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Determination of Screw and Nail Withdrawal Resistance of Some Important Wood Species

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Abstract: In this study, screw and nail withdrawal resistance of fir (*Abies nordmanniana*), oak (*Quercus robur* L.) black pine (*Pinus nigra* Arnold) and Stone pine (*Pinus pinea* L.) wood were determined and compared. The data represent the testing of withdrawal resistance of three types of screws as smart, serrated and conventional and common nails. The specimens were prepared according to TS 6094 standards. The dimensions of the specimens were 5x5x15cm and for all of the directions. Moreover, the specimens were conditioned at ambient room temperature and 65±2% relative humidity. The screws and nails were installed according to ASTM-D 1761 standards. Nail dimensions were 2.5mm diameter and 50 mm length, conventional screws were 4x50mm, serrated screws were 4x45mm and smart screws were 4x50mm. Results show that the maximum screw withdrawal resistance value was found in Stone pine for the serrated screw. There were no significant differences between Stone pine and oak regarding screw withdrawal resistance values. Conventional screw yielded the maximum screw withdrawal resistance value in oak, followed by Stone pine, black pine and fir. Oak wood showed the maximum screw withdrawal resistance value for the smart screw, followed by Stone pine, black pine, and fir. Oak wood showed higher nail withdrawal resistances than softwood species. It was also determined that oak shows the maximum nail withdrawal resistance in all types. The nail withdrawal resistances at the longitudinal direction are lower with respect to radial and tangential directions.

Keywords: Screw, nail, withdrawal resistance, oak, Stone pine, black pine, and fir.

1. Introduction

The rigidity of furniture and other wooden furniture accessories depends on the type and thickness of the wood, as well as how the wooden pieces were put together. Screws and nails are widely used as joint components of furniture construction and since each wood species has its own properties, they also have different screw and nail withdrawal resistances. Therefore, it is important for both producers and consumers to be aware of the best screw and nail withdrawal resistance for the various wood species.

Ferah performed nail withdrawal resistance experiments at tangential, radial and cross-section angle penetration into wood of two different humidity levels (12% and 30%) [1]. Tangential surface screw withdrawal resistance experiments were performed according to TS 6094 and ASTM-D1761 standards on seven wood species that were obtained in the “Elmali Ciglikara Sedir Research Forest” and “Abant-Bolu region”. They determined that Sessile oak had the maximum screw withdrawal resistance value, followed by *Fagus orientalis*, red pine, black pine, Lebanese cedar and respectively. Uludag Fir was found to have the minimum screw withdrawal resistance value, while the maximum value was obtained from Sessile oak, followed by *Fagus orientalis*, red pine, black pine, Lebanese cedar and respectively, and the lowest value was obtained from Uludag fir.

Doganay determined parallel and perpendicular screw withdrawal resistance for three types of screws (17x17, 18x25 and 20x30 types) commonly used in Werzalit wood furniture production [2]. The results of the experiments show that the most effective material in screw withdrawal resistance from both directions is the Fagus orientalis wood, followed by Werzalit, MDF and particleboard, respectively.

Raczkowscha determined that the nail withdrawal resistance of Scotch pine juvenile wood is lower than that of heartwood [3]. This was found in 30% perpendicular to grain and 10% parallel to grain. He also stated that there is a linear relationship between nail withdrawal resistance and the density of wood; nail withdrawal resistance perpendicular to grain in juvenile wood is lower than in older wood with the same density.

Fujita determined that investigations were carried out on a withdrawal-resistance, in the case when nails were driven on a specimen in air drying condition through the five kinds of Sugi-woods (*Cryptomeria japonica*) growing at Takakuma University Forest, Kagoshima Prefecture [4]. The five kinds of Sugi-wood are Yakusugi-, Measasugi-, Yoshinosugi-, Kumotoushisugi- and Obiarakawasugi-wood aged 52,27,28 and 28,respectively. In this paper, 1. Concerning the withdrawal-resistance the highest value was noted in Yakusugi-wood, and the lowest one in Obiarakawasugi-wood. 2. A average withdrawal-resistance was ascertained to be dependent on the specific gravity of Sugi-wood growing at Takakuma University Forest. 3. Withdrawal-resistance to respective nail types, which were assorted into chequered-head countersunk-smooth type and -screw type, was decreasing in accordance with the width of average annual ring. But a withdrawal-resistance to wood screw was independent of the width of annual ring.

