Osman Perçin[1], Şekip Şadiye Yasar[2], Mustafa Altunok[3], Oğuzhan Uzun[4],

Determination of Screw Withdrawal Resistance of Some Heat-Treated Wood Species

Određivanje otpora toplinski obrađenog drva izvlačenju vijaka

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ABSTRACT • *In this study, the screw withdrawal resistance of heat-treated hornbeam (Carpinus betulus L.), black pine (Pinus nigra Arnold) and Uludağ fir (Abies bornmuellerinana Mattf.) was determined according to the ASTM D 1761 standard. For this purpose, wood materials were heat treated at 150, 170, 190 and 210 °C for 3 h. After the heat treatment, the screw withdrawal resistance of the wood was determined in radial, tangential and transverse directions. As a result, the screw withdrawal resistance values decreased with increasing heat treatment temperature and the lowest resistance was obtained in the wood heat-treated at 210 °C. In terms of wood species, the highest screw withdrawal resistance was found in hornbeam (Carpinus betulus L.), while the lowest value was observed in black pine (Pinus nigra Arnold). Additionally, in terms of the cross-sectional direction, the highest screw withdrawal resistance was determined in the tangential direction, while the lowest resistance value was observed in the transverse direction.*

Key words: *heat treatment, black pine, hornbeam, Uludağ fir, screw withdrawal resistance*

SAŽETAK • *Ovim je istraživanjem određena veličina otpora drva izvlačenju vijaka na uzorcima od toplinski obrađenog drva graba (Carpinus betulus L.), crnog bora (Pinus nigra Arnold) i turske jele (Abies bornmuelleriana Mattf.), u skladu s normom ASTM D 1761. Za tu svrhu drvni su materijali toplinski obrađeni pri 150, 170, 190 i 210 °C tijekom tri sata. Nakon toplinske obrade određen je otpor drva izvlačenju vijaka na radijalnome, tangencijalnome i poprečnom presjeku drva. Rezultati istraživanja pokazali su da se vrijednosti otpora drva izvlačenju vijaka smanjuju s povećanjem temperature njegove toplinske obrade, a najmanji otpor zabilježen je za drvo toplinski obrađeno pri 210 °C. S obzirom na vrstu drva, najveći otpor izvlačenju vijaka izmjeren je na uzorcima od drva graba (Carpinus betulus L.), a najmanja je vrijednost izmjerena za uzorke od drva crnog bora (Pinus Nigra Arnold). S obzirom na presjek drva, najveći je otpor izvlačenju vijaka izmjeren na tangencijalnome, a najmanji na poprečnom presjeku drva.*

Ključne riječi: *toplinska obrada, crni bor, grab, turska jela, otpor izvlačenju vijaka*

[1] Author is assistant professor at Necmettin Erbakan University, Faculty of Fine Arts, Department of Interior Architecture and Environmental Design, Konya, Turkey. [2]Author is assistant professor at Gumushane University, Gumushane Vocational High School, Department of Design, Gumushane, Turkey. [3]Author is professor at Gazi University, Faculty of Technology, Department of Wood Products Industrial Engineering, Ankara, Turkey. [4]Author is assistant professor at Cankırı Karatekin University, Technical and Business College, Çankırı, Turkey.

[1] Autor je docent Sveučilišta *Necmettin Erbakan*, Fakultet likovnih umjetnosti, Odjel za uređenje interijera i dizajn okoliša, Konya, Turska. [2]Autor je docent Sveučilišta Gumushane, Strukovna visoka škola, Odjel za dizajn, Gumushane, Turska. [3]Autor je profesor Sveučilišta Gazi, Tehnološki fakultet, Odjel za industrijski inženjering drvnih proizvoda, Ankara, Turska. [4]Autor je docent Sveučilišta Cankırı Karatekin, Tehnički i poslovni koledž, Çankırı, Turska.

