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DETERMINATION OF SOME MECHANICAL PROPERTIES AND NAILS WITHDRAWAL RESISTANCE OF HEAT TREATED FIR WOOD (*ABIES BORRISI*- REGIS)

Andromachi MITANI
Aristotle University of Thessaloniki, Faculty of Forestry and Natural Enviroment
Laboratory of Wood products and Furniture Technology
Thessaloniki 54124 , tel.+30-2310-998898, fax.+30-2310-998947
E-mail: amitani@for.auth.gr

Ioannis BARBOUTIS
Aristotle University of Thessaloniki, Faculty of Forestry and Natural Enviroment
Laboratory of Wood products and Furniture Technology.
Thessaloniki 54124, tel.+30-2310-998898, fax.+30-2310-998947
E-mail: jbarb@for.auth.gr

Abstract

The present study evaluated the effects of heat treatment at 180^{0}C and 200^{0}C for 3, 5 and 7 in the presence of air in an oven, on the mechanical properties and withdrawal resistance of two different types of nails for Greek fir wood (Abies Borissi – regis Mattf.). Static bending properties (MOR and MOE), impact bending strength, compression strength parallel to the grain, and hardness (Janka) in radial and tangential directions were examined. The results showed that the highest mean value of MOR was 81.77N/mm^2 for untreated wood in contrast to the lowest of about 57.89N/mm^2 at 7h at 200^{0}C. MOE was higher at 3h and 5h for 180^{0}C treatment conditions with increases of 0.71% and 1.79%, respectively. Hardness in radial and tangential directions decreased the most, 38.81%, for 7h at 200^{0}C. Impact bending strength had a significant decrease of 44.09% after the extreme treatment of 7h at 200^{0}C comparated to untreated samples. Finally, the withdraw al resistance of both types of nails decreased beyond 3h at 180^{0}C but the resistance of helically-threaded nails decreased more for treatments beyond 3h at 200^{0}C.

***Key words**: heat treatment; fir wood; mechanical properties nails withdrawal resistance.*

INTRODUCTION

Thermal modification of wood at elevated temperatures under air, nitrogen, oil or steam increases the dimensional stability, and reduces hygroscopicity, thus improves the decay resistance of wood which in turn leads to enhancing its resistance against biological attack. Furthermore heat treatment methods can achieve better heat insulation and new shades of color as an alternative to tropical hardwood, but this also can reduce certain elements of its strength properties. These changes result from the cleavage and degradation of hemicelluloses, depolymerization and condensation of lignin and the formation of a host of low molecular weight degradation products including organic acids, formaldehyde, furfural and aldehydes (Schultz et al. 2008).

Nails are the most common mechanical fastenings used in wood construction. There are many types, sizes, and forms of nails. Both withdrawal and lateral resistance are affected by the wood, the nail, and the condition of use. The resistance of a nail shank to direct withdrawal from a piece of wood depends on the density of the wood, the diameter of the nail, and the depth of penetration. The surface condition of the nail at the time of driving also influences the initial withdrawal resistance (Rammer 2010).

Nails are widely used as joint components of furniture construction and since each wood species has its own properties, they also have different screw and nail withdrawal resistances. Therefore, it is important for both producers and consumers to be aware of the best screw and nail withdrawal resistance for the various wood species (Aytekin 2008).

The strength and stability of any structure depend on the material of the elements used, but also heavily on the connections that hold the elements together. In most, wood structures connections are some of the most important components. Generally, connections are equally important in furniture construction as in wooden structures because they are the critical links between the elements of the structure providing structural rigidity (Kariz et al. 2013).

Heat treatment affects the mechanical properties of wood, which can influence the withdrawal resistance of nails. Lower withdrawal strength can be explained by the the lower shear strength of the heat treated wood. A reduction in shear strength after thermal treatment can be explained by the partial conversion of polyoses which make up to 20% of the middle lamella of the cell wall (Kariz et al. 2013).

Korkut (2008) studied the Abies bornmuellerinana Mattf fir wood using different temperatures (120ºC, 150ºC and 180ºC) and duration 2h, 4h and 10h. Compression strength, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain was also tested. The results indicated that treated samples had lower mechanical properties compared to the control samples. Studies by Korkut (2008) also confirmed that there is a strong relationship between temperature and treatment durations and mechanical properties in that the longer the treatment, the greater the decrease in the mechanical properties. Sahin (2010) examined the modulus of rupture (MOR), modulus of elasticity in bending (MOE), impact bending strength, and compression strength, in addition to swelling and shrinkage of Abies bornmuellerinana Mattf at 190ºC and 212ºC for 2h. The results indicated that the most affected mechanical properties were MOR and IBS for fir wood. The reduction in MOE was lower than the reduction in MOR and impact bending strength.

