

# THE EFFECT OF SHORT TIME THERMAL TREATMENT ON SWELLING OF FIELD MAPLE (*ACER CAMPESTRE* L.) AND FIR (*ABIES ALBA* MILL.)

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## Abstract

From the immemorial time wood is highly abundant and well-performing material. Further one due to practical use the wood heat treatment, as a process for improving its properties has been enhanced in the recent time. *Abies alba* Mill and *Acer campestre* L. are among the most wide spread species in Albanian forest and among the most useful types of wood in Albanian wood industry. The objective of this study is to investigate the influence of short time heat treatment on dimensional stability and the mass loss of these two species. Wood samples are treated in three different temperatures (180 °C, 200 °C, 220 °C) and two different time durations of 15 and 30 minutes. After the heat treatment, the mass loss is determined for treated samples. Treated and untreated samples are immersed in water and the swelling is determined. According to the results obtained, wood swelling undergoes a considerable reduction in the case of wood treatment at a temperature of 220 °C for the longest time duration of 30 minutes. The higher percentage of weight loss after the thermal treatment (9.66% for the maple and 10.77% for the fir) was measured in the samples treated in a 220 °C for 30 minutes. The results of both treated and untreated wood were given for comparative purposes.

Keywords: wood treatment, thermal applications, maple, fir, swelling, wood modification, timber processing

## INTRODUCTION

As an alternative method to the wood preservation through use of chemical agents is considered the thermal treatment (Vernois, 2001; Militz, 2002; Chanrion and Schreiber, 2002), considering this one not only as an approach for removes water from wood but also causes significant transformation in the chemical composition of wood (Kocaefe *et al.*, 2008). From the immemorial time wood materials are widely used and dependable material for construction works and used in a very broad range

of applications like furniture, building, road works, water works etc. The large variety in timber species guarantees that there is always a species with the required properties for a specific purpose. The economic impact of timber products is therefore considerable. Following Grönquist *et al.* (2019) wood also has a number of disadvantages in case of furniture because it is a hygroscopic material, while have advantage for self-shaping timber elements, while other studies (Holstov *et al.*, 2015; Rüggeberg *et al.*, 2015) have been done in order to improve the disadvantageous properties of wood.

The methods brought out based on the results of these studies are commonly named “wood modifications”. More modifications of wood can be defined as a process that improves the properties of wood, producing a new material that when disposed at the end of the product life cycle doesn't present an environmental hazard any greater than unmodified wood (Hill, 2006). Further on the heat treatment is a wood modification method as well. The principal effect gained by heat treatment of wood is reduced hygroscopicity (Grönquist *et al.*, 2019) with an main advantages of wood treated in this manner are increased resistance to different types of biodegradation and improved dimensional stability, without the use of (toxic) chemicals (Kocaefe *et al.*, 2008). Further on the heat treatment changes some physical, mechanical and chemical properties of wood, that is, dimensional stability, equilibrium moisture content (EMC), color of wood, bending strength, relevant strength, hardness, amount of wood polymers, biological durability etc. (Mazela *et al.*, 2004; Yildiz *et al.*, 2006; Gündüz *et al.*, 2008). In the recent decades there has been conducted series of surveies in order to improve the disadvantages of wood, started from 1920 when Tiemann showed that the drying at high temperatures decreased the equilibrium moisture. (Kollman, 1936; Stamm and Hansen, 1937; Seborg *et al.*, 1945) used heat treatment to improve the wood disadvantages.

