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The Effects of Heat Treatment, Wood Species and Adhesive Types on Screw Withdrawal Strength of Laminated Veneer Lumbers

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Abstract

Aim of study: The objective of this study was to evaluate the effects of heat treatment temperature on the screw withdrawal strength on laminated veneer lumbers (LVL).

Material and Methods: The LVL samples were prepared in the form of ten layers that 2 mm thickness from the European oak (*Quercus petreae* L.), Oriental beech (*Fagus orientalis* L.), scotch pine (*Pinus sylvestris* L.) and poplar (*Populus nigra* L.) veneers bonded with two-component polyvinyl acetate (PVAc-D4), melamine formaldehyde (MF) and polyurethane (PU) adhesives and then heat treatment was applied to the prepared samples. The test samples were subjected to heat treatment at 185 and 212 °C for 2h.

Main Results: Consequently, according to wood type, the highest screw withdrawal strength was determined in Oriental beech, with respect to the adhesive type in MF adhesive. The screw withdrawal strength of samples was decreased with increasing treatment temperature. In the interaction of the wood materials, type of adhesive and treatment temperature, it was the highest in control beech samples bonded with MF and the lowest in poplar samples bonded with PU which heat-treated at 212°C. It was also observed that the lowest strength loss due to the treatment temperature was found in oak samples and in MF adhesive.

Research highlights: Screw withdrawal strengths were directly related to wood type and density, heat treatment temperature and adhesive type.

Keywords*:* Heat Treatment, Screw Withdrawal Strength, Laminated Veneer Lumber, Adhesive

Isıl İşlem, Ağaç Türü ve Tutkal Çeşidinin Lamine Edilmiş Tabakalı Malzemelerde Vida Çekme Direncine Etkisi

Öz

Çalışmanın amacı: Bu çalışmanın amacı ısıl işlemin lamine edilmiş tabakalı malzemelerde vida çekme direncine etkisinin belirlenmesidir.

Materyal ve Yöntem: Test örnekleri, 2 mm kalınlığında meşe (*Quercus petreae* L.), Doğu kayını (*Fagus orientalis* L.), sarıçam (*Pinus sylvestris* L.) ve kavak (*Populus nigra* L.) kaplamalarından, 10 katmanlı olarak, çift bileşenli polivinilasetat (PVAc-D4), melamin formaldehit (MF) ve poliüretan tutkalları ile lamine edilerek hazırlanmış ve sonra ısıl işlem uygulanmıştır. Test örneklerine 185 ve 212 °C'de 2 saat ısıl işlem uygulanmıştır.

Sonuçlar: Sonuç olarak ağaç türüne göre en yüksek vida çekme direnci Doğu kayınında, tutkal türüne göre ise MF tutkalında belirlenmiştir. Vida çekme direnci ısıl işlem sıcaklığının artması ile azalmıştır. Ağaç malzeme, tutkal türü ve ısıl işlem sıcaklığı etkileşimine göre en yüksek vida çekme direnci MF tutkalı ile lamine edilen kontrol kayın örneklerde, en düşük ise PU tutkalı ile lamine edildikten sonra 212 °C'de ısıl işlem uygulanan kavak örneklerde belirlenmiştir. Ayrıca ısıl işlem uygulamasından kaynaklanan en düşük vida çekme direci MF tutkalı ile lamine edilen meşe örneklerde tespit edilmiştir.

Araştırma Vurguları: Vida çekme direnci ağaç türü, yoğunluğu, ısıl işlem sıcaklığı ve tutkal türü ile doğrudan ilişkilidir.

Anahtar Kelimeler*:* Isıl İşlem, Vida Çekme Direnci, Lamine Edilmiş Tabakalı Malzemele, Tutkal

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Introduction

Wood material is used intensively as a structural material in buildings, external facade coverings, flooring and roofing framework materials, bridges, docks, furniture and in many other areas, due to the many excellent properties (such as a good strength to weight ratio, aesthetic appearance, low cost, strength properties etc.) of wood materials (Lyons and Ahmed, 2005; Hill, 2006). It has become necessary to efficient use this renewable natural material, which has been a source of indispensable raw materials in the lives of human beings throughout history.

The use of wood material as a single piece in long and curved forms is unsuitable or may not be manufactured from solid wood, due to production difficulties and economic reasons. Structural composite lumbers started to be produced with the objective of correcting-improving some of these undesired properties (Bal and Efe, 2015; Keskin, 2001). Engineered wood products (Laminated Veneer Lumber-LVL, Glued Laminated Timber-Glulam, Oriented Strand Lumber-OSL; Paralel Strand Lumber-PSL) are structural composites that have been gaining successes in the construction and woodworking industry (Lam, 2001; Güller, 2001). The laminated veneer lumber, which is a product of engineering, has many superior properties, such as higher mechanical properties compared to the solid wooden materials, which represent the same species, have a more homogeneous structure, can be obtained in standard measurements and have a high dimensional stability (Burdurlu, Kılıç, Ilce & Uzunkavak, 2007; Çolak, Aydın, Demırkır & Çolakoğlu, 2004).

The chemicals that are used in the preservation or modification of wood materials is harmful to the environment and health, developments in wood modification have accelerated considerably due to a number of circumstances of which the environmental awareness (Homan and Jorissen, 2004; Boonstra, 2008).

