# COMPRESSION STRENGTH, HARDNESS AND SHEAR STRENGTH OF HEAT TREATED BEECH (FAGUS ORIENTALIS) WOOD IN BUFFERED MEDIUMS

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**Abstract-** Hydrothermal treatment of beech wood in buffered mediums was carried out by aim of controlling the destructive effect of acids formed by degradation of carbohydrates on strength properties. Different mediums (water, buffer5, 7 and 8) and temperatures (160 and 180 °C) were used. Mechanical properties of specimens including compression strength (∥,⊥), hardness and shear strength were determined. FTIR spectra focusing on indexes of carbohydrates degradation obtained and according to findings, results of mechanical tests were analyzed.Hydrothermal treatment in buffer 5 (acidic medium) caused a considerable loss in mechanical properties, while treatment in buffer 7 (neutral medium) and buffer 8 (alkaline medium)did notchanged the mechanical properties, significantly. It can be concluded that buffering the medium of hydrothermal treatment in neutral level prevents the strength loss and extends the usage of heat-treated wood in load-bearing applications.

**Keywords-** Hydrothermal Treatment, Buffered Medium, Mechanical Properties, Crystallinity Index

## I. INTRODUCTION

During the last decades, an increased interest in novel methods to modify the chemical structure of wood has come into view. These new modification methods aim to improve various properties of wood, such as reduction in the emission of volatile organic compounds (Manninen et al. 2002), stress reduction (Dwianto et al. 1998; Kamdem et al. 2002; Talaei et al, 2012), improved dimensional stability, improvement of colour uniformity and improved durability (Kamdem et al. 2000; Sailer et al. 2000). During heat treatment, there are considerable changes in the chemical composition of wood.

The presence of water or water vapour affects the thermal modification and heat transfer within the wood (Talaei et al. 2010). In closed systems, water evaporated from the wood remains as high pressure steam during the process. Steam can act as an inert blanket to limit oxidative processes (Hill, 2006). The presence of water also affects the reaction chemistry, although this depends upon the amount of water present and whether or not it is lost from the treatment system. The heating of wood in the presence of water or steam results in the accelerated formation of organic acids (primarily acetic acid) that catalyse the hydrolysis of hemicelluloses, and to a lesser extent the amorphous cellulose (Talaei and Karimi 2012). The generation of these acids is also enhanced in the presence of air (wet oxidation). Hydrothermal processing results in the hydrolysis of polysaccharide due to the action of hydronium ions generated by autonionization of the water, although the formation of hydronium ions from acetic acid is more important (Garrote et al., 1999). Temperature ranges from 150 °C to 230°C are generally used, because hydrolysis is very slow at lower temperatures(Hill, 2006).Loss of hemicelluloses leads to an increase in the degree of crystallinity of wood samples, in addition to those changes related degradation and rearrangement of the amorphous cellulose content. Since the cellulose content remains unchanged up to 150°C (although changes in DP can occur), the hemicellulose content decreases. The loss of hemicelluloses is faster in closed systems due to the increase of acidic vapours that catalyse sugar hydrolysis (Hill. 2006).

The various chemical changes invariably lead to the modification of the various physical properties of wood, but also reduction in strength properties (Kamdem et al. 2002). However, the loss of strength properties has always been one of the main disadvantages for a commercial utilization of thermallytreated wood.Pretreatment of wood with borate salt has been found to decrease thermal induced degradation in wood (Awoyemi, 2008; Winandy 1997) and this is obviously due to the balancing of the release of acetic acid from the hemicelluloses.

It is therefore essential to investigate the effect of buffered mediums on the degree of strength loss during hydrothermal treatment in order to derive the maximum benefit from its application. The aim of this paper is to study the effect of different buffered mediums in hydrothermal treatmentto control the destructive effect of acids formed by degradation of carbohydrates on strength properties.FTIR spectroscopy has been found effective to analyze the chemical structure of wood as a whole (Faix 1992).

FTIRanalysis has been used to study the chemical transformations in hydrothermal treated beech wood (Talaei and Karimi, 2012).

