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THE EFFECT OF HEAT TREATMENT ON THE WITHDRAWAL CAPACITY OF SCREWS IN FIR WOOD (*Abies borisii-regis*)

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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 withdrawal resistance of three different types of screws for Greek fir wood (Abies Borissi – regis Mattf.). According to the results of the thermally modified samples in comparison with the untreated wood it seems that the screw with the diameter differs statistically at an important level at all treatments except the samples modified at 180^{0}C for 5 and 7 hours. The other two types of screw with the biggest diameter differ statistically significant at all treatments except the samples which are modified at 180^{0}C for 3 hours. Additionaly, the correlation between screw withdrawal capacity and mass loss of heat treated wood is estimated. The dependency between the screw withdrawal capacity and the mass loss was found to be best described by a regression equation with R^2 of 0.97 for the first type of screw, and R^2 of 0.93 for the second and third type of screw.

Key words: *heat treatment; fir wood; withdrawal capacity; screw.*

INTRODUCTION

Wood as biological burning material is influenced and disintegrated under conditions of high temperature. Thermal elaboration of temperature levels of up to 200^{0}C is performed with the main aim of achieving new properties of the material such as changes in color, improved and reinforced biological endurance and increased dimensional stability. The thermal modification of wood could be described as: wood is undergone a process under controlled conditions of temperature, time and in some cases with controlled presence of moisture or oxygen.

This process could have as a result moisture decline, chemical modifications of the polymerical components of wood, alterations in the natural endurance of wood, decline in its hugroscopicity, changes in color and finally in its mechanical strength after a particular combination level of temperature and time (Militz 2002).

Screws and nails are widely used in joining wooden constructions and due to the fact that every kind of wood has different properties, their withdrawal resistance from wood is various. This resistance depends on the density and the specific gravity of wood, the depth of the penetration, the screw or the nail's diameter, the wood endurance, the specie of wood, the moisture content and the temperature exposure of the material and finally the kind of the screw or nail (Ayketin 2008).

Generally the specie of wood with low density restrains nails better than other specie with higher density conception (Soltis 1999). As it has already been mentioned above, the thermal treatment influences the mechanical properties of wood. Therefore, there is great possibility of reducing the withdrawal resistance of the joints. In temperatures above 160^{o}C and specifically above 210^{0}C the withdrawal resistance is seriously decreased due to the mechanical degradation of the elaborated wood, while the treatment duration does not seem to play such an important role in the endurance of the joint. Moreover, the reduced resistance of the joint can be due to the reduction of the shear strength after the thermal treatment. The lower shear strength is combined with the moisture content and density of wood, therefore, it is also combined with the strength of the withdrawal resistance of the joint (Kariz et al. 2013).

Kariz et al, studied the withdrawal capacity of the screw in thermally modified fir sawn wood (Picea abies Karst.) in temperatures 150, 170, 190, 210 and 230^{0}C. According to the results, the withdrawal capacity of screw was reduced with the increase of the temperature and the duration of the treatment, regardless of the radial and the tangential direction. The statistical analysis showed that the values of the withdrawal capacity for the modified wood differed significantly according to the untreated specimens. The mass and density loss is the main cause of the reduction of the strength. The researchers mention that the distortion of the restraint area of the screw was getting bigger while the temperature and the duration of the treatment increased.

OBJECTIVE

This study was conducted to assess the effect of heat treatment withdrawal resistance of three types of screws of Abies Borissi-regis Mattf. fir wood which is one of the most important commercial wood that is produced in Greece. The correlation between screw withdrawal capacity and mass loss was also investigated.

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 ± 2^{0}C 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/cm^3 (SD 0.040).

Subsequently, heat treatment process was conducted in a controlled temperature, small, laboratory heating unit (80x50x60cm) where three different durations (3h, 5h and 7h,) were applied at 180^{o}C and 200^{0}C 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 ± 2^{0}C and 60 ± 5% relative humidity for 15 days to attain EMC.