Heat treatment is a natural wood modification method that without added chemical substances (Yildiz, Yildiz & Gezer, 2005) and the heat-treated wood has a growing market in outdoor applications such as exterior cladding, window and door joinery, garden furniture, and decking. There are also many indoor applications for heat-treated wood such as flooring, paneling, kitchen furnishing, and interiors of bathrooms and saunas (Viitaniemi, 2000). The heat treatment of wood changes its chemical composition by degrading cell wall compounds and extractives (Militz, 2002; Tjeerdsma and Militz, 2005). As a consequence of the loss of mechanical strength, heat-treated wood is not recommended for use in load-bearing constructions (Viitaniemi, 1997).

Different type of fastener such as nails, screws, bolts, dowels, staples and metal and wood-based connectors has been widely used in most wood structures and woodworking industry for a long time (Taj, Najafi & Ebrahimi, 2009; Muthike, Muisu & Githiomi, 2013). Screws are widely used in joins is one of the most important connector to connect solid or laminated timber (Varghese, 2017). Previous studies have shown a significant impact between screw withdrawal strength, treatments on wood materials, density and moisture content of wood, screw specifications, screw depth of insertion etc. (Özçifçi, 2009; Eckelman, 1975; Kjucukov and Encev, 1977; Tenorio, Moya & Muñoz, 2011). In a study made where heat treatment was implemented at different temperatures (150, 170, 190, 210 and 230°C) the effect of heat on screw withdrawal resistance was researched in spruce wood (*Picea abies* Karst.). In conclusion, as the temperature increased, the screw withdrawal resistance decreased (Kariz, Kuzman & Sernek, 2013). In a similar study, where heat treatment was implemented at 140, 180 and 210°C the screw withdrawal resistance in a radial, tangential and transverse section in European spruce (*Picea abies* L.) was researched. At the conclusion of the study, it was determined that heat treatment negatively affected the screw withdrawal resistance of wooden materials (Gašparík, Barcík, Boruvka & Holeček, 2015).

The amount of use of heat-treated wood and laminated wood materials increases in the outdoor and indoor applications of woodworking industry (Viitaniemi, 2000;

Esteves and Pereira, 2009; Çolakoğlu, Colak, Aydın, Yıldız & Yıldız, 2003; Vlosky, Smith, Blankenhorn & Haas, 1994).

Song, Xu & Zhang (2018) studied that the effect of modification conditions gluing processes, pressing parameters and assembly patterns on some physical, mechanical and interfacial properties of poplar LVL composites. Test results showed that the optimum parameters for preparing LVL composites were found to be 1.3% (y-aminopropyltriethoxysilane), 330 g/m^2 (double-sided adhesive) 160°C temperature and 1.2 MPa pressing pressure. In the another study, Song, Wei, Ren & Zhang (2017) researched that effect of termal treatment or alkali treatment of veneers on the some mechanical properties of plywood composite materials. For this aim eucalyptus veneers and polyethylene films as formaldehyde-free adhesives were used. Plywood composite materials heated at 100, 120, 140 and 160°C for 0.5, 1.0, 1.5, and 2 h. Test results showed that both treaments improved the MOR, MOE and WSS (wet shear strength) properties of composites.

The stability of any wood or wood-based building system is composed of interconnected whole building elements and directly related to the performance of the fastening elements (Celebi and Kilic, 2007). Screws are one of the fastenings used the most in the joinings implemented in woodworking industry. The increasing demand for both heat-treated wood and laminated wood products leads to expanded trade offers and requires knowledge of the screw withdrawal strength heat-treated wood and laminated wood materials. The objective of this study was to evaluate the effects of heat treatment on screw withdrawal resistance of laminated veneer lumber that heat-treated at 185 and 212 °C for 2 h.

Material and Methods

In this study, veneers were obtained from European oak (*Quercus petreae* L.), Oriental beech (*Fagus orientalis* Lipsky), scotch pine (*Pinus sylvestris* L.) and poplar (*Populus nigra* L.) logs (2 mm thick) and they stored in a suitable environment until equilibrium moisture for four weeks before the gluing process. The veneers without defects were selected and resized in samples with 150 x 950 mm (width x length). The veneers were prepared from purchased logs by the random selection method from the Siteler in Ankara/Turkey. The samples were glued with polyvinyl acetate (PVAc-D4- modified with 5% of Turbo Hardener 303.5), melamine formaldehyde (MF) and polyurethane (PU) adhesives. Adhesives were obtained from commercial firms in Turkey. Properties of adhesive are shown in Table 1 (Keskin, 2001; Sahin Kol, Ozbay & Altun, 2009; Kleiberit, 2017). The PU and PVAc-D4 adhesives purchased from Kleiberit firm in Ankara and MF from Gentaş Co. in İstanbul.