OBJECTIVE

This study was conducted to assess the effect of heat treatment on the mechanical properties (static bending strength, impact bending strength, compression strength and hardness) and withdrawal resistance of two types of nails of Abies Borissi-regis Mattf. fir wood which is one of the most important commercial wood that is produced in Greece.

MATERIAL, METHOD, EQUIPMENT

The investigated material, fir sawn wood (Abies Borissi-regis Mattf.), of Greek origin, was selected from the Greek university forest in Pertouli. These logs were skidded to the sawmill where they were cut into 3.5cm thickness flitches with 15cm width and 50cm length in order to be treated. These flitches were conditioned in laboratory space for about 1 year under 20 ± 2oC and 60 ± 5% relative humidity. The average moisture estimated according to ISO 3130:1975 was 12.27% (SD 0.18) while the average density (oven dry weight/volume at 12.27% (SD: 0.18) moisture) of timber used were 0.40g/cm3 (SD 0.040).

Subsequently, heat treatment process was conducted in a controlled temperature, small, laboratory heating unit (80 x 50 x 60cm) where three different durations (3h, 5h and 7h,) were applied at 180oC and 200oC in the presence of air. The specimens were placed in the unit after reaching the desired temperature. Once heat treating was completed, the specimens were conveyed for air conditioning at 20 ± 2oC and 60 ± 5% relative humidity for 15 days to attain EMC and then, flitches were cut into cross-sectional dimensions 2x2x50. From the above flitches the final specimens were formed, after defects' removal, according to respective standards (Table 1). Ten replicates per treatment were designated for each strength test, with total 200 samples for all strength properties.

Table 1

Properties studied and the respective standards

Property	Dimensions (cm)	Standard
Density (basic)	2 x 2 x 2,5	ISO 3131:1975
Moisture content	2 x 2 x 2,5	ISO 3130:1975
Compression strength	2 x 2 x 6	DIN 52185:1976
Bending strength	2 x 2 x 37	ISO 3133:1975
Hardness (Janka)	2 x 2 x 6	ISO 3350:1975
Impact bending strength	2 x 2 x 28	ISO 3348:1975
Withdrawal capacity of nails	5 x 5 x 3	EN 13446:2002

Bending (Modulus of Rupture and Modulus of Elasticity) and compression strength properties were carried out on a Universal Testing Machine (SHIMADZU UH-300kNA) and the rate of crosshead-movement was adjusted at 6mm/min, so that the maximum load was reached within 1.5 ± 0.5min, according to standards. The loading continued until a break of the specimen occurred. The impact bending strength test was carried out on an Amsler Universal Wood Testing machine at 24cm span with center loading. Additionally, the hardness (Janka) test measuring the force required to embed a

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half steel ball of 11.28mm diameter into radial and tangential surface of wood was carried out in the same machine.

The wood samples preparation for the insertion of the nail, the nail withdrawal resistance procedure and the maximum strength calculation was made based on the standard EN 13446: 2002. Two different types of nails type 1: annularly threaded and type 2: helically threaded (Fig. ?), were used for the experimentation whose features are: Nail 1: diameter: 2.98mm and length: 70.10mm, nail 2: diameter: 2.74mm and length: 70.10mm.

The dimensions of the wood samples according to the standard are 50mm x 50mm. By determining the surface centre of the sample with the use of a hammer and without creating a hole, the penetration of the nail into the mass of the wood was conducted until the bottom of the nail to exceed at least 1cm from the sample.

The checking procedure of the withdrawal resistance strength was conducted in the strength machine SHIMADZU UH-300kNA where the rate of cross-head movement was adjusted to 5.5mm/min. The moisture content of the samples during the experiment was for the untreated sample: 10.86%, 180 C-3 hours: 9.77%, 180 C-5 hours: 8.02%, 180 C-7 hours: 7.46%, 200 C-3 hours: 6.71%, 200 C-5 hours: 6.30%, 200 C-7 hours: 5.89%.

The results expressed as the maximum load and according to the standard from the formula:
f= Fmax / d * 1

where:

Fmax: Maximum withdrawal load
d : nominal diameter of fastener
lp : depth of penetration of fastener

One way analysis of variance (ANOVA) comparing the differences of values at 0.05 level was examined in order to determine the significant differences among miscellaneous heat treatment combinations on mechanical properties.