The wood samples preparation for the insertion of the screws, the withdrawal resistance procedure and the maximum strength calculation was made based on the standard EN 13446: 2002 (Fig. 1). Three different types of screws were used for the experimentation whose features are: Screw 1: diameter: 2.96mm and length: 60.15mm, Screw 2: diameter: 4.97mm and length: 60.15mm, Screw 3: diameter: 5.80mm and length: 60.15mm.

Fig. 1.
Samples used in tests to determine withdrawal capacity of screws in radial direction.

The dimensions of the wood samples according to the standard are 50mmx50mm. By determining the surface centre of the sample with the use of drilling equipment and creating a hole, the penetration of the screws into the mass of the wood was conducted until the bottom of the screws 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^{0}C-3 hours: 9.77%, 180^{0}C-5 hours: 8.02%, 180^{0}C-7 hours: 7.46%, 200^{0}C-3 hours: 6.71%, 200^{0}C-5 hours: 6.30%, 200^{0}C-7 hours: 5.89%.

The results expressed as the maximum load and according to the standard from the equation (1):

$$f= Fmax / d * 1 \quad (1)$$

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 screws withdrawal capacity.

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pp. 89-93

RESULTS AND DISCUSSION

At Table 1, the mean values of the withdrawal resistance of the different types of screws are presented in Newton as well as the withdrawal capacity per surface unit. As we realize by the results, screw No 1 seems to have increase of its strength regarding the first two treatments at 180^{0}C for 3 to 5 hours. This fact means that the withdrawal capacity of the particular screw improved after the thermal operation. Accordind to the statistical analysis of the results, the increase that was noticed during the first treatment for 3 hours is statistically significant while the increase in the 5 hours treatment is not considered statistically signifacant. Regarding the other two types of screws the same phenomenon wan not noticed - they showed a slight reduction. Taking the results into account, we can conclude that the withdrawal capacity is reduced in proportion to the temperature increase and to the duration, however, without noticing intense reduction with the change of temperature to 200^{0}C but only a relatively serious reduction during the last treatment at 200^{0}C for 7 hours.

In addition, as we can notice at Table 1, the type of screw No 3 shows greater stregth Fmax than the other two types of screws due to bigger diameter of the spiral, except some cases in which type No 2 seems to exceed, however, the difference is slght and is certainly unimportant. It is worth mentioning that at the 200^{0}C treatments the second type of screw shows higher values of withdrawal capacity compared with the third type of screw while regarding the last treatment even the first type of screw shows greater values in comparison with the third type of screw. This phenomenon can be explained because of the friability of the thermally modified woodand the reduction of its density mainly at the intense treatment in which the biggest spiral seems to be operate negatively regarding the withdrawal resistnance of the screw.

The same is not noticed in the untreted wood and is neither noticed at the milder treatment at temperature 180^{0}C.

Table 1

Strenght and average withdrawal capacity of the screws for wood that was heat treated at different temperatures