## II. MATERIALS AND METHODS

### 2.1 Buffer preparation

Alkaline buffer (buffer 8), neutral buffer (buffer 7) and acidic buffer (buffer 5) were selected as mediums of the hydrothermal treatment. Preparation of buffer mixtures was performed according to Table 1.

Table 1. Preparation method of buffer mixtures (Alexeyev, 1967)

| pH | Mixture method |
|---|---|
| 5 | 257.5 ml $Na_2Hpo_4.2H_2O$ (0.2 M)+ 292.5 ml Citric acid $C_6H_8O_7.H_2O$ (0.1 M) |
| 7 | 411.75 ml $Na_2Hpo_4.2H_2O$ (0.2 M)+ 88.25 ml Citric acid $C_6H_8O_7.H_2O$ (0.1 M) |
| 8 | 483.25 ml $Na_2Hpo_4.2H_2O$ (0.2 M)+ 13.75 Citric acid $C_6H_8O_7.H_2O$ (0.1 M) |

### 2.2 Heat treatment

Specimens were cut for mechanical tests from heartwood of breast height beech log and completely soaked in buffer mixtures for 4 weeks. Heat treatment was carried out in the laboratory digester including 4 cylinders. Cylinders were filled of wood specimens and the aqueous mediums (water, buffer 5, buffer 7 and buffer 8) separately. Temperatures of 160°C and 180°C were applied and source of applied heat was melt glycerin. Treatment duration was constant 45 minutes at temperature. Other conditions were kept steady for all treatments. To have enough quantity specimens for each test, treatments were repeated as well. After heat treatment, cylinders were cooled gradually to avoid any tension and specimens kept in the temperature and humidity control chamber at a temperature of 20°C and 65%relative humidity in order to equilibrate to about 12% moisture content.

### 2.3 Mechanical tests

Mechanical properties determined in this study were compression strength perpendicular to grain, compression strength parallel to grain, hardness (radial and tangential)and shear strength. Heat treated and untreated specimens were inspected by Instron model 4486 according to ASTM D143 (1992).

Compression parallel to grain is analogous to bending-type failure rather than axial-tape failure. As long as specimen width is great enough to prevent bucking, $C_{\parallel}$is solely an axial property. Compression perpendicular to grain is stress at proportional limit. There is no clearly defined ultimate stress for this property.Hardness (radial and tangential) defined as resistance to indentation using a modified Janka hardness test, measured by the load required to embed an 11.28-mm (0.444-in.) ball to one-half its diameter. Shear strength parallel to grain is the ability to resist internal slipping of one part upon another along the grain. Values presented are average strength in radial and tangential shear planes.

## III. RESULTS AND DISCUSSION

Loss in strength in strongly influenced by the conditions of heat treatment. Strength loss is faster in closed systems compared to open systems, under hygrothermal compared to hydrothermal conditions, and in air compared to anaerobic conditions (Hill, 2006).

The effect of the heat treatment on the mechanical properties of beech wood was in line with the degradation pattern and changes in crystallinity index and carbonyl peak noted earlier (Talaei and Karimi, 2012). The effects of heat treatment in different mediums and temperatures on Density, compression strength, hardness and shear strength are shown in Figure 1-6, respectively. It is difficult to directly compare the laboratory heat treatment process used in this investigation with the full-scale industrial process, but nevertheless, interesting indications can be outlined. Buffering the treatment medium in neutral or alkaline level seems to avoid significant decreases in compression strength ($\parallel$,$\perp$), hardness and shear strength compared with controls.

