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SHORT NOTE

INFLUENCE OF THERMAL TREATMENT ON MECHANICAL STRENGTH OF SCOTS PINE (*PINUS SYLVESTRIS* L.) WOOD

Vasiliki Kamperidou, Ioannis Barboutis, Vasileios Vasileiou
Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Laboratory of Wood Products and Furniture Technology
Thessaloniki, Greece

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ABSTRACT

In this study, mechanical properties of Scots pine wood (*Pinus sylvestris* L.) were determined after its thermal treatment at 200°C, for three different time periods of 4, 6 and 8 hours. Bending strength (MOR), modulus of elasticity (MOE), impact bending strength, compression strength and hardness in tangential and radial direction, which are properties of great significance for the strength and stability of wooden structures and furniture, were examined and compared to the corresponding untreated pine wood properties. Equilibrium moisture content (EMC) and density of treated and untreated specimens were also estimated.

KEYWORDS: Bending strength, mechanical, modification, Scots pine, thermal treatment.

INTRODUCTION

Under constant attempts to implement enhancing processes, are some of the poor properties of wood, referring mainly to dimensional instability and susceptibility to microorganism attacks. Several preservatives have been proposed and developed so far, in order to provide a solution, which, however, are accompanied by the concern of people about the potential hazard to human health and environment. Modification of wood is a method that came to fill this gap, providing the improvement of some crucial wood properties without carrying the environmental impact of preservatives. Specifically, thermal modification, which is one of the oldest and easiest methods of wood modification, seems to improve dimensional stability and biological durability of wood, even though some mechanical properties appear to deteriorate with treatment intensity. There is a high interest in the research field of wood modification and extensive research has been done so far, evaluating the influence of thermal treatment on the physical, hygroscopic and mechanical properties of wood, in order to optimize the treatment conditions for each species, according to the desirable properties for each kind of application. The objective of the current study is to evaluate the effect of thermal treatment at 200°C for variable durations, on the mechanical properties of Scots pine wood, in order to elucidate the potential range of applications of the treated material in wooden structures and furniture and comprehend the behaviour of this wood species after its thermal treatment.

MATERIAL AND METHODS

Boards of Scots pine wood (*Pinus sylvestris* L.) were cut in the following dimensions: 35 mm thickness x 70 mm width x 400 mm length. Prior treatment, the boards had a nominal (EMC) of 11.63 % and mean density of 0.505 g.cm^{-3}. For the thermal treatment of the boards, a laboratory heating unit (80 x 50 x 60 cm), capable of controlling the temperature within a range of ±1°C was used. The temperature applied during the thermal treatment was constantly 200°C, under atmospheric pressure environment, in the presence of air and the treatment duration was 4, 6 and 8 hours. Eight boards were used in each treatment. After a conditioning period of two months (20 ± 2°C, 60 ± 5 % humidity), EMC and density of the specimens were estimated. The boards were cut in final cross section dimensions for the measurement of mechanical properties, according to the respective standards (density: ISO 3131: 1975, moisture content: ISO 3130: 1975, compression strength: DIN 52185: 1976, bending strength: ISO 3133:1975, hardness (Janka): ISO 3350: 1975, impact bending strength: ISO 3348: 1975).

RESULTS

As the intensity of thermal treatment increases, the values of bending strength (MOR) and MOE in bending appear to decrease. Mean value of MOR of 4 hours treated specimens was found to be 0.34 % lower than the corresponding value of untreated wood specimens, while the 6 and 8 hours treated specimens recorded 14.6 and 25.90 % lower MOR values, respectively. The mean value of MOE of the specimens treated for 4 hours was found to be 4.4 % lower compared to the respective value of untreated specimens, whereas the mean MOE value of 6 and 8 hours treated specimens marked decreases of 3.5 and 5.83 %, respectively. Generally, the reduction in MOE was found to be smaller than that of MOR.

Tab. 1: Mean value of MOR, MOE, impact bending strength and compression strength.

Treatment	MOR (N.mm^{-2})	MOE (N.mm^{-2})	Impact bending strength (J.cm^{-2})	Compression strength (N.mm^{-2})
Control	81.39 (9.22)*	9532.13 (967.61)	2.75 (0.99)	50.49 (4.74)
4 h	81.11 (6.10)	9112.87 (886.98)	2.73 (0.95)	57.44 (4.79)
6 h	69.51 (5.87)	9198.96 (317.03)	2.28 (0.74)	53.57 (2.97)
8 h	60.31 (10.01)	8976.73 (762.48)	2.14 (0.99)	52.95 (3.73)

*Numbers in parentheses represent the standard deviation of ten replicates

The impact bending strength values of treated specimens generally recorded a decrease, while the compression strength of treated specimens demonstrated an increase, compared to values of untreated specimens. The impact bending strength values of specimens treated for 4 hours marked 0.69 % lower strength compared to the strength level of untreated specimens, while the values of 6 and 8 hours treated specimens decreased 17.09 and 22.34 %, respectively, compared to the control specimens. Noticeable is the fact that, the decrease of impact bending strength is initially gradual, whereas as the treatment duration increases, the impact bending strength values tend to decrease abruptly, compared to untreated wood.

