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Selected mechanical properties of thermally modified American ash wood

WALDEMAR MOLIŃSKI, EWA FABISIAK, ŁUKASZ ŚRODECKI
Department of Wood Science, Poznan University of Life Sciences

Abstract: The compressive strength and bending strength along the grains as well as the elasticity modulus of American ash wood were determined for thermally modified samples and unmodified samples at the moisture content of 6%. Thermal modification of wood was shown to lead to a decrease in all mechanical parameters measured. The reduced values of mechanical parameters of modified wood could be only partly explained by its decreased density as a result of thermal treatment. As followed from the results, specific strength and specific elasticity modulus were better indicators of thermal degradation of wood than its absolute mechanical parameters.

Keywords: ash wood, thermal modification, compressive strength, bending strength, elasticity modulus

INTRODUCTION

As follows from the hitherto published papers on mechanical properties of thermally modified wood, it can show higher compressive strength, higher bending strength along the grains, higher linear elasticity modulus and hardness than the unmodified correspondent, depending on the parameters of treatment and wood species. Other properties such as tensile strength perpendicular and parallel to grains, shearing strength, dynamic bending strength and impact strength are always deteriorated (Thermo Wood® Handbook, 2003; Windeisen et al. 2009). Li Shi et al. (2007) studied a few species of Canadian wood and reported that thermal modification of wood causes a considerable decrease in its static bending strength and a small decrease in its elasticity modulus. The elasticity modulus of thermally modified birch and ash wood was even by 15 - 30% higher than that of the unmodified wood. Changes in the Brinell hardness number were clearly dependent on the type of modified wood. For wood from pine, spruce and birch trees usually an increase in the hardness was observed, both in longitudinal and in transversal directions, moreover it was more pronounced on transverse surfaces. On the other hand, the hardness of thermally modified ash tree was in all directions lower than that of the unmodified wood. Decrease in all mechanical parameters of wood after thermal treatment was observed also for nazel wood (*Corylus colurna* L.) modified at temperatures from the range 120 - 180°C (Korkut & Hiziroglu 2009). For black pine wood (*Pinus nigra* Arn.) a decrease in the compressive strength along the grains was reported, irrespective of the temperature and time of treatment (Gündüz et al. 2008). Results of these studies are completely different from the earlier reports by Boonstr et al. (2007) for two species of pine wood (*P. radiata* D. and *P. sylvestris* L.) and for spruce wood (*Picea abies* Karst.). Borrega & Kärenlampi (2008), who studied mechanical properties of thermally modified wood as a function of the decrease in its mass, reported that mechanical strength, strain on failure and impact strength decreased with decreasing mass of wood. The wood stiffness did not decrease with decreasing mass up to the decrease of 3%, for greater mass decrease it also decreased with decreasing mass. The same authors also found out that all mechanical parameters of wood were the lowest when modification was performed in dry state.

Mechanical parameters of thermally modified wood were usually referred to those of control unmodified samples, conditioned at the same temperature and relative air humidity. It means that the mechanical parameters of the modified wood were determined at a lower moisture content of wood tissue than that of the control samples. This fact was noted by Arnold (2010) who studied the influence of moisture content of wood on the bending strength of thermally modified beech wood. In view of the above we decided to compare certain mechanical parameters of thermally modified and unmodified American ash wood at a similar moisture content of these two samples.

METHODS

The material studied was wood from American ash tree (*Fraxinus americana)* in the form of trimmed boards of 25 mm in thickness, in which annual rings were tangent to the broader surface. Thermal modification was performed in one of the sawmills near Leszno (Poland) according to the procedure described in ThermoWood®Handbook, Finnish Thermowood Association, Helsinki 2003. The control samples were sections of about 350 mm in length cut off the above boards. The moisture content of the material subjected to modification was close to 12%. The modification was performed at 190 or 200°C for two hours. After the modification and conditioning in open space, from the modified boards a few slats of the cross section size 25x25 mm were cut out and planned to the cross section size 20x20mm. Analogous slats were cut out from the control material. From the slats of the modified and unmodified material, the samples for determination of compressive strength and bending strength along the grains, of the lengths 30 and 300 mm, were prepared. Special care was taken to make sure that the slats from the thermally treated and control material were the twinned pieces, so originated from the same place in the board and covered the same annual rings. The samples with any defects were left out and the good quality samples modified at either temperature were conditioned in desiccators above the oversaturated NaCl solution. The mass increase of the samples was monitored till it remained unchanged. The control samples were kept in the laboratory conditions. After conditioning the modified samples had the moisture content similar to that of the control samples; that is close to 6%. The compressive strength and bending strength were measured on a test machine Zwick 50, whose software permitted calculation of the above parameters and elasticity modulus.

RESULTS

Analysis of the mechanical properties of wood, including thermally modified samples, needs to be made with reference to its density. Results of measurements of the American ash wood density, prior to and after modification, performed at the moisture content close to 6%, are presented in Table 1. These data confirm the earlier reports by Weiland & Guyonnet 2003, Gündüz et al. 2008; Borrega & Kärenlampi 2008; Gonzalez- Pena & Hale 2009, saying that thermal treatment of wood causes a decrease in its density, and the decrease is the greater the higher the temperature of treatment. The thermal treatment of American ash wood for 2 hours at 190°C led to almost 6% decrease in the wood density, while the treatment at 200°C – to about 12% decrease in the density of wood relative to that of the initial material.