RESULTS AND DISCUSSION

From the results of the table 1, it has been found that the fir wood strength is gradually decreased after the thermal modification comparing to the untreated samples. In particular, strength reduction in compression with duration increase of thermal modification is observed, as well as temperature increase. According to the results, we conclude that the temperature increase affected strength in compression more substantially than the increase of the treatment duration. Moreover, it has been found out that thermal modification affected negatively the fir wood strength in impact, except for the samples subjected to thermal modification at 180 C for 3 hours, on which a very slight strength increase has been observed which is not statistically significant according to statistical analysis. On the contrary, concerning the rest of the strength tests, a strength reduction in impact has been noticed as long as the duration and the temperature of the treatment were increasing. According to statistical analysis the referred decrease is statistically significant as regards all of treatment. In this case also, we infer that temperature constitutes a more significant factor of strength reduction than that of treatment duration. As far as hardness is concerned, it has been ascertained that thermal modification affected fir wood hardness positively both in radial and tangential direction, only in the case of treatment at 180ºC for 3 hours where this particular increase is statistically significant. In addition, it is being observed that after wood treatment at 180ºC for 5 hours, hardness does not present any important differences which are not statistically significant, apart from a slight decrease comparing to the untreated samples regarding radial direction, while in tangential direction a slight increase is observed, comparing also to the untreated samples. An abrupt and intense hardness reduction is noticed after wood treatment at 180ºC for 7 hours while there is no difference in wood hardness at 200ºC for 3 hours treatment comparing to the previous one. As time goes by, at 5 and 7 hours at 200ºC, an even more intense decrease is observed whereas tangential direction, as for treatment at 200ºC for 7 hours, gave the lowest rates. More generally, it has come up that tangential direction shows lower hardness than the radial one, both in the modified wood and the untreated samples. As it is mentioned before all different thermal treatments differ statistically significant except for treatment at 180ºC for 5 hours as for both tangential and radial directions.

Table 2

Heat treatment conditions and the mechanical properties of heat treated and untreated Fir wood

Properties		Different heat treatment conditions						
		Untreated	180º C-3 hours	180º C-5 hours	180º C-7 hours	200º C-3 hours	200º C-5 hours	200º C-7 hours
Modulus of Rupture (MOR) (N/mm^2)	$\bar{x}$	**81.77**	**79.56**	**71.31**	**68.36**	**66.54**	**58.20**	**57.89**
	± s	5.42	4.75	5.86	6.81	6.51	5.19	4.57
	s²	29.4	22.62	34.39	46.49	42.38	26.97	20.96
	cv	0.06	0.05	0.08	0.09	0.09	0.08	0.07
Modulus of Elasticity (MOE) (N/mm^2)	$\bar{x}$	**10898**	**11126**	**11093**	**9386**	**9176**	**8868**	**8796**
	± s	1169	1096	725.97	691.6	802.5	588.7	566.1
	s²	13677	12030	52704	47842	64402	34660	32052
	cv	0.1	0.09	0.06	0.07	0.08	0.06	0.06
Impact Bending Strenght (J/cm^2)	$\bar{x}$	**5,84**	**5,88**	**5,08**	**4,54**	**4,10**	**3,66**	**3,26**
	± s	0,55	0,38	0,32	0,30	0,42	0,37	0,32
	s²	0,30	0,15	0,10	0,09	0,18	0,13	1,10
	cv	0,09	0,06	0,06	0,06	0,10	0,10	0,09
Compression Bending Strenght (N/mm^2)	$\bar{x}$	**61.12**	**55.13**	**52.99**	**50.96**	**49.88**	**49.37**	**49.12**
	± s	1.39	1.42	2.29	0.92	1.89	1.54	2.64
	s²	1.94	2.02	5.26	0.85	3.57	2.37	6.97
	cv	0.02	0.02	0.04	0.01	0.03	0.03	0.05
Hardness Radial (kN)	$\bar{x}$	**2,49**	**2,74**	**2,4**	**1,96**	**1,95**	**1,68**	**1,64**
	± s	0,05	0,08	0,10	0,11	0,07	0,12	0,10
	s²	0	0	0,01	0,01	0	0,01	0,01
	cv	0,02	0,08	0,04	0,05	0,03	0,07	0,06
Hardness Tangential (kN)	$\bar{x}$	**2,32**	**2,77**	**2,39**	**1,95**	**1,94**	**1,67**	**1,42**
	± s	0,08	0,06	0,08	0,10	0,07	0,08	0,12
	s²	0	0	0	0,01	0	0	0,01
	cv	0,03	0,06	0,03	0,16	0,03	0,05	0,08

