COMPETITIVE ANALYSIS OF MECHANICAL PROPERTIES OF THERMALLY MODIFIED WOOD PRODUCED IN SUNFLOWER OIL

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ABSTRACT

Thermally modification processes change mechanical properties of wood. These changes depend on the temperature treatment. In this article are reported mechanical properties changes in spruce, beech and poplar wood, modified in temperature 200 °C sunflower oil. It is determined: density, bending strength, compressive strength on fiber direction, sharing strength on fiber direction, splitting strength on received wood according to BDS 16987:89. About comparison are studied mechanical properties of untreated samples. It is proven that the modified wood in sunflower oil has lower density and lower bending strength in parallel comparing with untreated wood.

Key words: thermally modified wood, mechanical properties, beech-, spruce-, poplar- wood.

INTRODUCTION

The timber is widely used as building material and structural building elements. Unprotected wood which is exposed in outdoor conditions provokes a variety of degradations reactions as a result of different atmospheric factors: humidity, heat, sunlight and radiation, UV rays, fungi (Evans, P. D. et al.:1992; Reinprecht, L.: 1998). Moisture content promotes the fungal attack and degradation of wooden cells (Langendorf, G.: 1988; Evans, P. D. et al.:1992; Reinprecht, L.:1998; Rossnev, B. et al.:2007). In the past, timber preservation was carried out by chemical treatments compounds, some of them including components that are toxic and poisonous for both the environment and human health (Langendorf, G. (1988); Reinprecht, L.: 1998). The heat treatment of the wood in high temperatures ranging from 180 to 220 ºC is one of the wood modification methods which by mild pyrolysis is used as an alternative to chemically impregnated timber (Viitaniemi et al.:1996; Bazyar, B.,:2012; Shi, J. L. at. al.,:2007). Some researches had developed heat-treatment methods. They are suitable for industrial applications to improve dimensional stability, durability and other properties of timber (Dirol, D. and R. Guyonnet: 1993; Viitaniemi et al.:1996; Syrjanen, T. and K. Oy: 2001; Weiland et al.:2003). The properties of thermally modified timber of many wood species are widely studied in different countries. The results of these researches are presented in many papers, whereas the Bulgarian production it is still poorly known (Panayotov, P. A. and J. Georgiev: 2013). In this research, timber of three species (spruce, beech and poplar) was modified in sunflower oil in temperature 200 °C.

MATERIALS AND METHODS

Thermal modification is carried out on spruce (Picea abies), poplar (Populus italiana I-214) and beech (Fagus silvatica) wood samples, dried in an electrical chamber at 103±2 ºC till constant weight. The samples dimensions are: 25 x 25x 480 mm; 40 x 40 x 480 mm; 55 x 55 x 480 mm, last one in longitudinal directions. Wood specimens were thermally treated in sunflower oil. The heat treatment plans consist of two successive thermal stability areas. First one is at 135 ºC in order to reach thermal homogenization of the wooden elements. The second one was performed at 200 ºC. This reseach is comparable for six different series of the modified and untreated spruce; beech and poplar wood. The first index shows wood spies in this order: spruce-PcAb; poplar-PoIt; beech-FaSy. Untreated wood are obtained in drying kiln with temperature 103 °C till constant weight. They are marked with second index N. The wood for modification is the same as untreated before treatment. The processes are organized like heat treatment in determinate temperature regime (figure 1) in sunflower oil environment. The series which are obtained in sunflower oil are marked with second index "T".

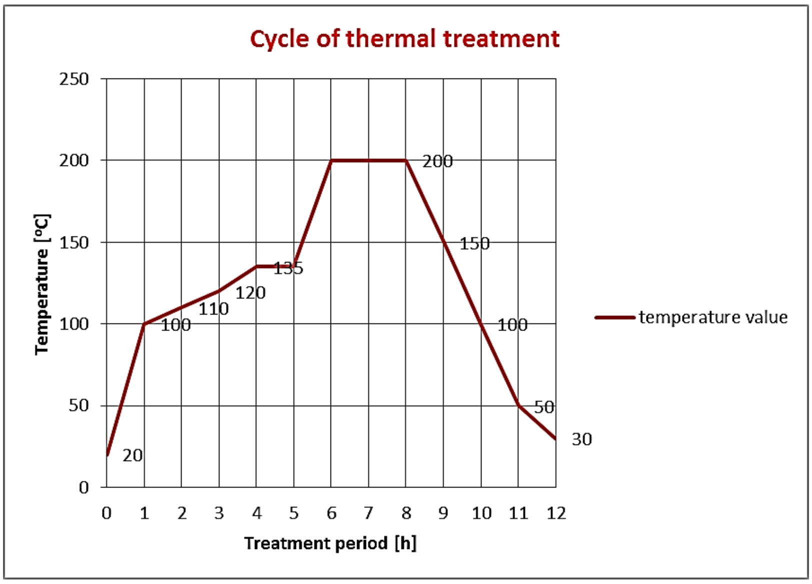

Figure 1: Plan of heat treatment in sunflower oil.