Broker and Krause performed static and dynamic screw withdrawal experiments on three layered particleboard, European Spruce grown in Norway, and European Birch wood with 9 types of screws. They concluded that the screw withdrawal resistance value is linearly proportional with screw length and screw diameter [5].

Bues and his colleagues pounded 2x40 mm sized nails into 250 20x20x110 dimensional wood samples which were obtained from scattered cuttings of pine wood and measured their withdrawal resistances [6]. They used screws of 20 mm groove length, 1.8 mm cog step, and 60° cog angle on nail holes of 2 mm diameter. After suitable conditioning, they measured screw and nail withdrawal resistances on radial and tangential directions as 50 N/s, and determined the relationship between the density and screw and nail withdrawal resistance [6]. As a result, they determined average nail withdrawal resistance as 1.27 KN in radial direction, 1.06 KN in tangential direction with 0.50 g/cm^3 average density and with 12% humidity. They also determined average screw withdrawal resistance as 1.48 KN in radial direction and 1.42 KN in tangential direction at the same conditions. The meaningful differences in the screw and nail withdrawal resistance values in the tangential and radial directions were established by 20% of nails and 4% of screws. They determined that screw withdrawal resistance of the screws was 16% higher in radial direction and 34% higher in tangential direction than nails.

Reardon and Boughton examined 6 types of grooved nails on 7 species of pine [7]. They determined that nail withdrawal resistances of grooved nails are 2-3 times higher than that of smooth trunk nails. However, there is no relationship between the density of wood types and withdrawal resistance values.

Kim concluded the effect of nail direction and time elapse after nailing into the static withdrawal resistance by nailing 4.9-5.1 mm length and 0.25-0.26 mm diameter nails into pine and larix wood [8]. As a result, Kim determined that there is a linear relationship between static withdrawal resistance and humidity amount. Kim presented the relationship in both species of wood in tangential, radial and longitudinal directions.

Kanamori and his coworkers measured withdrawal resistance of nails that were nailed into dried wood samples of *Picea jezoensis*, *Larix leptolepis* and *Quercus crispula* [9]. Five humidity levels were analyzed. It was determined that nail withdrawal resistance of circular ribbed nails (max. 2.9 mm diameter) decreases during the process. The majority of this decrease occurs in the first phase. For the helical ribbed nails (max 3.2 mm diameter), nail withdrawal resistance does not change or increase unessential. In addition, nail withdrawal resistance of *Quercus crispula* is twice as that of the two other wood types.

Kanamori and his coworkers compared nail withdrawal resistance of common wire nails, helitical ribbed nails and galvanized circular ribbed nails that were nailed tangentially, radially and longitudally nailed into three types of wood (*Picea jezoensis*, *Larix leptolepis* and *Quercus crispula*) [10]. They performed experiments in three different conditions; nailed into undried wood over a 6 month drying period, nailed into dried wood, over a 7 month humidity taken and humidity release period, nailed into dried wood over 15 months at equilibrium humidity.

Kjucukov and Encev measured screw withdrawal resistance of screws with different lengths (13-60 mm) and different diameters (1.5-8 mm) that were screwed into *Abies alba* wood in three directions [11]. As a result, they determined that there is no relationship between screw withdrawal resistance and screw length, and there is a linear relationship between screw withdrawal resistance and screw diameter.

Kjucukov and Encev performed with 1.5-6.0 mm diameters screws on *Fagus orientalis* and determined that there is a linear relationship between screw withdrawal resistance and screw diameter [12]. This result confirms the experiment results on fir wood.

Lexa concluded nail withdrawal resistances of steal nails covered with an epoxy resin that was nailed into dried and green spruce, fir, and *Fagus orientalis* wood [13]. He determined that the nail withdrawal resistances of covered nails are smaller, the nail withdrawal resistances of covered nails are higher on the dried wood, and the nail withdrawal resistances of covered nails are slowly diminished.

Bacher nailed nails on wood with 60% humidity and measured the nail withdrawal resistance during the drying period from 60% humidity to 0% [14]. As a result, he determined that nail withdrawal resistance diminishes when the wood humidity amount decreased to the leaf saturation point.

Hellawel concluded nail withdrawal resistance in the wood samples at fresh, air dried, partially dried and moistened conditions just after nailing, and the effect of drying and time on this property [15]. He concluded that Rimu wood generally has higher nail withdrawal resistance than Radiata pine wood.

