INFLUENCE OF THERMAL MODIFICATION ON SELECTED PROPERTIES OF SCOTS PINE WOOD (*PINUS SYLVSETRIS L.*).

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Abstract

The heat treatment is often applied to wood to improve its properties. This study examined the effect of heat treatment on certain mechanical properties of Scots pine (Pinus sylvestris L.), which is widely used in industry. The influence of thermal treatment on the compression strength, shear strength, modulus elasticity in bending, static bending strength, cleavage strength and Brinell hardness has been investigated. Wood was subjected to heat treatment under atmospheric pressure at varying temperatures (150, 160, 170 and 180 °C) in overheated steam. Modification of Scots pine wood affected mechanical properties of wood but observed changes (bending strength, modulus of elasticity, Brinell hardness) are not statistically significant. Only increase of compression strength along the fibers and decreased cleavage strength are clear. Optimal temperature of thermal modification ranges from 160 to 170 °C.

Key words: *Scots pine wood, thermal modification, mechanical properties*

INTRODUCTION

Effects of researches indicate changes in technical characteristics of wood treated with different methods of modification [Zaman et al. 2000, Yildiz 2002, Hill 2007]. The thermal modification of wood is one of the active modification methods and finds its greatest utility [Hill 2007]. The active method results in changes in the cell wall or wood surface or both of these [Yildiz 2002]. This kind of modification is based on the effects which occur in wood treated with external factor, such as temperature [Viitaniemi 1993, Militz 2002, Esteves and Pereira 2009]. Process of modification requires specialized environment. The amount of oxygen cannot exceed 2 %. Process of thermal modification may be done in steam, nitrogen, oil bath or in exhaust gases environments. Various technologies have been developed in different countries. The most common technology is modification in overheated steam environment, therefore it is known best.

Results of this modification are changes in chemical and mechanical properties of wood. Thermal modification is a process of partial pyrolysis of wood in low oxygen environment. It leads to change in chemical composition of wood, such as degradation of hemicellulose and transformation of cellular wall. Hemicellulose degradation starts in 140 - 150 °C temperature, and cellulose degradation starts in over 150 °C. Degradation and transformation of lignin (relative increase in amount of lignin) and removal of volatile

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components such as resin is also occurring during process of modification. Products formed in wood, such as organic acids, lead to decrease of pH. Hydroxide content, i.e. alcohols and phenols decreases as well. Maintaining constant process parameters is extremely important [Hill 2007, ThermoWood 2003].

The effect of changes in chemical composition and structure are the changes of wood properties, namely: equilibrium moisture content (EMC) is approximately 50 % lower than moisture content of unmodified wood, increase the dimensional stability (shrinkage and swelling of wood are about 50 % less) and increased shape stability, increased thermal insulation, increased resistance to biological corrosion, coniferous wood partially freed from the resin and volatile substances, color change - during thermal processing comes to darken the color of wood, which gives the effect of the appearance of tropical wood. Moreover, wood subjected to thermal modification is an ecological product, its use, possible recycling are completely safe for human health and the environment [Zaman et al. 2000, Militz 2002, Yildiz 2002, Bekhta and Niemz 2003, Esteves and Pereira 2009, Niemz, Hofmann and Retfalvi 2010, Bakar, Hizirogle and Tahir 2013].

Usually, the heat treatment process involves exposing wood to temperatures ranging from 160 to 260 °C. The duration of heat treatment generally vary 15 min to 24 h depending on the process, wood species, samples size, moisture content of samples and the desired mechanical properties, resistance to biological attack and dimensional stability of the final product [Militz 2002]. Treating wood at lower temperatures for longer time periods does not produce the desired properties. Temperatures over 150 °C change the physical and chemical properties of wood gradually [Syrjanen and Oy 2001]. At temperatures over 150 °C the strength properties start to weaken but other properties are improved e.g. durability, dimensional stability. The wood becomes more brittle, and bending and tension strength decrease by 10–30 %. Therefore, the use of heat-treated wood in load-bearing constructions is much restricted [Militz 2002, Yildiz 2002, Hill 2011].