Since the 1950's research has been done on thermal modification of wood, based on heat treatment of (fresh or conditioned) wood at relative high temperatures: 230–260 °C (Seborg *et al.*, 1953; Kollmann and Schneider, 1963; Stamm and Hansen, 1937; Kollmann and Fengel, 1965; Noack, 1969; Burmester, 1973 and 1975; Giebel, 1983; Hillis, 1984; Bourgois and Guyonnet, 1988). The approaches on heat treatment indicated that heat treatment of wood improves wood physical properties by reducing hygroscopicity and improving dimensional stability (Viitaniemi, 1997; Santos, 2000). In different European research teams were developed methods that are based on thermal treatment of wood (e.g. Bourgois and Guyonnet, 1988; Viitaniemi and Jämsä, 1996; Boonstra *et al.*, 1998; Sailer *et al.*, 2000; Weiland and Guyonnet, 2003). The key differences between these methods are based on the materials used (e.g. wood species, fresh or dried wood, moisture content, dimensions), process conditions applied (e.g. one or two process stages, wet or dry process, heating medium, oxygen or nitrogen as sheltering gas, heating and cooling down velocity) and the equipment necessary for treatment (e.g. process vessel, kiln). In these contexts different types of commercial heat treatments are developed in Europe. Several wood species are used, with different process conditions, depending on species and the final use of the product. All these processes use sawn wood and treatment temperatures vary from 160 °C to 260 °C. Researchers use long time heat treatment, which means a time more than 2 hours in

order to affect the physical and chemical properties of wood as (4, 8 and 12 h – Kocaefe *et al.*, 2008; 8 h – Hakkou *et al.*, 2006; 2–24 h – Esteves *et al.*, 2008; 2–8 h Akyildiz *et al.*, 2009, etc). On the other hand there are also some approaches using short duration heat treatments that have been carried out. (Mburu *et al.*, 2007) applied short time of heat treatment of 30 min as well as long time duration of 1, 5, 7, 15 hours to evaluate the resistance against termites and several wood fungi. They used *Grevillea robusta* an African wood species of low durability, treated at temperatures of 240 °C, 250 °C and 260 °C. It was shown that the durability of this wood was increased against termites and basidiomycetes even when the duration of heat treatment was short (30 min). Shi *et al.* (2007) studied the resistance of thermally-modified and ACQ-C treated aspen (ACQ-C: copper-ammonia and/or copper-ethanolamine), jack pine, yellow poplar and Scots pine against the brown the brown-rot fungus and Eastern U.S. subterranean termite. They treated the wood at 210 °C for 15 min. The results showed that the thermally- modified wood was less resistant to fungus decay and termite attack than ACQ-C treated wood. Kocaefe *et al.* (2010) studied the effect of heat treatment conditions on the mechanical properties of North American pine. The wood was treated in different temperatures (120 °C, 160 °C, 200 °C, 210 °C, 220 °C, 230 °C) for three durations of time (15 min, 30 min, 45 min). The results showed that increase in exposure time decreased the MOE (modulus of elasticity) and MOR (modulus of rupture). The screw withdrawal strength of heat treated wood was lower than that of untreated wood.

Barboutis *et al.* (2011) studies the effects of short time thermal treatment (15 min and 30 min) on dimensional stability and mechanical properties of lime wood (*Tilia cordata*). The results showed that the dimensional stability was increased for the heat treated wood, but the mechanical properties were decreased significantly. In our approach was considered the influence of short time heat treatment on variation of dimensional stability after the immersion of wood in water and the mass loss of *Abies alba* Mill. and *Acer campestre* L. *Abies alba* Mill. and *Acer campestre* L. are among the most wide spread species in Albanian forest and among the most used types of wood in Albanian wood industry. The sequences of heat treatment on wood properties were not studied till now for Albanian species and this survey can be considered a useful contribution in this field.

## MATERIALS AND METHODS

The sample materials were collected in Saranda Region, south of Albania. The samples were sawn in dimensions 40 × 40 × 10 mm and there were put numbers for every sample. The samples were prepared according the UNI ISO 3130 standard. After this, the samples were conditioned to 8–9% moisture content at 20 °C and 60% relative humidity. This was

done to prevent splitting and discoloration of wood during heat treatment. For each experiment and each type of wood 10 specimens were prepared. After this, for all the samples weight and the tangential and radial dimensions were measured.