1 INTRODUCTION
1. UVOD

In recent years, as a result of increasing environmental consciousness, consumers have started to question the possible toxic effects of wood-modification applications using chemicals on the environment. This phenomenon has paved the way for developing alternative modification methods to preserve wood material – an eco-friendly and sustainable source. Heat treatment using adjustable treatment parameters is one of them i.e. an alternative modification method to chemical use that increases the wood dimensional stability and enhances its resistance against biological attack by reducing hygroscopicity and generating molecules toxic to fungi (Hill, 2006; Wang and Cooper, 2005). In this method, wood materials are heated in an oxygen-free environment at a temperature between 150 and 250 ºC. The heat treatment processes have been known for a very long time and they include several different methods. The main differences between the heat treatment processes are to be seen in the process conditions (process steps, oxygen or nitrogen, steaming, wet or dry process, the use of oils, steering schedules, etc.) (Militz, 2002). The heat-treated wood materials have very broad application areas ranging from outdoor uses such as sidings, doors, windows and garden furniture to indoor uses such as floors, paneling, baths and saunas (Viitaniemi, 2000). The dimensional stability and biological resistance of heat-treated wood materials increases, while their mechanical resistance decreases, which makes their use in load-bearing systems limited (Bekhta and Niemz, 2003; Esteves and Pereira, 2009; Korkut, 2008; Yildiz 2002; Korkut and Guller, 2008). The color of wood changes, and changes in mechanical properties have also been observed as a result of the heat treatment. Changes observed in physical and mechanical properties of heat-treated wood materials influence their performance in applications either positively or negatively (Ayan and Ciritcioğlu, 2012).

Some factors of the wood material, especially species and thickness, have some effects on the rigidity and durability of the wood structure elements. The screws are commonly used as joint components of the wood construction in engineered wood structures and, since each wood species has its own properties, they also have different screw withdrawal resistance. Therefore, the determination of this withdrawal resistance for some wood species is important for wood applications (Aytekin, 2008). The durability and stability of each structure depends on the performance of the fasteners. The screws are one of the fasteners widely used in the woodworking and furniture industries. Therefore, the knowledge regarding the withdrawal resistance of screws for wooden building elements will provide useful information about the durability and stability of the whole system (Celebi and Kilic, 2006). The number of screws, pilot-hole diameters, screw depth and material cross-sections should be taken into consideration in wood or wooden material applications (Faherty and Williamson, 1998; Koch, 1972).

Poncsák *et al*. (2006), investigated the effect of high heat treatment temperature on screw withdrawal resistance of birch (*Betula papyrifera*). They indicated that some decreases in screw withdrawal resistance were observed as a result of high temperature. Kocaefe *et al*. (2008) investigated the effects of heat treatment on technological properties of jack pine (*Pinus banksiana* Lamb.) and aspen (*Populus tremuloides* Michx.). They stated that screw withdrawal resistance of heat-treated jack pine decreased, but this decrease was not significantly different from the control samples. Also, screw withdrawal resistance of heat-treated aspen was found to be relatively higher than that of untreated samples. Kariz *et al*. (2013) determined the screw withdrawal resistance in the radial and tangential direction on the heat-treated spruce (*Picea abies* Karst.) at 150, 170, 190, 210, and 230 °C. The results indicated that there was a greater decrease in screw withdrawal resistance for heat treatment conditions, and they concluded that the size of deformation around the screw increased at higher temperatures based on the analysis of the images of the deformed surface left by the screws.

The amount of use and application areas of heat-treated wooden materials has substantially increased. Most of the joints use screws. Thus, the determination of screw withdrawal resistance of heat-treated wood materials is of importance in terms of high efficiency and strength of the structure. The aim of this study is to determine screw withdrawal resistance of the samples produced from heat-treated hornbeam (*Carpinus betulus* L.), black pine (*Pinus nigra* Arnold) and Uludag fir (*Abies bornmuelleriana* Mattf.).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Hornbeam (*Carpinus betulus* L.), black pine (*Pinus nigra* Arnold), and Uludağ fir (*Abies bornmuellerinana* Mattf.) were selected randomly from timber merchants as test materials because of their wide use in industry. Special emphasis was given for the selection of wood materials; non-deficient, proper, knotless, and normally grown (without zone line, reaction wood, decay, or damage caused by wood decay fungi) materials were selected. The samples were cut into in the dimensions of 60 (thickness) x 60 (width) x 780 (length) mm before the heat treatment, including radial, tangential and transverse cross-sections. The wood samples were conditioned to 12 % moisture contents (MC) in a conditioning device at 20 °C (± 2) and 65 % (± 5) relative humidity for two months before being planed and cut into small specimens.

