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Varnish adhesion strength in natural aged wood material

Doğal yaşlanmış ağaç malzemede vernik tutunma direnci

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Varnish Adhesion Strength in Natural Aged Wood Material

Highlights

- *In this study, fresh and naturally aged oak (Quercus petrea* L.*), Scotch pine (Pinus sylvestris* L.*) and chestnut (Castanea sativa* M.*) woods were used in the experiments.*
- *Polyurethane, acrylic and water-based varnishes were applied to the surface of the samples.*
- *The results of the research, it was determined that the age period of wood did not have an effect on the varnish adhesion strength.*

Graphical Abstract

Adhesion strength of some varnishes on fresh and naturally aged wood material was determined.

Figure. Adhesion strength measurements

Aim

It is aimed to determine the adhesion strength values of some varnishes applied to the surface of naturally aged and fresh wood material.

Design & Methodology

Experiments, 360 test samples, 180 of which are fresh and 180 naturally aged wood materials, varnish adhesion strength was determined according to TS EN 462.

Originality

In the study, the data obtained as a result of experimental studies in accordance with the relevant national and international standards were used.

Findings

It has been determined that the age period has no effect on the varnish adhesion strength. Adhesion strength was determined in polyurethane varnish (4.009 N/mm^2), acrylic varnish (3.754 N/mm^2) and water-based varnish (1.286 N/mm^2) as varnish type.

Conclusion

Oak and chestnut can be used in works where high varnish adhesion strength is required, and it is recommended to use acrylic and polyurethane varnish as varnish.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Varnish Adhesion Strength in Natural Aged Wood Material

Araştırma Makalesi / Research Article

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ABSTRACT

This study, it is aimed to determine the adhesion strength of varnish layers applied to the surface of fresh and naturally aged wood materials. For this purpose, oak (Quercus Petrea L.), chestnut (Castanea sativa M.) and Scots pine (Pinus sylvestris L.) wood materials were used for each wood species, age period, section direction and varnish type. A total of 360 test samples were prepared and polyurethane, acrylic and water-based varnishes were applied to their surfaces. The adhesion strength of the samples was determined by the pull-off test following TS EN 4624. The statistical analyzes of the data obtained as a result of the experiments were made with the MSTAT-C package software, and the significance values between and within the groups were determined. According to the results of the research, it was determined that the age period did not affect the varnish adhesion strength the highest adhesion strength at the wood species level was obtained in chestnut (3.361 N/mm^2), followed by oak (3.191 N/mm^2) and Scots pine (2.248 N/mm^2). At the varnish type level, the highest adhesion strength was obtained in polyurethane varnish (4.009 N/mm2), followed by acrylic varnish (3.754 N/mm^2) and water-based varnish (1.286 N/mm^2), respectively. In the section direction comparisons, the adhesion strength was found higher in the tangential direction (3.098 N/mm^2) and higher in the radial direction (2.935 N/mm^2). In the comparison level of age period-varnish type, the highest was obtained in polyurethane varnish (4.307 N/mm^2) applied to the surface of naturally aged wood material, and the lowest was obtained in water-based varnish (1,167 N/mm^2) applied to the surface of naturally aged wood material.

Keywords: Varnish, adhesion strength, naturally aged wood.