Table 1. Properties of the adhesives

Properties	MF	PU	PVAc-D4
Density(g/cm^3)	1.2	1.13	1.12
pH	9.3	7	3
Viscosity (at 20°C)	60(cPs)	8000(mPa.s)	12000(mPa.s)
Amount applied (g/m^2)	200	200	200

Production of LVL was conducted in laboratory conditions at Gazi University, Faculty of Technology, Department of Wood Products Industrial Engineering in Ankara. The adhesives were spread to one surface of veneer by using a roll. The spreading rate of adhesive was approximately 200 g/m^2. The pressure applied by the hot press for the LVL boards were 1 N/mm^2 for poplar and scotch pine veneers and 1.2 N/mm^2 for oak and beech veneers. The duration of the press and the temperature were 20 min and 80 °C, respectively for MF and PVAc-D4, and 20 min and 60 °C for PU adhesive. Enough panels were produced for each of the test groups according to TS EN 386 (1999) and they were stored for one week for exact curing. Panels were heat treated at 185°C and 212°C in a heat treatment oven under a normal atmosphere controlled in ±1°C temperature sensitivity under hot steam. The heat treatment temperature was applied according to the temperature and method described in the Finnish ThermoWood Handbook (Finnish ThermoWood Association, 2003). Also this range of temperatures for heat treatment has been tested by some researchers (Martinka, Kačíková, Rantuch & Balog, 2016; Budakçı, Pelit, Sönmez & Korkmaz, 2016; Gurleyen, Ayata, Esteves & Cakicier, 2017).

The used heat treatment process divided into three continuous phases (Figure1). In the first phase oven temperature was increased to 100 °C for 6 h, then temperature was increased to 130°C for 12 h, in the second phase temperature was increased from 130 °C to 185 °C and 212 °C for 6 h and these temperatures were kept constant for 2 h, in the final phase temperature of the oven was decreased to initial temperature for 12 h. At the end of the heat treatment process, 10 mm edges were cut off of the panels. Then, ten test samples were prepared with a dimension of 50x50x20 mm for each of the test groups from the LVL panels, according to the TS EN 13446 (2005) standard, as shown in Figure 2. Screw withdrawal strength test was carried out according to ASTM D 1761 (2000) with the testing speed was 2.5 mm/min. and test was applied until the screws were completely separated from specimens.

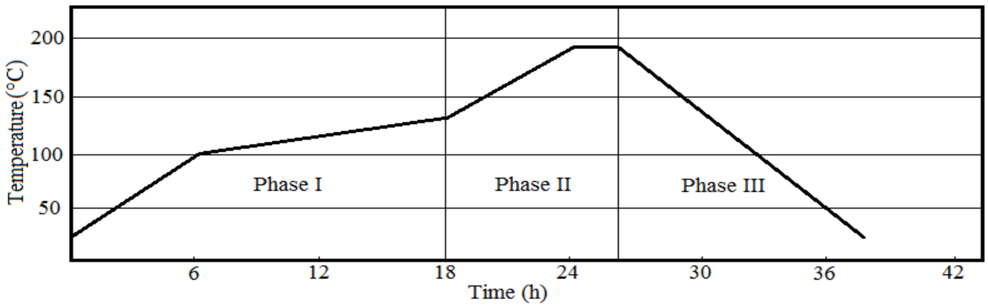

Figure 1. Example of a heat treatment process

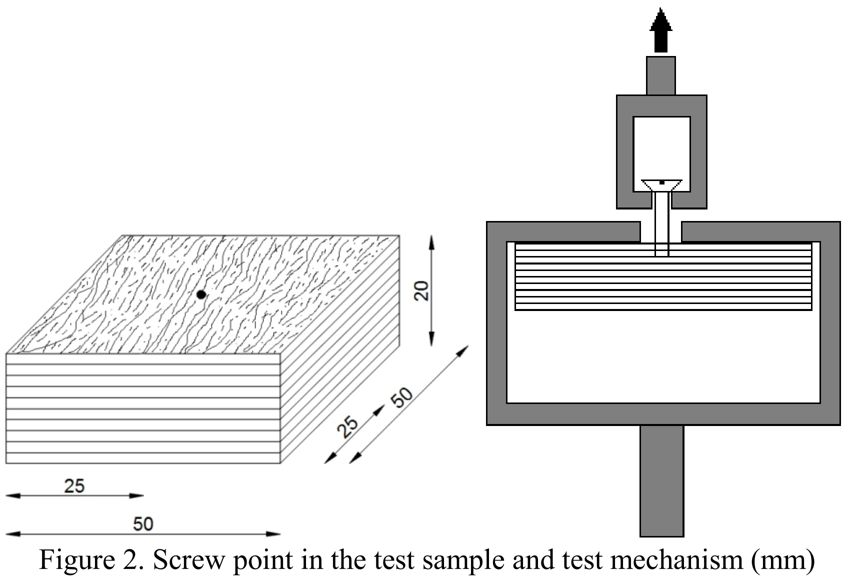

Figure 2. Screw point in the test sample and test mechanism (mm)

Before screw withdrawal test, the test samples were conditioned to constant weight at 65±5% relative humidity and at a temperature of 20±2°C. At the end of this period, air-dried density of test samples was determined according to TS 2472 (1976). For the air-dry density, the test samples with a dimension of 20x20x30 mm were kept under the conditions of 20±2 °C and 65±5 % relative humidity until they reached to a constant weight. Before the screwing operation, pilot holes were drilled to the samples surface. The pilot hole diameters and depths for the screws are given in Table 2.

Table 2. Pilot hole diameters and depth

Type of screw	Diameter of screws (mm)	Pilot hole diameter (mm)	Pilot hole depth (mm)	Screwing depth (mm)
4 x 50	3.95	2.5	12±0.5	17±0.5

The screw withdrawal strength was calculated by the following equation.

$$\sigma s = \frac{F_{max}}{h(2\pi r)}$$

Where; σs: screw withdrawal strength (N/mm^2), *Fmax* is the maximum load (N), *h(2πr)* the surface area of screw-exposed to friction (mm^2).