The specimens of all different treatment durations applied in this experiment were found to ensure a little higher compression strength values compared to the untreated wood specimens. The mean compression value of 4 hours treated specimens was found to be 13.76 % higher than untreated wood, while the 6 and 8 hours treatment resulted in 6.09 and 4.88 % higher compression strength.

As it is evident, the hardness values of the treated specimens demonstrated a decrease due to thermal treatment. According to Tab. 2, in the first 4 hours of the treatment, the hardness values recorded an abrupt decrease, whereas by increasing the duration, the hardness values marked a slight increase, without reaching the strength level of control specimens. The mean hardness in tangential direction value, of the 4 hours treated specimens was measured to be 25.13 % lower than the untreated wood value, while the 6 and 8 hours treatment resulted in slighter decreases of 24.73 and 9.34 %, respectively. This tendency of hardness values was similar for both tangential and radial direction of the specimens. The mean hardness in radial direction value of the 4 hours treated specimens was measured to be 26.37 % lower than the corresponding value of the untreated wood, while the 6 and 8 hours treatment resulted in quite lower decreases of 22.29 and 19.58 %, respectively. As it is clearly indicated, the hardness values seem to be intensely deteriorated in 4 hours treatment, compared to untreated specimens, while treatments longer than 4 hours seem to change this tendency and slightly increase the hardness of Scots pine wood.

Tab. 2: Mean values of Janka hardness in tangential and radial direction.

Treatment	**Tangential hardness (kN)**	**Radial hardness (kN)**	**Mean hardness (kN)**
Control	2.62 (0.24)*	2.51 (0.32)	2.56 (0.28)
4 h	1.96 (0.37)	1.85 (0.34)	1.91 (0.35)
6 h	1.97 (0.39)	1.95 (0.37)	1.96 (0.38)
8 h	2.38 (0.28)	2.02 (0.27)	2.20 (0.33)

*Standard deviation is referred in parenthesis

Furthermore, the EMC of all heat-treated samples decreased in relation to the untreated wood, even for the less intensive treatment of 4 hours at 200°C and the higher the duration of the thermal treatment was, the higher the decrease of the respective EMC was. Specifically, the EMC of untreated pine wood specimens was 11.63 %, while after the thermal treatment and a conditioning period of four weeks the EMC value of 4 and 6 hours treated specimens were found to be 5.82 and 5.68 %, respectively and 5.48 % for 8 hours treated specimens. This clearly suggests that thermal treatment affects in great extent the dimensional stability and absorbing capacity of wood, while this EMC value reduction could be related to the mass loss (hemicelluloses degradation) and the hydroxyl groups loss that have occurred during thermal treatment. To thermal degradation of polysaccharides, substance losses (volatile extractives) and the simultaneous formation of other constituents in the wood mass, during the thermal treatment process, could be attributed the decrease of the mechanical properties, the physical properties and the change in behavior of thermal treated pine wood (Fig. 1).

The density of the treated specimens was decreased from 0.505 to 0.412 g.cm^{-3} for specimens treated for 4 hours at 200°C, to 0.411 for 6 hours treated specimens and 0.409 g.cm^{-3} for 8 hours treated specimens, which correspond to decreases of 18.41, 18.61 and 19 %, respectively. The density decrease is related not only to moisture content decrease, but also to mass loss due to thermal modification.

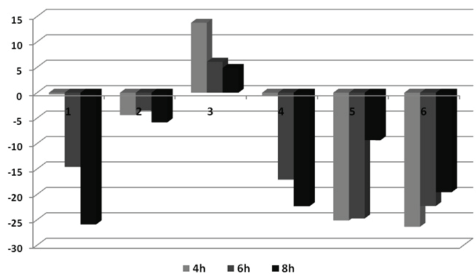

Fig. 1: Change of the treated specimens properties. 1.) MOR (N.mm^{-2}), 2.) MOE (N.mm^{-2}), 3.) Compression strength (N.mm^{-2}), 4.) Impact bending strength (J.cm^{-2}), 5.) Tang. hardness (kN), 6.)Rad. hardness (kN).