Doğal Yaşlanmış Ağaç Malzemede Vernik Tutunma Direnci

ÖZ

Bu çalışmada, yeni ve doğal yaşlanmış ağaç malzemelerin yüzeyine uygulanan vernik katmanlarının tutunma dirençlerinin belirlenmesi amaçlanmıştır. Bu amaca uygun olarak, meşe (*Quercus petrea* L.), kestane (*Castanea sativa* M.) ve sarıçam (*Pinus sylvestris* L.) ağaç malzemelerden her bir ağaç türü, yaş periyodu, kesit yönü ve vernik çeşidinin için 10'ar adet olmak üzere toplam 360 adet deney örneği hazırlanarak yüzeylerine poliüretan, akrilik ve su bazlı vernikler uygulanmıştır. Örneklerin tutunma direnci TS EN 4624'e uygun olarak çekme testi (pull-off test) ile belirlenmiştir. Deneyler sonucunda elde edilen verilerin, MSTAT-C paket yazılımı ile istatistiksel analizleri yapılarak gurup içi ve guruplar arası anlamlılık değerleri belirlenmiştir. Araştırma sonuçlarına göre, yaş periyodunun vernik tutunma direncine etkisinin bulunamadığı tespit edilmiştir. Ağaç türü düzeyinde en yüksek tutunma direnci kestanede (3,361 N/mm^2) elde edilmiş, bunu meşe (3,191 N/mm^2) ve sarıçam (2,248 N/mm^2) izlemiştir. Vernik çeşidi düzeyinde en yüksek tutunma direnci poliüretan vernikte (4,009 N/mm2) elde edilmiş, bunu sırasıyla akrilik vernik (3,754 N/mm^2) ve su bazlı vernik (1,286 N/mm^2) izlemiştir. Kesit yönü karşılaştırmalarında tutunma direnci teğet yönde (3,098 N/mm^2), radyal yönden (2,935 N/mm^2) daha yüksek bulunmuştur. Yaş periyodu-vernik çeşidi ikili karşılaştırma düzeyinde en yüksek doğal yaşlanmış ağaç malzeme yüzeyine uygulanan poliüretan vernikte (4,307 N/mm^2), en düşük ise doğal yaşlanmış ağaç malzeme yüzeyine uygulanan su bazlı vernikte (1,167 N/mm^2) elde edilmiştir.

Anahtar Kelimler: Vernik, tutunma direnci, doğal yaşlanmış ağaç malzeme.

1. INTRODUCTION

The number of products which are manufactured by wood material increases from time to time in the wood work industry. In addition, the wood material can protect itself in case of outside effects such as weathering, temperature, and biological changes. However, the wood material durability life span is not so long due to the physical, chemical, and mechanical weathering. Therefore, the layers of wood material are covered using impregnate and proper surface application based on the purpose of usage [1, 2]. Nevertheless, the layers of varnish do not always show perfect performance. Especially, to sustain the long-term strength of varnish layers, the adhesion and cohesion forces should be balanced properly. However, the balance situation might show imbalanced due to the production companies' improper formulation. Moreover, the surface tension increases due to excessive cohesion force implementation higher than the requirement. For that reason, while the adhesion decreases the surface shake increases [3-7].

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In literature, the type of wood and varnish is important for adhesive resistance whereas the thickness of layers is not significant for the adhesive resistance. The adhesive resistance shows the highest value in the broad-leaved woods while the lowest value is detected in the coniferous wood. Furthermore, the adhesive resistance presents the highest value with polyurethane varnish and acrylic varnish. The varnish sticking resistance is mostly performed to evaluate layers performance. The sort of varnish is the most significant parameter related to the reason for differences in adhesive resistance [8].

The different applications with water-based varnish are reasonable for strength and adhesive resistance [9]. The increased layer influences polymer groups varnish [10] and the water-based varnish applications for different materials have weak compared to the solvent-based varnish [11].

To obtain strong adhesive force, the wood material surface smoothness is reduced using tools that are utilized to make the protective surface. Besides, the air where is between the wood material layers should be removed from the adhesive surface [12, 13]. According to the literature review, if the size of molecules increases adhesive resistance decreases [10, 14]. There are many factors affecting adhesion resistance, the most important of which is surface roughness [15].

Water-based varnish type has lower layer thickness than polyurethane, cellulosic, and synthetic varnishes [16].

The varnish adhesive resistance is an important parameter to decide the limitations of application fields and layer performance [17, 18].

Natural ageing is defined as a material loss of its physical and mechanical properties with unrenewable of them [19]. The wood material is exposed to physical, chemical, and mechanical degradation because of ageing. For this research, the oak (Quercus Petrea L.), Scotch pine (Pinus sylvestris L.) and chestnut (Castanea sativa M.) wood are natural ageing around 100 years was selected in the usage area. Moreover, the green version of the woods is used to compare adhesive resistance among ageing and green woods.

2. MATERIAL and METHOD

2.1. Wood Material

In this research, the oak (Quercus Petrea L.), Scotch pine (Pinus sylvestris L.) and chestnut (Castanea sativa M.) wood types are selected due to their properties such as being widely used in the woodwork industry and high life span. The selected experiment samples are natural ageing about 100 years in the usage field. The wood material was selected based on TS 2470. According to TS 2470, the material has a perfect, knot-free, proper annual ring, fungus, and rotting-free, and proper growth [20].