An important issue is to identify opportunities to increase the usefulness of domestic wood (sourced from local current supply). This is because of the characteristics of the material most often harvested - Scots pine (*Pinus sylvestris* L.). Scots pine has superior technological properties and high usage potential. It is an important tree species in the forest products industry of Poland. It is estimated that pine forests account for nearly 70 % of the resources base in Poland. This is the reason why softwood (mainly pine) dominates in the processing of the timber industry. Pine wood is used for extended production of many type of products, e.g. wooden joinery (elements of windows and doors), elements used in external conditions (terrace boards, garden furniture, etc.). However, Scots pine wood has a limited usefulness. The dominant part of trunk volume is sapwood (about 2/3 the thickness of the trunk - Kozakiewicz and Krzosek 2013). Sapwood part of the tree has a lower resistance to corrosive agents biological, like wood without heartwood (poplar, linden, alder, birch, beech) or unstained heartwood (fir, spruce) [EN 350-2:1994].

MATERIAL AND METHODS

Wood species selected for the research is Scots pine (*Pinus sylvestris* L.) - names according to EN 13556:2003. The selected timber used to tests was avoided of defects typical for wood such as: knots, cracks, insects, resin leaks, signs of fungal infection (no evidence of blue stain change colour indicating a biological degradation). Wood samples predicted to modification were of size of 25x100x500 mm (last dimension along the fibers) and included both sapwood and heartwood (50:50). The heating temperature and duration were selected close to the technological drying regimes. Modification temperature was 150, 160, 170 and 180 °C. The process was typical, included four phases: drying wood (12 h) at temperature 105 °C, gradual heating wood to maximum temperature (5 ÷ 8 h), proper thermal modification of wood during 2,5 h in overheated steam and cooling and seasoning (12 h).

Preparation of samples to determine wood properties took place after wood modification. For determination of cleavage strength and Brinell hardness 20 samples were prepared and 40 samples for determination other properties. Mechanical tests were performed according to the standards: ISO 3130:1975, ISO 3131:1975, ISO 3787:1976, PN-D-04102:1979, ISO 3133:1975, ISO 3349:1975, PN-D-04106:1954, EN 1534:2011. Prior to the determination of wood properties, wood was conditioned in air at a temperature close to 20±3 °C and relative humidity 65±5 %.

RESULTS AND DISCUSSION

Scots pine wood after thermal modification in overheated steam changes its moisture content (moisture content of sapwood and heartwood is lower) as other thermal modified wood [Wang and Cooper 2005, Estaveset al. 2008]. In normal climate conditions, moisture content of not modified wood ranges 11 to 12 %, while under the same conditions of terms moisture content of wood after thermal modification was 7 to 8 %. The increase in temperature of modification from 150 to 180 °C causes only a slight decrease in moisture content. Both in case of not modified wood and wood treated elevated temperature, moisture content of sapwood zone was higher than moisture content of heartwood zone (Table 1).

Before thermal treatment wood density was aproximately 587 $kg \cdot m^{-3}$ (in each group density ranged from 583 to 597 $kg \cdot m^{-3}$). Due to the process of modifying the mass of wood is reduced by approximately 3 ÷ 4 % (1 % changes in density). Similar results were reported by several authors [e.g. Viitaniemi 1993, Esteves et al. 2008].

Analysis of the results of determining the mechanical properties of wood indicates that the effect of thermal modification is not clear (Table 2). The reason of this is fact that the results are affected by different levels of equivalent moisture content of wood modified in different temperatures. Some researchers indicate influence of thermal modification on decrease the mechanical properties of wood [Yildiz 2002, Juodeikiene 2009] and the others indicated the increase of mechanical properties [e.g. Bonstra 2008]. In this case, the reference level is extremely important as well as maintaining constant conditions of samples conditioning or the desire to compare properties of wood of the same moisture content.

Table 1. The statment of result evoluation of moisture content after conditioning in normal climate conditions (air temperature 20 °C and RH 65 %)

Scots pine:	Unit*	Heat treatment [°C]				
		None	150	160	170	180
sapwood	Avg.	**12,1**	**7,9**	**8,0**	**8,0**	**7,6**
	S.	±0,4	±0,9	±0,2	±0,3	±0,4
heartwood	Avg.	**11,3**	**7,5**	**7,3**	**7,0**	**6,7**
	S.	±0,5	±0,5	±0,4	±0,3	±0,9

* Avg. – average value, S. – standard deviation.