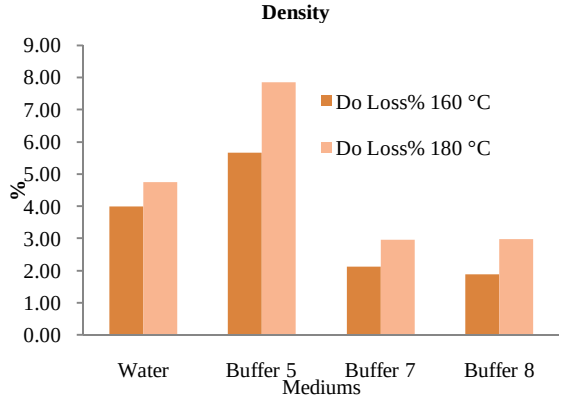



**Fig. 1. Density loss after hydrothermal treatment of beech wood in buffered mediums**

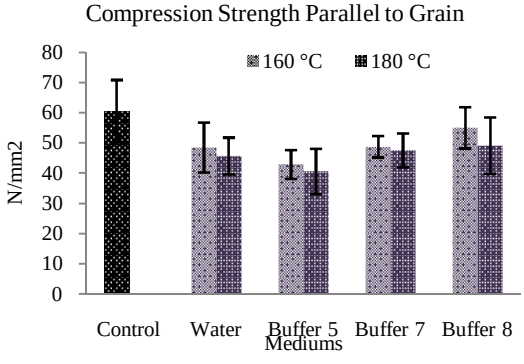



**Fig. 2. Compression strength of hydrothermally treated beech wood in buffered mediums (Parallel to grain)**

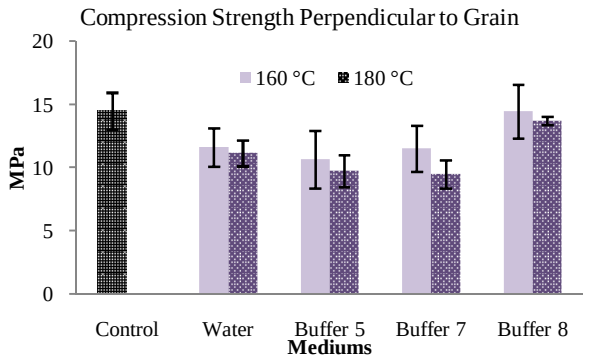



**Fig. 3. Compression strength of hydrothermally treated beech wood in buffered