Moreover, the natural ageing chestnut the oak and the Scotch pine are selected from Kocaeli-Karamürsel, Yozgat-Sorgun and Ankara respectively. The fresh woods are chosen from a company where is in Ankara/ Siteler. Afterwards, wood samples were prepared in the radial and tangential section directions.

2.2. Varnish

In this research, water-based, polyurethane, and acrylic semi matt varnish types are preferred.

2.2 Preparation of the Test Samples

The dry air moisture content-based wood material is prepared as 110x110x12 mm for the template. Afterwards, the fresh part of the timber is prepared with 100x100x10 mm dimensions. Additionally, the fresh wood is organized as the type of wood as number 3, cutting direction and age period as number 2 and type of varnish as number 3. Moreover, the total number of samples are prepared as 360 with (3x2x2x3x10). The experiment conditions are 20±2 ℃ temperature and 65±5% relative humidity. The samples wait in climatized and far from direct sunlight. Subsequently, 20 samples are selected for pre-control randomly. The selected samples have 12% average humidity.

<u>Moisture determination</u>

The moisture decision is applied based on TS 2417 [21]. The samples are weighted using (M_r) $\pm$0.01 gr analytical balance. Subsequently, the samples are waited in 103$\pm$2 ℃ drying-oven until constant weight. Afterwards, the samples are cooled down with a desiccator that includes phosphorus pentoxide (P_2O_5) until to obtain dry weight (M_o). According to the information the moisture content can calculate by the following formula;

$$R = \frac{M_r - M_o}{M_o} \qquad (1)$$

Mr: Damp weight
M_o: Full dry weight

<u>Density</u>

The density measurement is implemented based on TS 2472 [22]. The samples which are dry air conditions waited in 20$\pm$2 ℃ temperature and 65±5% relative humidity under climatized area. On the other hand, the fully dried samples are waited in an airing cupboard under 103±2 ºC temperature until constant weight. After those applications, the samples are weighted with (M) $\pm$0.01 gr analytical balance, and the dimensions of the samples are ±0,01 mm measured using digital micrometer calipers. As a result of the steps, the dry air density is computed in Equation (2) and the fully dry density is evaluated in Equation (3).

$$\delta_{12} = \frac{M_{12}}{V_{12}} \qquad (2)$$

M_{12}: Air dry weight
V_{12}: Air dry volume

$$\delta_0 = \frac{M_0}{V_0} \qquad (3)$$

M_0: Full dry weight
V_0: Full dry volume

The samples are varnished based on ASTM-D 3023 standards [23]. The varnish preparation is done according to the companies' specification in case influencing layers performance. The viscosity experiment is utilized through a 4 mm viscos meter with 20±2 ˚C temperature and 65±5 relative humidity in climatized conditions, then the viscosity is decided as 18 second (98-100 cp). The implementation of timber block and layer varnish is done using a 2 bar pressure and 1.4 mm tip opening blowgun.

During application, the blowgun and sample distance is 20 cm in height and the air is operated perpendicular to the fibers then parallel to the fibers as normal crossing layers. After each application, the layers are waited for drying for 24 hours. The dried samples are prepared for the next application using 400 number emery. The application is repeated for two layers of timber block varnish and two final varnish layers.

<u>*Determination of the amount of solids*</u>

The determination of solid matter for varnish is computed based on the TS EN ISO 3251 [24]. The tare weight of the varnish is determined utilizing Ø 6 cm concave glass watch. 5 gr of varnish is added to the concave glass watch tool in drying oven 60 ºC until to reach constant weight. After drying oven application, the solvents are evaporated and the samples are weighted again to decide the amount of solid matter (Sm).

$$V_a = Ww - T \quad (4)$$

$$E_s = Ww - Dw \qquad \%\,Sm = \frac{V_a - E_s}{V_a} \times 100$$

Va= Varnish applied *Ww= Wet weight*
Es= Evaporating solvent *T= Tare*
Sm= Solid matter *Dw= Dry weight*

<u>*Dry film thickness determination*</u>

Before the experiment, the thickness of the layer is determined by a 5μm precision comparator based on ASTM D-1005-95 [25].

