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Properties of thermally modified ash wood (*Fraxinus americana*) in the aspect of its affinity to water

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Abstract: *Properties of thermally modified ash wood (Fraxinus americana) in the aspect of its affinity to water.* The paper reports on the changes in the hygroscopic equilibrium of ash wood after thermal modification at different values of the relative air humidity and the degree of the wood swelling in transversal directions. It is shown that in the range of molecular sorption the thermal modification of wood causes a greater reduction in its hygroscopicity than in the range of capillary sorption. The reduction in the degree of wood swelling is also found greater in the tangent direction than in the radial one. The reduced swelling of the thermally modified wood is directly related to its decreased hygroscopicity with respect to that of unmodified wood.

Keywords: Ash wood, thermal modification, equilibrium moisture content, swelling

INTRODUCTION

Recently, increased interest has been observed in thermal modification of wood. It has been prompted by ecological character of this type of modification and the high quality of the final product that is characterised by reduced hygroscopicity, improved size stability and resistance to biotic decomposition. Moreover, thermal modification gives wood of attractive dark colour that can successfully imitate that of exotic wood (upon specific programme of modification) (Hill 2006, Akyildiz & Ates, 2008). Thermal modification eliminates the imperfections of the natural wood colour. From among many known and applied on industrial scale processes of thermal wood modification, particularly attractive is that developed in Finland (ThermoWood®Handbook, Finnish Thermowood Association, Helsinki 2003). According to Boonstr (2008), the interest in thermal treatment of wood follows also from the need to inhibition of excessive exploitation of wood of desired technological properties coming from tropical forests and from restrictions on the use of toxic chemicals for modification of wood from trees of European species.

The positive effect of thermal treatment on reduction of wood hygroscopic character has been already known (e.g. Kollmann & Shneider 1963). According to Kollmann & Fengel (1965) the limit temperature of wood treatment causing reduction in its hygroscopicity depends on the species of wood. For example for pine wood it is as low as 100°C, while for oak wood it is 130-150°C. Popper et al. (2005) analysed sorption isotherms recorded for five species of wood modified at 100, 150 and 200°C and a control sample and reported that reduction in the wood sorption abilities is noted already after its preliminary heating at 100°C, whereas significant differences appear for wood modified in higher temperatures. The analysis of isotherms within the Hailwood-Horrobin model has shown that the changes take place in the range of chemisorption and in that of capillary sorption. The reduced hygroscopicity of thermally modified wood and its reduced moisture-caused deformations follow from the reduction of hydroxyl groups in wood substance, related mainly to decomposition of hemicelluloses, relative increase in the crystallinity of cellulose and partial degradation and cross linking of lignin (Boonstra et al. 2007, Windeisen et al. 2009). Many authors have indicated that the affinity of thermally modified wood to water depends not only on the parameters of modification but also on the wood species.

This study was undertaken to determine the equilibrium moisture content at different relative air humidities, maximum swelling in transversal directions in wood from American ash (*Fraxinus americana*) subjected to thermal modification according to the method developed in Finland. This paper presents part of the results obtained at the Department of Wood Science, at Poznan University of Life Sciences.

METHODS

The experiment was performed on 4 trimmed boards of 25 mm in thickness and 100 cm in length, in which the annual rings were tangent to its broader surface. Each board was divided into two parts, of which the shorter one was about 350 mm long. The parts were marked to be able to identify them. The longer parts were subjected to modification, while the shorter ones were treated as controls. The process of modification was carried out according to the procedure described in ThermoWood®Handbook, Finnish Thermowood Association, Helsinki 2003, at 190 or 200°C for 2 hours. After modification and conditioning in the open space, the slabs were cut out of the boards and planned to the cross section of 20x20mm. Analogous slabs were cut out of the control board and shaped to the same size. Care was taken to make sure that the bars from the thermally treated and control material were the twinned pieces, so originated from the same place in the board. The bars were labelled to permit identification of the twinned bars. The samples to be studied of 10 mm in length were cut out from the bars. The samples were dried to oven dry state, measured and weighted and the density of wood in each sample was determined. All the samples were placed in desiccators above an oversaturated salt solution ensuring the relative air humidity of $\varphi=25\pm2\%$. The samples were conditioned in such conditions till stabilisation of their mass. After their weighting and measurements of all dimensions, the samples were moved to desiccators in which the relative air humidity was $\varphi=45\pm2\%$ and again after reaching the equilibrium moisture content they were weighted and measured and moved to subsequent desiccators of $\varphi=75\pm2\%$ and $\varphi=85\pm2\%$ over water table. Measurements were performed on ten control samples and ten samples modified at 190˚C or 200˚C.