Table 1. American ash wood density in control samples and thermally modified samples (TM) at 190 or 200°C measured at the moisture content 6%

Density, ρ [kg/m^3]			Change density [%]
Kind of the material			
Control	TM 190°C	TM 200°C	
672-701-729	623-660-719	-	-5.85
691-723-759	-	620-633-652	-12.59

As the compressive strength of wood is closely correlated to its density, the thermally modified wood shows lower mechanical strength than unmodified one. Thermal treatment at 190^{o}C and 200^{o}C caused a decrease in the compressive strength along the grains by 10 and 20%, respectively, Table 2. As follows from analysis of the specific mechanical strength of the wood, the decrease in the mechanical strength thermally modified wood is not only a consequence of the decrease in its density. The specific mechanical strength of ash wood modified at 190°C is by about 5% lower than that of the control sample, while that of the wood modified at 200°C is by about 10% lower than that of the control one, it can be concluded that the decrease in wood density is only partly responsible for the decrease in the wood mechanical strength. The other part of the decrease is assigned to structural changes in the cell wall. These results prove that the earlier reports e.g. in ThermoWood®, Handbook (2003) claiming that the thermally modified wood has greater mechanical strength than the unmodified one are misconceptions following from the fact that the mechanical strength of the modified and unmodified wood was compared for wood tissues of different moisture content as the modified and unmodified wood conditioned in the same environmental conditions (temperature and relative air humidity) reach different equilibrium moisture contens.

Table 2. Compressive strength of thermally modified and control wood samples measured at the moisture content close to 6%

Sample type	Mean density ρ [kg/m^3]	Mean moisture content MC [%]	Compressive strength R_c [MPa]	Change in compressive strength R_c [%]	Specific compressive strength Rcs [km]
Control	701	5.98	72-77-80	-10.39	11.0
TM 190^O C	660	5.71	60-69-76		10.5
Control	723	5.61	70-78-85	-20.51	10.7
TM 200^O C	633	5.25	58-62-65		9.7

Reduction in the mechanical strength of wood as a result of its thermal modification is greater on bending. For the modification at 190 and 200^{o}C the change in bending strength was 26 and 34% (Table 3), which indicates that the mechanical bending strength is more sensitive to the structural changes taking place upon thermal modification. The changes in cell wall structure (first of all depolymerisation of cellulose) have a greater effect on the bending strength than the changes in wood density. This conclusion follows from the fact that the changes in the specific mechanical strength are only by 3 and 6% smaller than the changes in absolute values expressed in MPa.

Table 3. Bending strength of thermally modified and control samples measured at the moisture content MC ≈ 6%

Sample type	Mean density ρ [kg/m^3]	Mean moisture content MC [%]	Bending strength MOR [MPa]	Change in bending strength MOR [%]	Mean specific bending strength MORs [km]
Control	708	5.96	125-146-164	-26.71	20.6
TM 190^O C	672	5.91	83-107-129		16.0
Control	744	6.17	121-134-140	-34.33	18.0
TM 200^O C	677	4.56	55-88-125		13.1

Thermal modification of ahs wood also resulted in a decrease in the elasticity modulus determined in the static tests upon wood compression and bending. The elasticity modulus of all wood samples studied is given as mean values in Table 4. Analysis of the changes in elasticity moduli with those in mechanical strength parameters reveals that the modulus determined upon wood compression changes to a greater degree than the compressive strength of the wood. Decrease in the elasticity modulus is smaller when it is determined in the tree-point bending test.

Table 4. Mean values of the elasticity modulus determined upon bending and compression of wood at the moisture content close to 6%

Elasticity modulus determination	Elasticity modulus [MPa]					
	Type of samples					
	Control	TM 190°C	Change in [%]	Control	TM 200°C	Change in [%]
Compression	16281	12500	-23.21	13518	10516	-22.21
Bending	13358	11693	-12.46	11931	11335	-5.00

CONCLUSIONS

1. Thermally modified ash wood shows a reduced compressive strength and bending strength along the grains as well as lower elasticity modulus determined in the tests upon wood compression and bending relative to the corresponding parameters of the unmodified wood, at comparable moisture content of these two types of wood.
2. The reduction in mechanical parameters of thermally modified wood relative to those of unmodified one can be only partly explained by decrease in wood density, a considerable contribution to this process comes also from defects of cell walls.
3. The specific mechanical strength and specific elasticity modulus are more reliable indicators of thermal degradation of wood than the absolute values as the specific ones take into regard the changes in wood density.

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Streszczenie: *Wybrane mechaniczne właściwości drewna jesionu amerykańskiego modyfikowanego termicznie.* W pracy przedstawiono wyniki oznaczeń wytrzymałości na ściskanie i zginanie wzdłuż włókien oraz modułu sprężystości drewna jesionu amerykańskiego modyfikowanego termicznie i porównano je z analogicznymi wielkościami oznaczonymi dla drewna niemodyfikowanego przy wilgotności 6%. Wykazano, że modyfikacja termiczna drewna przyczyniła się do obniżenia wszystkich mierzonych parametrów mechanicznych. Stwierdzono, że obniżone, w porównaniu z drewnem wyjściowym, wartości parametrów mechanicznych drewna modyfikowanego, można tylko częściowo tłumaczyć obniżoną jego gęstością. Wykazano, że lepszym wskaźnikiem degradacji termicznej drewna od jego bezwzględnych parametrów mechanicznych jest wytrzymałość właściwa oraz właściwy moduł sprężystości.

Corresponding author:
Department of Wood Science
Poznań University of Life Sciences
60-627 Poznań, Poland
ul. Wojska Polskiego38/42
e-mail: knod@up.poznan.pl