2.3. Determination of Varnish Layer Adhesion Strength

The experiment samples are prepared based on TS EN 24624 standards with 23±2 ºC temperature and 50±5% relative humidity inside the climatized cupboard for 24 hours [26].

The varnish adhesion strength (X) is evaluated as MPa (Mega Pascal), MPa = 1 N/mm^2

$$X = 4F / \pi . d^2 \text{ [27].} \quad (5)$$

Figure 1 presents an experiment cylindrical roller which is produced of stainless steel with the adhesion surface is rectified. The acrylic-based wood glue (Penloc GTI) is applied with 150±10 g/m^2 under the experiment roller. Afterwards, the rollers are mounted middle of the experimental set-up, shown in Figure 2.

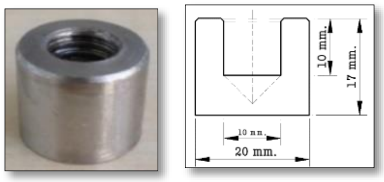

Figure 1. Experiment Rollers / Test Cylinder Section.

The rollers are mounted in the middle of the samples in 5 minutes under equal pressure. The samples waited in a wood gin for 24 hours, illustrated in Figure 2.

Figure 2. Bonding of test cylinders with the help of mold

The working principle of the experimental setup is based on pulling the Ø 20 mm steel cylinders from the adhered sample surface. The samples, which are adhered to the experimental cylinders, were taken from the extrusion die. Afterwards, to ensure that the tensile force is effective only on the area where the metal cylinder is applied, the acrylic-based adhesive residues that overflowed during the adhesion of the cylinder to the surface were cleaned. The experiments were applied using pneumatic adhesion based on the TS EN 4624 [28] at Gazi University Wood Products Industrial Engineering. The tensile strength experiment was performed based on TS EN 311 as less than 1 Kgf within 60 seconds [29].

2.5. Evaluation of the data

Each wood was classified as wood type (3), section direction (2), age period (2) and varnish type (3). According to the experiment pattern, each sample has been prepared as 10 numbers and a total of 360 numbers of samples have been organized for the experiment. Subsequently, the varnish tensile strength was analyzed utilizing multivariable variation (MANOVA). When the difference was detected among the groups the Duncan method provided a comparison between the groups. The comparison factors were separated as homogenous groups and analyzed based on success rating using the least-squares differences. The outcomes were evaluated by MSTAT-C within a 0.95 confidence interval.

3. RESULTS

Table 1. Air dry and full dry density values (g/cm^3)

Wood Material/ Age Period	WOOD TYPES					
	Scotch pine		Oak		Chestnut	
	Dry Air	Fully Dry	Dry Air	Fully Dry	Dry Air	Fully Dry
Fresh	0.55	0,51	0.77	0.73	0.62	0.58
Natural Aged	0.48	0.46	0.70	0.66	0.58	0.54

The specific weight of the fully dried fresh aged wood types is heavier than the natural aged wood material. The reason for the less specific weight of the naturally aged material is related to natural weathering due to age.

Table 2. Adhesion strength values (N/mm^2)

Wood Type/ Age Period	Water-based				Polyurethane				Acrylic			
	Radial		Tangential		Radial		Tangential		Radial		Tangential	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
F. Scotch pine	1.340	0.46	1.939	0.54	3.101	0.50	3.642	0.80	2.995	0.70	2.570	0.88
NA. Scotch pine	1.234	0.60	1.318	0.18	3.529	0.77	3.257	0.68	2.702	0.71	2.342	0.65
F. Oak	1.068	0.25	0.953	0.13	3.239	0.82	3.951	0.82	4.694	0.90	5.150	0.96
NA. Oak	1.177	0.37	0.959	0.16	5.228	1.24	4.525	0.92	3.832	0.71	3.517	0.52
F. Chestnut	1.352	0.32	1.783	0.40	3.816	1.11	4.522	1.01	3.738	0.66	4.725	1.07
NA. Chestnut	1.259	0.49	1.056	0.24	4.385	1.11	4.650	1.01	3.873	0.69	4.903	1.11

$\bar{X}$ *: Arithmetic Average* *s: Standard Deviation* *F: Fresh* *NA: Natural Aged*

According to the wood type, age period, section direction and varnish type, the adhesion strength showed differences among the parameters. To determine the reason for the difference, the variation analysis was done and shown in Table 3.