RESULTS

The ash wood density measured for the modified and unmodified samples are presented in Table 1. They confirm the earlier reports of Weiland & Guyonnet (2003), Gündüz et al. (2008), Borrega & Kärenlampi (2008), Gonzalez- Pena & Hale (2009) indicating that thermal treatment of wood in high temperatures causes decrease in the wood density, which is the greater the higher the temperature of modification. This decrease is related to degradation of certain chemical components of wood and evaporation of some of the products of decomposition and extraneous components of wood.

Table 1. Density of American ash wood in oven dry state before and after thermal treatment

Kind of the material	Density [kg/m^3]			Density loss [%]		
	min	average	max	min	average	max
Control	640	680	710	3.4	4.4	5.2
Modified 190deg	610	650	680			
Control	575	650	690	6.3	7.1	7.9
Modified 200deg	535	600	650			

Dehydration of hemicelluloses and relative increase in the degree of cellulose crystallinity as well as the reaction of polycondensation of lignin lead to the reduced hygroscopicity of wood. It is well seen in Fig. 1 presenting approximate (because of the method of equilibrium moisture content determination) sorption isotherms of modified and unmodified wood. Each point in the plot is a mean value calculated for the 10 samples. The relation between EMC and the relative humidity was approximated by a third degree polynomial. The degree of reduction in equilibrium moisture content of thermally modified wood (MC_{mod}) in relation to that of the control wood (MC_c), shown in Fig. 1, bottom panel, is calculated as

$$MC_{loss} = \frac{MC_c - MC_{mod}}{MC_c} \times 100\ [\%].$$

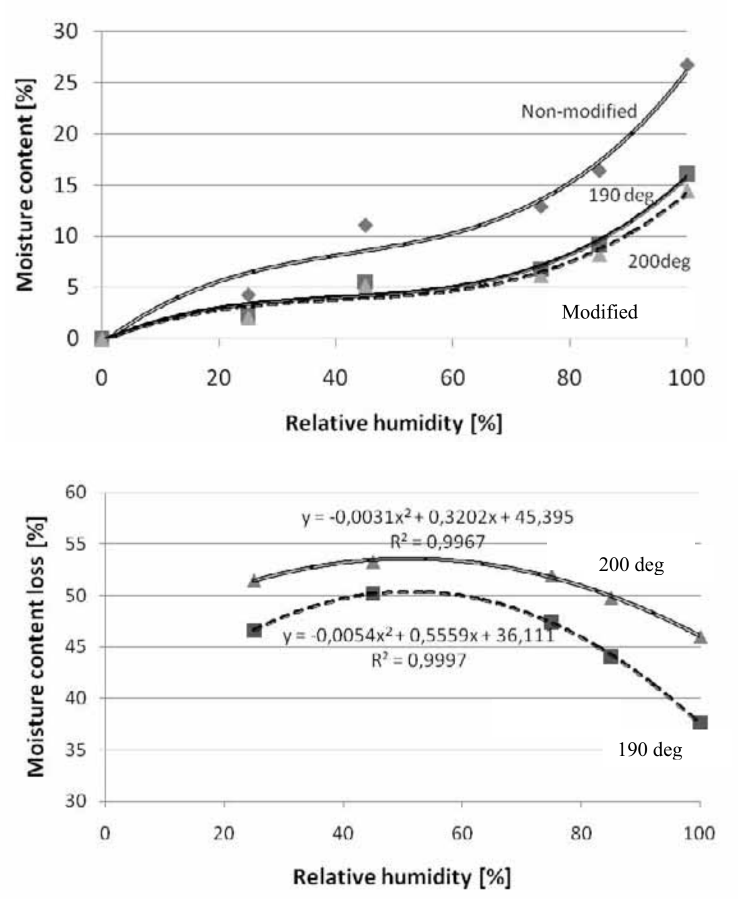

Fig. 1. The effect of thermal treatment of American ash wood on its equilibrium moisture content at different relative air humidity values

As follows from the plot of this relation, in the range of molecular sorption (up to φ of about 60%), the decrease in the equilibrium moisture content of thermally modified wood is greater than in the range of capillary sorption. This conclusion seems obvious taking into regard that thermal modification of wood leads to a decrease in the amount of hydroxyl groups (mainly as a result of hemicelluloses degradation), so to a decrease in the number of centres to which water molecules can be attached. This phenomenon causes a reduction on swelling of the modified wood, and hence, a reduced development of the surface of capillary. This is the reason for decreased equilibrium moisture content in the range of higher relative air humidity. The question why the difference between the equilibrium moisture content of the control wood and thermally modified wood decreases in the range of higher relative air humidity will be possible to answer after exact analysis of development of the inner surface area of wood as a function of its moisture content.