The plan is showing the temperature change over time of the treatment in a medium of sunflower oil to all types of wood pieces. Maximum temperature reached 200ºC is maintained for two hours. It is determined: density, ultimate strength in compression parallel to the grain; static bending strength, shearing strength parallel to the grain, splitting strength on received wood according to BDS 16987:89. As comparison are studied mechanical properties of untreated samples. The samples for all research were cut from heat-treated and untreated wood elements (boards). The samples used for determination static hardness and density are 16 from series with measurement (dimensions) 50x50x50 mm, respectively tangential, radial and longitudinal. The 16 samples with measurements 10x10x20 mm (respectively tangential, radial and longitudinal) for each series, according to BDS 16987:89. Strength parallel to the grains is determinate on 16 samples with measurements 10x10x20 mm (respectively tangential, radial and longitudinal) for each series, according to BDS 16987:89. The static bending strength is determinate on 16 samples with measurements 10x10x150 mm (respectively tangential, radial and longitudinal) for each series, according to BDS 16987:89. The sharing strength parallel to the grains is determined on 16 samples with measurements 20x30x50 mm (respectively tangential, radial and longitudinal) for each series, according to BDS 16987:89. The splitting strength is determinate on 16 samples with measurements 20x20x50 mm (respectively tangential, radial and longitudinal) for each series, according to BDS 16987:89. All of tests are conducted with universal machine and equipment of Brinel.

All the received results are standard deviation proved. Statistical calculations were based on 95 % confidence level. The control of differences reliability is calculated coefficients of Student by formula (1):

$$t = \frac{Aver._1 - Aver._2}{\sqrt{StEr_1^2 + StEr_2^2}} \geq 3 \qquad \textbf{(1)}$$

where: ***t*** is coefficient of Student; ***Aver.*** is average values; ***StEr*** is standard error.

The differences are reliable, when coefficient has value more of 3.

RESULTS AND ANALYSIS

Mechanical properties average values of thermally modified (heat treated) beech, poplar and spruce wood, compared to the properties of untreated wood of the same species are presented in table 1, 2, 3, 4 and 5.

In table 1 are presented average value of the density, determined on specimens of static Brinel hardness.

Table 1: Density of samples (n=16) for determined static hardness by Brinel

Index of wood species	Variation statistical parameters					Moisture content [%]
	Aver., [kg/m³]	Stand.Dev. [kg/m³]	St.Er. [kg/m³]	Var [%]	p [%]	
FaSyN	735.06	8.65	2.16	1.17	0.29	11.8
FaSyT	861.56	9.40	2.35	1.09	0.27	4.2
PoItN	375.56	9.39	2.34	2.50	0.62	11.5
PoItT	736.38	8.36	2.09	1.13	0.28	5.4
PcAbN	410.93	9.99	2.49	2.44	0.61	10.8
PcAbT	441.94	8.38	2.09	1.89	0.48	5.1

Legend: *FaSy – fagus; PoIt – poplar I – 214; PcAb – spruce; N – untreated wood; T – thermally treated (modified) wood; Stand.Dev. – standard deviations; St.Er. – standard error; Var – variation coefficient.*

The samples are dried in temperature 170±10 ºC in period of 21 hours (3x7 = 21 hours) to take out remaining oil quantity after heat treatment. After drying the samples are conditioned in temperature 20 ºC and relative air humidity 55–65 % for a month before measure and tests. It is shown that density increase after treatment. The highest value of density has modified beech: 862 kg/m³. The standard deviation differences are reliable, because the coefficients of Student are higher than 3. The difference between density of untreated and modified beech from 126.5 kg/m³ is reliable, because coefficient of Student has value of 40.28. The spruce wood samples have lowest density increase (PcAbT). It's density difference is 31.01 kg/m³, which is reliable with Student's coefficient of 9.54. The density difference between untreated and modified wood (360.82 kg/m³) is reliable with Student's coefficient value of 114.9. Therefore oil is remaining in wood after treatment and conditioned. Depending on the case, it may be positive or negative result about exploitation. In these cases the remaining quantity must be taken of wood with final vacuum or other methods. In table 2 is presented the average value of the ultimate strength in compression parallel to the grain.