Noguchi and Sugihara compared nail withdrawal resistance of chrome nickel and iron nails that were nailed longitudinally, radially, tangentially at static and dynamic conditions on 6x6x30 cm experiment samples of *Cryptomeria japonica*, *Fagus crenata* and *Chamaecyparis* [16]. They determined that nail withdrawal resistance at static nailing is higher than dynamic nailing. They concluded that nail withdrawal resistance decreases with time in the density of wood in both nailing types. It was also found that the nail withdrawal resistance is maximized for tangentially nailing nails. They formulated equations on nail withdrawal resistance and wood density, nail diameter and time after nailing.

Mack compared static nail withdrawal resistance of flat and ribbed nails on wet and air dried Radiata pine and Eucalyptus wood after different periods [17]. He concluded that ribbed nails show high nail withdrawal resistance values on soft and hard wood during and after the nailing period.

Scholten found that the highest nail withdrawal resistance values were obtained from sharp tip nails on wood with low density [18]. Wood with high density did not divide after nailing. He proposed common nails for wood with high division resistances.

Stern and Price measured nail withdrawal resistance of different shaped nails on the structural quality of southern yellow pine [19]. As a result, they concluded that circular ribbed and screw dented nails show higher resistances than common wire nails. There was also a linear relationship between nail withdrawal resistance and nail diameter in big diameter nails and this relationship was higher than predicted.

Ayyildiz and Malkocoglu, carried on the screw withdrawal resistance of stem wood material of *Fagus orientalis* Lipsky., *Alnus glitunosa* subsp. *barbata* (C.A.Mey) Yalt., *Castenea sativa* Mill., *Picea orientalis* (L.) Link., and *Pinus sylvestris* L. [20]. The wood samples of these tree species were collected from forest districts in Gümüshane, Trabzon and Artvin located in Eastern Black Sea region of Turkey. Tests were carried out according to the TS 6094 and ASTM-D 143 and ASTM-D 1761 on 60 samples of each one of the tree species. Half of the samples had 12% and the other half had 30% moisture contents. The dimensions of wood materials on which the tests were carried out were 50x50x150 mm. Screws used for withdrawal tests were 4.5 mm in diameter and 40 mm in length. Two screws were inserted into lead holes at right angles on the tangential surface, 26 mm penetration. In this study, the results presented that the highest screw withdrawal resistance was found for oriental beech among the five tree species. The order of screw withdrawal resistance from the higher to the lower was found as follows; alder, chestnut, pine, spruce. In regards to moisture effects, the screw withdrawal resistances were found to be higher at the 12% moisture content.

In this study, screw and nail withdrawal resistance of fir (*Abies nordmanniana*), oak (*Quercus robur* L.) black pine (*Pinus nigra* Arnold) and Stone pine (*Pinus pinea* L.) wood were determined and compared. This study includes the comparison of nail and screw withdrawal resistances for the same species and between other species. The resistance values were obtained from all of the directions (radial, tangential, longitudinal) of wood specimens. The data represent the testing of withdrawal resistance of three types of screws as smart, serrated and conventional and common nails.

2. Materials and Methods

2.1. Materials

The, wood species used in the experiments are Anatolian black pine (*Pinus nigra* Arnold), Uludag Fir (*Abies nordmanniana*), nut pine (*Pinus pinea* L.) and sessile oak (*Quercus robur* L.) growing naturally in the Western Black Sea region of Turkey. In this region, Uludag fir and Anatolian black pine are present at altitudes between 1700-1800 meters of forest area between Ayikaya and Yedigoller. Sessile oak wood is present in the Bartin forest between 200-600 meters in altitude and Stone pine is present between the Bartin and Amasra towns Cakraz township border, between 32°22`13`` - 32°35`05`` east longitude and 41°42`21``-41°48`68`` north parallels, Cakraz-Dindar parish Cunukduzu sites, 12 km apart from Amasra. Stands present between 50-150 meters altitude and the average gradient of land is between 20- 60%. Random sample areas were chosen from homogeneous stands.

In the selection of wood, direction, inclination, altitude, diameter, and growing environment properties were considered. It was carefully determined that the trunk formation of the wood were not branched, gnarled, curled, or having abnormal peak forms. Therefore, the species used in this work represent their land characteristics and have the best trunk structure.

