected randomly at lumberyard of SINANI sawmill. Boards were produced from logs harvested by sawmill itself from forests of Librazhdi region, central Albania. From selected boards were obtained pieces which presented neither deformations nor wood structure defects. Taking into account the presence of red heart in beech wood, the pieces were selected from sapwood zone.

From each piece was saw one strip with dimensions of section 55x55 mm, and length the same as the piece. After, the strips were planed up to the section's dimensions 50x50 mm and were cut in samples with dimensions 50x50x50 mm. Samples presented clear radial, tangential and cross-sections. There were produced 64 samples in total, which were assigned to 4 different test groups. Group 1 with only 8 samples was used as the control group. The other three groups consisted of 18 samples each.

Before treatments all samples were dried at 103±2°C until to the moisture content 0%. After that, the oven dried samples were measured by digital calliper (accuracy 0.001 mm) and weighted by digital weight scale (accuracy 0.01 g), in order to calculate the respective density. Heat treatments were conducted in small temperature controlled chamber (France Etuves, FRANCE). There were used three different temperatures, 180, 200 and 220 °C at atmospheric pressure for 2 hours.



**Fig.1** Thermal chamber used for the treatment

After treatment, the samples were weighted again and the weight loss (WL) was calculated by formula:

$$WL = \frac{W_{BT} - W_{AT}}{W_{BT}} \times 100 \quad [\%]$$

where:

$W_{BT}$ —the weight of oven dried samples before treatment (g);  $W_{AT}$ —the weight of samples after heat treatment.

Treated and untreated samples were conditioned until when the moisture content of untreated samples arrived to 12%. Then, the samples were tested on a 20 kN universal mechanical testing machine (Controlab, FRANCE) to evaluate the Brinell hardness (HB) respectively to radial and tangential sections, applying the load 2800 N. The hardness was calculated by formula:

$$HB = \frac{2 \times F}{\pi \times D \times (D - \sqrt{D^2 - d^2})} \quad [N/mm^2]$$

where:  $F$  – the load applied (N);

$D$  – diameter of the steel ball (mm);

$d$  – diameter of indentation made by steel ball on the surface of the test sample (mm).



Fig.2 Testing machine

### 3. Results and discussion

A darkness of samples color was observed after treatment. The darkness was intensified for higher heating temperatures. This is a well-known phenomenon. The color is affected by the temperature and the time of treatment. It also depends on whether springwood or latewood is used (FTA, 2003). Studies showed that heat treated beech has darker color to radial and tangential sections. The color difference in its surface decreased depending on treatment intensity, meanwhile the color saturation decreased proportionally to treatment severity (Mitani and Barboutis, 2014). The color can be used to estimate the brittleness of heat treated wood as well as an indicator of the process conditions (Phuong, et al, 2007; Guller, 2012).



Fig.3 Increase of darkness for treated samples

In table 1 are presented summarised results of oven dried density (D), weight loss (WL) and Brinell hardness referring to radial (HBR) and tangential (HBT) sections for 4 groups of samples.

Table 1 Test results

Property	Values	Group 1 control group	Group 2 180°C	Group 3 200°C	Group 4 220°C
D	Mean g/cm <sup>3</sup>	0.68	0.668	0.671	0.68
	Std.Dev.	0.029	0.03	0.024	0.03
	Coef.Var. %	0.043	0.045	0.036	0.044
WL	Mean %	-	3.57	5.33	9.46
	Std.Dev.	-	0.54	0.59	0.46
	Coef.Var. %	-	0.15	0.11	0.05
HBR	Mean N/mm <sup>2</sup>	51.03	49.39	48.39	40.81
	Std.Dev.	4.47	5.12	5.6	4.11
	Coef.Var. %	0.09	0.1	0.12	0.1
HBT	Mean N/mm <sup>2</sup>	50.02	49.4	49.12	42.22
	Std.Dev.	3.64	2.73	4.29	7.84
	Coef.Var. %	0.07	0.06	0.09	0.19

Group 1 was not treated and served to compare the effects of heat treatments on other three groups. The results showed that all three treated groups were affected by heating temperature. The effects were more visible as the temperature was higher. The weight loss for temperatures 180, 200 and 220 °C were respectively 3.57, 5.33 and 9.46%. It was noted from 200 to 220 °C the weight decreased more rapidly. Similar results have been reported by other previous studies (Bal, 2015). A strong correlation existed between temperature and weight loss with a coefficient value of 0.974. The figure 4 shows the relation between heating temperature and weight loss.

