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Mechanical Performance of Woodwork Joinery Produced by Industrial Methods

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Abstract

In this study, the improvement of the mechanical properties of wood material were investigated to determine the effects of heat treatment (thermo-process) and impregnation processes held in open-air conditions on the mechanical performance of woodwork joinery. To this end, pine (*Pinus sylvestris* L.) and chestnut (*Castanea sativa*) species grown in our country were used which have significant natural and commercial value. Actual sizes of the examples of woodworks were set out diagonally.

In the double-tenon construction and glue type polyurethane (PU) and D4 adhesives used. Diagonal woodwork and the test samples prepared by class at 185°C temperature with a thermo-vapor process protections apply. Thus, thermo-treated wood joinery was obtained. After application of the heat treatment by immersion, the test samples, and a 5% solution of tannin and oak with a natural pine cone resin made impregnation process. Then, the impregnation of natural wood (control) only heat-treated and heat treatment+impregnated samples kept for one year in outdoor conditions. At the end of the waiting period, on samples prepared by the principles stated in TS 2472 and TS 7251 EN 107 standard "Windows-Test Methods-Mechanical Experiments," according to the principles specified in standard performance tests (diagonal compression test, windows hang test) and microscopic observations and investigations to determine the cellular changes were made. These observations suggest that the natural form treated and untreated samples and comparison of window wings holding the external environment gained strength during the degradation and the reasons for this deterioration was detected against the impregnated material. Experimental density measurements on samples without waiting in outdoor conditions before, after waiting and waiting, as periodic process was determined by performing the difference.

In this study, experiments were carried out on diagonal examples and especially examples in actual size woodwork. In addition, natural oak tannin solution impregnation process was used. From previous research literature diagonal examples have been used not only in instances of life-size woodwork. In addition, thermo-transaction and impregnation process used in conjunction studies, natural pine resin is used, and there is no such study created a solution. This also shows that the original value of our work.

Keywords: Thermo process; Wood material; Wood preservation; Wood modification; Mechanical properties; Industrial woodwork; Microscopic examination

Introductıon

Wood material occupies a significant place in human life thanks to the developments in woodworking industry. Wood material is preferred for its many favorable properties and advantages such as easy processing, isolation, being lightweight, strength, naturality and aestheticity Özalp [1]. However, inflammability, insect infestation induced degradation, fungi induced decomposition, change in its size depending on balance humidity altered by ambient temperature and relative humidity, and fading in color and decomposition due to sunlight exposure, resulting from being an organic material, are considered as its disadvantages Kurtoğlu [2].

It is important to protect, increase longevity and physical durability of the wood material which is exposed to factors such as fungi, insects, ultraviolet rays from the sun in the outer environment. The methods applied to protect the wood material from these factors are called as "modification", the most prevalent ones being impregnation Ayar [3] and thermo-process.

Wood and wood products, being of the conventional material group, are used after being treated with various modification processes, as massive material or wood-derived products. Wood material is widely used chiefly in the flooring and walls of the wooden houses and in wood constructions, and also in the roof, moulding and scaffolding works. Particularly the producers who refrain from PVC material prefer again wood material especially for the production of window and door frames in constructions. Different techniques and corner joinings are applied in the production of door and window frames. These corner joinings come under more diagonal traction – pressure tension influence when faced with the door and window frames' self-weights and other external loads Tokgöz, Kap, and Özgan [4].

In the course of the use of the wooden frames, problems such as deformation in the casement geommetry arise, and these bring about difficulties in opening and closing Arslan, Subaşı, and Altuntaş [5]. The studies related to this problem are not found to be sufficient in the literature.

Thermo-process is an important wood modification method in which the size stabilization is established without the use of any chemical substance. By this way, volumetric swelling can be reduced approximately by 50% and thermo-processed wood can be safely used in the outer environment, without any requirement for the

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chemicals that are hazardous to the environment and human health. However, thermo-process completely destroys the natural preservative substances (i.e. tannin, resin) intrinsic to the wood material Altınok, Perçin, and Doruk [6].