The specimens were prepared according to TS 6094 standards [21]. The measurements of the specimens were 5x5x15cm and for all of the directions and for all of the wood species. Moreover, the specimens were conditioned at 20±2°C and 65±2% relative humidity to adjust their equilibrium moisture content as 12%.

The screws and nails were installed according to ASTM-D 1761 standards [22]. Nail measurements were 2.5mm diameter and 50 mm length, screws were 4x50mm, serrated screws were 4x45mm and smart screws were 4x50mm. The tests performed for every three direction, for four different wood species, for three types of screws and common nail and 20 replicates for each group were tested. For every specimen; 2 nails for every three directions with the total of 6 nails were used. 2 screws of 3 different types of screws on every direction with the total of 6 screws were embedded. Every nails and screws were used once. Nails and screws were embedded according to TS 6094 [21].

2.2. Methods

Screw withdrawal resistance was determined by the application of the maximum resistance of oven dried wood perpendicular the grain. The followed by equation was used for this purpose:

$$P = 15700 \times G^2 \times D \times L \tag{1}$$

Where;
P : The maximum pull of power (kgf)
G : The density of the wood (g/cm^3)
D : The diameter of the screw body (mm)
L : The depth of the ribbed part of the screw (mm)

Design values were determined using the following equation:

$$P = 2840 \times G^2 \times D \tag{2}$$

Where;
P : The allowed design value (groove portion of screw for 25.4 mm insertion depth for each) (kgf)

Obtained values in equation (2) are higher than 1/6 of that obtained in equation (1).

Tests were carried out according to the TS 6094 [21] and ASTM-D 1761 [22] on 20 samples of each one of the tree species. Half of the samples were 12% and the other half were 30% moisture contents.

3. Results and Discussion

As a result of the experiments, data were obtained by using 4 types of wood: oak (*Quercus robur* L.), Stone pine (*Pinus pinea* L.), fir (*Abies nordmanniana*) and black pine (*Pinus nigra* Arnold), 3 types of screws (smart screw, serrated screw, and conventional screw), and one type (2,5x5) of nail. These data represent resistance values of three different directions (tangential, longitudinal, and radial).

3.1. Withdrawal resistances for radial direction

In this section, nail and screw withdrawal resistance of wood specimens for radial direction were compared. Representative statistical data of withdrawal resistances for radial direction are presented in Table 1. Radial direction resistance values of nails have lower values with respect to that of screws.

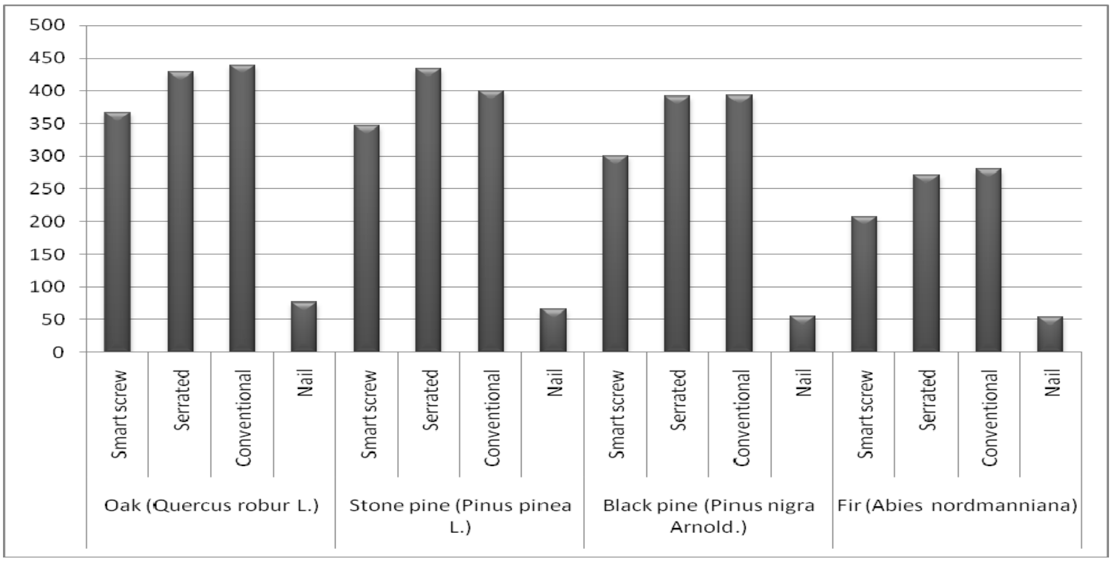
According to results, the highest resistance value for radial direction was obtained from oak as 439.75 kgf with conventional type screw. Conventional screws also performed best for every species except Stone pine.

