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HYGROSCOPICITY OF THERMALLY MODIFIED POPLAR (POPULUS SPP.) WOOD

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Abstract:
Boards of poplar wood were subjected to thermal treatment at 180°C and 200°C, for durations of 2, 4, 6, 8 and 10 hours, in order to investigate the effect of heat treatment on the hygroscopic properties. Specifically, the change of equilibrium moisture content, density, swelling and absorption of wood were examined, in order to determine the significance of treatment temperature and duration in the enhancement of wood hygroscopicity. Generally, swelling in tangential direction proved to be quite higher than swelling in radial direction, while thermal treatment enhanced in great extent swelling in tangential and radial direction and the absorption of the specimens as well. Swelling in tangential direction decreased within the range of 8.17% and 33.3% for specimens treated at 180°C and the range of 43.85% and 65.09% for specimens treated at 200°C for 2-10 hours, referring to the final measurement after 72 hours of water immersion. In radial direction, the swelling decrease ranged between 2.47% and 28.45% for specimens treated at 180°C and between 19.62% and 60.87% for specimens treated at 200°C for 2-10 hours, respectively, after 72 hours immersion. Most of the heat treatments resulted also in absorption decrease, attesting the improvement of the poplar wood hygroscopic behavior. Finally, as it was proved, the higher the treatment temperature that is applied, the shorter is the duration, needed for the same swelling and absorption decrease level to be achieved.

Key words: *hygroscopic properties; modification; poplar; swelling; thermal treatment.*

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INTRODUCTION

Intensive efforts have been made all these years by researchers and the industrial world as well, in order to enhance the appearance, the behavior and therefore, the quality of wood. Heat modification is one of the methods that have been long ago proposed and used, in order to improve some drawbacks of wood, like the hygroscopic nature of the material, the low resistance to microorganism attacks, as well as, the discolouration of wood surface during its exposure in conditions of external environment. As it has been proven, this method of wood modification prolongs the service life of the wood products, increases the usability of wood, especially for wood species of lower density and natural durability, while the production cost remains quite low, since no chemical substances are used. Generally, this quite easy, cheap and environmentally friendly wood modification method has been developed in Europe during the last decade and it seems to have large commercial potential in future (Mburu *et al.* 2008, Ates *et al.* 2010).

Thermal treatment seems to initiate a complex process of polymer degradation and possible cross-linking with degradation products, which substantially changes the initial structure of wood and the interaction between the wood polymers. During the treatment, hemicelluloses start to decompose first among the wood polymers, due to the low molecular weight that makes them more reactive. Furthermore, amorphous parts of cellulose decompose, lignin softens, while hydrophilic groups modify, presenting a decrease. As a result of this process, treated wood at high temperatures loses its reabsorbing water capacity, acquiring a more hydrophobic behaviour compared to untreated wood. Treated wood is characterized also by improved biological resistance against fungi and microorganisms attacks, lower density and equilibrium moisture content (EMC), increased wettability, improved resistance to natural weathering, colour uniformity and stability (Awoyemi *et al*. 2009). There is a high interest in the research of several thermally modified wood species and extensive research has been conducted so far, evaluating the influence of thermal treatment on the hygroscopic properties of wood (Tjeerdsma and Militz 2005, Zivkovic *et al.* 2008, Gunduz *et al.* 2009, Metsa and Kortelainen 2010 etc.), but as it became evident, there is little information in literature about the changes of hygroscopic properties of heat treated poplar (*Populus sp*.) wood. Futhermore, poplar wood is chosen to be used in this thermal treatment experiment, also because this species, as a fast-growing one, is characterized by unfavorable properties, such as low strength and stiffness, low durability, dimensional instability, which are a clear hindrance for widespread utilization of this material in the furniture industry and thermal treatment of its mass could potentially enhance some physical and hygroscopic properties and thus, the behavior of poplar wood.

Therefore, the objective of the current research is to determine the influence of thermal treatment at 180^{o}C and 200^{o}C for 2, 4, 6, 8 and 10 hours, on the dimensional stability (absorption and swelling), density and EMC of poplar wood.