Three different temperatures (180 °C, 200 °C, 220 °C) and two different time durations of 15 and 30 minutes were applied to the samples. The samples were placed in the oven after the desired temperature was reached.

After the heat treatment, the weight is measured for the samples. After this, the samples were conditioned at 20 °C and 60% relative humidity for ten days. The weight and dimensions were measured again after the conditioning and the weight loss is determined because of high temperature treatment.

All the samples were immersed in the water. The dimensions were measured after 1, 4 and 6 days of immersion in water. For each species is calculated the swelling. Statistical analysis was performed using paired Student t-test, where p values < 0.05 were considered as significant.

## RESULTS AND DISCUSSION

### Maple and Fir Swelling as a Result of Thermal Treatment

According to the results of the wood swelling measurements and analyzing the values in the

Tab. I and II, and correspondent charts it is noticed that swelling of wood (maple and fir) doesn't undergoes any considerable reduction by the thermal treatment at a temperature 180 °C, for 15 and 30 minutes respectively. This happen because the wall cell structure doesn't change under this temperature.

Wood swelling (maple and fir) undergoes a considerable reduction in the case of wood treatment at a temperature of 220 °C. Increasing the temperature to 220 °C leads to a destroy of cell wall structure by reducing the ability of the wood to be associated with water molecules, thus to be swelled. Wood swelling (maple and fir) undergoes a considerable reduction in the case of wood treatment at a temperature of 220 °C for the longest time duration of 30 min. The statistical significance is reflected through the  $p < 0.05$  (0.025 and 0.045 for the tangential treatment and 0.010 and 0.018 for the radial one in case of maple, while the values are in case of fir these values are respectively 0.037, 0.007 and 0.0012 for the tangential and radial thermal treatments).

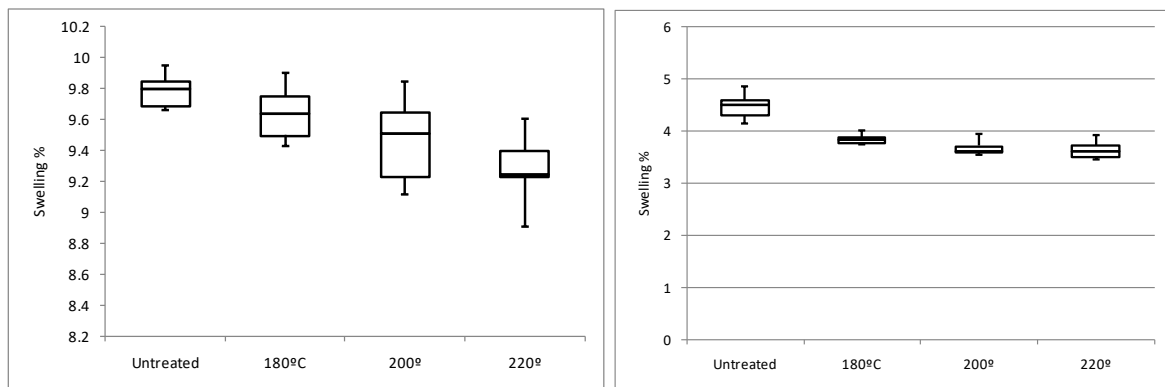
According the Fig. 1 and Fig. 2 results that tangential swelling of maple wood presented through box plots thermally treated (220 °C for 30 min) decreases respectively 47%, 45.7% and 46.2% after 1, 4 and 6 days immersion in water versus untreated wood. Radial swelling of maple wood, thermally treated (220 °C for 30 min) decreases respectively 48.2%, 48.5% and 50.5% after 1, 4 and 6 days immersion in water versus untreated wood.