Altinok et al. in 2009, tested the Scotch pine and Uludag fir woods gluing with PVAc-D3 and PVAc-D4 in single and double mortise wooden frame corner joinings, and reported Scotch pine and PVAc-D4 glue as having the highest diagonal tension performance, while Uludağ fir and PVAc-D3 were reported to have the lowest Altınok, at al. [7]

In the study of Alen et al. in 2002, thermo-process was applied to spruce wood (*Picea abies* L.) at 180-225°C temperature for 2-8 hours, and it was found in the chemical examinations of thermo-processed samples that carbohydrates had been more decomposed than lignin during the thermo-process procedure Alen et al. [8]

Aydemir and Gündüz in 2009 stated that in the thermo-processes and above 150°C, the color of the wood had darkened, and biological resistance and constancy in terms of size had improved. Additionally in the same study, it was reported that a reduction in the mechanical properties and alteration in the chemical structure of the wood had occured, and for this reason the utilization areas of the wood material were curtailed Aydemir and Gündüz [9].

Korkut et al. in 2008, subjected beech and maple (Acer trautvetteri Medw.) woods to thermo-process at different temperatures (120°C, 150°C and 180°C) and for different times (2 h, 6 h, 10 h). They stated that as the temperature and the duration of the thermo-process increase, technological properties of the wood material are decreased Korkut at al. [10].

Bekhta and Niemz in 2003, determined that in beech wood (Fagus orientalis L.) mechanical properties and bending strength had decreased by 5%-40% and modulus of elasticity (MOE) by 4%-9%, stabilization in terms of size had increased and wood color had darkened Bekhta and Niemz [11].

Edlundl and Jermer in 2004 stated that there had not been any decomposition for 2 years in the samples of Scotch pine and spruce woods thermo-processed at 220°C and for 4 hours (Edlundl and Jermer) [12].

In the study of Follrich et al. in 2006, it was determined that the adhesion on the surfaces brought together by polyethylene in thermo-processed spruce woods had broken, and for this reason the contact angle had increased. It was determined in mechanical experiments that the bonding strength between the polyethylene and wood surfaces was higher than non-thermo-processed wood material Follrich et al. [13].

In the study of Hakkoul 2005, it was established that there had been a sharp change in the water retension capacity of fir, poplar wood, beech and pine species of woods -kept in steam environment for 8 hours- after the thermo-process in between the temperature of 100°C-160°C, and the bonding angle had reached an average of 90 degrees. Changes in wettability had been seen in between 100°C-160°C without any detected weight loss, and it was detected that the wettability of the wood had been unaffected at high temperatures Hakkoul [14].

In the study of Ishikawa et al. in 2004, changes in the humidity content of the sugi wood *(Cryptomeria japonica* D. Don) at high temperature was investigated. It was detected that the loss in the wood structure resulting from the thermo-process at 160°C was significant, and this loss had affected the humidity values. It was seen that the losses which might occur at 120°C were not significant. Thermo-process and temperature degree were found to be effective on the balance humidity of the wood. In the closed thermo-process systems with vapor is done, the saturated vapor was detected to increase the deterioration on the surface and interior parts of wood Ishikawa et al. [15].

Johansson and Mor'en in 2006 investigated the changing in color and resistance properties of birch wood at 175°C and 200°C temperatures and at 1 h, 3 h, and 10 h. Results showed that color and balance humidity were not related with resistance properties Johansson and Mor'en [16].

The aim of this study was to determine the effects of wood modification (thermo-process and impregnation with natural wood preservatives) and weathering on the mechanical performance of industrial woodwork joinery samples. At the same time, since the carbohydrates and resins (natural preservatives), which are of the wood components, decompose before lignin and cellulose and move away from the wood in the form of gas during thermo-process, the wood becomes slack and deprived of natural preservative substances (tannin and resins). With regard to this situation, a new dimension is brought to the research by the impregnation of tannin and pine resin solution into both woods of research after thermo-process.