MATERIAL AND METHODS

Poplar (*Populous sp*.) wood, of Greek origin and naturally dried for one and a half years was used in this experiment. The wood was obtained from a local wood industry of Thessaloniki. The boards were cut parallel to grain and the dimensions of the boards, intended for thermal treatment, were of 25mm thickness x 50mm width x 120mm length. Before treatment, the boards were stored in a conditioned room under ambient conditions (20±2^{o}C temperature and 60±5% relative humidity) and were allowed there for about two months to reach a nominal equilibrium moisture content (EMC) of 10.32%, to avoid drying damage. The mean density (oven-dry mass/volume measured at 10.32% moisture content) of the poplar wood before the treatment was measured to be 0.395g/cm^3. Some of the boards were kept in its original condition (untreated wood), while the other boards were reserved for the thermal treatments.

For the treatment of the boards, a laboratory heating unit of 80cm x 50cm x 60cm dimensions, with two different thermometers was used, a conventional zinc one incorporated in the unit and also, a thermometer of digital indication with temperature sensor inside the drying oven, and therefore, the unit was capable of controlling the temperature within a range of ±1^{o}C. The temperature applied during the thermal treatment was constantly stable, while the treatment was implemented under atmospheric pressure, in the presence of air. The boards placed in the kiln, were of 10.32% moisture content, as mentioned above, and the temperature of 180^{o}C or 200^{o}C was pre-set in the kiln. Five different time durations of 2, 4, 6, 8 and 10 hours were determined to be used for the thermal treatment of the boards and six boards were used for each treatment.

All boards were selected from the kiln stack in a pattern that ensured samples were removed from the top, middle and bottom of the stacks, as well as, from the right, center and left of the stacks. At the end of the treatment, samples were cooled and stored in desiccators before weighing. The weight loss (WL) after heat treatment was estimated according to the following equation (Eq.1):

$$WL\ \% = [(m_o\ m_{ht}) / m_o]\ *100 \qquad (1)$$

m_o - air-dried weight of the specimen before thermal treatment in g.
m_{ht} - weight of the specimen measured directly after the thermal treatment in g.

Weight measurements of the specimens were also made after 7 and 14 days after thermal treatment, in order to detect the rhythm of reconditioning progress and the gradual increase of specimen weight during the conditioning process at 20±2^{o}C temperature and 60±5% relative humidity. After 4 weeks of reconditioning, EMC and density of the specimens were measured. Afterwards, the boards were put through a planer in order to clean both the top and bottom surface of them and then, they were cut in final cross section dimensions for the measurement of hygroscopic properties (2x2x2.5cm), according to the respective standard (ISO 3130:1975). All sample pieces were defect free with as straight a grain as possible. For each test 10 specimens were prepared.

The swelling (in radial and tangential direction) and the absorption percentage measurements were conducted after the immersion of the samples in water of 20±3^{o}C temperature, for 1, 3, 6, 24 and 72 hours.

RESULTS AND DISCUSSION

According to the results (Table 1), the weight loss of the specimens, measured immediately after each thermal treatment was proved to increase relatively with the intensity of the treatment (duration), which means that the treatment causes not only the release of the whole moisture content of the specimen, but also, the loss of wood mass, including the volatile extractives and a part of chemical constituents, such as hemicelluloses. During the conditioning period the specimens tend to regain moisture from the atmosphere of the control climate room and this gradual progress of conditioning process is depicted in Table 1.

Table 1

Mean values of weight loss (%) caused by thermal treatment at 180 and 200^{o}C and weight increase (%) during conditioning period

Temp.	Treatment Duration	Weight loss immediately after treatment (%)	Weight increase after 7 days (%)	Weight increase after 14 days (%)
180^{o}C	2h	9.26 (0.47)*	5.40 (0.41)	6.31 (0.41)
	4h	10.02 (0.28)	4.76 (0.25)	5.56 (0.29)
	6h	10.46 (0.42)	4.66 (0.60)	5.33 (0.34)
	8h	12.07 (1.40)	4.65 (0.15)	5.20 (0.12)
	10h	12.33 (1.50)	4.39 (0.12)	5.13 (0.22)
200^{o}C	2h	13.48 (1.32)	3.82 (0.18)	4.36 (0.11)
	4h	16.77 (1.61)	3.92 (0.18)	4.32 (0.12)
	6h	19.12 (1.45)	3.98 (0.10)	4.37 (0.10)
	8h	21.77 (1.45)	4.25 (0.16)	4.63 (0.17)
	10h	23.40 (2.31)	4.44 (0.25)	4.84 (0.22)