Table 3. Analysis of variance results on the effect of wood type, age period, section direction and varnish type on adhesion strength.

Factors	Degree of Independence	Sum of Squares	Mean of Squares	F Values	P ≤0,05
Wood Type (A)	2	50.206	25.103	45.9771	0.0000*
Age Period (B)	1	0.089	0.089	0.1638	NS
Interaction (AB)	2	1.322	0.661	1.2107	0.2993**
Section Direction (C)	1	2.395	2.395	4.3857	0.0370*
Interaction (AC)	2	4.915	2.457	4.5009	0.0118*
Interaction (BC)	1	6.529	6.529	11.9581	0.0006*
Interaction (ABC)	2	0.567	0.284	0.5197	NS
Varnish Type (D)	2	542.640	271.320	496.9330	0.0000*
Interaction (AD)	4	50.601	12.650	23.1693	0.0000*
Interaction (BD)	2	18.335	9.168	16.7907	0.0000*
Interaction (ABD)	4	18.542	4.635	8.4901	0.0000*
Interaction (CD)	2	0.264	0.132	0.2417	NS
Interaction (ACD)	4	7.188	1.797	3.2913	0.0115*
Interaction (BCD)	2	2.312	1.156	2.1173	0.1220**
Interaction (ABCD)	4	1.691	0.423	0.7742	NS
Error	324	176.901	0.546		
Sum	359	884.497			

*: Difference is significantly based on 0.05 ***: Difference is insignificant based on 0.05 NS (Nonsignificant): Insignificant*

Varnish adhesion strength values were evaluated based on wood type, section direction, wood type-section direction, age period- section direction, varnish type, wood type-varnish type, age period-varnish type, wood type-age period and varnish type and the last combination was a section direction-varnish type. All combination was computed as the statistical approach. The significant values were considered using the Duncan method.

Table 4. Duncan test results at the wood species level (N/mm^2)

WOOD TYPE					
Scotch pine		Oak		Chestnut	
$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
2.498	B**	3.191	A	3.361	A*
LSD ± 0.1876					

$\bar{X}$ *: Arithmetic average HG: Homogenous group* **: The highest adhesion strength* ***: The lowest adhesion strength*

Table 5. Duncan test results at the level of section direction (N/mm^2)

SECTION DIRECTION			
Radial		Tangential	
$\bar{X}$	*HG*	$\bar{X}$	*HG*
2.935	B**	3.098	A*
LSD ± 0,1532			

Table 6. Duncan test results at the wood species-section direction level (N/mm^2)

WOOD TYPE/ SECTION DIRECTION											
Scotch pine				Oak				Chestnut			
Radial		Tangential		Radial		Tangential		Radial		Tangential	
$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
2.483	C**	2.512	C	3.206	B	3.176	B	3.115	B	3.607	A*
LSD ± 0.2653											

According to wood type-section direction valuation, the highest adhesion strength was decided in the tangential cutting direction in the oak wood whereas the lowest adhesion strength was determined radially and tangentially of the scotch wood. The oak wood was considered insignificant in terms of statistical approach. Moreover, the chestnut had reasonable results in radial and tangential.

Table 7. Duncan test results at age period-section direction level (N/mm^2)

WOOD MATERIAL AGE PERIOD/SECTION DIRECTION							
Fresh				Natural Aged			
Radial		Tangential		Radial		Tangential	
$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
2.816	C**	3.248	A*	3.054	AB	2.948	BC
LSD ± 0.2166							

Based on the wood material age period/section direction way experiment, fresh age wood material tangential way shown the highest adhesion strength while the radial way presented the lowest adhesion strength values.

Table 8. Duncan test results at the varnish type level (N/mm^2)

VARNISH TYPE					
Water-based		Polyurethane		Acrylic	
$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
1.286	C**	4.009*	A	3.754	B
LSD ± 0.1876					

Table 9. Duncan test results at the wood type-varnish type level (N/mm^2)

Varnish Type	WOOD TYPE					
	Scotch pine		Oak		Chestnut	
	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
Water-based	1.458	D	1.039	E**	1.362	DE
Polyurethane	3.382	B	4.236	A	4.410	A*
Acrylic	2.652	C	4.298	A	4.310	A
LSD ± 0.3249						

In terms of wood material and varnish type, the highest adhesion strength was detected in the chestnut-polyurethane/acrylic varnish and oak-polyurethane and acrylic varnish whereas the lowest adhesion strength was determined in oak water-based varnish type.