Material and Methods

Wood materials and glues

In the experiments, Scotch pine (*Pinus sylvestris* L.) and chestnut (*Castanea Sativa*) wood types were used. Wood materials were obtained by the method of random selection in the site of Woodworking Ankara. Wood materials' being natural in color, clean, smooth parallel to grain and part of the sapwood, free of decay, growth defects, insect and fungi damages were ensured. For gluing of the experimental samples, two-component polyvinyl acetate (PVAc-D4) and polyurethane based Desmodur VTKA were used. Two-component polyvinyl acetate (PVAc-D4) was hardened by the addition of 5% hardener (Turbo hardener 303.5) [17]. According to BS EN 204, PVAc-D4 can be aligned with the pasting quality of D4 by increasing the durability to moisture by adding 5% hardener to the Klebit 303 glue solution [18].

Impregnation solution and process:

As impregnation material, pine resin (95% liquid) and tannin (5% liquid) solution was used. Liquid pine resin was obtained by dissolving the solid resin in the fresh pine cones in hot water at 80-90^{0}C. The tannin was joined up to 5% of the weight of pine resin solution. After dipping in pine solution, the draft samples were impregnated by keeping in the solution for 45 minutes. At the end of each period, the samples were removed from the solution and their surfaces were air-dried. The impregnated samples were kept in air-conditioning fridge under 20 ± 2°C temperature and 65% ± 5% relative humidity conditions until reaching moisture balance. Impregnated samples, retention rate of which to be determined, were dried in the oven at 55^{o}C until reaching constant weight, cooled in desiccator and weighed. Thus, the amount of net impregnation of each sample, whose exact dry weight was determined after impregnation, was calculated from the equation below.

$$\mathbf{ANI} = ((M_s - M_o)/M_o) \times 100$$

Where ANI is Amount of Net Impregnation (%) Ms [g] is the oven dry weight after impregnation and M_0 [g] is the oven dry weight before impregnation of the same sample.

Preparation of frame samples

The diagonal test samples were prepared as 60 frame In first place.

120 L-Type samples were obtained by cutting four samples from each of the 60 frame second stage.

To be used as the L-Type samples for diagonal compression performance, 120 test samples were prepared as a 2×2×3×10 combination of 2 wood species (pine, chestnut), 2 glue types (PVAc D4, VTKA PUR), and 3 processes (control, heat treated, heat treated+impregnated).

The preparation of test samples was initiated with heat treatment. The heat treatment was applied to draft-size wood pieces via thermowood method (175°C - 36 h). These pieces of heat-treated samples were cut with 0.1 mm precision and opened by automatic control of the machine to obtain corner bridle joint components which were then assembled and was impregnated (Figure 1).

The corners were mounted by applying each type of glue on a 150 g/m² basis with a brush to the surfaces of test samples. The pressure was applied by pressing to corner joints samples and they were allowed to harden for 24 hours.

Weathering of test samples

The control samples, heat treated samples and heat treated+impregnated samples were waited between 22.04.2012 - 22.04.2013 (for 12 months), according to the principles of ASTM G7 standard [19]. They were placed, in Ankara-Turkey, facing to the south and in 45° oblique position to the ground (Figure 2).

The lowest level of the test sample was 50 cm in height. The attention was paid to the hay etc. around the stand with organic residues in soil, which increase water content. These months' climatic conditions, such as the following, have been identified for each month in Graphics by the Center for Meteorology (Figure 3) [20].

Methods

The diagonal compression test experiments were held on the basis of ASTM 1037 in 800 Kp stage of Universal Testing Machine with a capacity of 5 tons in the material laboratory of the Faculty of Technology of Gazi University [21]. Experimental device was set to take forward speed of 2 mm/min. The maximum force, read from the machine, was recorded in N (Figure 4).