Changes in the degree of wood swelling as a function of the relative air humidity are qualitatively similar to those in sorption isotherms. Because of limited volume of the paper, we present only the results of the maximum degree of wood swelling in transversal directions (Fig. 2). According to Fig.2, thermal modification of wood at 190 and 200°C caused the reduction in its swelling by 32% and 55% in the tangential direction and by 32% and 52% in

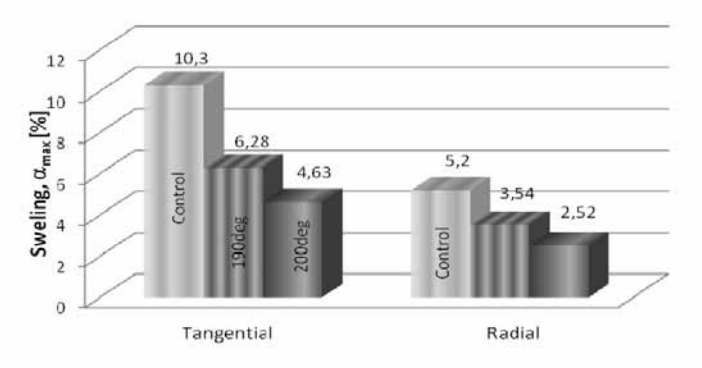

Fig. 2. Maximum swelling of American ash wood in transversal directions

the radial direction, respectively. The reduced swelling of thermally modified wood is a result of its decreased hygroscopicity. It can be concluded because the relation between the degree of the wood swelling as a function of its moisture content, shown for the tangential direction in Fig. 3, is the same as for unmodified wood.

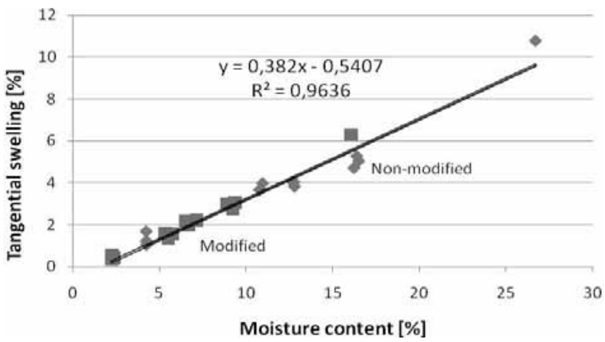

Fig. 3. The degree of wood swelling in the conditions of air humid versus its equilibrium moisture content

CONCLUSIONS

1. Thermal treatment of American ash wood at 190 or 200°C for 2 hours causes a decrease in its density by 4.5 and 7%, respectively.
2. The degree of reduction in the equilibrium moisture content of thermally modified wood is greater in the range of molecular sorption than in the range of capillary sorption.

3. Decrease in the wood hygroscopicity as a result of thermal modification is directly related to its reduced swelling relative to that of the unmodified wood.

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Streszczenie: *Właściwości drewna jesionu amerykańskiego (Fraxinus americana) modyfikowanego termicznie w aspekcie jego powinowactwa do wody.* W pracy przedstawiono wyniki pomiarów wilgotności równowagowej drewna jesionu modyfikowanego termicznie dla różnych wartości wilgotności względnej powietrza oraz stopień jego spęcznienia w kierunkach porzecznych. Wykazano, że w zakresie sorpcji molekularnej modyfikacja termiczna drewna powoduje większą redukcję higroskopijności niż w obszarze sorpcji kapilarnej. Stwierdzono także, że redukcja stopnia spęcznienia drewna jest nieco większa dla kierunku stycznego niż dla kierunku promieniowego. Zmniejszone pęcznienie drewna modyfikowanego jest ściśle związany z umniejszoną jego higroskopijnością w porównaniu z drewnem niemodyfikowanym.

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