** Numbers in parentheses represent the standard deviation of ten replicates*

As the treatment temperature and duration increase, the weight loss, which is recorded immediately after the treatment, seems to increase. This weight loss increase of the treated specimens is partially attributable to moisture content decrease, to evaporation of some volatile extractives and potentially to thermal degradation of polysaccharides in wood mass. As it is obvious, during the conditioning period in a room of ambient conditions after the treatment, the specimens treated at mild conditions, displayed lower weight increase owing to moisture absorption, compared to the specimens that were subjected to more intense treatments, whereas the differences were not statistically significant. Quite noticeable is the fact that the treatment at 200^{o}C and duration of 8-10h presented a slight increase of the moisture absorption rhythm, which could be explained by the damage of wood, in other words the destruction of cell walls and the mass loss.

The equilibrium moisture content of all heat-treated samples decreased considerably compared to the initial untreated wood, even for the less intensive treatment of 2 hours at 180^{o}C. More specifically, the EMC of poplar wood specimens, after the thermal treatment of 2-10 hours at 180^{o}C and a conditioning period of four weeks recorded a decrease percentage that ranged between 37.02% and 52.73%, while the specimens treated at 200°C for 2-10 hours presented a decrease of between 52.6% and 54.81% (Table 2). This EMC reduction clearly suggests that thermal treatment affected in great extent the dimensional stability and water absorbing capacity of wood. Thermal treatment appeared also to cause a decrease in density of wood specimens and specifically, thermal treatment of 2-10 hours at 180°C resulted in density losses of between 11.14% and 20.1%, respectively, while the specimens treated for the same periods at 200°C demonstrated density loss ranging between 6.84% and 22.28%. The decrease in density is related both to moisture content decrease after treatment that was just mentioned and to mass loss caused by thermal degradation of hemicelluloses and evaporation of volatile constituents of wood.

Table 2

Equilibrium moisture content (EMC) and density of the control and treated specimens

Temp.	Duration	EMC	EMC Decrease (%)	Density	Density Loss (%)
180°C	Control	9.39 (0.20)*	-	0.395 (0.03)	-
	2h	5.92 (0.33)	37.02	0.351 (0.03)	11.14
	4h	5.25 (0.24)	44.10	0.344 (0.01)	12.99
	6h	4.79 (0.39)	49.00	0.335 (0.03)	15.32
	8h	4.49 (0.23)	52.19	0.319 (0.01)	19.27
	10h	4.44 (0.21)	52.73	0.316 (0.03)	20.10
200°C	2h	4.45 (0.16)	52.60	0.368 (0.02)	6.84
	4h	4.30 (0.05)	54.18	0.346 (0.03)	12.41
	6h	4.27 (0.20)	54.49	0.334 (0.01)	15.44
	8h	4.25 (0.07)	54.72	0.311 (0.05)	21.27
	10h	4.24 (0.10)	54.81	0.307 (0.03)	22.28