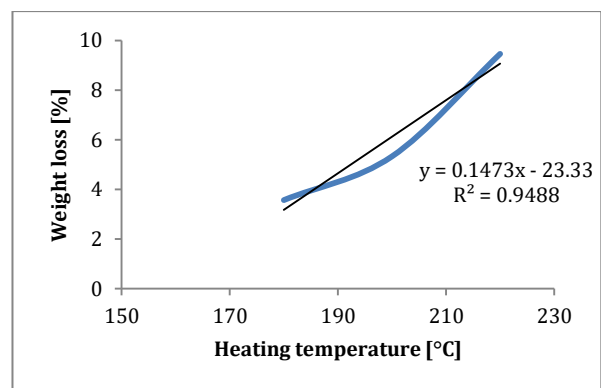
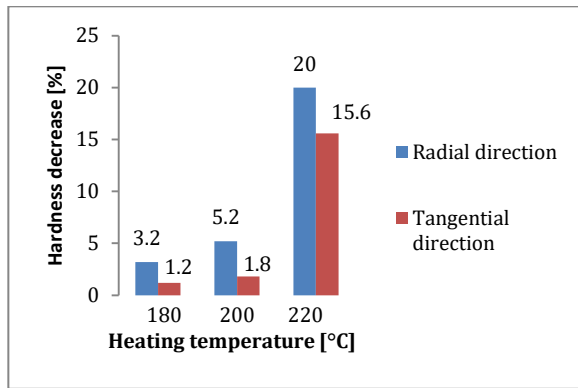


Fig.4 Relation between heating temperature and weight loss

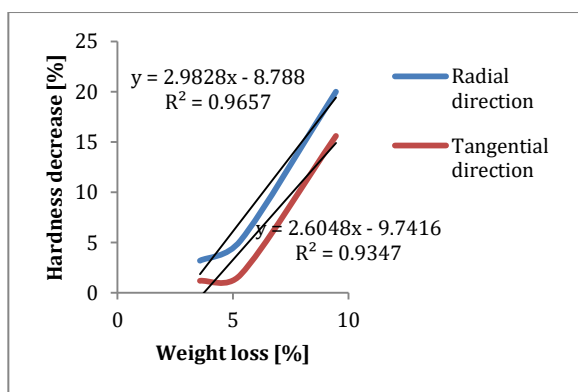
With regard to Brinell hardness it was noted for temperatures 180 and 200 °C the reductions were not considerable for both sections, meanwhile for temperature 220 °C the hardness presented a strong decrease. Figure 5 shows the decrease in percentage of Brinell hardness for two directions regarding to heating temperatures.



**Fig.5** The decrease in percentage of Brinell hardness

The reductions of hardness in tangential section were lower than those in radial section, especially for temperatures 180 and 200°C. For these temperatures the decrease in radial section is more than double of radial one. Several studies have shown different effects on static hardness of beech. Some of them showed at temperature 165°C the hardness of beech (*Fagus sylvatica L.*) wood was decreased with 2% in radial section, while for tangential section it was increased with 3%. Respectively, at temperature 210°C the hardness was decreased with 37 and 24% (Boruvka, et al, 2018). By the other hand, studies regarding to Turkish beech (*Fagus orientalis* Lipsky) showed higher hardness decrease in tangential section than radial one (Percin, et al, 2016). However, both studies mentioned above showed clearly decrease of static hardness of beech wood at higher temperatures.

According to obtained results was noted a strong correlation between weight loss and hardness decrease. This, because of both parameters depends mainly on the depolymerisation reactions of wood polymers, which means degradation mainly of hemicelluloses, followed by more heat resistant celluloses as well as lignin. The degradation develops more intensively at higher temperatures (Kotilainen, 2000). Figure 6 shows the relation between weight loss and hardness decrease during heat treatment.



**Fig.6** Relation between weight loss and hardness decrease during heat treatment

## Conclusions

Regarding to static hardness it seems that Albanian beech wood presents relatively strong resistance against heating treatment up to 200°C at atmospheric pressure. Above this temperature its hardness decreases rapidly up to 20%. Decrease of hardness in tangential section is lower than in radial one. There is a strong positive relation between weight loss and hardness decrease.

Taking into account positive effects of heat treatment on physical properties of wood as well as the reacting of Albanian beech hardness towards heating treatment it seems that a positive perspective does exist for utilisation of heated beech for a proper indoor and outdoor application as stairs, floor tiles and parquet.

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