In the evaluation of the data, the MSTAT-C statistical software program was used for the statistical evaluation of the results. The MSTAT-C computer-based statistical program developed by Michigan State University, USA. The values of the factor effects of heat treatment temperature, wood type and adhesive type on screw withdrawal strength were determined using the analysis of variance (MANOVA) procedure. When the difference between groups were found to be significant, Duncan Test was used to determine the difference between means at prescribed level of α=0.05.

Results and Discussion

Determined arithmetic value of air-dry density and standard deviation of heat-treated and control samples bonded with the adhesives prior to screw withdrawal test are shown in Table 3.

According to the Table 3, density values decreased with increasing temperature. It is evident from the results that these values were all lower in heat-treated samples than in control samples. This situation may be due to the degradation of wood polymers. The density loss of the heat-treated wood is due to the degradation and depolymerization reactions of wood polymers (cellulose, hemicelluloses and lignin), mainlythe hemicelluloses which are the most thermally-sensitive wood components (Fengel and Wegener, 1989; Hillis, 1984). The result is parallel to previously published study for different species (Keskin, 2001; Yildiz, Gezer & Yıldız, 2006; Kaygin, Gündüz & Aydemir, 2009; Korkut et al., 2008). Also, Korkut and Güller (2008) reported a reduction of air-dry density values of heat-treated red-bud maple (*Acer trautvetteri* Medw.) wood. Determined arithmetic value of screw withdrawal strength and standard deviation of heat-treated and control samples bonded with the adhesives are shown in Table 4.

The average screw withdrawal strength of calculated values obtained from the test samples according to the types of material and process are given in Table 5.

Table 3. The average air-dry density and standard deviation of heat-treated and control samples bonded with the adhesives

Wood type	Adhesive type	Heat treatment	Air- dry density (g/cm^3)		Wood type	Adhesive type	Heat treatment	Air-dry density (g/cm^3)	
			Mean	sd				Mean	sd
Poplar	PVAc-D4	Control	0.431	0.030	European Oak	PVAc-D4	Control	0.711	0.019
		185 ºC	0.382	0.009			185 ºC	0.662	0.031
		212 ºC	0.351	0.010			212 ºC	0.631	0.018
	PU	Control	0.422	0.029		PU	Control	0.682	0.019
		185 ºC	0.354	0.019			185 ºC	0.653	0.021
		212 ºC	0.331	0.018			212 ºC	0.601	0.019
	MF	Control	0.410	0.010		MF	Control	0.673	0.020
		185 ºC	0.362	0.011			185 ºC	0.641	0.030
		212 ºC	0.341	0.028			212 ºC	0.622	0.033

Table 3 (continued)

Scotch pine	PVAc-D4	Control	0.594	0.009	Oriental Beech	PVAc-D4	Control	0.742	0.010
		185 ºC	0.531	0.019			185 ºC	0.651	0.021
		212 ºC	0.503	0.010			212 ºC	0.633	0.019
	PU	Control	0.582	0.028		PU	Control	0.752	0.030
		185 ºC	0.524	0.030			185 ºC	0.661	0.015
		212 ºC	0.501	0.020			212 ºC	0.641	0.026
	MF	Control	0.571	0.023		MF	Control	0.722	0.022
		185 ºC	0.522	0.032			185 ºC	0.681	0.019
		212 ºC	0.503	0.022			212 ºC	0.661	0.017

Mean: arithmetic value, sd: standard deviation

Table 4. The average screw withdrawal strength and standard deviation of heat-treated and control samples bonded with the adhesives

Wood type	Adhesive type	Heat treatment	Screw withdrawal strength (N/mm^2)		Wood type	Adhesive type	Heat treatment	Screw withdrawal strength (N/mm^2)	
			Mean	sd				Mean	sd
Poplar	PVAc-D4	Control	7.08	0.389	European Oak	PVAc-D4	Control	20.10	0.943
		185 ºC	5.101	0.192			185 ºC	17.74	0.327
		212 ºC	4.465	0.637			212 ºC	14.89	0.925
	PU	Control	7.705	0.449		PU	Control	19.70	0.330
		185 ºC	5.764	0.221			185 ºC	17.10	0.270
		212 ºC	4.125	0.425			212 ºC	12.50	1.882
	MF	Control	9.752	0.581		MF	Control	21.40	1.215
		185 ºC	8.728	0.241			185 ºC	19.11	0.462
		212 ºC	7.001	0.382			212 ºC	16,70	0.676
Scotch pine	PVAc-D4	Control	9.228	0.347	Oriental Beech	PVAc-D4	Control	20,90	0.325
		185 ºC	6.691	0.234			185 ºC	17.90	0.398
		212 ºC	5.815	1.205			212 ºC	15.16	0.386
	PU	Control	12.30	0.635		PU	Control	21.70	0.433
		185 ºC	10.03	0.641			185 ºC	18.83	0.296
		212 ºC	7.886	0.761			212 ºC	13.60	1.237
	MF	Control	10.33	0.999		MF	Control	23.70	0.743
		185 ºC	12.12	0.441			185 ºC	20.70	0.595
		212 ºC	8.482	1.139			212 ºC	17.10	0.741

Table 5. Average withdrawal strength due to heat treatment temperature, wood and adhesive type

