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THE EFFECT OF THERMAL MODIFICATION ON SELECTED PHYSICAL PROPERTIES OF WOOD OF SCOTS PINE (*PINUS SYLVESTRIS* L.)

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ABSTRACT

The attempt was made to find a correlation between the density of thermally modified pinewood treated at various temperatures and times and its compressive strength and modulus. The highest correlation coefficients were obtained for the temperature of 160°C and short modification times. Under these conditions, an increase of strength properties occurred. The highest size changes of the analysed samples were observed at higher temperatures, accompanied by a marked weight loss and decrease in both compressive strength and modulus of elasticity. The data obtained allow predicting modified wood strength on the base of its density. Changes in the density and strength of modified wood are caused by a fundamental change in the structural composition of the wood.

KEYWORDS: Pine wood, density, compressive strength, modulus of elasticity.

INTRODUCTION

Thermal modification of wood is applied in order to improve some of its physical and chemical properties that make such modified wood more attractive for use. Properties of thermally modified wood were studied as early as in the 30s of the past century. One of the first studies were conducted by Stem and Hansen (1937) and related to the dimensional stability of wood (swelling and shrinkage). Investigations are still of interest; various conditions of modifying were applied (particularly with the use of steam) along with methods of analysis of modified wood (Wikberg and Maunu 2004, Haw and Schultz 1985, Alen et al. 2002, Zaman et al. 2000).

Some of wood physical properties change irreversibly during thermal modification. Wood swelling and shrinkage decrease up to 50 %, as well as wood equilibrium moisture content (EMC) in comparison to the native wood, wood density is reduced by 15 %, the pH values of the wood also decreases and its biological resistance increases. Mechanical properties of wood also change; for example, higher compression strength parallel to the grain is obtained by about 20 % (birch)

to 40 % (spruce) respectively to time and temperature modifications. The bending strength of wood decreases, but the modulus of elasticity remains approximately at a same level (Grześkiewicz and Dąbrowski 2004, Schneider and Rusch 1973, Viitaniemi and Jämsä 1996, Kubojima et al. 2000, Hilis 1984). As a result of thermal modification of wood its colour changes, which applies to the entire cross section of wood. The colour achieved is similar to that of certain exotic wood species, allowing imitation (Bekhta and Niemz 2003, Sundqvist 2002).

High temperature of wood modification results in changes in the chemical composition of wood. Series of chemical reactions take place (Rowell 2002, Yildiz and Gumukaya 2007). The most important of them are degradation of hemicelluloses and increase in cellulose crystallinity. These processes lead to changes in the content of structural wood constituents and extractives as well (Parysek and Zakrzewski 2006, Zawadzki et al. 2007, Yildiz et al. 2006), which in turn causes the change in the physical properties of wood.

MATERIAL AND METHODS

The pine wood (*Pinus sylvestris* L.) used in the investigations was obtained from a single board with no defects. Rectangular samples with dimensions of 20×20 mm cross-section and 30 mm height (parallel to the grain) were cut from the sapwood and divided into eight groups of 38 samples. The way of samples collection was in order to ensure each group was similar density distribution, which is showed in Tab. 1. Each group of samples was modified in different conditions of the temperature and time of the process.

Tab. 1: Density distribution of the samples collected in the groups.

	Density of the group (kg.m^{-3})						
Group (conditions)	**Average**	**Standard deviation, σ**	**Minimum**	**1st quartile**	**Median**	**3rd quartile**	**Maximum**
Reference (unmodified)	543	16	519	528	540	559	575
Oven-dried (105°C 12 h)	543	16	518	532	545	553	580
160°C 2 h	542	17	511	530	543	555	575
160°C 6 h	545	20	508	532	546	563	580
160°C 10 h	538	15	511	525	540	553	564
200°C 2 h	549	19	509	533	552	565	577
200°C 6 h	549	14	516	538	550	563	567
200°C 10 h	545	17	510	532	545	558	577

The first group of samples (reference) was stored at room temperature under normal atmospheric conditions (65 % humidity). The second set was oven-dried for 12 h at 105°C. The next three groups were dried as well and then modified at 160°C successively for 2, 6 and 10 h, respectively. The last three groups were dried and successively modified at 200°C for 2, 6 and 10 h, respectively.

Modification procedure

Pinewood samples were modified according to the following procedure:

Step 1: Oven-drying of samples at 105±1°C, for 12 h, in order to evaporate water from the samples.

Step 2: Oven-heating of samples at the target temperatures (160±1°C or 200±1°C) for assumed time (2, 6 or 10 h).

Step 3: Placing samples in a desiccator in order to cool down the samples to room temperature and constant weight without access of moisture.

