Effect of Heating Temperature on Compression Strength of Beech Wood

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***Abstract*— A study was carried out to evaluate the effects of heating treatment on compression strength parallel to grain 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 4.34, 6.87 and 10.12%. Regarding to compression strength parallel to grain it was noted a positive approach to heating treatment at atmospheric pressure. The compression strength increased up to 12% for treatment at 180°C. For higher temperatures the strength started to decrease, but in all cases was above compression strength of non treated wood. It seems that thermal treated Albanian beech wood presents a suitable choice for indoor and outdoor utilisation for desks and chairs.**

***Index Terms*— beech, compression strength, heat treatment.**

I. Introduction

Improving wood properties as well as its performance during application has always been a primary concern. In this framework many novel methods have been developed during last decades which aim to improve dimensional stability, color uniformity, durability and stress reduction. One of these methods is thermal treatment. It has been recognized decades ago as useful method to improve the dimensional stability of wood and its decay resistance [1].

Thermal treatment has positive impact mainly on physical properties of wood and its biological durability, while on mechanical ones negative consequences are evident [2]–[4]. This approach is due to considerable changes in the chemical composition of wood caused during treatment [5]. These changes start appears at about 150°C and become more evident as the temperature becomes higher [6]. Hemicellulose, which has high oxygen content, degrades faster than cellulose and lignin and at lower temperatures [3], [7]. The exact temperature for the onset of hemicelluloses degradation varies on the mode of treatment and ranges from 90-150°C. 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 [5]. By the other hand cellulose starts decomposition at high temperatures, 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 has the best ability to withstand heat. Lignin’s mass start to decrease above 200°C, because of its chemical bonds start to break. It affects biological durability, strength and paintability of heat treated wood [8].

There are several variables which effect on heat treatment, such as time and temperature of treatment [3], wood species [9], [10], treatment atmosphere and sample dimensions [6], initial moisture content [11], maturity of wood [12], [13], use of catalysts [7] as well as wet and dry systems [14].

Beech (*Fagus sylvatica* L.) is one of the most important European hardwoods. It has high density and presents good physical and mechanical properties, but his biological durability leaves much to be desired.

Treatment of European beech (*Fagus sylvatica* L.) at two different values of temperature, 165 and 210°C showed 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 [15]. By the other hand 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 it noticeably [16].

Beech wood used in desks and chairs is subject, among others, to compression loads parallel to grain. In this framework the aim of this paper is to evaluate the influence of heat temperature on compression strength parallel to grain 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 for chairs and desks.

II. Materials and Methods

The study was based on comparative laboratory method, cause-consequence [17]. 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 compression strength parallel to grain of beech (*Fagus sylvatica* L.) wood 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 in compression strength. The study was carried out at the Faculty of Forestry Sciences of Tirana, during the period March 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

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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 were produced strips with dimensions of section 25x25 mm, and length the same as the piece. After, the strips were cut in pieces (samples) with length 40 mm. There were produced 104 samples in total, which were assigned equally to 4 different test groups. Group 1 with was used as the control group. The number of samples was calculated referring to the standard ISO 3129 [18], using the formula as below:

$$n_{\min} = \frac{C_V{}^2 \times t^2}{p^2} \qquad (1)$$

C_V – coefficient of variation, 13% according to the standard ISO 3129;

t – index of result authenticity (a half length of the confidence interval in fractions of the standard deviation), 1.96;

p – index of test precision, 5%.

Before heating 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 a temperature controlled small chamber (France Etuves, FRANCE). There were used three different temperatures, 180, 200 and 220 °C at atmospheric pressure for 2 hours.

Figure 1: Thermal chamber used for the treatment

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

$$WL = \frac{W_{BT} - W_{AT}}{W_{BT}} \times 100 \quad [\%] \qquad (2)$$

W_{BT} – weight of oven dried samples before treatment (g);

W_{AT} – weight of samples after heat treatment (g).

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) applying the method specified by the standard ISO 13061-17 [19]. The ultimate strength in compression (CS) parallel to the grain was calculated by formula:

$$CS = \frac{F\max}{a \times b} \quad [\text{N.mm}^{-2}] \qquad (3)$$

F_{max} – the maximum load (N);

a and b – cross-sectional dimensions of test piece (mm).

Figure 2: Testing machine

III. RESULTS AND DISCUSSION

The first thing to notice was the darkness of samples color after treatment. The darkness was intensified for higher heating temperatures. 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 [20].

In Table 1 are presented summarized results of oven dried density (D), weight loss (WL) and compression strength parallel to the grain (CS) for 4 groups of samples. Group 1 was not treated and served to compare the effects of heat treatments on other three groups.