2.1 Preparation of test samples and their heat treatment
2.1. Priprema uzoraka i njihova toplinska obrada

The small clear specimens were cut into 50 x 50 x 150 mm pieces for withdrawal tests before the heat treatment. Then they were completely dried at a temperature of 103±2 ºC until they had a constant weight. Completely dried samples were taken from the drying

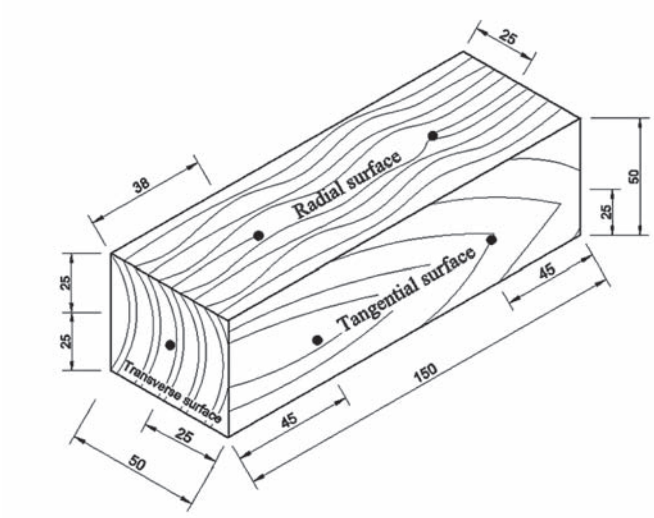

Figure 1 Test samples used for screw withdrawal resistance and screw positions
Slika 1. Uzorak drva za određivanje otpora izvlačenju vijaka s prikazom njihova položaja

oven and weighed on an electronic balance to the precision of 0.01 g. The heat treatment applications were conducted in a temperature controlled small heating unit. 4 different temperatures (150, 170, 190 and 210 °C and for 3 h.) were applied to specimens under atmospheric pressure and in the presence of air. After heat treatment, treated and control samples were conditioned to 12 % moisture contents (*MC*) in a conditioning chamber at 20 °C (± 2) and 65 % (± 5) relative humidity to reach equilibrium moisture content. The test samples used for screw withdrawal resistance tests, and screw positions are shown in Fig. 1. (ASTM D 1761, 2000).

The screws were driven into pilot holes, 70 % of the core diameter of the screw and 15 mm depth, drilled on the face of the specimens. Six wood screws (4 x 50) for each sample were used for the withdrawal tests (Fig. 1). All of the screws were embedded 32 ± 0.5 mm deep in the surface of the test samples. The withdrawal resistance was determined in the radial, tangential, and transverse directions. Screw-withdrawal resistance tests were carried out using the universal test equipment, in accordance with the ASTM D 1761 standard. During the tests, the loading rate was 2 mm/min for all tests. Ten test samples for the withdrawal resistance tests were prepared for each group. The screw-withdrawal resistance values were calculated according to Equation 1.

$$\sigma_s = \frac{F_{max}}{2 \cdot \pi \cdot r \cdot h} \quad (1)$$

Where:
σ_s – screw-withdrawal resistance, N/mm^2
F_{max} – maximum load, N
$2 \cdot \pi \cdot r \cdot h$ – surface area of the screw exposed to friction, mm^2.

Weight loss (*WL*) after heat treatment was calculated according to Equation 2.

$$WL = \frac{M0 - M1}{M0} \cdot 100 \quad (2)$$

Where *WL* is weight loss (%), M_0 is the initial oven dried mass of the wood sample before the treatment and M_1 is the oven dried mass of the same sample after the treatment.

2.2 Analysis of data
2.2. Analiza podataka

MSTATC statistical software package was used for the statistical evaluation of the results and to show the effects of the type of wood material and the temperature of heat treatment on screw-withdrawal resistance. The interactions between these factors were determined using multivariate analysis of variance (MANOVA). The comparisons were made using the critical values obtained from the LSD (least significant difference) test, and the factors causing the differences were identified.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The average values and standard deviations of weight loss (*WL*), density, and equilibrium moisture content (*EMC*) of heat-treated and control wood are given in Table 1.