Pinewood modification, when conducted in aerobic conditions, allows observing the changes in samples density and strength of wood, especially in the mild conditions – at lower temperatures and shorter times of modification.

Sample preparation for strength analysis:

Pinewood samples, both reference (stored at room temperature), dried only and thermally modified were submitted to strength analysis.

Density decrease was measured for each single sample.

Compression strength and elasticity modulus parallel to the grain were determined for all samples. Compressive strength values were calculated with an accuracy of 0.5 MPa, according to the formula:

$$R_{CW} = \frac{P}{A}$$

where: P - destructive force (N),
A – cross-section area (mm^2).

Analyses of wood strength were conducted using INSTRON 3382 mechanical testing system.

RESULTS AND DISCUSSION

Every species of wood can be subjected to thermal modification, but for each species the optimum parameters of the process have to be chosen individually. This results largely from the physico-chemical properties of selected wood species. One of the most important factors influencing the choice of modification conditions and the subsequent application range is wood density and strength associated with it. Therefore, our aim was to find correlations and relationships between wood density and compressive strength along with modulus of elasticity in the case of pinewood (*Pinus sylvestris* L.), which has been subjected to thermal modification at different times and temperatures.

The results of changes in wood density of Scots pine (*Pinus sylvestris* L.) modified at 160°C and 200°C at various times of heating are shown in Figs. 1 and 2, respectively. Decrease of density was measured for each sample separately. Density of samples modified at 160°C for 2, 6 and 10 h decreased by 3.4 to over 4 % as compared to the initial values. At this temperature, modification time influences the density decrease, but the dependence is mild, if compared with the next experiment.

Greater changes in wood density were observed when modification was conducted at 200°C. The heating time at this temperature significantly differentiates wood density, while the density decrease after 10 hours heating is the strongest (over 7 %) compared with reference samples.

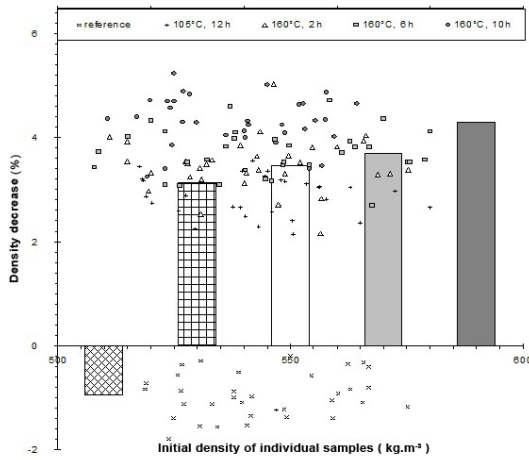

Fig. 1: Density changes of pinewood modified at 160°C.

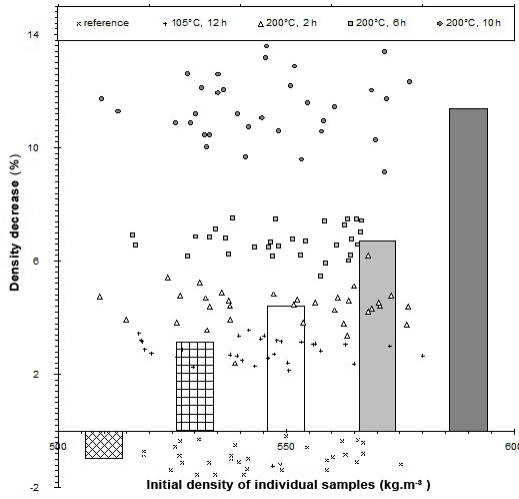

Fig. 2: Density changes of pinewood modified at 200°C.

Lowering of wood density at 200°C is caused mainly by fundamental changes in wood composition. These are connected with decrease of extractives content along with significant carbohydrate polymers degradation, especially hemicelluloses, in these conditions kg.m^{-3}.

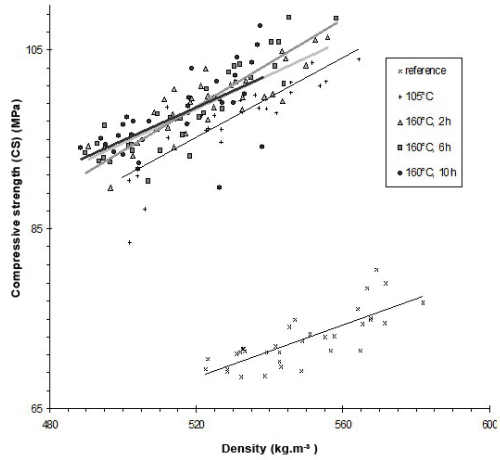

Fig. 3: Compressive strength changes of pinewood modified at 160°C.