Table 1. Statistical values for the radial withdrawal resistances (kgf).

Wood Species	Material	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
Oak *Quercus robur* L.	Smart	366,65	37,003	291	451	20
	Serrated	428,10	68,995	331	633	20
	Conventional	439,75	46,253	368	521	20
	Nail	76,40	10,450	61	99	20
Stone pine *Pinus pinea* L.	Smart	346,70	55,291	292	482	20
	Serrated	433,90	54,367	347	550	20
	Conventional	399,30	54,075	314	550	20
	Nail	65,70	16,023	45	100	20
Black pine *Pinus nigra* Arnold.	Smart	300,15	38,456	236	372	20
	Serrated	391,85	43,359	299	469	20
	Conventional	392,95	76,751	290	638	20
	Nail	55,55	9,897	42	83	20
Fir *Abies nordmanniana*	Smart	207,10	36,082	146	286	20
	Serrated	271,35	47,291	193	395	20
	Conventional	279,85	58,654	198	406	20
	Nail	53,60	7,937	38	67	20
TOTAL		281,81				320

Nail and screw withdrawal resistances for radial direction were presented in Figure 1. According to data, oak and Stone pine performed similarly. The lowest values were obtained from fir wood.

Figure 1. The histogram of nail-screw withdrawal resistances for radial direction.



3.2. Withdrawal resistances for tangential direction

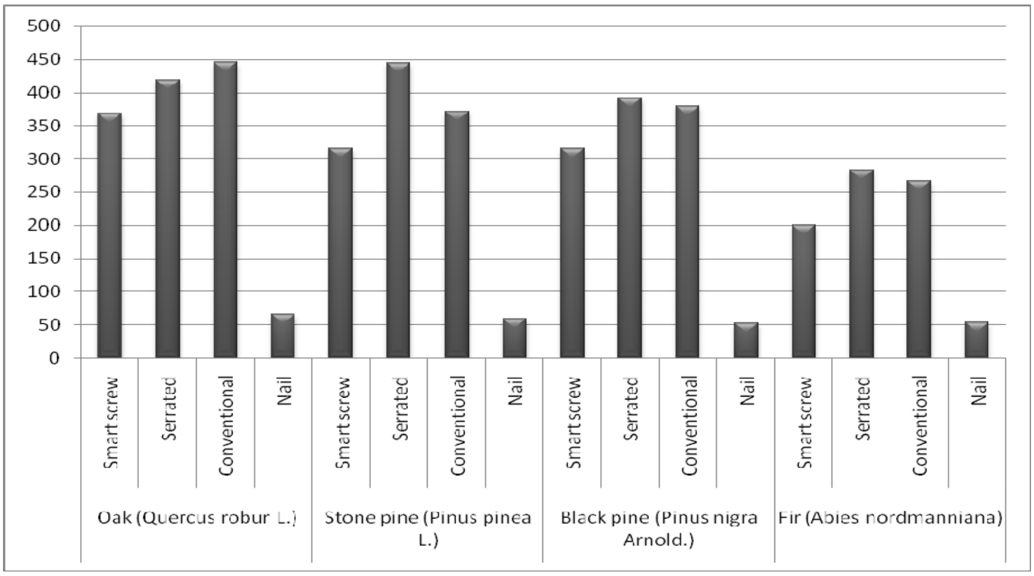
The highest value was obtained from oak with conventional type screws as 445.70 kgf. Besides, Stone pine performed quite similarly with serrated screw. The results related to tangential withdrawal direction resistance, are tabulated and presented in Table 2.

Table 2. Statistical values for the tangential withdrawal resistances (kgf).