mediums (Perpendicular to grain)**

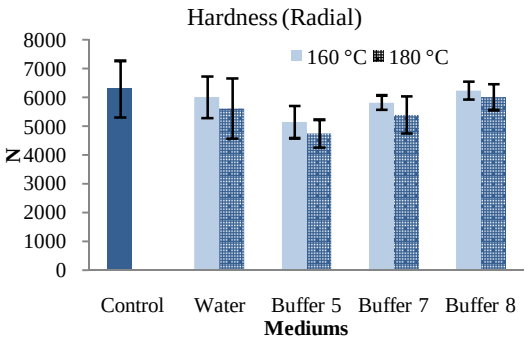



**Fig. 4. Hardness (radial surface) of hydrothermally treated beech wood in buffered mediums**

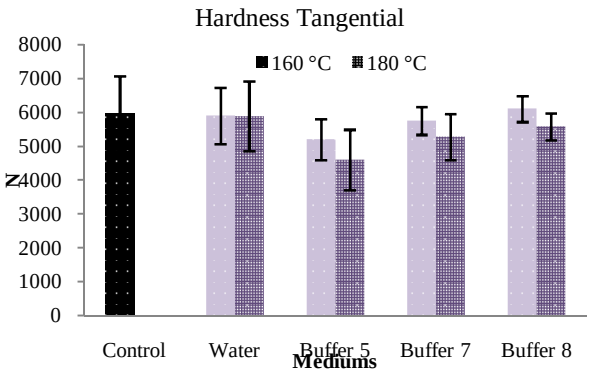



**Fig. 5. Hardness (tangential surface) of hydrothermally treated beech wood in buffered mediums**

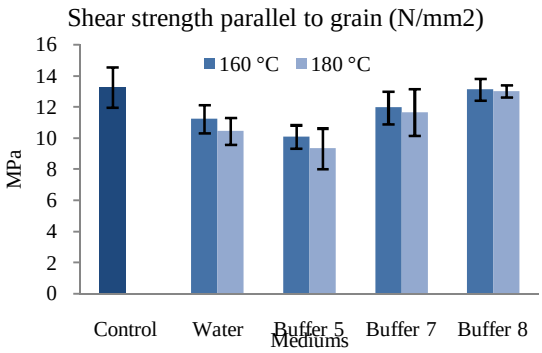
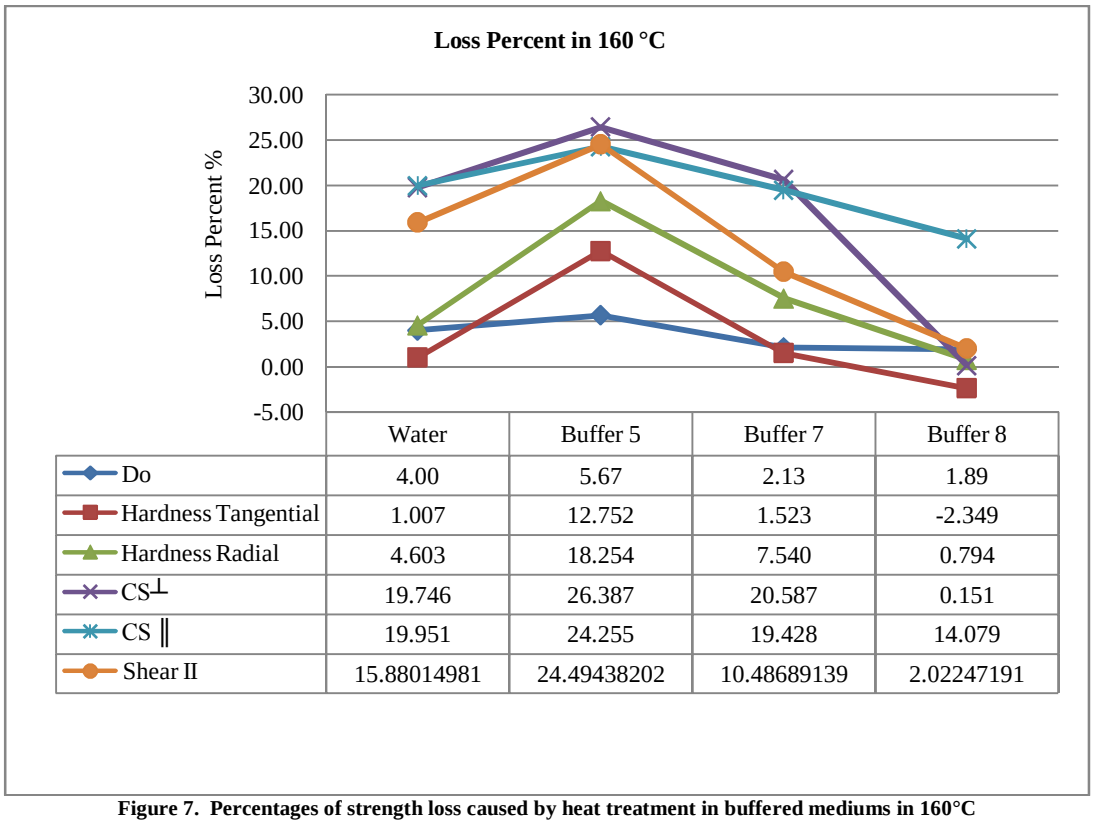