DISCUSSION

These results are generally in agreement with research findings of Shi et al. (2007) who studied the mechanical behavior of spruce, pine, fir, aspen and birch wood by using thermowood heat-treatment process (at 200°C or higher for 3 h). They recorded a decrease of 22-28 % in MOR of heat-treated jack pine wood, while the decrease in MOE of heat-treated pine ranged between 10 and 15 %. Nevertheless, they revealed that heat-treated pine wood was of higher radial, tangential, and longitudinal hardness compared to untreated wood. Additionally, similar results were reported by Korkut et al. (2008) who applied Scots pine wood to thermal treatment under atmospheric pressure at varying temperatures (120, 150 and 180°C) for varying durations (2, 6 and 10 h) and found that compression strength, MOR, MOE, Janka-hardness, impact bending strength and tension strength perpendicular to grain deteriorated after the treatment. Korkut and Güller (2008) reported that the mechanical properties decreased with increasing temperature and time, except for hardness, which increased slightly till 180°C for 8 hours, but it decreased with increasing temperature and time, probably due to further structural degradation. Finally, Boonstra et al. (2007) subjected Radiate pine, Scots pine and Norway spruce to a two-stage heat treatment and proved a clear effect on the mechanical properties of softwood species. The tensile strength parallel to the grain, bending strength and impact bending strength presented large decreases, whereas the compressive strength increased. Referring to other thermal treated softwood species, similar results were recorded. Esteves et al. (2008) treated Maritime pine using hot air for 2-24 hours at 170-200°C and found that MOE was little affected by the treatment, while MOR decreased much more. Kocaefe et al. (2010) estimated the effect of several heat treatment conditions (120-230°C) on the mechanical properties of North American jack pine wood and revealed that MOE, MOR, hardness and screw withdrawal strength were deteriorated significantly at temperatures higher than 200°C. Many researchers who thermally treated pine wood concluded in similar results referring to mechanical properties (Ates et al. 2009, Kol 2010 etc.). Since the findings of the literature previous researches on mechanical properties of heat treated wood are not always compatible with each other, especially for compression and hardness, further research should be conducted, including strength in combination with chemical composition tests, as well.

CONCLUSIONS

As the intensity of the treatment increases, the density and EMC value decreases, MOR, MOE, hardness and impact bending strength also tend to decrease, while the compression strength values demonstrated an increase. Consequently, before the application of thermal treated wood in furniture and other kinds of structures, it should be paid special attention in the types of loads that prevail or interact with each other in each wooden structure, while tests on the joints strength, using wooden elements of treated wood and tests of the whole furniture strength are indispensable before the use.

REFERENCES

1. Ates, S., Akyildiz, M.H., Özdemir, H., 2009: Effects of heat treatment on Calabrian pine (*Pinus brutia* Ten.) wood. BioResources 4(3): 1032-1043.
2. Boonstra, M., Van Acker, J., Tjeerdsma, B., Kegel, E., 2007: Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents. Annals For. Sci. 64(7): 679-690.
3. Esteves, M.B., Domingos, J.I., Pereira, M.H., 2008: Pine wood modification by heat treatment in air. BioResources 3(1): 142-154.
4. Kocaefe, D., Poncsak, S., Tang, J., Bouazara, M., 2010: Effect of heat treatment on the mechanical properties of North American jack pine: Thermogravimetric study. J. Mater. Sci. 45(3): 681-687.
5. Kol, H.S., 2010: Characteristics of heat-treated Turkish pine and fir wood after thermowood processing. Journal of Environmental Biology 31(6): 1007-1011.
6. Korkut, S., Akgül, M., Dündar, T., 2008: The effects of heat treatment on some technological properties of Scots pine (*Pinus sylvestris* L.) wood. Bior. Technol. 99(6): 1861-1868.
7. Korkut, D.S., Güller, B., 2008: The effects of heat treatment on physical properties and surface roughness of red-bud maple (*Acer trautvetteri* Medw.) wood. Bior. Technol. 99(8): 2846-2851.
8. Shi, J.L., Kocaefe, D., Zhang, J., 2007: Mechanical behaviour of Quebec wood species heat-treated using thermowood process. Holz als Roh- und Werkstoff 65(4): 255-259.

Vasiliki Kamperidou, Ioannis Barboutis, Vasileios Vasileiou
Aristotle University of Thessaloniki
Faculty of Forestry and Natural Environment
Laboratory of Wood Products and Furniture Technology
54124 Thessaloniki
Greece
Phone: +30-2310-998895
Corresponding author: vkamperi@for.auth.gr