* $\bar{x}$= average; ±s= standard deviation; s²=Variance; cv= coefficient of variation

Finally, concerning the bending results, it has been found out that fir wood strength gradually reduced after thermal modification while the duration and time of it were increasing. In this case too, as it was mentioned about the previous mechanical properties of wood, temperature increase played a more substantial role than duration increase did. As it is noticed from the results when wood was submitted to thermal modification at 200ºC, the strength reduction in bending was more important. According to statistical analysis the only treatment condition that does not differ statistically significant is at 180ºC. On the other hand, the modulus of elasticity of the fir wood indicated improvement after thermal modification concerning wood processing at 180ºC for 3 and 5 hours which are not statistically significant. By contrast, as the duration and temperature became more intense, the modulus of elasticity showed decrease. The increase percentages of the elasticity modulus in conditions of 180ºC for 3 and 5 hours were recorded at 2,1 and 1,79% respectively comparing to the untreated samples (Fig. 1). Conversely, the decrease percentages about the conditions 180º C for 7 hours and 200ºC for 3,5 and 7 hours were estimated at 13,87 , 15,79 , 18,62 and 19,18 respectively comparing to the untreated samples. By observing the decrease percentages of the elasticity modulus we can conclude that it was not affected as significantly as the rest of the mechanical properties of the thermally modified fir wood but the decreases between treated and untreated samples are statistically significant.

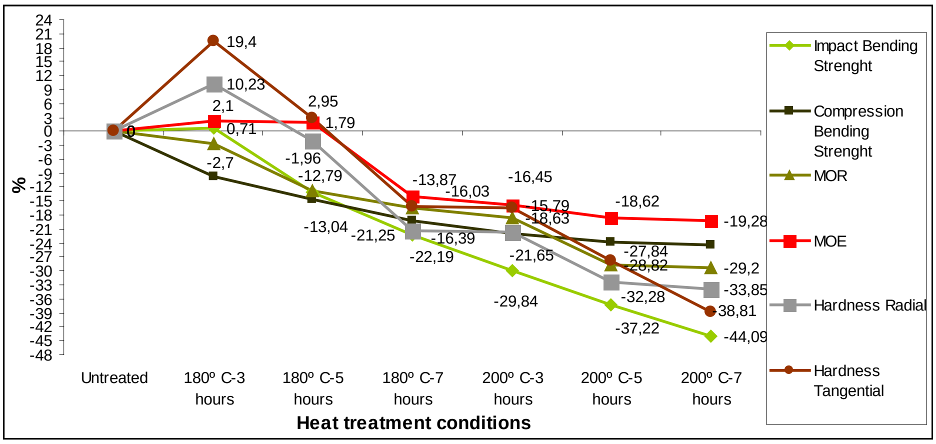

Fig. 1.
The increase/decrease rates of the mechanical properties after heat treatment of fir wood

In the table 2, the mean values of the withdrawal resistance of the two different types of nails in Newton and their rupture modulus per unit surface area are recorded. Fmax in Newton express the final maximum strength which is required in better way than f in N/mm². According to the results of the chart below, the required strength for the nail withdrawal resistance seems to decrease as the temperature and duration of the thermal modification increase.

Table 3

Nail withdrawal resistance of heat treated and untreated Fir wood

Heat treatment conditions	**Units**	**Fir wood– Nail withdrawal resistance after heat treatment**			
		Nail 1		**Nail 2**	
		Fmax (N)	**f (N/mm²)**	**Fmax (N)**	**f (N/mm²)**
Untreated	$\bar{x}$	**954,8**	**15,9**	**600,7**	**10,91**
	± s	51,54	0,84	41,97	0,76
	s²	0,05	0,05	0,06	0,07
	cv	2657	0,71	1761	0,58
180º C 3 hours	$\bar{x}$	**915,5**	**15,18**	**594,6**	**10,71**
	± s	76,2	1,27	44,49	0,79
	s²	0,08	0,08	0,07	0,07
	cv	5807	1,63	1979	0,63
180º C 5 hours	$\bar{x}$	**835,6**	**13,94**	**474,3**	**8,59**
	± s	63,62	1,04	37,88	0,72
	s²	0,07	0,07	0,07	0,08
	cv	4048	1,08	1435	0,52
180º C 7 hours	$\bar{x}$	**784,1**	**13,04**	**401**	**7,24**
	± s	66,08	1,09	16,47	0,3
	s²	0,08	0,08	0,04	0,04
	cv	4367	1,18	271,33	0,09
200º C 3 hours	$\bar{x}$	**619,6**	**10,3**	**334,2**	**6,04**
	± s	57,84	0,97	30,46	0,54
	s²	0,09	0,09	0,09	0,09
	cv	3346	0,95	928,4	0,29
200º C 5 hours	$\bar{x}$	**405,5**	**6,78**	**293,7**	**5,33**
	± s	31,96	0,53	21,63	0,39
	s²	0,07	0,07	0,07	0,07
	cv	1022	0,28	468,01	0,15
200º C 7 hours	$\bar{x}$	**331,2**	**5,5**	**271,6**	**4,9**
	± s	30,43	0,5	24,65	0,46
	s²	0,09	0,09	0,09	0,09
	cv	926,4	0,25	607,82	0,21