Types of material and process	Statistical Value	
Wood Type	X (N/mm^2)	HG*
Poplar	6.636	D
Scotch pine	9.210	C
European oak	17.69	B
Oriental Beech	18.84	A
Adhesive type	X	HG**
MF	14.59	A
PU	12.60	B
PVAc-D4	12.09	C
Heat treatment temperature	X	HG***
Control	15.32	A
185 ºC	13.28	B
212 ºC	10.63	C

*LSD: 0.1666, **LSD: 0.1443, ***LSD: 0.1443, HG: Degree of Homogeny, X: Mean

With respect to the mean values in Table 5, during the single comparison of factor types, the effect of wood type on the screw withdrawal strength values was found to be significant. Regarding the wood type, the screw withdrawal strength was found to be highest in Oriental beech samples and the lowest in the poplar samples. This situation may be result from high density poroperties of beech wood. Çağatay, Efe, Burdurlu & Kesik (2012) reported that the high density has an important factor in the screw withdrawal strength of wood material. Regarding adhesive type the screw withdrawal strength was found to be highest in the MF adhesive and the lowest in the PVAc-D4 adhesive. This result may be due to the properties of MF adhesive that least affected by the heat. According to the heat treatment, the highes screw withdrawal strength was found in control samples. The screw withdrawal strength decreased with increasing heat treatment temperature. Compared to the control sample, total loss in screw withdrawal strength was obtained as 30.6%. Results of multiple variance analysis for impact of wood type, adhesive type and heat treatment temperature for screw withdrawal strength are given in Table 6.

Table 6. Multiple variance analysis Results of screw withdrawal strength

Factor Source	Degrees of freedom	Sum of squares	Mean square	F value	$P < 0.05$ (Sig)
Factor A	3	9989.126	3329.709	10300.8417	0.0000
Factor B	2	419.765	209.882	649.2959	0.0000
AB	6	139.997	23.333	72.1826	0.0000
Factor C	2	1323.176	661.588	2046.6988	0.0000
AC	6	165.499	27.583	85.3319	0.0000
BC	4	60.251	15.063	46.5982	0.0000
ABC	12	50.042	4.170	12.9008	0.0000
Error	324	104.732	0.323		
Total	359	12252.587			

Factor A: Wood type (Poplar, Scotch pine, European oak, Oriental beech); Factor B: Adhesive type (MF, PU, PVAc-D4); Factor C: Heat treatment temperarure (185 ºC, 212 ºC)

Difference between the effects of wood type, adhesive type and heat treatment temperature on screw withdrawal strength were found statistically significant (α = 0.05). The average values of the withdrawal strength concerning the interaction of heat treatment temperarure, wood and adhesive type are given in Table 7. The Duncan test carried out in order to determine these differences and results are given in Table 8.

Table 7. Average withdrawal strengths for the interaction of heat treatment temperature, wood and adhesive type

Types of material and process	Statistical values	
Wood type +Adhesive type*	X(N/mm^2)	HG
Oriental beech+MF	20.50	A
European oak+MF	19.07	B
Oriental beech+PU	18.04	C
Oriental beech+ PVAc-D4	17.98	C
European oak+ PVAc-D4	17.58	D
European oak+PU	16.43	E
Scotch pine+MF	10.31	F
Scotch pine+PU	10.07	F
Poplar+MF	8.49	G
Scotch pine+ PVAc-D4	7.25	H
Poplar+PU	5.87	I
Poplar+ PVAc-D4	5.55	J
Treatment temperature+ Wood type**	X	HG
Control+Oriental beech	22.10	A
Control+European oak	20.40	B
185°C+Oriental beech	19.14	C
185°C+European oak	17.98	D
212°C+Oriental beech	15.29	E
212°C+European oak	14.70	F
Control+Scotch pine	10.62	G
185°C+ Scotch pine	9.62	H
Control+Poplar	8.18	I
212°C+Scotch pine	7.39	J
185°C+Poplar	6.53	K
212°C+Poplar	5.20	L
Adhesive type+ Treatment temperature***	X	HG
Control+MF	16.29	A
Control+PU	15.35	B
185°C+MF	15.16	B
Control+PVAc-D4	14.33	C
185°C+PU	12.93	D
212°C+MF	12.32	E
185°C+PVAc-D4	11.86	F
212°C+PVAc-D4	10.08	G
212°C+PU	9.53	H

*LSD:0.2886, **LSD: 0.2886, ***LSD:0.2499, HG: Degree of Homogeny, X: Mean

In the interaction of wood and adhesive type, highest screw withdrawal strength was obtained in Oriental beech+MF (20.50 N/mm^2) whereas the lowest in Poplar+PVAc-D4 (5.55 N/mm^2). In terms of the interaction of heat treatment temperature and wood type, highest screw withdrawal strength was found in untreated Oriental beech (22.10 N/mm^2) whereas the lowest in poplar wood that was heat-treated at 212°C (5.20 N/mm^2). With regard to the adhesive type and heat treatment temperature, highest screw withdrawal strength was obtained in untreated MF adhesive (16.29 N/mm^2) whereas the lowest in PU adhesive that was heat-treated at 212°C (9.53 N/mm^2). The all types of adhesive were adversely affected by heat treatment, while PU was the most affected type of glue. This situation may be related to the adhesive's chemical structure. In a study conducted by Clauß, Joscak & Niemz (2011) was determined that thermal stability of laminated wood joints. They reported that with increasing heat treatment temperature, as in other adhesive type, the PUR showed significant disadvantages at 220 °C.