Table 2: Compressive strength parallel to the grain

Index of wood species	Variation statistical parameters					Moisture content [%]	DensityD_w [kg/m³]
	Aver., [N/mm²]	Stand. Dev. [N/mm²]	St.Er. [N/mm²]	Var [%]	p [%]		
FaSyN	46.71	1.69	0.42	3.62	0.9	11.8	786
FaSyT	44.89	4.41	1.10	9.81	2.4	4.7	1082
PoItN	30.82	1.02	0.25	3.31	0.8	11.5	419

Index of wood species	Variation statistical parameters					Moisture content [%]	DensityD_w [kg/m^3]
	Aver., [N/mm^2]	Stand. Dev. [N/mm^2]	St.Er. [N/mm^2]	Var [%]	p [%]		
PoItT	30.15	2.15	0.54	7.15	1.8	5.6	1013
PcAbN	27.86	0.91	0.23	3.25	0.8	10.8	421
PcAbT	25.20	2.08	0.52	8.27	2.1	4.8	369

Legend: *FaSy – fagus; PoIt – poplar I-214; PcAb – spruce; N – untreated wood; T – thermally treated (modified) wood; Stand.Dev. – standard deviations; St.Er. – standard error; Var – variation coefficient*

Compressive strength parallel to the grains is showing as lower values result of thermally treatment processes (fig. 2), but the differences are not reliable. For example beech wood, before treatment has a value of 46.71 N/mm^2 and value of 44.89 N/mm^2 after treatment. The difference of 1.82 N/mm^2 is not reliable, because Student coefficient is 1.54, lower of 3. Probably the decrease depends on oil penetration in cell's lumens.

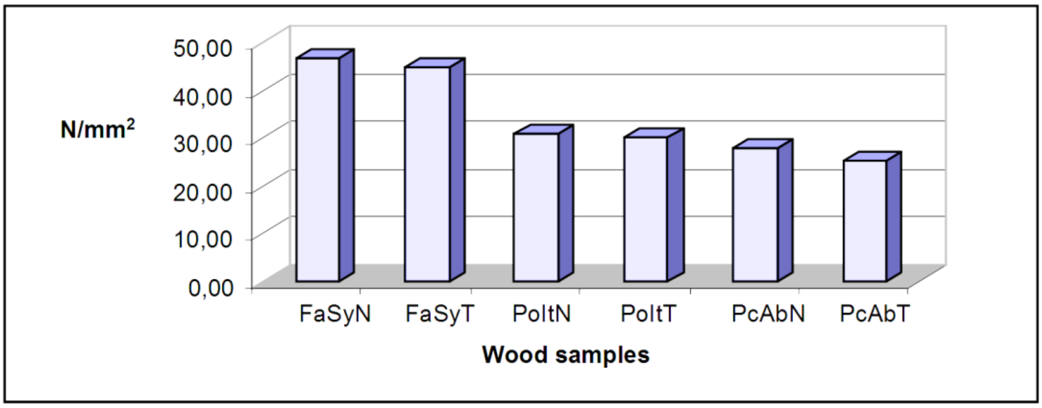

Figure 2: Compressive strength parallel to the grains.

In table 3 is presented the average values of the bending strength. The results show that thermally treated wood has lower values in bending strength. For example in beech the decrease of bending strength is 30 % in radial and 40 % in tangential direction. The results are reliable; because Student coefficient has value more of 3.

Table 3: Bending strength

Index of wood species	Variation statistical parameters					Moisture content [%]	Density, D_w [kg/m^3]
	Aver., [N/mm^2]	Stand.Dev N/mm^2	Stan.Error [N/mm^2]	Var %	p %		
FaSyNr	109.03	5.69	1.42	5.2	1.3	10.6	786
FaSyNt	101.77	6.21	1.55	6.1	1.5	10.6	786
FaSyTr	76.51	4.59	0.87	6.0	1.1	4.3	1082
FaSyTt	61.38	5.28	1.32	8.6	2.1	4.3	1082
PoItNr	62.36	6.31	1.58	10.1	2.5	11.3	419
PoItNt	58.60	7.26	1.82	12.4	3.1	11.3	419
PoItTr	44.14	6.59	1.64	14.9	3.7	4.8	1013
PoItTt	43.82	6.68	1.67	15.2	3.8	4.8	1013
PcAbNr	66.38	8.24	2.06	12.4	3.1	10.7	369
PcAbNt	55.71	6.51	1.63	11.7	2.9	10.7	369
PcAbTr	38.61	7.42	1.85	19.2	4.8	5.5	421
PcAbTt	34.43	5.36	1.34	15.5	3.9	5.5	421