Evaluation of data

Multiple analyses of variance were made in order to determine the effects of wood type, adhesion type, heat treatment and impregnation in wood frame corner joints. In case of mutual interactions of sources of variance being significant according to α=0.05, for which factors are the differences important was identified by Duncan test. Duncan test was used as the post-hoc analysis.

Results and Discussions

Density and retention amount

The densities of the L-type samples were determined according to TS 2472 (1976) [22]. Density and retention amount of L-type samples are given below (Table 1).

As it can be inferred from Table 1, the heat treatment reduced the density of both wood species. In case of increase in the moisture content, although density rises again in control samples, this increase was not observed in the heat treated samples. As compared to chestnut wood, more retention occured in pine wood due to its low density.

Diagonal compression performance on L-Type samples

The diagonal compression performances of the L-type samples were determined according to TS 7251 EN 107 (2003) [23]. Statistical means of the diagonal compression performances at the levels of wood type, glue type and process type of the L-type samples before and after the natural aging are summarized in Table 2.

According to Table 2, when all samples are examined at the wood and glue levels before and after the natural aging (weathering) process, the interaction of chestnut wood with PVA-D4 glue is found to have the highest performance.

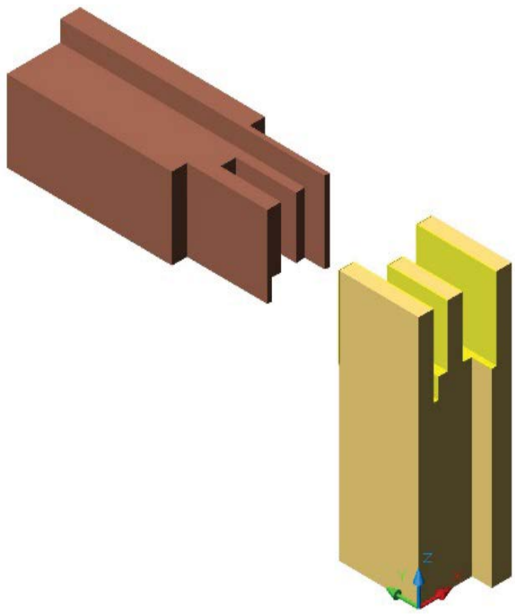


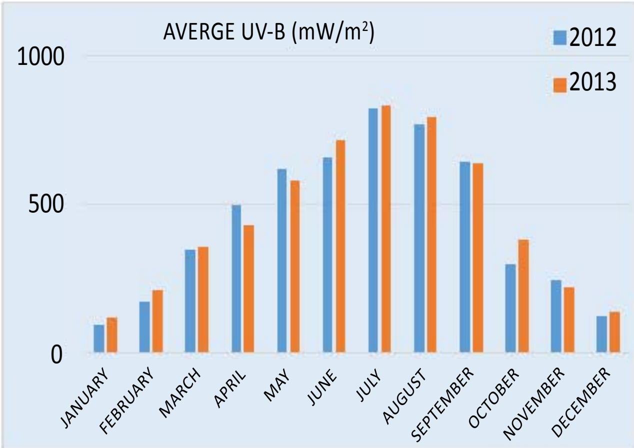
Figure 1: Illustrated corner bridle joint components.

Figure 2: Samples placed in oblique position.

Multiple analysis of variance results for the diagonal compression performances of L-Type samples obtained with variations in wood type, glue type and process type are given in Table 3.

According to Table 3; wood type, adhesive type, process type and the differences between these dual and triple interactions' effects on the diagonal compression were statistically significant (α=0.05). Duncan test was performed to determine which groups are significantly different. Diagonal compression performance values (N) by triple interactions of wood type, glue type and process type of L-type samples are given in Figure 5.

According to Figure 5; the triple interaction of control-chestnut with D4 glue was found to have the highest performance value (5726.71 N), while the triple interaction of heat treated-pine with D4 glue samples had the lowest value (1822.82 N). Excluding the control samples, the highest performance was obtained in the chesnut-heattreated-D4 combination. Others performed close to each other.