Modification of wood in the temperature range 150 - 180 °C resulted in a slight increase in static bending strength and compressive strength along the fibres. Despite the increase in the value of strength, the change is not statistically significant. The samples of modified wood after bending test were smoother compared to the unmodified wood (contained much less needle-like splinters). Partially this was also correlated with temperature modification - the smoothest scraps were obtained in testing samples of wood after modification at 180 °C. Typically, during bending test the samples broke up into two separate parts while the unmodified wood "kept" in the upper band squeeze. These changes indicate occurring transformation in the internal structure of wood modification - wood becomes more brittle and is more prone to rupture.

Table 2. The statment of result of evoluation of influence if thermal treatment on mechanical properties

Heat treatment	Unit *	Density	Compression strength	Bending strength	Modulus of elasticity in bending	Cleavage strength	Brinell hardness
[°C]		kg·m^{-3}	MPa	MPa	MPa	MPa	MPa
None	Avg.	**583**	**63,3**	**107**	**11450**	**0,371**	**19,5**
	±S.	64	7,9	18	1880	0,043	4,5
150	Avg.	**579**	**75,6**	**122**	**12230**	**0,299**	**18,8**
	±S.	71	11,2	29	2490	0,037	6,2
160	Avg.	**590**	**76,8**	**119**	**12480**	**0,297**	**19,0**
	±S.	59	12,3	25	2230	0,043	5,2
170	Avg.	**572**	**80,1**	**108**	**12040**	**0,295**	**20,6**
	±S.	68	8,4	26	2370	0,042	6,5
180	Avg.	**580**	**79,8**	**117**	**12010**	**0,266**	**19,4**
	±S.	79	9,5	34	2700	0,030	4,1

* Avg. – average value, S. – standard deviation.

The influence of thermal modification of Scots pine on modulus elasticity in bending was similar as in case of static bending and compression strength. Thermal modification of wood at temperature range of 150 - 180 °C caused a slight increase in the modulus of elasticity. This increase is siginificant. The results show the high diversity of modulus of elasticity.

Average value of initial cleavage strength (the lowest of all strength) was 0,371 MPa (Table 2). Thermal modification negatively affected by the decrease in cleavage resistance. Modification at a temperature of 150-170 °C has reduced resistance to cleavage to 80% of initial value. Modification at temperature of 180 °C reduced the cleavage strength to approximately 70% of initial value. Higher temperatures cause degradation of wood tissue [Hill 2007, ThermoWood 2003], which is evident in lowering resistance to cleavage. This feature is important in the woodwork of windows pointing to the danger of splitting of wood during driving screws - mounting hardware or the danger of chipping the profile elements. In order to preserve adequate cleavage strength of Scots pine wood for joinery is unlikely to conduct wood modification process at temperatures higher than 170 °C.

The results of tests confirmed that treatment at temperatures in ranges 150-180 °C does not cause changes of wood hardness (Table 2). The average values of Brinell hardness are similar and taking into account the high diversity of density typical for softwood of inhomogeneous structure of annual rings, it should be considered that there are no significant differences between hardness of control wood and hardness of wood after modification. Modification of Scots pine wood at temperatures from 150 to 180 °C did not influence significant on hardness changes.

CONCLUSION

Modification in overheated steam of Scots pine wood affected mechanical properties but observed changes (bending strength, modulus of elasticity, Brinell hardness) are not significant. Only increase of compression strength along the fibers and decreased cleavage strength are clear. The optimum temperature of modification should be in the range of 160 to 170 °C. This ensures the increase the static bending strength, elastic modulus in bending as well as compressive strength with acceptable strength weakening cleavage strength. Parallel to mechanical properties changes, thermal treatment caused decrease wood density and moisture content.

Density, moisture content, compression, bending and cleavage strength and Brinell hardness and other properties (durability, dimension stability, steadiness of color) of Scots pine wood are very important in application of this material to wooden joinery. This is reason to continue designation of possibility of use thermal modification of Scots pine wood in future research.

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