* $\bar{x}$= average; ±s= standard deviation; s²=Variance; cv= coefficient of variation

Temperature appears to be, in this occasion too, the most significant factor of strength reduction in relation to the treatment duration. According to the statistical analysis of the results, we came to the conclusion that the reduction occurred during the first treatment at 180º C for 3 hours was not statistically noticeable, unlike the other treatments where the differences were statistically important concerning both types of nails. According to statistical analysis all of different thermal treatments differ statistically significant in relation to untreated wood samples except for the first treatment at 180º C for 3 hours concerning both of two types of nails.

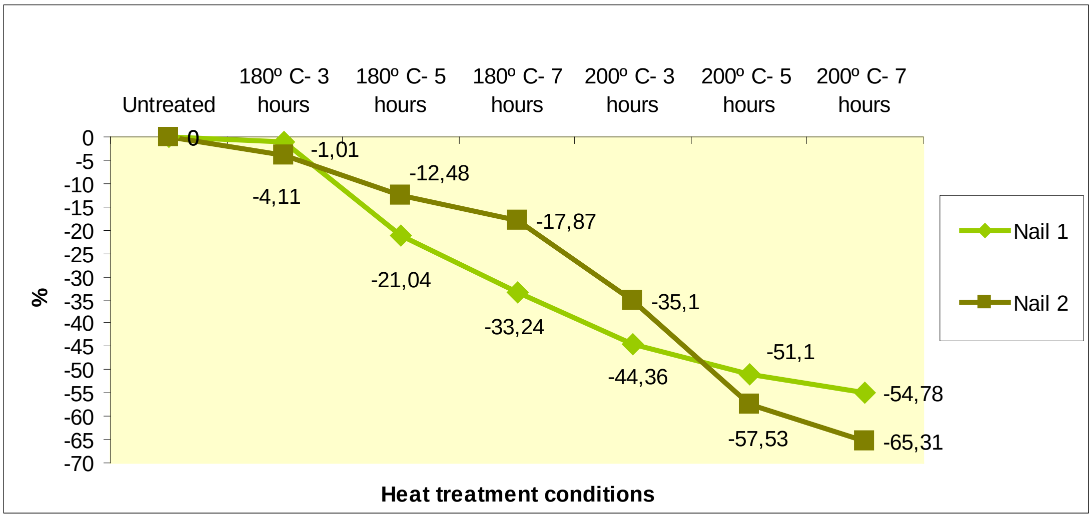

Fig. 2.
The increase/decrease rates of the nail withdrawal resistance after heat treatment of fir wood

In diagram 2 the reduction rates of the nail withdrawal resistance are shown and as we can notice, the reduction rates concerning type 1 of the nails seem to be higher until the 200 C for 3 hours treatment whereas, during the two last treatments, the reduction of the nail type 2 seems to be higher.

CONCLUSIONS

Taking into account the conditions of the treatments, the results have a less or more significant influence on fir wood mechanical properties.

To sum up, the MOR generally had not been affected as the specimens were subjected to heat treatment conditions up to the limit of 3h. Following the 3h the MOR seems to decrease rapidly. The same behaviour was observed in compression strength as in MOR. Moreover, heat treatment seems not to affect negatively the MOE of fir wood, since a MOE increase in the two first treatments was observed, namely at 180 C for 3 and 5h. while subsequently, the more the treatment duration and temperature increased, the more the MOE decreased. As for the strength in impact and the change in hardness, the same phenomenon is observed, which an increase is during the first treatment and a decrease in the following treatments.

Regarding the strength of the thermally modified wood in the nail withdrawal resistance, it appears that after the completion of the 180 C for 3h treatment, the strength reductions noticed are statistically significant.

The decrease in the strength properties depending on wood species and treatment conditions can be explained by the rate of thermal degradation and losses of substance as a result of treatment process.

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