As shown in Table 1, the weight loss values generally exhibited a decrease with increasing heat treatment temperature. The highest weight loss values were obtained from heat-treated at 210 ºC for black pine, hornbeam, and Uludağ fir (4.91 %, 6.98 %, and 3.72 %, respectively). The weight loss of the wood is one of the most important features in heat treatment and is commonly referred to as an indication of the quality. The weight loss depends on the wood species, heating medium, temperature, and treatment time (Esteves and Pereira, 2009). Alén *et al*. (2002) studied the weight loss of heat-treated spruce at temperatures between 180 °C and 225 °C during 4 to 8 h and found 1.5 % weight loss at 180 °C for 4h and 12.5 % at 225 °C for 6h. Similar results were also found in previous studies (Yildiz, 2002; Ozcifci *et al*. 2009; Malek *et al*. 2013). The weight loss of the heat-treated wood samples is due to the degradation of the wood polymers depending on the heat treatment temperature and treatment time, the hemicelluloses generally being the most thermally-sensitive wood components (Poncsák *et al*. 2006; Yildiz *et al*. 2006).

As shown in Table 1, the oven-dried density values decrease with increasing heat treatment temperature for three wood species. The heat-treated wood samples at a temperature of 210 °C gave the lowest air-dried density values when compared with other conditions studied. While the maximum effect of the heat treatment was recorded at 210 °C, the minimum effect was recorded at 150°C. Gunduz *et al.* (2009) studied the effects of heat treatment on the density properties of hornbeam. Their research indicated that the minimum density loss of 0.76 % occurred at treatment conditions of 170 °C for 4 h, whereas the maximum density loss of 16.12 % occurred at treatment conditions of 210 °C for 12 h. Another study showed a similar reduction of air-dried density for heat-treated Anatolian black pine wood (Akyildiz *et al*. 2009).

Table 1 Average values of WL, density and EMC of heat-treated wood
Tablica 1. Prosječne vrijednosti gubitka mase, gustoće i ravnotežnog sadržaja vode toplinski obrađenog drva

Wood species *Vrsta drva*	**Heat treatment temperature** *Temperatura toplinske obrade*	***WL*** %			**Density** g/cm^3			***EMC*** %		
		X	*sd*	*N*	*X*	*sd*	*N*	*X*	*sd*	*N*
Black pine *crni bor*	Control	-	-	-	0.511	0.016	10	13.35	0.788	10
	150 °C	1.12	0.106	10	0.506	0.012	10	10.41	0.612	10
	170 °C	2.11	0.127	10	0.501	0.018	10	9.78	0.422	10
	190 °C	3.18	0.143	10	0.494	0.017	10	8.12	0.476	10
	210 °C	4.91	0.175	10	0.484	0.018	10	6.89	0.246	10
Hornbeam *grab*	Control	-	-	-	0.653	0.014	10	11.83	0.433	10
	150 °C	1.22	0.105	10	0.646	0.015	10	9.17	0.274	10
	170 °C	2.34	0.191	10	0.634	0.011	10	8.44	0.251	10
	190 °C	3.93	0.397	10	0.623	0.014	10	7.23	0.211	10
	210 °C	6.98	0.434	10	0.601	0.015	10	5.11	0.212	10
Uludağ fir *turska jela*	Control	-	-	-	0.426	0.011	10	12.42	0.363	10
	150 °C	0.91	0.111	10	0.422	0.012	10	10.16	0.319	10
	170 °C	1.76	0.222	10	0.417	0.011	10	9.83	0.315	10
	190 °C	2.79	0.131	10	0.411	0.013	10	7.67	0.298	10
	210 °C	3.72	0.135	10	0.407	0.012	10	6.26	0.191	10

WL - weight loss / *gubitak mase*; *EMC* - equilibrium moisture content / *ravnotežni sadržaj vode*; *X* - average value / *prosječna vrijednost*; *sd* - standard deviation / *standardna devijacija*; *N* - the number of test samples / *broj uzoraka*

Also, Korkut and Bektaş (2008) conducted research on heat-treated Uludağ fir (*Abies bornmuellerinana* Mattf.) and Scots pine (*Pinus sylvestris* L.) and confirmed that the air-dried density values decreased. The conversion of hemicelluloses into volatile products and evaporation of some extractive substances play an important role in decreasing density values after heat treatment (Esteves *et al*., 2008).