Mounths	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Avr. Temperature (C⁰)	0,4	1,9	6,1	11,3	16,2	20,2	23,6	23,3	18,7	13,1	7,0	2,6
Avr. Highest Temperature(C⁰)	4,4	6,5	11,7	17,2	22,3	26,7	30,2	30,2	25,9	19,9	12,9	6,6
Avr. Lowest Temperature(C⁰)	-3,0	-2,2	1,0	5,6	9,7	13,1	16,0	16,0	11,7	7,3	2,5	-0,6
Avr. Sunny Time (h)	2,5	3,5	5,2	6,3	8,4	10,2	11,4	11,0	9,2	6,5	4,4	2,3
Avr. Rainly Day	12,2	11,0	10,9	11,9	12,5	8,6	3,7	2,8	3,9	6,8	8,5	11,8

Figure 3: Graphic and table of UV-B radiation between 2012-2013 years and metrological data [20].

Figure 4: Universal test machine and test sample.

Wood types	0% MC (gr/cm³)		12% MC (gr/cm³)		Retention amount (kg/m³)
	control	Heat treated	control	Heat treated	Heat treated + impregnated
Pine	0.48	0.44	0.50	0.44	11.26
Chestnut	0.54	0.53	0.59	0.55	10.96

Table 1: Density and retention amount of L-type samples.

Conclusions

This study was performed in order to determine the effect of wood modification (heat treatment and Short-term -45 min- dip impregnation method with natural pine resin and tannin solution) on the specific gravity, diagonal compression performance and deformation by aging. Following conclusions can be drawn from this study.

Density and retention amount

The heat treatment, one of the wood modification techniques, reduced the density of both wood types. After heat treatment and impregnation were hold the situation of the both wood types in the natural aging. This decrease of 9% in the pine samples, 7% in the chestnut sample realized. During the aging in natural environment (weathering) and heat treatment especially natural woods heavy loss; degradation to such as lignin, cellulose and extractives of wood components is reportedly due [8,9].

With the wood types impregnated in a solution of pine cone resin and tannin, the maximum retention was obtained in the pine wood. The reason for this may be the higher degree of degradation in pine and more amount of space.

Diagonal compression performance on the L-type samples

The element that makes up the advanced performance of L-type samples is its ability to resist diagonal test forces. This resistance constituent factor is the adequacy of the sticking of samples' corner joining components. Specifically, the adhesive's resistance to natural aging is the

Process	Wood Types	L-Type Samples	
		PVAc-D4	D-VTKA
Control (Before Weathering)	Pine	2554.31	3116.41
	Chestnut	6813.94	5217.69
Control (After Weathering)	Pine	2111.23	2597.84
	Chestnut	5726.71	4384.26
Heat Treated (After Weathering)	Pine	1822.82	2761.22
	Chestnut	3316.38	2886.69
Heat Treated + İmpregnated (After Weathering)	Pine	2844.28	2862.61
	Chestnut	2884.05	2797.75

Table 2: Statistical means of the performance of diagonal compression performance (as N).

Source of variance	SD.	Sum of Squares	Average of Squares	Value of F	P ≤ 0.05
Wood type (A)	1	38845630.208	3884530.208	160.5797	0.0000
Process type (B)	2	19626690.017	9813345.008	40.5663	0.0000
Interaction (AB)	2	26744116.217	13372058.108	55.2773	0.0000
Glue type (C)	1	1481851.875	1481851.875	6.1257	0.0149
Interaction (AC)	2	12407971.408	12407971.408	51.2920	0.0000
Interaction (BC)	2	7516243.550	3758121.775	15.5353	0.0000
Interaction (ABC)	2	5567584.017	2783792.008	11.5076	0.0000
Error	108	26126141.300	241908.716		
Sum	119	138316228.592			

Table 3: Multiple analyses of variance for the diagonal compression performances of L-Type samples.