**Fig. 6. Shear strength of hydrothermally treated beech wood in buffered mediums**

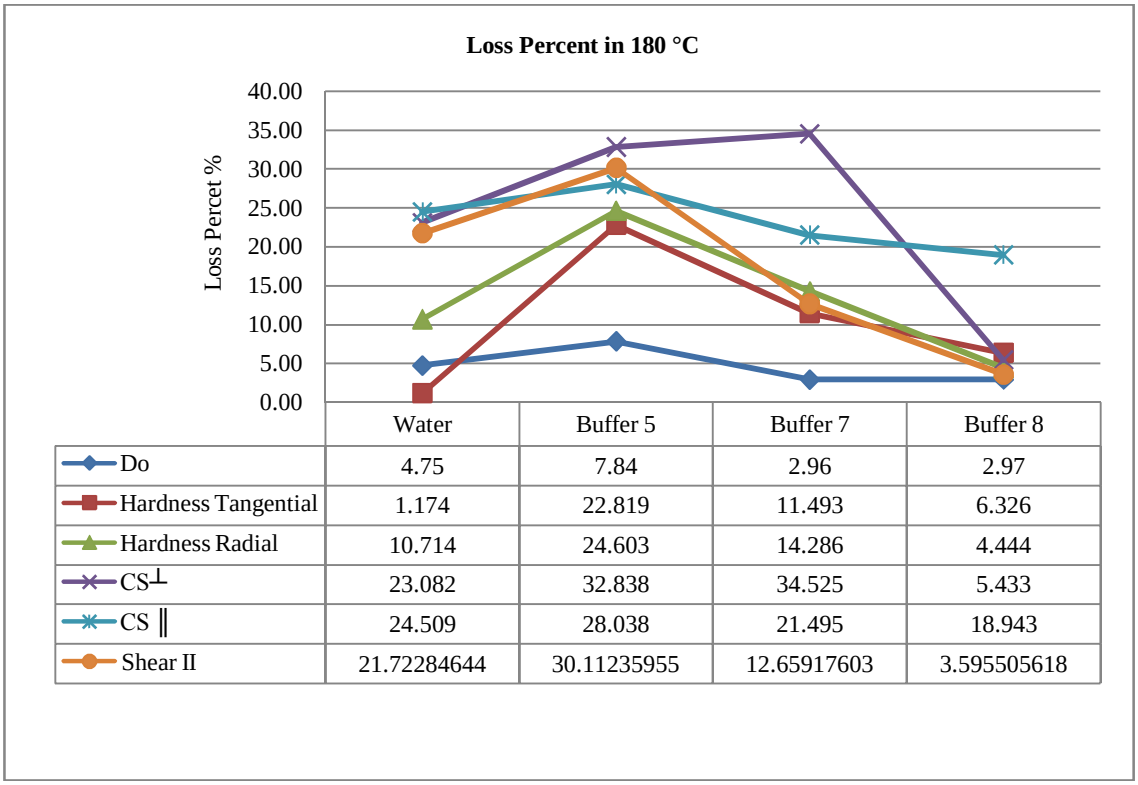
Percentages of strength loss caused by heat treatment in buffered mediums are shown in Figure 7 and 8. Treatment in 160 °C almost showed a minor decrease in strength properties in contrast to 180 °C.




| | Water | Buffer 5 | Buffer 7 | Buffer 8 |
|---|---|---|---|---|
| Do | 4.00 | 5.67 | 2.13 | 1.89 |
| Hardness Tangential | 1.007 | 12.752 | 1.523 | -2.349 |
| Hardness Radial | 4.603 | 18.254 | 7.540 | 0.794 |
| CS⊥ | 19.746 | 26.387 | 20.587 | 0.151 |
| CS ‖ | 19.951 | 24.255 | 19.428 | 14.079 |
| Shear II | 15.88014981 | 24.49438202 | 10.48689139 | 2.02247191 |

**Figure 7. Percentages of strength loss caused by heat treatment in buffered mediums in 160°C**

**$D_0$: Density oven-dried, CS: Compression Strength**




| | Water | Buffer 5 | Buffer 7 | Buffer 8 |
|---|---|---|---|---|
| Do | 4.75 | 7.84 | 2.96 | 2.97 |
| Hardness Tangential | 1.174 | 22.819 | 11.493 | 6.326 |
| Hardness Radial | 10.714 | 24.603 | 14.286 | 4.444 |
| CS⊥ | 23.082 | 32.838 | 34.525 | 5.433 |
| CS ‖ | 24.509 | 28.038 | 21.495 | 18.943 |
| Shear II | 21.72284644 | 30.11235955 | 12.65917603 | 3.595505618 |

**Figure 8. Percentages of strength loss caused by heat treatment in buffered mediums in 180°C**

## CONCLUSIONS

Release of acid during hydrothermal treatment was found to be dependent on the treatment medium and temperature applied. Generally, the order of strength loss was observed in specimens treated in buffer 5> water> buffer 7> buffer 8. The strong interaction between the mediums of treatment and strength properties of specimens observed. According to the results, it can be concluded that neutral and alkaline buffers (7 and 8) neutralize the released acids and fix the pH on neutral level, so they chemically control the destructive effect of released acids on strength properties of wood. Conclusively, in order to ensure maximum prevention of strength loss at a reasonable cost and extend the usage of heat-treated wood in load-bearing applications, heat treatment in buffer 8 is recommended especially when carrying out heat treatment in the vicinity of the temperatures used in this research.

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