Legend: *FaSy – fagus; PoIt – poplar I-214; PcAb – spruce; N – untreated wood; T – thermally treated (modified) wood; Stand.Dev. – standard deviations; St.Er. – standard error; Var – variation coefficient; r –radial direction; t –tangential direction.*

In table 4 is presented the average value of the shearing strength parallel to the grain. The results show that thermally treated wood has lower values of sharing strength. Sharing strength is decreasing in beech wood with 46.5 % in radial and 41.8 % in tangential direction after treatment. The changes in poplar wood are notable; sharing strength is reduced to 57.1 % in radial and 57.7 % in tangential direction. Spruce wood sharing strength reduces lowest. The all results are reliable; because Student coefficient has value more of 3.

Table 4: Shearing strength parallel to the grain

Index of wood species	Variation statistical parameters					Moisture content [%]	Density, D_w [kg/m^3]
	Aver., [N/mm^2]	Stand.Dev N/mm^2	Stand.Er N/mm^2	Var %	p %		
FaSyNr	19.31	1.99	0.49	10.3	2.6	10.8	786
FaSyNt	20.53	2.37	0.59	21.5	2.9	10.8	786
FaSyTr	10.32	1.85	0.46	17.9	4.5	4.2	1082
FaSyTt	11.95	2.06	0.52	17.2	4.3	4.2	1082
PoItNr	9.21	1.45	0.36	15.7	3.9	11.5	419
PoItNt	11.48	1.86	0.46	16.2	4.0	11.5	419
PoItTr	3.95	0.85	0.21	21.5	5.3	5.4	1013
PoItTt	4.86	0.78	0.19	16.1	4.3	5.4	1013
PcAbNr	10.08	1.78	0.45	17.6	4.5	10.7	369
PcAbNt	12.30	2.14	0.53	17.4	4.3	10.7	369
PcAbTr	7.12	1.36	0.34	13.1	4.7	5.7	421
PcAbTt	8.31	1.45	0.36	17.4	4.3	5.7	421

Legend: *FaSy – fagus; PoIt – poplar I-214; PcAb – spruce; N – untreated wood; T – thermally treated (modified) wood; Stand.Dev. – standard deviations; St.Er. – standard error; Var – variation coefficient; r – radial direction; t-tangential direction.*

In fig.3 is presented wood test samples tested in shearing strength.

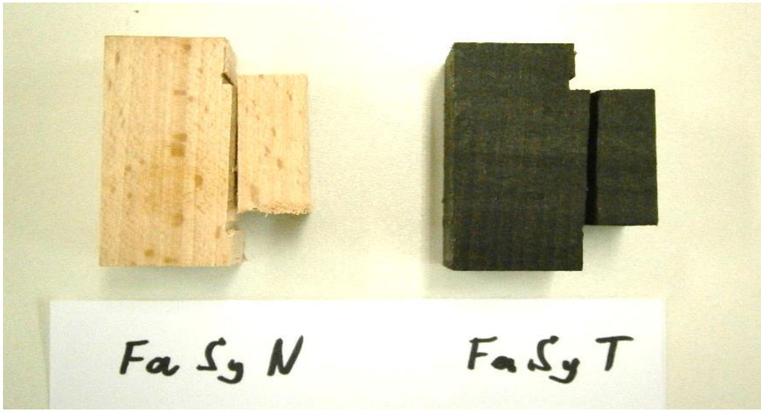

Figure 3: Wood test samples tested shearing strength test.

In table 5 is presented the average value of the Splitting strength parallel to the grain.