Wood Species	Material	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
Oak *Quercus robur* L.	Smart	368,50	29,204	325	427	20
	Serrated	419,00	46,630	355	513	20
	Conventional	445,70	31,052	386	519	20
	Nail	66,30	9,559	54	89	20
Stone pine *Pinus pinea* L.	Screw	315,50	43,090	259	396	20
	Serrated	444,10	57,434	340	525	20
	Conventional	371,40	61,466	290	486	20
	Nail	59,40	14,162	37	97	20
Black pine *Pinus nigra* Arnold.	Smart	315,95	54,755	236	428	20
	Serrated	391,60	35,596	329	442	20
	Conventional	379,80	57,427	297	562	20
	Nail	52,80	10,227	36	67	20
Fir *Abies nordmanniana*	Smart	200,05	29,336	156	254	20
	Serrated	282,80	30,319	237	331	20
	Conventional	266,60	55,890	134	365	20
	Nail	53,35	4,561	43	60	20
TOTAL		277,05				320

According to Figure 2, oak, Stone pine and black pine performed quite similarly. Fir had the lowest values for every screw and nail tested.

Figure 2. The histogram of nail-screw withdrawal resistances for tangential direction.



3.3. Withdrawal resistances for longitudinal direction

In this section, nail and screw withdrawal resistance of wood specimens for longitudinal direction were compared. According to results, the highest resistance values for longitudinal direction were obtained from oak and black pine as 362.85 kgf and 257.25 kgf respectively with conventional type screw. The lowest resistance value was obtained from black pine as 197.10 kgf with smart screw.

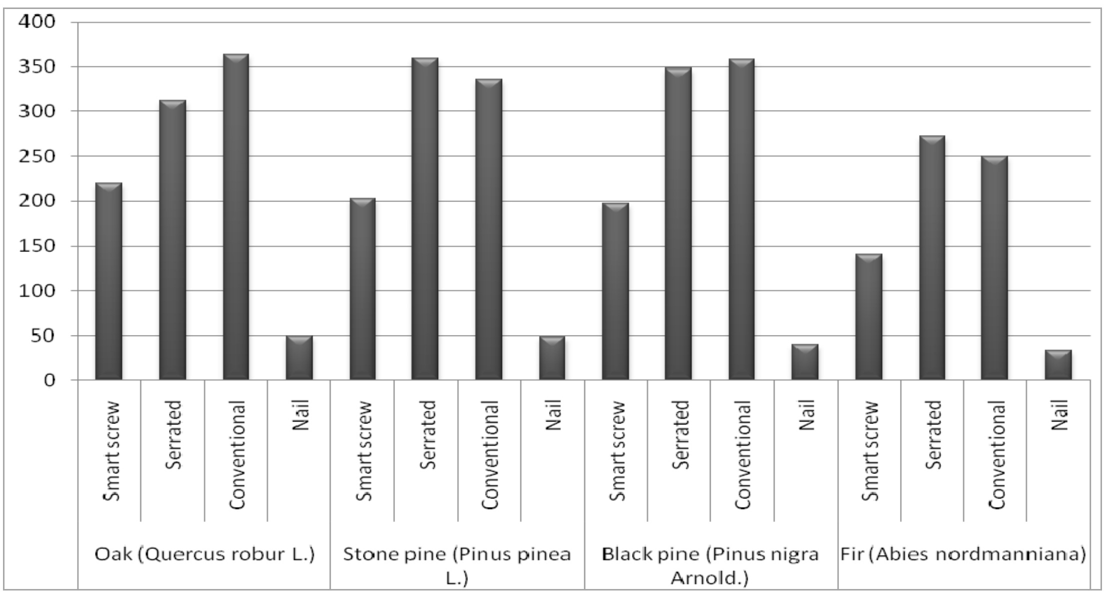
The results related to tangential withdrawal direction resistance, are tabulated and presented in Table 3.

Table 3. Statistical values for the longitudinal withdrawal resistances (kgf).

Wood Species	Material	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
Oak *Quercus robur* L.	Smart Screw	220,40	35,466	154	286	20
	Serrated	311,30	40,066	245	433	20
	Conventional	362,85	37,581	297	418	20
	Nail	49,10	8,277	41	76	20
Stone pine *Pinus pinea* L.	Smart Screw	202,10	35,859	162	279	20
	Serrated	359,15	55,543	279	459	20
	Conventional	335,60	63,741	248	500	20
	Nail	49,00	10,306	31	72	20
Black pine *Pinus nigra* Arnold.	Smart Screw	197,10	25,171	144	238	20
	Serrated	347,40	32,032	265	407	20
	Conventional	357,25	56,676	281	521	20
	Nail	39,70	7,941	25	33	20
Fir *Abies nordmanniana*	Smart	140,10	16,290	114	174	20
	Serrated	272,00	29,523	220	325	20
	Conventional	249,25	69,254	173	418	20
	Nail	32,70	7,706	20	46	20
TOTAL		220,31				320

According to results, oak, Stone pine, black pine and performed quite similarly (Figure 3). Fir performed lowest values for every screw and nail.