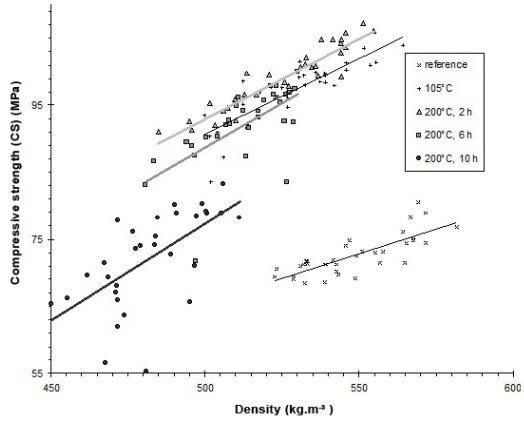

Fig. 4: Compressive strength changes of pinewood modified at 200°C.

Changes in wood density due to temperature effects are related to their mechanical properties. The results are shown in the following figures. The changes in compressive strength of pinewood modified at the temperature of 160 and 200°C were presented in the Figs. 3 and 4, while moduli of elasticity were compared in the Figs. 5 and 6, respectively. All data are presented according to density, individually for each sample of thermally modified wood.

In the case of modification conducted at 160°C, increase of wood compressive strength is observed, regardless of the time of treatment. When compared with oven-dried wood (105°C), of about 0 % moisture content, compressive strength wood after modification at 160°C is similar. On the base of the data obtained, in accordance with literature, high polymerisation degree carbohydrates (like cellulose) are supposed not to be significantly affected by thermal modification. Degradation of smaller macromolecules, like hemicelluloses, results in their content lowering, which is advantageous from the viewpoint of compressive strength of wood.

Wood samples modified at 200°C for a period of 6 and 10 h have a reduced compressive strength in comparison with both the reference samples and the oven-dried ones. In these conditions severe changes in wood composition occurs (Zawadzki et al. 2007), connected with not only hemicelluloses, but cellulose degradation as well. Such chemical changes occurring in pinewood cause decrease of compressive strength during prolonged modification.

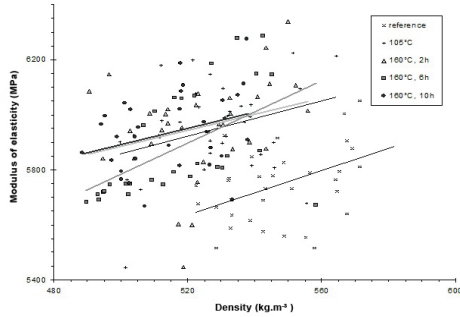

Fig. 5: Elasticity modulus changes of pinewood modified at 160°C.

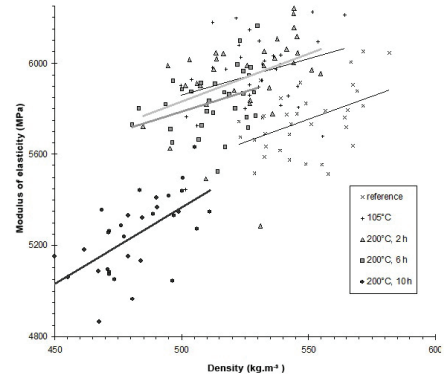

Fig. 6: Elasticity modulus changes of pinewood modified at 200°C.

Moduli of elasticity of reference, dried only and modified pinewood are shown in the Figs. 5 and 6. Similarly to the case compressive strength dependence on density, the changes in elasticity modulus are the highest when the heating at 200°C is applied for 10 h.

In most cases, the obtained correlation coefficients are very small in comparison with those obtained for compressive strength but show the dependence is probable.

CONCLUSIONS

In summary it can be concluded that changes in density, compressive strength and elasticity modulus parallel to the grain are caused by chemical changes occurring in the thermally modified wood. The major effect of increasing the strength properties of wood modified at high temperatures is due to hemicelluloses decomposition. They are less stable during heating than other structural components, namely cellulose and lignin.

Milder conditions of the modification, like lower temperature and shorter time of treating, favour the increase of wood compressive strength and modulus. Raising the temperature, with prolonged heating for 10 h causes a very sharp decrease of compressive strength and modulus. In comparison with the samples modified at 160°C for 2 h the average compressive strength is lower by almost 28 %. Estimated dependencies of compressive strength and modulus of thermally modified wood on its density were linear. The highest correlation coefficients were obtained for 160°C and shorter treating times. At higher temperature, size changes of the analysed samples were the highest, accompanied by a marked loss of weight.

Relationships obtained, presented in the figures allow to predict compressive strength and elasticity modulus of thermally modified pinewood (*Pinus sylvestris* L.) with some probability from simple measurements of wood density.

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