I: Swelling percentage of thermally treated and untreated maple wood, \*\* denotes level of significance of 0.05

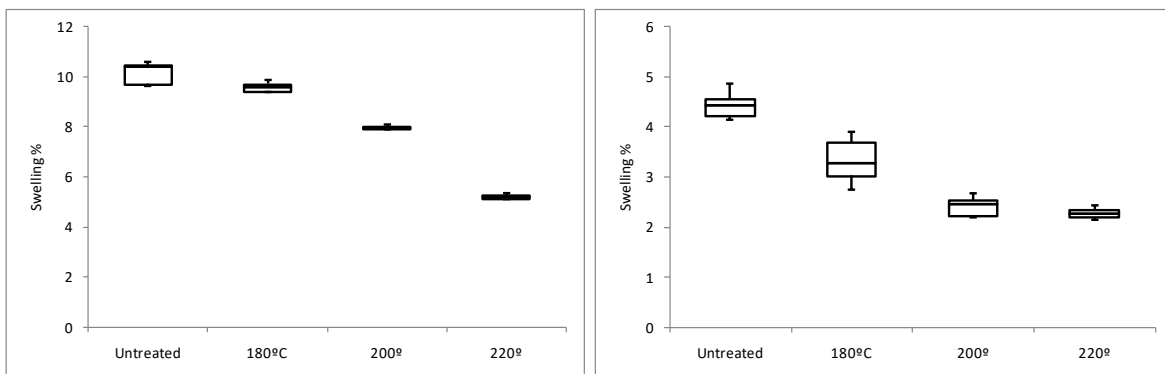
MAPLE	180°			200°			220°			Untreated		
	1 day	4 days	6 days	1 day	4 days	6 days	1 day	4 days	6 days	1 day	4 days	6 days
Tangential												
15 min	9.43	9.60	9.90	9.12	9.57	9.85	8.91	9.23	9.61	9.66	9.70	9.95
SD	0	0.17	0.47	-0.39	0.06	0.34	-0.34	-0.02	0.36			
VAR	0.022	0.009	0.032	0.077	0.001	0.056	0.057	0	0.064			
	0.071**			0.106**			0.025**					
30 min	9.39	9.56	9.87	7.89	7.93	8.12	5.12	5.27	5.35			
SD	-0.29	-0.04	0.27	-0.01	-0.05	0.14	-0.12	0.03	0.11	-0.11	-0.07	0.18
VAR	0.023	0.001	0.034	0.004	0.001	0.009	0.008	0	0.005	0.006	0.002	0.016
	0.0502**			6.24**			0.045**			0.024*		
Radial												
15 min	3.74	3.89	4.01	3.56	3.72	3.95	3.47	3.59	3.72			
SD	-0.14	0.01	0.13	-0.18	-0.02	0.21	-0.12	0	0.13			
VAR	0.009	0.005	0.008	0.016	0	0.021	0.007	0.0071	0.008	4.15	4.52	4.87
	0.019**			0.007**			0.010**					
30 min	3.70	2.76	3.91	2.21	2.54	2.67	2.15	2.33	2.41			
SD	0.25	-0.69	0.46	-0.26	0.07	0.20	-0.14	0.04	0.12	0	0.01	0.36
VAR	0.029	0.242	0.102	0.034	0.002	0.019	0.010	0	0.006	0.066	0	0.063
	0.054**			0.0007**			0.0018**			0.129 *		