Heat treatment conditions	Units	Fir wood- Screw withdrawal capacity of treated and untreated samples					
		Screw 1(2.96 mm)		Screw 2(4.97 mm)		Screw 3(5.80 mm)	
		Fmax (N)	Withdrawal capacity (N/mm²)	Fmax (N)	Withdrawal capacity (N/mm²)	Fmax (N)	Withdrawal capacity (N/mm²)
Untreated	**X**	**1861**	**31,3**	**2349**	**23,54**	**2565**	**21,97**
	±s	76,79	1,31	92,16	0,93	186,33	1,56
	V	0,04	0,04	0,03	0,03	0,07	0,07
	s²	5897	1,73	8494	0,88	3472	2,46
180° C 3 hours	**X**	**2037**	**34**	**2351**	**23,34**	**2339**	**19,96**
	±s	127	2,12	160,23	1,59	189,51	1,61
	V	0,06	0,06	0,06	0,06	0,08	0,08
	s²	1614	4,51	2567	2,55	3591	2,59
180° C 5 hours	**X**	**1942**	**32,59**	**2152**	**21,54**	**2316**	**19,86**
	±s	95,79	1,59	104,15	1,05	131,36	1,1
	V	0,04	0,04	0,04	0,04	0,05	0,05
	s²	9176	2,54	1084	1,11	1725	1,21
180° C 7 hours	**X**	**1821**	**30,54**	**2135**	**21,28**	**2237**	**17,43**
	±s	120,7	1,99	161,64	1,63	97,5	0,85
	V	0,06	0,06	0,07	0,07	0,04	0,04
	s²	1457	3,97	2612	2,68	9507	0,73
200° C 3 hours	**X**	**1765**	**29,52**	**2021**	**20,12**	**2012**	**17,15**
	±s	150,1	2,5	131,4	1,29	95,16	0,78
	V	0,08	0,08	0,06	0,06	0,04	0,04
	s²	2255	6,29	1729	1,68	9056	0,61
200° C 5 hours	**X**	**1593**	**26,75**	**1927**	**19,22**	**1878**	**16,08**
	±s	118,0	1,93	108,44	1,13	167,73	1,41
	V	0,07	0,07	0,05	0,05	0,08	0,08
	s²	1393	3,75	1175	1,28	2813	2,01
200° C 7 hours	**X**	**1432**	**23,85**	**1687**	**16,75**	**1415**	**11,99**
	±s	107,1	1,76	149,95	1,41	102,31	0,86
	V	0,07	0,07	0,08	0,08	0,07	0,07
	s²	1149	3,1	2248	1,98	1046	0,75

* X = average; ±s= standard deviation; s²=Variance; cv= coefficient of variation

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pp. 89-93

Regarding the modulus of rupture of the three different types of screw, the exactly opposite result is noticed. The modulus of rupture is the stregth of withdrawal per surface unit. Thus, the bigger spiral diameter we have, the smaller the modulus of rupture is. According to the statical analysis of the results, regarding the first type of the screw statistically significant differences are noticed at the 180^{0}C.

Treatments for 3 hours at 200^{0}C for 7 hours compared with the non-modified wood. In accordance with the results of the thermally modified samples compared with the untreated wood it seems that the first type of screw differs significantly as concerns all treatments ecxept the modified samples at 180^{0}C for 5 and 7 hours. However, the second and the third type differ significantly at all treatments except the samples modified at 180^{0}C for 3 hours.

In Fig. 2 the mass loss of the samples after heat treatment is depicted and as we can notice, mass loss gradually increased after heat treatment while the duration and time of it were increasing.

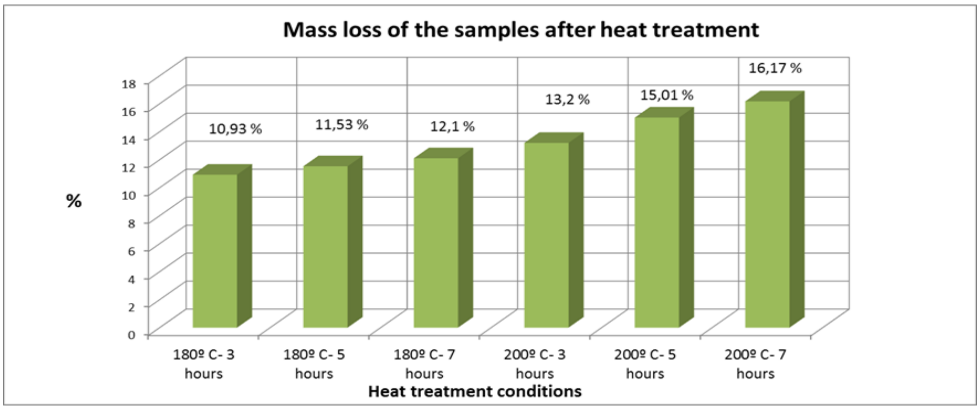

Fig. 2.
Mass loss of the samples after heat treatment.