* Numbers in parentheses represent the standard deviation of ten replicates

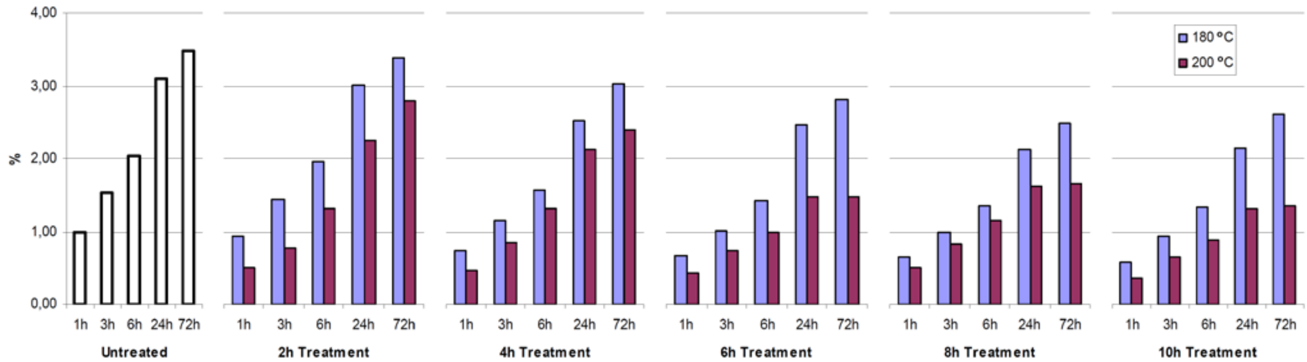

Fig. 1
Percentage of radial swelling of the control specimens and specimens treated at 180 and 200°C, measured after an immersion of 1, 3, 6, 24 and 72 hours in water.

Referring to hygroscopic properties, all the thermal treatments used in the specific experiment seemed to enhance the hygroscopic behavior of poplar wood specimens (Fig. 1). Swelling in tangential direction was proved to be decidedly higher than swelling in radial direction. Neverthelless, thermal treatment was revealed to enhance more efficiently the tangential swelling, than radial swelling, which means that the anisotropy of wood improved. As the duration and temperature of thermal treatment was intensifying, tangential swelling tended to decrease and this tendency was similar in the case of swelling in radial direction. Worth mentioning is the fact that when the treatment duration exceeded the 8 hours, especially in the treatment of 180°C, the swelling values of both tangential and radial direction slightly increased, distincly without approaching the swelling levels of the control specimens. This phenomenon was not apparent in the treatment of 200°C (Fig. 1, 2).

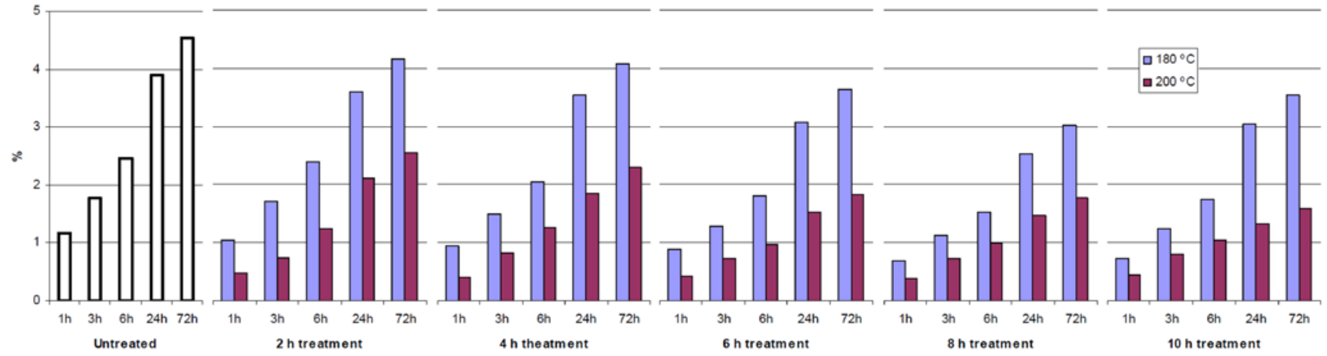

Fig. 2
Percentage of tangential swelling of the control specimens and specimens treated at 180 and 200°C, measured after an immersion of 1, 3, 6, 24 and 72 hours in water.