## II: Swelling percentage of thermally treated and untreated fir wood, \*\* denotes level of significance of 0.05

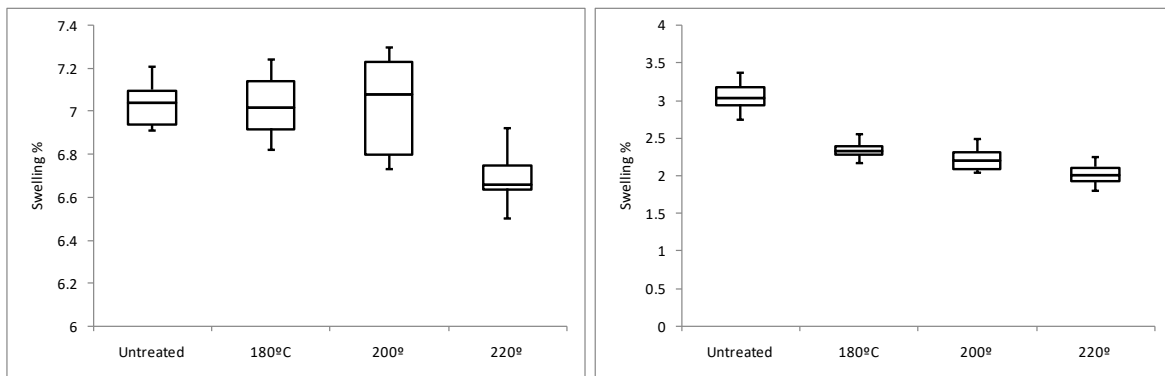
FIR	180°			200°			220°			Untreated		
	1 day	4days	6days	1 day	4days	6days	1 day	4days	6days	1 day	4days	6days
Tangential												
15 min	6.82	6.96	7.24	6.73	6.85	7.12	6.5	6.65	6.95	6.91	7.02	7.21
SD	-0.18	-0.04	0.24	-0.17	-0.05	0.22	-0.2	-0.05	0.25			
VAR	0.017	0.001	0.027	0.014	0.001	0.024	0.02	0.001	0.031			
	0.203**			0.176**			0.037**					
30 min	6.78	6.92	7.14	5.02	5.11	5.92	2.32	2.71	2.84	-0.12	-0.02	0.17
SD	-0.16	-0.02	0.20	-0.33	-0.24	0.57	-0.3	0.09	0.22			
VAR	0.013	0	0.018	0.054	0.028	0.162	0.046	0.003	0.023			
	0.184**			0.048**			0.007**					
Radial												
15 min	2.18	2.28	2.56	2.05	2.10	2.49	1.81	1.99	2.26	2.75	3.01	3.38
SD	-0.16	-0.06	0.22	-0.16	-0.11	0.28	-0.45	-0.03	0.24			
VAR	0.012	0.001	0.024	0.013	0.006	0.038	0.022	0	0.028			
	0.052**			0.031**			0.0012**					
30 min	2.07	2.17	2.32	1.07	1.48	2.03	0.94	1.12	1.24	-0.29	-0.03	0.34
SD	-0.11	-0.01	0.14	-0.45	-0.04	0.11	-0.07	0.01	0.13			
VAR	0.006	0	0.008	0.104	0.001	0.126	0.0128	0	0.009			
	0.008**			0.0019**			0.0012**					



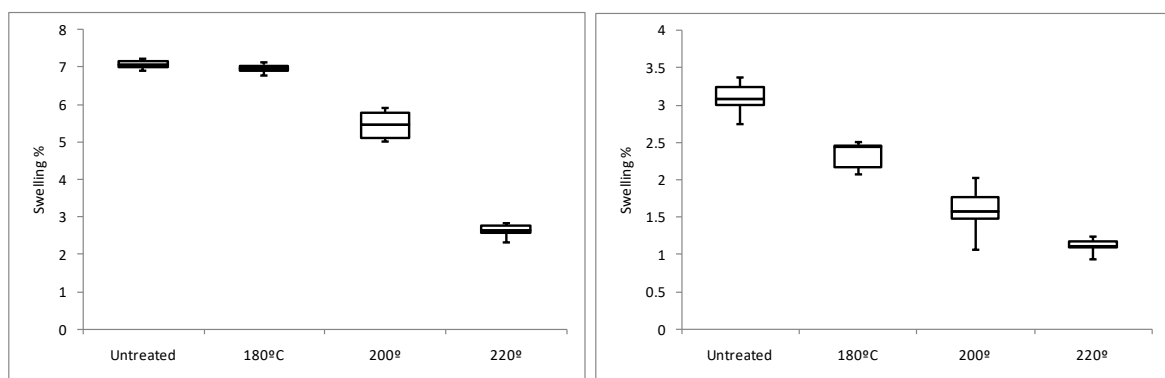
1: Box-plot of swelling percentage distribution of maple for 15 min (Left tangential and right radial treatment)