Table 10. Duncan test results at age period-varnish type level (N/mm^2)

Wood Material Age Period	VARNISH TYPE					
	Water-based		Polyurethane		Acrylic	
	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
Fresh	1.406	D	3.712	C	3.979	B
Natural Aged	1.167	D**	4.307	A*	3.528	C
LSD ± 0.2653						

As a result of the wood material and varnish type data analysis, the natural aged-polyurethane application showed the highest adhesion strength whereas the lowest value was recorded in fresh and natural aged water-based varnish type.

Table 11. Duncan test results at the wood species-age period-varnish variety level (N/mm^2)

Wood Material Age Period	WOOD TYPE/VARNISH TYPE					
	Water-based		Polyurethane		Acrylic	
	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
Fresh Scotch pine	1.640	E	3.372	C	2.783	D
Natural Aged Scotch pine	1.276	EF	3.393	C	2.522	D
Fresh Oak	1.010	F**	3.595	C	4.922	A*
Natural Aged Oak	1.068	F	4.877	A	3.674	C
Fresh Chestnut	1.568	E	4.169	B	4.232	B
Natural Aged Chestnut	1.157	EF	4.650	AB	4.388	B
LSD ± 0.4595						

According to Table 11, the fresh oak that was applied acrylic varnish and the natural aged which was implemented polyurethane varnish showed the highest adhesion strength whereas the fresh and natural aged oak wood material which was applied water-based varnish showed the lowest adhesion strength. The fresh age chestnut-polyurethane, fresh age chestnut-acrylic and the naturally aged chestnut-acrylic application were considered as insignificant in terms of statistical outcomes.

Table 12. Duncan test results at the level of wood type-section direction-varnish type (N/mm^2)

Varnish Type	WOOD TYPE/SECTION DIRECTION											
	Scotch pine				Oak				Chestnut			
	Radial		Tangential		Radial		Tangential		Radial		Tangential	
	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
Water-based	1.287	GH	1.629	G	1.123	GH	0.956	H**	1.305	GH	1.419	GH
Polyurethane	3.315	E	3.450	DE	4.233	BC	4.238	BC	4.233	BC	4.586	AB
Acrylic	2.848	F	2.456	F	4.263	BC	4.333	AB	3.806	CD	4.814	A*
LSD ± 0.4595												

According to the result of the varnish type outcome, the highest adhesion strength was recorded in the chestnut which was applied on the acrylic varnish along with the tangential direction. Furthermore, the chestnut showedthe lowest adhesion strength with water-based varnish along with the tangential direction. The water-based varnish presented the lowest adhesion strength value in all cases.

4. CONCLUSIONS and SUGGESTIONS

According to the literature review, the adhesion strength of the coniferous wood is lower than the broad-leaved wood [8]. The literature shows that the varnish application along with the tangential direction has higher adhesion strength compared to the radial direction [30].

- Based on the section direction, the tangential direction showed the higher adhesion strength compared to the radial direction.

The reason for higher adhesion strength in the tangential direction is related to the void which is among the specifications of the structure of the cells and increasing surface area. Moreover, the increased surface area provides high mechanical adhesion strength.

- According to the varnish type outcomes, the highest adhesion strength was decided polyurethane varnish, acrylic varnish, and water-based varnish respectively.

The literature shows that polyurethane has the highest adhesion strength in previous research [32], thus the information was proved in this research applications.

- The highest varnish adhesion strength was recorded in solvent-based varnish type due to the chemical reaction on the material surface.

Furthermore, the reason for the highest varnish strength of the polyurethane is related to the content of cellulose in wood material.

- Due to the evaporation of the solvent material, the water-based varnish presented the lowest adhesion strength.