Table 8. Duncan test results of screw withdrawal strength (N/mm^2)

Process types	X N/mm^2	HG	Process types	X N/mm^2	HG
Oriental beech+MF+Control	23.70	A	Scotch pine+PU+Control	12.30	K
Oriental beech+PU+Control	21.70	B	Scotch pine+MF+185°C	12.12	K
European oak+MF+Control	21.40	BC	Scotch pine+MF+Control	10.33	L
Oriental beech+ PVAc-D4+Control	20.90	CD	Scotch pine+PU+185°C	10.03	LM
Oriental beech+MF+185°C	20.70	D	Poplar+MF+Control	9.752	M
European oak+ PVAc-D4+Control	20.10	E	Scotch pine+ PVAc-D4+Control	9.228	N
European oak+PU+Control	19.70	E	Poplar+MF+185°C	8.728	NO
European oak+MF+185°C	19.11	F	Scotch pine+MF+212°C	8.482	O
Oriental beech+PU+185°C	18.83	F	Scotch pine+PU+212°C	7.886	P
Oriental beech+ PVAc-D4+185°C	17.90	G	Poplar+PU+Control	7.705	P
European oak + PVAc-D4+185°C	17.74	G	Poplar+ PVAc-D4+Control	7.080	Q
Oriental beech+MF+212°C	17.10	H	Poplar+MF+212°C	7.001	Q
European oak+PU+185°C	17.10	H	Scotch pine+ PVAc-D4+185°C	6.691	Q
European oak+MF+212°C	16.70	H	Scotch pine+ PVAc-D4+212°C	5.815	R
Oriental beech+ PVAc-D4+212°C	15.16	I	Poplar+PU+185°C	5.764	R
European oak+ PVAc-D4+212°C	14.89	I	Poplar+ PVAc-D4+185°C	5.101	S
Oriental beech+PU+212°C	13.60	J	Poplar+ PVAc-D4+212°C	4.465	T
European oak+PU+212°C	12.50	K	Poplar+PU+212°C	4.125	T

LSD: 0.4998, HG: Degree of Homogeny, X: Mean

According to the Table 8, screw withdrawal strength of laminated wood decreased with increasing heat treatment temperature. Also, it is evident from the results that these values were all lower in heat-treated samples than in control samples in all test group. The reduces in the screw withdrawal strength on the test samples, depending on wood and adhesive species and heat treatment temperature which may be clarified by the thermal degradation and losses of materials as a result of heat treatment. According to the statistical analysis of the results, in the screw withdrawal resistance it showed significant differences between the control and heat-treated wood samples. Özcifci (2009) studied that screw withdrawal strength of laminated veneer lumber. He reported that the highest screw withdrawal strength was obtained in oak samples laminated with PF, the lowest was obtained in Uludag fir laminated with MF adhesive. Yörür, Tor, Günay & Birinci (2017) researched that screw withdrawal strength on plywood. They reported that test results showed that screw properties of test specimens bonded with PU adhesive higher than specimens bonded with PVAc.

Loss in screw withdrawal resistance of heat-treated wood due to the treated at high temperatures was reported by some authors in the literature (Poncsák, Kocaefe, Bouazara & Pichette, 2006, Aytin, Korkut, As, Ünsal & Gündüz, 2015; Kocaefe, Poncsák, Tang & Bouazara, 2010). Similar results were also found the laminated veneer lumber that heat-treated panels in the present study. This is probably due to the density losses in the wood and depolymerization reactions of wood polymers during the thermal degradation. Taghiyari, Gholamiyan & Karimi (2012) confirmed that the screw withdrawal strength is closely associated with the density of wood material. In addition, hemicelluloses degrade first among the wood polymers during the heat treatment wood, cellulose and lignin are also modified at higher temperature. So, changes in physical and mechanical properties are related to the degradation of chemical component of wood (Poncsák et al., 2006; Bekhta and Niemz, 2003; Hill, 2006).

Conclusions

In this study, screw withdrawal resistance of laminated veneer lumber was determined manufactured from European oak (*Quercus petreae* L.), Oriental beech (*Fagus orientalis* L.), scotch pine (*Pinus sylvestris* L.) and poplar (*Populus nigra* L.) veneers bonded with PVAc-D4, MF and PU adhesives which heat-treated at 185 and 212°C for 2 h. Results showed that screw withdrawal strength and air-dried density values of test samples were decreased with increasing treatment temperature. Regarding the wood type, the highest screw withdrawal strength was found in Oriental beech samples and the lowest in poplar samples. According to adhesive type the highest screw withdrawal strength was found in MF adhesive. Also, the lowest strength loss due to treatment temperature was found in oak samples and MF adhesive. In the interaction of wood and adhesive type, highest screw withdrawal strength was obtained in beech veneer lumber bonded with MF. According to the interaction of heat treatment temperature and wood type, highest screw withdrawal strength was found in control beech samples. In the interaction of the wood materials, type of adhesive and treatment temperature, the highest strength was found in control beech samples bonded with MF adhesive as 23.70 N/mm^2. In the use of the laminated veneer lumber samples which heat-treated at higher temperature, oak or beech veneer bonded with MF adhesive is advised to obtain maximum withdrawal strength.

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References

ASTM D 1761. (2000). Standard methods of testing mechanical fastener in wood, nail, staple or screw withdrawal test. ASTM Standards, West Conshohocken, PA.