2: Box-plot of swelling percentage distribution of maple for 30 min (Left tangential and right radial treatment)



3: Box-plot of swelling percentage distribution of fir for 15 min (Left tangential and right radial treatment)



4: Box-plot of swelling percentage distribution of fir for 30 min (Left tangential and right radial treatment)

As is it is presented in Fig. 3 and 4 the tangential swelling of fir wood thermally treated (220 °C for 30 min) decreases respectively 66.4%, 61.4% and 60.6% after 1, 4 and 6 days immersion in water versus untreated wood. Radial swelling of fir wood, thermally treated (220 °C for 30 min) decreases respectively 65.8%, 62.8% and 63.3% after 1, 4 and 6 days immersion in water versus untreated wood. The box plot showed in the Fig. 4 for the radial treatment of the fir in both 200 °C and 220 °C very narrow variability around middle value (1.07, 1.48, 2.03 and 0.94, 1.12, 1.24 respectively).

### Maple and Fir Weight Changes as a Result of Thermal Treatment

- a) The wood **weight loss** is calculated directly after the thermal treatment and according Tab. III and Tab. IV, and it is seen that the lower percentage of weight loss after the thermal treatment (8.76% for the maple and 7.12% for the fir) was measured in the samples treated in a 180 °C for 15 min. The values are statistically significant  $p < 0.05$  (0.024). This happen because under these conditions of thermal treatment, the main effect that has affected weight loss was only the evaporation of water without destroying the wall structure. Similar results were gained by Barboutis *et al.* (2011), Boonstra *et al.* (1998), etc. The higher percentage of

III: Percent of weight loss after thermal treatment, weight increase and  $p^*$  value at  $\alpha = 0.05$  after air conditioning for maple

	15 min	30 min	15 min	30 min	15 min	30 min
Temperature	180 °C	180 °C	200 °C	200 °C	220 °C	220 °C
Weight loss (%)	8.76	9.6	8.85	9.62	9.2	9.66
Standard Dev.	2.4	1.2	3.77	0.34	2.07	0.27
p value $\alpha = 0.05$	0.024		0.026		0.082	
Weight increase (%)	4.14	4.61	4.37	4.87	4.58	3.92
Standard Dev.	1.1	1.02	1.07	1	0.7	0.5
p value $\alpha = 0.05$	0.031		0.052		0.01	

IV: Percent of weight loss after thermal treatment, weight increase and  $p^*$  value at  $\alpha = 0.05$  after air conditioning for fir

Time duration	15 min	30 min	15 min	30 min	15 min	30 min
Temperature	180 °C	180 °C	200 °C	200 °C	220 °C	220 °C
Weight loss (%)	7.12	8.85	9.13	10.66	10.44	10.77
Standard Dev.	1.3	0.65	1.27	1.59	0.45	0.52
p value $\alpha = 0.05$	0.500		0.037		0.491	
Weight increase (%)	3.83	4.35	4.52	4.87	4.95	3.87
Standard Dev.	0.1	0.1	0.84	1	0.1	0.16
p value $\alpha = 0.05$	0.0108		0.450		0.100	

weight loss after the thermal treatment (9.66% for the maple and 10.77% for the fir) was measured in the samples treated in a 220 °C for 30 minutes reflected through no statistical significance with  $p > 0.05$  (0.082). This is because due to the harsh conditions of thermal treatment, the chemical components of the cell wall structure have undergone significant transformations which have led to the loss of weight of the wood. The treatment in higher temperature caused higher depolymerization of hemicelluloses, consequently there was less water absorption in the cell wall (Boonstra *et al.*, 1998; Esteves *et al.*, 2008).

- b) The wood **weight increase** after the thermally treated wood is conditioned in  $T = 20\text{ °C}$  and  $\phi = 60\%$  for 10 days. Tab. III and IV, show that the lower percentage of weight gain after the

thermal treatment and the air conditioning (4.14% for the maple and 3.83% for the fir) was measured in the samples treated in mild treatment in 180 °C for 15 min. This result is because the samples have not managed to lose all initial moisture during thermal treatment.