Table 1: Test results

Pro perty	Values	Group 1	Group 2 180°C	Group 3 200°C	Group 4 220°C
D	Mean g/cm^3	0.689	0.68	0.684	0.681
	Std.Dev.	0.033	0.03	0.029	0.031
	Coef.Var. %	0.048	0.044	0.042	0.046
WL	Mean %	-	4.34	6.87	10.12
	Std.Dev.	-	0.66	0.69	0.58
	Coef.Var. %	-	0.15	0.1	0.06
CS	Mean N/mm^2	71.96	80.72	77.52	76.92
	Std.Dev.	4.029	4.526	5.311	5.428
	Coef.Var. %	0.056	0.056	0.069	0.071

The results showed that all three treated groups were affected by heating temperature. The weight loss for temperatures 180, 200 and 220 °C were respectively 4.34, 6.87 and 10.12%. It was noted from 200 to 220 °C the weight decreased more rapidly. Similar results have been reported by other previous studies [21]. A strong correlation existed between temperature and weight loss with a coefficient value of 0.998. The figure 3 shows the relation between heating temperature and weight loss.

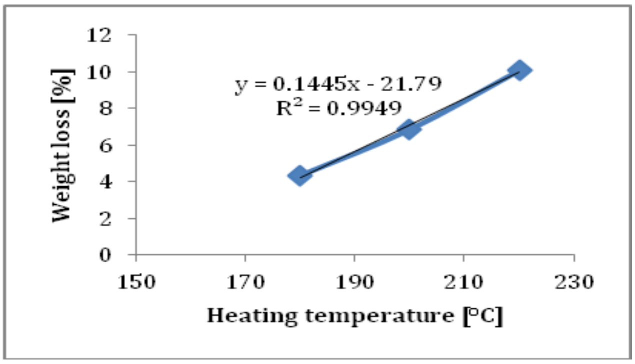

Figure 3: Relation between heating temperature and weight loss

With regard to compression strength it was noted an increase for all three temperatures. The biggest increase was for temperatures 180°C, meanwhile for temperatures 200 and 220°C the hardness presented a lower one. Figure 4 shows the increase in percentage of compression strength parallel to the grain regarding to heating temperatures.

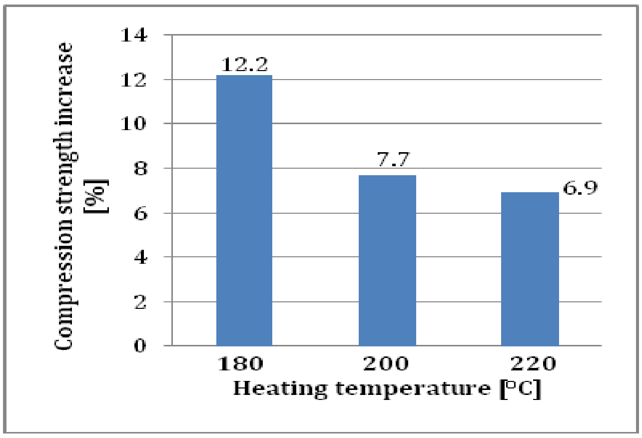

Figure 4: The increase of compression strength parallel to grain

Studies regarding to Turkish beech (*Fagus orientalis* Lipsky) have shown an increase of compression strength between 2.98 and 19.3% after thermal treatment at 150, 175 and 200°C. The highest compression strength was obtained at 175°C for 5 hours (87.49 $N.mm^{-2}$) and the lowest at 200°C for 5 hours (72.48 $N.mm^{-2}$). However, after heating at 200°C for 5 hours, compression strength showed a small decrease [16]. Other studies have shown similar results regarding to pine and fir [22]. Even for low treatment temperatures (130°C) the compression strength values showed a slight increase [23].
According to obtained results was noted a strong correlation between weight loss and increase in compression strength. Figure 5 shows the relation between weight loss and increase in compression strength during heat treatment.

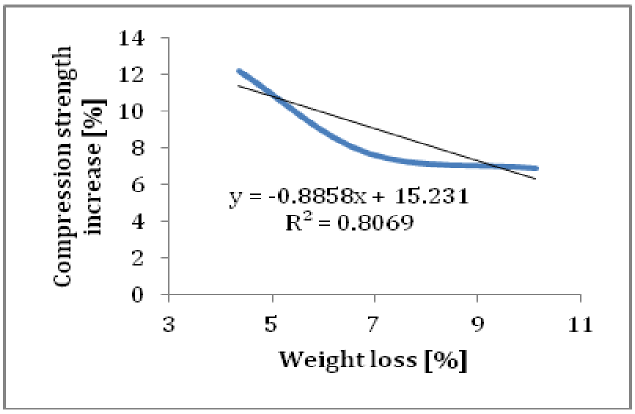

Figure 5: Relation between weight loss and compression strength parallel to grain during heat treatment

IV. Conclusions

Regarding to compression strength parallel to grain it seems that Albanian beech wood presents a positive approach to heating treatment at atmospheric pressure. Its strength increases up to 12% for treatment at 180°C. For higher temperatures the strength starts to decrease, but in all cases is above compression strength of non treated wood. There is a strong negative relation between weight loss and increase in compression strength.
Taking into account positive effects of heat treatment on physical properties of wood as well as the positive reacting of Albanian beech strength in compression parallel to grain towards heating treatment, seems that positive perspective exist for indoor and outdoor utilisation of heated beech wood for desks and chairs.

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