Table 1 shows the results of equilibrium moisture content (EMC) of black pine, hornbeam, and Uludağ fir treated at four different temperatures (150, 170, 190, and 210 °C) for 3 hours. Treatment at 150 °C resulted in the lowest values for the EMC. The wood samples heat treated at a temperature of 210 °C have the lowest EMC value of 5.11 % for hornbeam wood when compared with other species studied. On the other hand, the highest EMC value was 10.41% for black pine wood at a temperature of 150 °C. In addition, a lower effect of heat treatment was observed when the samples were treated at 150 °C. Accessibility of hydroxyl groups to water molecules becomes difficult due to the increasing cellulose crystallinity, as a result of the degradation of amorphous cellulose. This phenomenon causes a decrease in the EMC value (Bhuiyan and Hirai, 2005; Boonstra and Tjeerdsma, 2006). The hydrolysis of hemicellulose into less hygroscopic furfural polymers causes a decrease in the EMC value (Boonstra, 2008). The results of the multivariate analysis of the screw

Table 2 Results of the Analysis of Variance
Tablica 2. Rezultati analize varijance

Direction *Smjer*	**Factor** / *Činitelj*	**Degrees of Freedom** *Stupanj slobode*	**Sum of Squares** *Zbroj kvadrata*	**Mean of Squares** *Srednja vrijednost kvadrata*	**F value** *Vrijednost F*	**Level of significance** *Razina signifikantnosti* ($P \leq 0.05$)
Radial radijalni	Factor A	2	3104.977	1552.488	45026.8203	0.0000
	Factor B	4	410.528	102.632	2976.6372	0.0000
	Interaction A*B	8	404.066	50.508	1464.8908	0.0000
	Error	135	4.655	0.034		
	Total	149	3924.226			
Tangential *tangencijalni*	Factor A	2	2265.917	1132.959	42944.0058	0.0000
	Factor B	4	444.288	111.072	4210.1104	0.0000
	Interaction A*B	8	209.299	26.162	991.6657	0.0000
	Error	135	3.562	0.026		
	Total	149	2923.066			
Transverse *poprečni*	Factor A	2	2810.115	1009.057	34193.6653	0.0000
	Factor B	4	201.161	50.290	1704.1708	0.0000
	Interaction A*B	8	78.031	9.754	330.5276	0.0000
	Error	135	3.984	0.030		
	Total	149	2301.291			

Factor A - wood species / *vrsta drva*; Factor B - heat treatment temperature / *temperatura toplinske obrade*

Table 3 Comparative test results for the effect of wood species for radial, tangential, and transverse directions (N/mm²)
Tablica 3. Rezultati usporednog testa za mjerenje utjecaja vrste drva pri radijalnome, tangencijalnome i poprečnom presjeku drva

Wood species *Vrsta drva*	**Radial*** *Radijalni*		**Tangential**** *Tangencijalni*		**Transverse***** *Poprečni*	
	X	HG	*X*	HG	*X*	HG
Black pine / *crni bor*	16.26	C	16.78	C	14.92	C
Hornbeam / *grab*	25.95	A	25.31	A	22.78	A
Uludağ fir / *turska jela*	16.34	B	17.37	B	15.08	B

LSD: *0.07287, **0.06372, ***0.06845; X - average value / *prosječna vrijednost*; HG: homogeneous group / *homogena skupina*. Different letters in HG column refer to significant differences among wood species at 0.05 confidence level. / *Različita slova u stupcu označenome s HG potvrđuju postojanje signifikantne razlike između vrsta drva pri razini signifikantnosti 0,05*.

withdrawal resistance for the heat-treated and untreated (control) wood materials for the radial, tangential, and transverse directions are shown in Table 2.

The results of the analysis of variance indicated that the effects of the wood species, heat-treatment temperature and their interactions were found to be statistically significant ($P \leq 0.05$) for the radial, tangential, and transverse directions. The comparative LSD test results for different wood species are given in Table 3.