At Fig. 3,4 and 5 the correlations between the reduction of the withdrawal resistance of the three different types of screws and the loss of the wood mass after the thermal treatment are shown. According to the correlation level R^2 all three types of screw show a very strong relation with the mass loss. Particularly, the first type of screw showed a relation of 97% (R^2= 0.97) while the second and the third type 93% (R^2= 0.93).

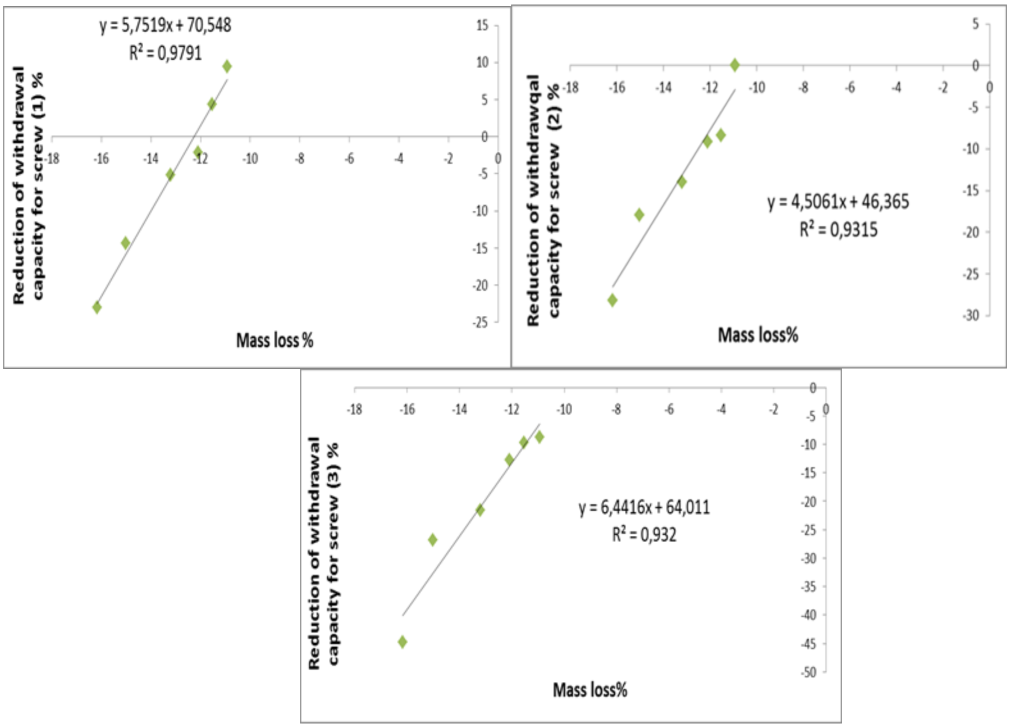

Fig. 3,4,5.
Correlation between screw withdrawal capacity and mass loss.

CONCLUSIONS

Taking into account the results of this research, we reach the following conclusions: Generally, the temperature of the thermal treatment was a more important factor compared with the duration of the treatment regarding the results of the research. The thermallymodified fir sawn wood showed mass loss and the withdrawal capacity of three different types of screws after thermal operation, showed reduction with the temperature increase and the treatment duration except screw No 1 which showed an increase during the first two treatments at 180^0C for 3 and 5 hours which was 8.62% and 4,1% in correspondence. The withdrawal capacity was more intense regarding the screw with the largest total diameter (thickness) while the screw with the smallest diameter showed weaker strength. The percentance of the reduction of the withdrawal resistance were fluctuated between 20.2% and 23.8% for screw No 1, between 0.87% and up to 28.83% for screw No 2 and between 9.15% and 44.4% for screw No 3.

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