The higher percentage of weight gain after the thermal treatment and the air conditioning (3.92% for the maple and 3.87% for the fir) was measured in the samples treated in 220 °C for 15 minutes in case of fir samples ( $p > 0.05$ ). This result is obtained because the samples after this thermal treatment reduced initial humidity, left all the volatile extractives but not yet reached the significant modifications of the structure of the cell wall. This has been confirmed also by Rüggeberg and Burgert, 2015; Grönquist *et al.*, 2019, etc.

## CONCLUSION

In this study two types of wood samples were subjected of short heat treatment at three different temperatures (180 °C, 200 °C, 220 °C) at two different duration times (15 min and 30 min). The effect of short heat treatment on tangential and radial swelling and dimensional stability was investigated. The differences in thermal treatment were confirmed through statistical analyses as well. The basic effect of high temperature treatment was on reducing wood swelling. The reducing of radial and tangential swelling was greater when samples were treated in highest temperature for 30 min which differed statistically significant from the corresponding values of the other treated samples in both wood species. The thermal treatment of wood for time duration 15 min does not have any significant effect on wood properties because the treatment does not change the wall structure. The reduction of wood swelling is greater for fir than maple. This can be explained with the fact that the maple wood is rich in extractives (the fir doesn't have extractives) so a part of thermal treatment time of maple wood goes for the disconnection of the extractives from the wall cell structure, while in the case of fir wood the thermal treatment time effects directly in the structure of wall cell.

## REFERENCES

- AKYILDIZ, M. H., ATES, S. and ÖZDEMİR, H. 2009. Technological and chemical properties of heat-treated Anatolian Black pine wood. *African Journal of Biotechnology*, 8(11): 2565–2572.
- BARBOUTIS, I., VASILEIOU, V., MITANI, A. and KAMPERIDOU, V. 2011. Effects of short time thermal treatment on some properties of wood lime. *Pro Ligno*, 7(4): 39–49.
- BARTŁOMIEJ, M., ROMAN, Z., WOJCIECH, G., GRZEGORZ, C. and MARIA, B. 2004. Resistance of thermally modified wood of basidiomycetes. *Electronic Journal of Polish Agricultural Universities (EJPAU)*, 7: 221–234.