The absorption percentage values of the treated specimens demonstrated a satisfing enhancement, compared to the corresponding values of the control specimens (Fig. 3). Increasing the treatment temperature and duration was proved to be beneficial for the absorption diminution and therefore, the dimensional stability enhancement, while exceeding the six hours of treatment absorption percentage values recorded a slight tendency of increase for both the treatments of 180°C and 200°C temperature. This fact could be explained by the potential permanent changes that usually occurr during thermal treatments of long durations like 8 or 10 hours, mainly in the chemical composition of the material and the physical properties, referring to mass loss, density loss, thermal degradation of the polysaccharides and lignin etc. Therefore, in a case of the specific conditions thermal treatment, being used in current study (dimensions, temperature etc.), the duration should not exceed the period of six hours, especially when the hygroscopic properties of the final material are of great importance. Additionally, it was proved that, the higher the applied treatment temperature, the shorter is the duration that is needed for the same swelling and absorption decrease level to be achieved. For instance, the absorption decrease level that was achieved after 6 hours of treatment at 180°C, was demonstrated after 2 hours of treatment at 200°C.

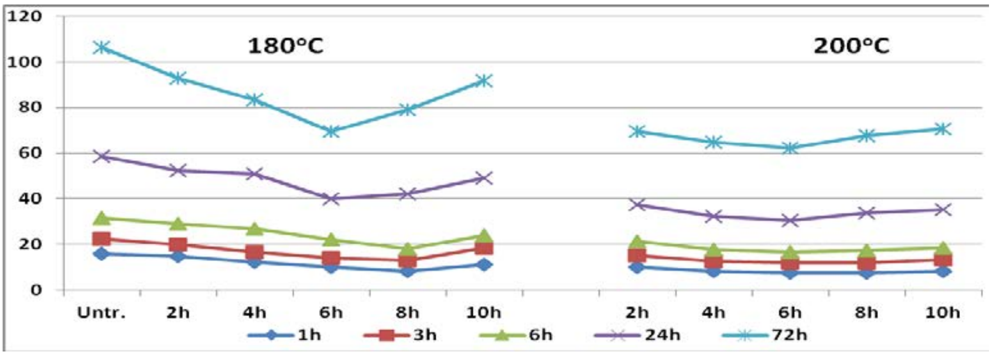

Fig. 3
Absorption percentage of the control specimens and specimens treated at 180 and 200°C, measured after an immersion of 1, 3, 6, 24 and 72 hours in water.

These results are generally in agreement with research findings of Gunduz *et al*. (2009) who studied the effects of heat treatment on physical properties of Camiyanı Black Pine wood and found that density and swelling percentage decreased by increasing heat treatment time and temperature. Similar results of hygroscopic properties of heat treated wood were recorded also by Vukas *et al*. (2010), Ates *et al*. (2010), Korkut and Guller (2008) etc.

As an under-valued and under-utilized tree, this species was selected as one, which could benefit from a new high temperature kiln process. The end result is a material with remarkably improved properties. The treatment process is useful for production of outdoor products, apart from indoor wooden structures, due to increased hydrophobic behavior and dimensional stability, and therefore, other water-related properties like the biological durability.

CONCLUSIONS

The current study was undertaken in order to examine the effects of heat treatment at 180°C and 200°C and various periods (2-10 hours) in the presence of air, on the weight, density and the hygroscopic properties of poplar wood. On the basis of the obtained results, as the intensity of the treatment (temperature and duration) increases, the density and the equilibrium moisture content (EMC) values of wood decrease. Swelling and absorption percentage values of the specimens appeared to be decreased, which clearly indicates the dimensional stability and the hygroscopic properties enhancement of the treated specimens. On the other hand, it was proved that in the case of the specific treatment conditions (specimen dimensions, temperature, atmosphere etc.), the treatment duration should not exceed the 6 hours, since the absorption percentage values started to slightly increase after 6 hours of treatment, independently of the treatment temperature, while the swelling percentage values started to slightly increase after 8 hours of treatment, especially in the case of treatment at 180°C. Consequently, in these treatment conditions the thermal treatment duration of 6 hours was found to reveal the higher hygroscopicity enhancement. Additionally, it was proved that, the higher the applied treatment temperature, the shorter is the duration, needed for the same swelling and absorption decrease level to be achieved.

Scientific knowledge and experience is necessary to be gained and expanded through further investigation on thermal treatment of poplar wood, in order to win the challenge of enhancing the hygroscopic properties and make a fast-grown species of low quality, like poplar wood able to be used in a wide variety of applications, competing other more durable and valuable species.

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