As shown in Table 3, the highest screw withdrawal resistance was achieved in the hornbeam (*Carpinus betulus* L.) wood, followed by Uludağ fir (*Abies bornmuellerinana* Mattf.) and black pine (*Pinus nigra* Arnold), respectively. The highest resistance values for black pine and Uludağ fir were found in the tangential direction, while the lowest value was observed in the transverse surface. This may be caused by the arrangement of wood cells and fiber angle orientations. The screw withdrawal resistance of the radial direction of the hornbeam wood was found slightly higher than that of its tangential direction. Regarding wood species, the maximum screw withdrawal resistance was determined in hornbeam wood. This may be due to its high density. The density of hornbeam wood was the highest among the three species of the present study (Table 1). In fact, the highest screw withdrawal resistance was also found in hornbeam wood, in radial, tangential, and transverse directions. It may, therefore, be concluded that density and species may have a decisive importance for screw withdrawal resistance. In literature, Bal *et al*. (2015) stated that there was a strong relationship between the screw withdrawal resistance and the density of wood and that the screw holding resistance of the higher density beech plywood was higher than that of other lower density plywood panels. Akyildiz and Malkoçoğlu (2001) reported that the screw withdrawal resistance increased with increasing density of wood. The comparative LSD test results for the heat treatment temperatures are given in Table 4.

As shown in Table 4, the highest screw withdrawal resistance in radial, tangential, and transverse directions was found in the heat treated samples at 150°C, while the lowest value was found in the heat treated samples at 210 °C. Table 4 clearly shows that increasing heat treatment temperature reduces the screw withdrawal resistance. The reason for screw withdrawal resistance decreasing after heat treatment may be caused by the mass losses as a result of the degradation of hemicelluloses and by degradation of wood (Viitanen *et al*. 1994; Fengel and Wegener, 1989). Also, the density plays an important role in the mechanical strength of wood. Gašparík *et al.* (2015) investigated the effect of the heat treatment on screw withdrawal resistance of wood. They reported that screw withdrawal resistance of the heat-treated wood decreased depending on lower density and moisture content of wood, which resulted from heat treatment. The results of the LSD test for a comprehensive comparison of the effects of wood species, surface section, and heat treatment temperature on the screw withdrawal resistance are shown in Table 5.

Table 4 Comparative test results for the effect of heat treatment temperatures for radial, tangential, and transverse directions (N/mm²)
Tablica 4. Rezultati usporednog testa za mjerenje utjecaja temperature toplinske obrade pri radijalnome, tangencijalnome i poprečnom presjeku drva

Heat treatment temperature *Temperatura toplinske obrade*	**Radial*** *Radijalni*		**Tangential**** *Tangencijalni*		**Transverse***** *Poprečni*	
	X	HG	*X*	HG	*X*	HG
Control	21.16	A	21.29	A	18.57	B
150 °C	20.94	B	21.40	B	18.73	A
170 °C	20.36	C	20.29	C	17.98	C
190 °C	18.09	D	18.82	D	17.10	D
210 °C	17.03	E	17.00	E	15.57	E

LSD: *0.09438, **0.08227, ***0.08837; *X* - average value / *prosječna vrijednost*; HG: homogeneous group / *homogena skupina*. Different letters in HG column refer to significant differences among wood species at 0.05 confidence level. / *Različita slova u stupcu označenome s HG potvrđuju postojanje signifikantne razlike između vrsta drva pri razini signifikantnosti 0,05*.

Table 5 Comprehensive comparison analysis of wood species, direction section, and heat treatment temperature on screw withdrawal resistance (N/mm[2])
Tablica 5. Cjelovita analiza utjecaja vrste drva, presjeka drva i temperature toplinske obrade drva na otpor izvlačenju vijaka (N/mm[2])

Wood species *Vrsta drva*	**Heat treatment temperature** *Temperatura toplinske obrade*	**Radial*** *Radijalni*		**Tangential**** *Tangencijalni*		**Transverse***** *Poprečni*	
		X	HG	*X*	HG	*X*	HG
Black pine *crni bor*	Control	17.50	F	18.46	F	16.21	G
	150 °C	17.28	G	18.23	G	16.37	F
	170 °C	16.45	I	16.87	K	15.43	H
	190 °C	15.17	L	16.12	M	14.01	M
	210 °C	14.89	M	14.24	N	12.58	N
Hornbeam *grab*	Control	29.98	A	28.74	A	24.16	B
	150 °C	29.23	B	28.35	B	24.59	A
	170 °C	27.88	C	26.12	C	23.44	C
	190 °C	22.19	D	23.12	D	22.32	D
	210 °C	20.48	E	20.21	E	19.38	E
Uludağ fir *turska jela*	Control	16.01	J	17.57	I	15.35	HI
	150 °C	16.32	I	17.63	I	15.22	IJ
	170 °C	16.76	H	17.89	H	15.07	JK
	190 °C	16.91	H	17.23	J	14.98	K
	210 °C	15.72	K	16.55	L	14.77	L