Aytin, A., Korkut, S., As, N., Ünsal, Ö. & Gündüz, G. (2015). Effect of heat treatment of wild cherry wood on abrasion resistance and withdrawal capacity of screws. *Drvna Industrija*, 66(4), 297-303.

Bal, B.C. & Efe, F.T. (2015). The effect of reinforcement with glass fiber fabric on some screw strength of laminated veneer lumber. *Düzce University, Journal of Forestry,* 11(2), 40-47.

Bekhta, P. & Niemz, P. (2003). Effect of high-temperature on the change in color, dimensional stability and mechanical properties of spruce wood. *Holzforschung,* 57, 539-546.

Boonstra, M. (2008). A two-stage thermal modification of wood. Ph.D. Thesis, Ghent University, Belgium and Université Henry Poincaré - Nancy, France.

Budakçı, M., Pelit, H., Sönmez, A. & Korkmaz, M. (2016). The effect of densification and heat-post treatment on hardness and morphological of wood materials. *BioResources,* 11(3), 7822-7838.

Burdurlu, E., Kılıç, M., Ilce, A.C. & Uzunkavak, O. (2007). The effects of ply organization and loading direction on bending strength and modulus of elasticity in laminated veneer lumber (LVL) obtained from beech (*Fagus orientalis* L.) and lombardy poplar (*Populus nigra* L.). *Construction and Building Materials,* 21(8), 1720-1725.

Celebi, G. & Kilic, M. (2007). Nail and screw withdrawal strength of laminated veneer lumber made up hardwood and softwood layers. *Construction and Building Materials,* 21(4), 894-900.

Clauß, S., Joscak, M. & Niemz, P. (2011). Thermal stability of glued wood joints measured by shear tests. *Eur. J. Wood Prod*., 69(1), 101-111.

Çağatay, K., Efe, H., Burdurlu, E. & Kesik, H.İ. (2012). Determination of screw holding strength of some wood materials. *Kastamonu University, Journal of Forestry Faculty*, 12(2), 321-328.

Çolak, S., Aydın, İ., Demırkır, C. & Çolakoğlu, G. (2004). Some technological properties of laminated veneer lumber manufactured from pine (*Pinus sylvestris* L.) veneers with Melamine added - UF resins. *Turkish Journal of Agriculture and Forestry,* 28(2), 109-113.

Çolakoglu, G., Colak, S., Aydın, I., Yıldız, U.C. & Yıldız, S. (2003). Effect of boric acid treatment on mechanical properties of laminated beech veneer lumber. *Silva Fennica,* 37(4), 505-510.

Eckelman, C.A. (1975). Screw holding performance in hardwoods and particleboard. *Forest Products Journal,* 25(6), 30-36.

Esteves, B.M. & Pereıra. H.M. (2009). Wood modification by heat treatment: A review. *BioResources,* 4(1), 370-404.

Finnish ThermoWood Association (2003). ThermoWood Handbook. Helsinki, Finland: Finnish ThermoWood Association.

Fengel, D. & Wegener, G. (1989). Wood chemistry, ultrastructure, reactions. *Walter de Gruyter*, 33, 333-335.

Gašparík, M., Barcík, Š., Boruvka, V. & Holeček, T. (2015). Impact of thermal modification of spruce wood on screw direct withdrawal load resistance. *BioResources,* 10(1), 1790-1802.

Gurleyen, L., Ayata, U., Esteves, B. & Cakicier, N. (2017). Effects of heat treatment on the adhesion strength, pendulum hardness, surface roughness, color and glossiness of scots pine laminated parquet with two different types of UV varnish application. *Maderas. Ciencia y tecnología,* 19(2), 213-224.

Güller, B. (2001). Wood Composits. *Süleyman Demirel University, Turkish Journal of Forestry*, A(2), 135-160.

Hillis, W.E. (1984). High temperature and chemical effects on wood stability. *Wood Science and Technology*, 18(4), 281-293.

Hill, C.A.S. (2006). *Wood modification: chemical, thermal and other processes.* Chichester, England: John Wiley & Sons, ltd.

Homan, W.J. & Jorissen, A.J.M. (2004). Wood modification developments. *Heron*, 49(4), 361-386.

Kariz, M., Kuzman, M. K. & Sernek, M. (2013). The effect of heat treatment on the withdrawal capacity of screws in spruce wood. *BioResources*, 8(3), 4340-4348.

Kaygın, B., Gündüz, G. & Aydemir, D. (2009). Some physical properties of heat-treated paulownia (*Paulownia elongata*) wood. *Drying Technology*, 27(1), 89-93.

Keskin, H. (2001). Technical properties of laminated wood material and possibility of using them in woodworking industry, Ph.D. Thesis, Gazi University, Ankara, Turkey.

Kjucukov, G. & Encev, E. (1977). The effect of screw dimensions on the withdrawal resistance in beech wood. *Holztechnologie,* 18(3), 149-151.

Kleiberit product catalog, (2017). https://www.kleiberit.com/en/media-library/info-sheets.html (10.04.2017).

Kocaefe, D., Poncsák, S., Tang, J. & Bouazara, M. (2010). Effect of heat treatment on the mechanical properties of North American jack pine: Thermogravimetric study. *Journal of Materials Science*, 45, 681-687.