- BOONSTRA, M., TJEERDSMA, B. and GROENEVELD, H. 1998. *Thermal Modification of Non-Durable Wood Species. Part 1. The Plato technology: thermal modification of wood*. Document No. IRG/WP 98-40123. International Research Group Wood Preservation.
- BOURGOIS, J. and GUYONNET, R. 1988. Characterization and analysis of torrefied wood. *Wood Sci. Technol.*, 22: 143–155.
- BURMESTER, A. 1973. *Investigation on the dimensional stabilization of wood*. Berlin: Dahlem.
- ESTEVEZ, B., DOMINGOS, I. and PEREIRA, H. 2008. Pine wood modification by heat treatment in air. *Bioresources*, 3(1): 142–154.
- CHANRION, P. and SCHREIBER, J. 2002. *Les Différents Procédés, Bois Traité par Haute Température*. Paris: Edition CTBA.
- GRÖNQVIST, P., WOOD, D., HASSANI, M., WITTEL, F., MENGES, A. and RÜGGERBERG, M. 2019. Analysis of hygroscopic self-shaping wood at large scale for curved mass timber structures. *Sci. Adv.*, 5(9): eaax1311.
- GUNDUZ, G., KORKUT, S., AYDEMİR, D. and BEKAR, İ. 2009. The Density, Compression Strength and Surface Hardness of Heat Treated Hornbeam (*Carpinus betulus* L.) Wood. *Maderas. Ciencia y tecnología*, 11(1): 61–70.
- HAKKOU, M., PETRISSANS, M., GERARDIN, P. and ZOULALIAN, A. 2006. Investigations of the reasons for fung durability of heat-treated beech wood. *Polymer Degradation and Stability*, 91(2): 393–397.
- HILLIS, W. 1984. High temperature and chemical effects on the wood stability. Part 1, General considerations. *Wood Sci. Technol.*, 18: 281–293.
- HILL, C. 2006. *Wood Modification-Chemical, Thermal and Other Processes*. Wiley Series in Renewable Resources. John Wiley & Sons, Ltd.
- HOLSTOV, A., BRIDGENS, B. and FARMER, G. 2015. Hygromorphic materials for sustainable responsive architecture. *Construct. Build Mater.*, 98: 570–582.
- KOCAEFE, D., PONCSAK, S. and BOLUK, Y. 2008. Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. *Bioresources*, 3(2): 517–537.
- KOCAEFE, D., PONCSAK, S., TANG, J. and BOUAZARA, M. 2010. Effect of heat treatment on the mechanical properties of North American jack pine: thermo gravimetric study. *Journal of Material Science*, 45(3): 681–687.
- KOLLMAN, F. 1936. *Technologie des Holzes und der Holzwerkstoffe*. Berlin: Springer Verlag.
- KOLLMANN, F. and SCHNEIDER, A. 1963. On the sorption behavior of heat stabilized wood. *Holz Roh-Werkst.*, 21(3): 77–85.
- KOLLMANN, F. and FENGEL, D. 1965. Changes in the chemical composition of wood by heat treatment. *Holz Roh-Werks.*, 12: 461–468.
- MBURU, F., DUMARCEAY, S., HUBER, F., PETRISSANS, M. and GERARDIN, P. 2007. Evaluation of thermally modified *Grevillea robusta* heartwood as an alternative to shortage of wood resource in Kenya: Characterisation of physicochemical properties and improvement of bio-resistance. *Bioresource Technology*, 98(18): 3478–3486.
- MILITZ, H. 2002. *Thermal treatment of wood: European processes and their background*. Document No. IRG/WP 02-40241. Stockholm, Sweden: International Research Group on Wood Protection.
- RÜGGERBERG, M. and BURGERT, I. 2015. Bio-inspired wooden actuators for large scale applications. *Plus One*, 10(4): e0120718.
- SAILER, M., RAPP, A. and LEITHOFF, H. 2000. *Improved resistance of Scots pine and spruce by application of an oil-heat treatment. Section 4-Processes*. Doc. No. IRG/WP 00-40162 International Research Group Wood Preservation.
- STAMM, A. and HANSEN, L. 1937. Minimizing wood and swelling: Effect of heating in various gases. *Ind. Eng. Chem.*, 29(7): 831–833.
- SEBORG, R., MILLET, M. and STAMM, A. 1945. Heat-stabilized compressed wood. Staypack. *Mech. Eng.*, 67(1): 25–31.
- SEBORG, R., TARKOW, H. and STAMM, A. 1953. Effect of heat upon the dimensional stabilization of wood. *J. For. Prod. Res. Soc.*, 3(9): 59–67.
- SHI, J. L., KOCAEFE, D. and ZHANG, J. 2007. Mechanical behavior of Quebec wood species heat-treated using ThermoWood process. *Holz Roh Werkst.*, 65: 255–259.
- VERNOIS, M. 2001. Heat treatment of wood in France – State of art. In: RAPP, A. O. (Ed.). *Proceedings of Special seminar “Review on Heat Treatment of Wood”*. Antibes, France February 9, 2001. Hamburg: BFH the federal research Centre for forestry and forest products, pp. 39–46.
- YILDIZ, S., GEZER, D. and YILDIZ, U. 2006. Mechanical and chemical behavior of spruce wood modified by heat. *Building Environ.*, 41(21): 1762–1766.
- WEILAND, J. J. and GUYONNET, R. 2003. Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy. *Holz Roh-Werkst.*, 61(2): 216–220.

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