*LSD: 0.1629, **:0.1425, ***: 0.1531, *X* - average value / *prosječna vrijednost*; HG: homogeneous group / *homogena skupina*. Different letters in HG column refer to significant differences among wood species at 0.05 confidence level. / *Različita slova u stupcu označenome s HG potvrđuju postojanje signifikantne razlike između vrsta drva pri razini signifikantnosti 0,05*.

The screw withdrawal resistance of wood species decreased with increasing temperature. Generally, in terms of direction, the lowest screw withdrawal resistance was found in transverse direction. The reason lies in the fact that the screws drawn perpendicularly in the surfaces were also in the direction of grain configuration of test samples. Therefore, it was concluded that it would be useful to take into consideration the effects of grain direction on withdrawal resistance.

Hornbeam was the most affected by heat treatment, while Uludağ fir (*Abies bornmuellerinana* Mattf.) was the least affected. In other words, screw withdrawal resistance in hornbeam decreased much more compared to other wood species. The reason for this was probably caused by degradation of hemicelluloses. The chemical composition of wood varies from species to species. In general, hardwoods contain more hemicellulose than softwoods (Baeza and Freer 2001). The degradation of the hemicelluloses starts to take place at a relatively low temperature (between 160 and 260 ºC). Also, the degradation of the hemicelluloses increases with heat treatment temperature and treatment time (Poncsák *et al*. 2006, Yildiz *et al*. 2011). The **s**oftwoods are more thermally stable than hardwoods, which is the result of their hemicellulose content and compositional differences (Fengel and Wegener, 1989). Perçin (2015) studied screw withdrawal resistance of laminated samples produced from heat-treated oak (*Quercus petraea* Liebl.) at 140, 170, 200 and 230 °C for 2 h and reinforced with carbon fibers. As a result, increasing heat treatment temperature decreased the screw withdrawal resistance of test samples. A study by Baltaci (2010) investigated the effects of heat treatment on screw withdrawal resistance of several wood species. He applied heat treatment to Scots pine, Oriental beech, Uludağ fir, and Carolina poplar at 120, 160, 200 ºC for 2 to 6 h. The highest screw withdrawal resistance was found in oriental beech, while the lowest resistance was found in Uludağ fir. Kariz *et al*. (2013) reported that heat treatment affected the screws withdrawal capacity of wood because of various factors, one of which was the decrease in density that resulted from high heat treatment temperature. The heat treatment resulted in a decrease in density, and this reduction in density became even more pronounced as the temperature of the heat treatment increased. Therefore, a relationship was observed between the decrease in density and the decrease in screw withdrawal resistance (Aytin *et al*. 2015).

4 CONCLUSIONS
4. ZAKLJUČAK

According to the results, the screw withdrawal resistance decreased with the increasing heat treatment temperature. In terms of the cross sectional direction, the lowest screw withdrawal resistance was found in transverse surface. In terms of wood species, the highest screw withdrawal resistance was found in hornbeam (*Carpinus betulus* L.), while the lowest resistance value was found in black pine (*Pinus nigra* Arnold). Screw withdrawal resistance was most affected by heat treatment when hornbeam (*Carpinus betulus* L.) was used. Screw-withdrawal resistance in heat-treated wood decreased with increasing temperature. Thus, it can be suggested that appropriate wood species should be selected for applications where heat-treated wood are to be used, and heat treatment should be carried out at appropriate temperatures.

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Corresponding address:

Assist. Prof. OSMAN PERÇİN, Ph. D.

Necmettin Erbakan University
Faculty of Fine Arts
Department of Interior Architecture and Environmental Design
42100, Konya, TURKEY
e-mail: opercin@konya.edu.tr