Korkut, D.S. & Güller, B. (2008). The effects of heat treatment on physical properties and surface roughness of red-bud maple (*Acer trautvetteri* Medw.) wood. *Bioresource Technology*, 99(8), 2846-2851.

Korkut, D.S., Korkut, S., Bekar, I., Budakcı, M., Dilik, T. & Çakıcıer, N. (2008). The effects of heat treatment on the physical properties and surface roughness of Turkish hazel (*Corylus colurna* L.) wood. *International Journal of Molecular Sciences*, 9(9), 1772-1783.

Lam, F. (2001). Modern structural wood products. *Progress in Structural Engineering and Materials*, *3*(3), 238-245.

Lyons, J. S. & Ahmed, M.R. (2005). Factors affecting the bond between polymer composites and wood. *Journal of Reinforced Plastics and Composites*, 24(4), 405-412.

Martinka, J., Kačíková, D., Rantuch, P. & Balog, K. (2016). Investigation of the influence of spruce and oak wood heat treatment upon heat release rate and propensity for fire propagation in the flashover phase. *Acta Facultatis Xylologiae Zvolen*, 58(1), 5-14.

Militz, H. (2002). Thermal treatment of wood: European Processes and their background. International Research Group on Wood Preservation, Document no. IRG/WP 02-40241. 33rd Annual Meeting, 12–17 May, Cardiff-Wales 4, 1–17.

Muthike, G., Muisu, F. & Githiomi, J. (2013). Withdrawal strength of nail-timber joints for kenyan grown cypress and pines. *International*

Journal of Applied Science and Technology, 3(3), 116-121.

Özçifçi, A. (2009). The effects of pilot hole, screw types and layer thickness on the withdrawal strength of screws in laminated veneer lumber. *Materials and Design*, 30(7), 2355-2358.

Poncsák, S., Kocaefe, D., Bouazara, M. & Pichette, A. (2006). Effect of high temperature treatment on the mechanical properties of birch (*Betula papyrifera*). *Wood Science and Technology*, 40(8), 647-663.

Sahin Kol, H., Ozbay, G. & Altun, S. (2009). Shear strength of heat-treated tali (*Erythrophleum Ivorense*) and ıroko (*Chlorophora Excelsa*) woods, bonded with various adhesives. *BioResources*, 4(4), 1545-1554.

Song, W., Xu, Z., & Zhang, S. (2018). Using surface modified E-glass fiber cloths to enhance poplar laminated veneer lumber composites: Effects of modification conditions, gluing processes, hot-pressing parameters, and assembly patterns on physical-mechanical and interfacial properties. *BioResources*, 13(1), 597-631.

Song, W., Wei, W., Ren, C. & Zhang, S. (2017). Effect of heat treatment or alkali treatment of veneers on the mechanical properties of eucalyptus veneer/polyethylene film plywood composites. *BioResources*, 12(4), 8683-8703.

Taghiyari, H.R., Gholamiyan, H. & Karimi, A. (2012). Effects of heat-treatment on screw and nail withdrawal resistance of nanosilver impregnated and untreated solid woods. *Current Nanoscience*, 8(4), 637-642.

Taj, M.A., Najafi, S. K. & Ebrahimi, G. (2009). Withdrawal and lateral resistance of wood screw in beech, hornbeam and poplar. *European Journal of Wood and Wood Products*, 67(2), 135-140.

Tenorio, C., Moya, R. & Muñoz, F. J. (2011). Comparative study on physical and mechanical properties of laminated veneer lumber and plywood panels made of wood from fast-growing *Gmelina arborea* trees. *Journal of Wood Science*, 57(2), 134-139.

Tjeerdsma B.F. & Militz, H. (2005). Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dryheat-treated wood. *Holz als Roh- und Werkstoff*, 63(2), 102-111.

TS 2472. (1976). *Wood - Determination of density for physical and mechanical tests.* Ankara, Turkey: Turkish Standards Institution.

TS EN 13446. (2005). *Wood - based panels - Determination of withdrawal capacity of fasteners.* Ankara, Turkey: Turkish Standards Institution.

TS EN 386. (1999). *Glued laminated timber- Performance requirements and minimum production requirements.* Ankara, Turkey: Turkish Standards Institution.

Varghese, P.C. (2017). Building Construction, PHI Learning Private Limited, Delhi.

Viitaniemi, P. (1997). Decay-resistant wood created in a heating process. A heat-treatment process of wood developed by VTT Building Technology yields timber products with enhanced properties. *Indusrtrial Horizons*, December: 22-23.

Viitaniemi, P. (2000). New properties for thermally-treated wood. *Industrial Horizons*. March: 9-13.

Vlosky, R.P., Smith, P.M., Blankenhorn, P.R. & Haas, M.P. (1994). Laminated veneer lumber: A United States Market Overview. *Wood and Fiber Science*, 26(4), 456-466.

Yildiz, S., Gezer, E.D. & Yıldız, U.C. (2006). Mechanical and chemical behavior of spruce wood modified by heat. *Building and Environment*, 41(12), 1762-1766.

Yildiz, U.C., Yildiz, S. & Gezer, E.D. (2005). Mechanical and chemical behavior of beech wood modified by heat. *Wood and Fiber Science*, 37(3), 456-461.

Yörür, H., Tor, Ö., Günay, M.N. & Birinci E. (2017). The effects of different variables on the direct screw withdrawal strength in plywood. *Kastamonu University, Journal of Forestry Faculty*, 17(2), 325-333.