Figure 3. The histogram of nail-screw withdrawal resistances for longitudinal direction.



3.4. Nail and screw withdrawal resistances for wood species

In this work, results were obtained from experiments on samples that were prepared by the TS 6094 fundamentals at 12% humidity for nail and three different screw types at different sample directions (radial, tangential and longitudinal).

According to results, the highest value among all of the directions and connection materials, oak with conventional screws performed the best following by Stone pine with serrated screws. In general, oak performed quite satisfactorily. These results are presented in Tables 4.

Table 4. Screw withdrawal resistance values (kgf).

Wood Species	Specific Gravity (g/cm³)	Conventional Screws			Serrated screw			Smart screw		
		R	T	L	R	T	L	R	T	L
Quercus robur L.	0,696	439,75	445,70	362,85	428,10	419,00	311,30	366,65	368,50	220,40
Pinus pinea L.	0,534	399,30	371,40	335,60	433,90	444,10	359,15	346,70	315,50	202,10
Pinus nigra Arnold	0,496	392,95	379,80	357,25	391,85	391,60	347,40	300,15	315,95	197,10
*Abies n*ordmanniana	0,438	279,85	266,60	249,25	271,35	282,80	272,00	207,10	200,05	140,10

(R: Radial direction, T: Tangential direction, L: Longitudinal direction)

The difference between screw withdrawal resistances of serrated screws and conventional screws are not notable. The screw withdrawal resistances are Stone pine, oak, black pine and fir, respectively.

The conventional screw gave the maximum screw withdrawal resistance on oak wood followed by Stone pine, black pine and fir wood, respectively.

There is no big screw withdrawal resistances difference between radial and tangential direction at sample directions. It was seen that the radial direction resulted the maximum screw withdrawal resistance values. Tangential direction follows it, but resistance values are close to the radial direction. The minimum screw withdrawal resistance value is presented by the longitudinal direction. The screw withdrawal resistances at the longitudinal direction are lower with respect to the radial and tangential directions.

It was seen that oak wood, one of the hard wood species, yielded higher screw withdrawal resistances than softwood species. It was determined that oak shows the maximum screw withdrawal resistance except for serrated screw.

For three factors (wood species, screw type and sample direction), oak wood showed the maximum resistance value followed by Stone pine, black pine and fir respectively. The average nail withdrawal resistance values according to wood species and three different sample directions are presented in Table 5.

In Table 5, it is seen that oak wood showed higher nail withdrawal resistances than softwood species. It was also determined that oak shows the maximum nail withdrawal resistance in all types. In sample directions, the radial direction shows the maximum nail withdrawal resistance, tangential direction follows it but resistance values are close to radial direction. The nail withdrawal resistances at the longitudinal direction are lower with respect to radial and tangential directions.

Table 5. Nail withdrawal resistance values (kgf).

Wood Species	Specific Gravity (g/cm³)	Nail withdrawal resistance values		
		R	T	L
Quercus robur L.	0,696	76,40	66,30	49,10
Pinus pinea L.	0,534	65,70	59,40	49,00
Pinus nigra Arnold	0,496	55,55	52,80	39,70
Abies nordmanniana	0,438	53,60	53,35	32,70

(R: Radial direction, T: Tangential direction, L: Longitudinal direction)

3. Conclusions

According to these results, the serrated screw has higher screw withdrawal resistance with respect to other screw types. In addition, it`s easy application yields an additional advantage. However, the usage of the serrated screw is not common today. In order to increase the performance, the usage of serrated screw should be increased.

It was determined that smart screws used in the connection of wooden materials to metals, gave the minimum screw withdrawal resistance. Because of the fact that these types of screws are produced for the metal connections, their cog structure is not suitable for wooden materials. Because of their easy application in the connection of metal and wooden materials, they are used broadly.

According to these results, it is clear that in the connection with nail and screw, radial direction connection by withdrawal screw will provide the maximum service life**,** longitudinal connections, nail and screw usage should be avoided.

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