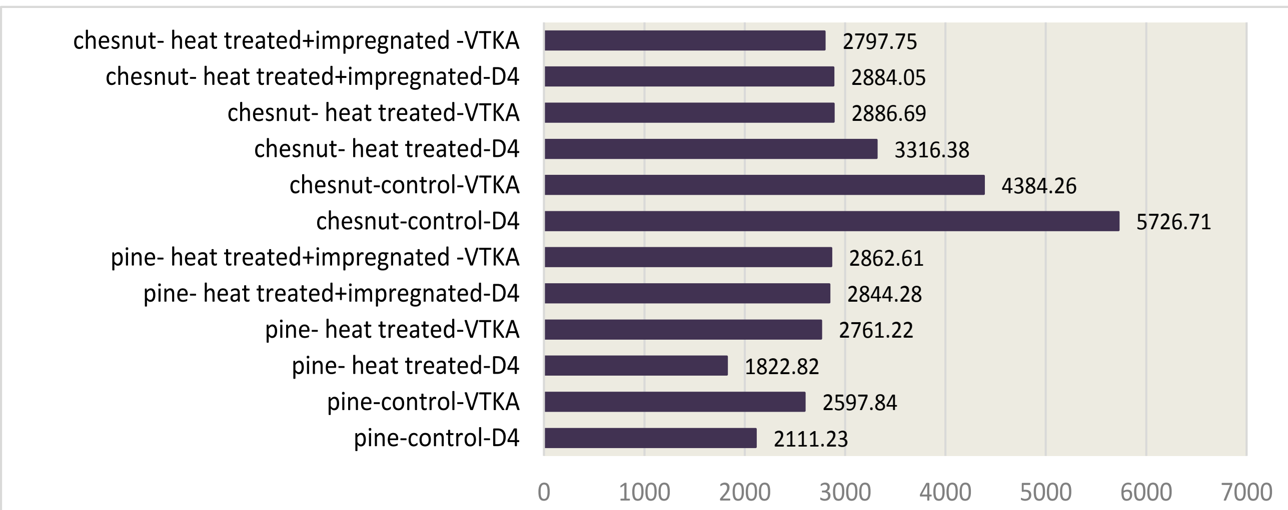


Figure 5: Diagonal compression performance values (N) by triple interactions of L-type samples.

Wood and glue type	Before aging	After aging					
	Control	Untreated	Change (%)	Heat-treated	Change (%)	Heat-treated+impregnated	Change (I%)
Pine-D4	2554.31	2111.23	-18	1822.82	-29	2844.28	+11
Pine-VTKA	3116.41	2597.84	-18	2761.22	-22	2862.61	-8
Chesnut-D4	6813.94	5726.71	-16	3316.38	-52	2884.05	-58
Chestnut-VTKA	5217.69	4384.26	-16	2886.69	-45	2797.75	-46

Table 4: Changes in performance by aging – heat treatment – impregnation.

most important determinant of performance in the L-type samples.

In this regard when the performance of the diagonal compression in the L-type samples is examined; the diagonal compression performance generally attained the highest value in the control experiments of both types of wood and glue before aging (Figure 3). Heat treatment decreased the performance of both types of wood. During the heat treatment process, wood materials became brittle and fragile. Therefore, some heat-treated samples were cracked or broken during the test.

As compared to the untreated (control) and non-aged samples of both wood and glue types; the changes in performance in the aged control samples, heat-treated samples and heat-treated+impregnated samples are given in Table 4.

In this case, the performance of untreated samples decreased between 16% and 18% by the aging acording control samples, in untreated samples of both wood and glue types decreased between 22% and 52% by the heat treatment, but increased only in heat-treated+impregnated pine samples.

In this case, in terms of performance; firstly Chesnut as the wood and VTKA glue as adhesive and secondly pine wood and D4 glue are recommended for the manufacture of joinery.

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