Table 5. Splitting strength parallel to the grain

Index of wood species	Variation statistical parameters					Moisture content [%]	Density D_w [kg/m^3]
	Aver. [kN/m]	Stand.Dev [kN/m]	Stand.Er. [kN/m]	Var [%]	p [%]		
FaSyNr	46.52	5.82	1.45	17.90	4.5	11.20	786
FaSyNt	50.89	7.23	1.81	14.20	3.5	11.20	786
FaSyTr	11.95	0.65	0.16	5.50	1.4	3.21	1082
FaSyTt	20.30	3.63	0.98	17.90	4.5	3.21	1082
PoItNr	246.63	21.48	5.37	8.70	2.2	11.30	419

PoItNt	269.13	25.37	6.34	9.40	2.3	11.30	419
PoItTr	127.00	10.26	2.56	8.10	2.0	3.25	1013
PoItTt	134.50	13.42	3.35	9.90	2.5	3.25	1013
PcAbNr	163.49	14.21	3.55	8.70	2.2	10.60	369
PcAbNt	218.51	19.75	4.93	9.04	2.2	10.60	369
PcAbTr	121.51	12.85	3.21	10.60	2.6	3.15	421
PcAbTt	136.13	16.27	4.06	11.90	2.6	3.15	421

Legend: *FaSy – fagus; PoIt – poplar I-214; PcAb – spruce; N – untreated wood; T – thermally treated (modified) wood; Stand.Dev. – standard deviations; St.Er. – standard error; Var – variation coefficient; r – radial direction; t-tangential direction.*

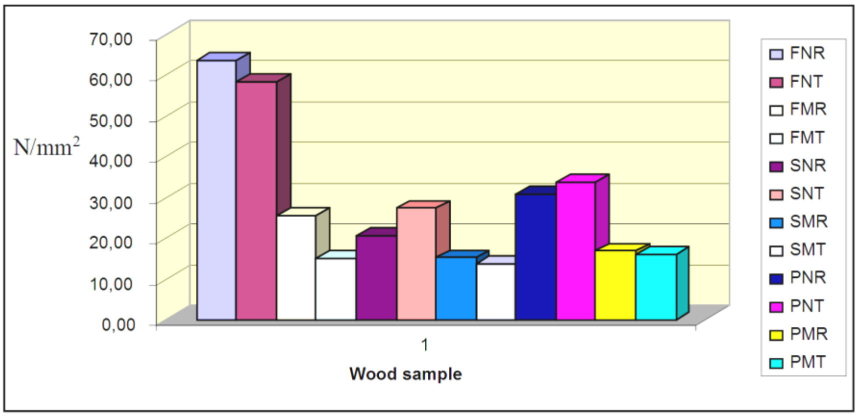

Figure 4: Splitting strength diagram

The analysis of the results shows that splitting strength of thermally modified wood is lower than natural. This is valid for all wood species. The differences are reliable with Student coefficients higher than 3.

In fig. 5 is presented test samples tested in sharing strength.

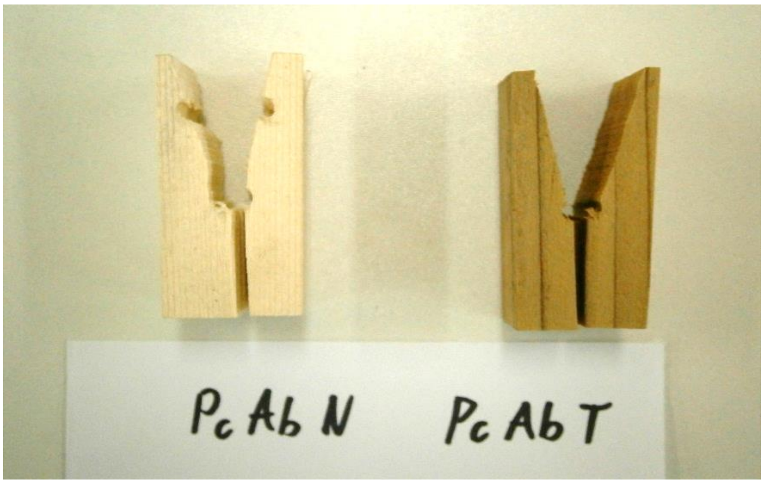

Figure 5: Splitting strength test samples.

CONCLUSION

The results of the initial tests show that the overall performance of the three species of trees grown in Bulgaria and treated by liquid heat treatment methods (in sunflower oil) is acceptable. Thermal modification changes the mechanical properties of wood. These changes depend on treating with temperature.

– Common to all tested mechanical properties of sunflower oil - treated wood shows essential reduction of strength parameters.

- Differences in tangential and radial direction of test samples are also significant, with a few exceptions.
- The results are expected due to the high temperature and oil in the treatment environment.
- There is a large amount of soaked oil and extracted substances from the timber.
- It might be concluded that the treated wood should not be used for structural elements under high load, only for decorative items.

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