According to the literature, the water-based varnish has weak properties such as low adhesion strength, low hardness and is not durable in case of mechanical effects whereas the solvent-based varnish has the highest adhesion strength [6, 31]. The water-based varnish leads to the thin varnish layer on the material because of the less amount of solid matter in it. The optical and solid view were not provided with water-based varnish compared to the solvent-based varnish that is polyurethane and acrylic [8].

- Age period was considered insignificant for adhesion strength.
- Fresh and natural aged wood material statistical outcomes were considered insignificant.
- The varnish application for fresh age and natural aged wood material has no reasonable difference.

In conclusion, the age period is not important for varnish adhesion strength. To obtain higher adhesion strength solvent-based polyurethane and acrylic varnish and oak and chestnut are recommended.

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DECLARATION OF ETHICAL STANDARDS
The authors of this article declares that the materials and methods used in their studies do not require ethical committee approval and/or legal-specific permission.

AUTHORS' CONTRIBUTIONS
Kenan KILIÇ: Conducted the experiments, analyzed the results and wrote the article.
Cevdet SÖĞÜTLÜ: Designed the experiment, wrote the article and analyzed the results.

CONFLICT OF INTEREST
There is no conflict of interest in this study.

REFERENCES
[1] Özgenç, Ö., Bilici, E., Durmaz, S., Söğütlü, C., Emik, S. "Enhancing weathering durability of pre-protected and unprotected wood by using bark extracts as natural UV absorbers in waterborne acrylic coating", ***Journal of Coatings Technology and Research,*** 19(1), 303-321, (2022).

[2] Van den Bulcke, J., Rijckaert, V., Van Acker, J. ve Stevens, M., "Adhesion and weathering performance of waterborne coatings applied to different temperate and tropical wood species", ***Journal of Coating Technology Research,*** 3(3):185-191, (2006).

[3] Budakçı, M., "Pneumatic Adhesion Test Device Design and Production", ***Gazi University Technical Education Faculty Journal of Polytechnic***, 9(1):53-58, (2006).

[4] Nelson, G.L., "Adhesion", Paint and Coating Testing Manual, Chapter 44, ***ASTM Special Technical Publication***, Philadelphia, P.A., 513-523, (1995).

[5] Corcoran, E. M., "Adhesion", Painting Testing Manual, Chapter 5.3, ***ASTM Special Technical Publication***, Philadelphia, P.A., 314-332, (1972).

[6] Sönmez, A., Budakçı, M., Surface Treatments in Woodworking II, Protective Layer and Paint/Varnish Systems, ***Gazi University Faculty of Technical Education***, Ankara, (2004).

[7] Kúdela, J. ve Liptáková E., "Adhesion of coating materials to wood", ***Journal of Adhesion Science and Technology***, 20(8):875-895, (2006).

[8] Vitosytė J., Ukvalbergienė K. and Keturakis G., "The effects of surface roughness on adhesion strength of coated ash (*Fraxinus excelsior* L.) and birch (*Betula* L.) wood, ***Materials Science***, 18: 347-351, (2012).

[9] Sönmez, A., Budakçı, M., Yakın, M. "The Effects of Water Solvent Varnish Applications on Wood Material on Hardness, Gloss and Adhesion Resistance", ***Journal of Polytechnic***, 7 (3): 229-235, (2004).

[10] Söğütlü, C., Sönmez, A., "The Effect of UV Lights on Color Changes on Some Local Wood Processed with Differential Preservatives", ***J. Fac. Eng. Arch. Gazi University,*** 21(1):151-159, (2006).

[11] Yakın, M., "Determination of Hardness, Gloss and Adhesion Strength of Water Based Varnishes", ***M. Sc. Thesis***, Gazi University Institute of Science and Technology, (2001).

[12] Kurtoğlu, A., General Information, "Wood Material Surface Treatments", Vol1, ***İ.Ü. Faculty of Forestry Forest Ind. Eng. Dept***., Istanbul. (2000).

[13] Sönmez, A., "Surface Treatments in Woodworking I", Preparation and Coloring, ***Gazi University Faculty of Technical Education***, Ankara, (2000).

[14] Döngel, N., Küreli, İ., Söğütlü, C., "The Effect of Dry Heat for the Colour and Gloss Changes on the Wood and Wood Based Floor Covering Materials", ***Journal of Polytechnic,*** 11(3), 255-263, (2008).

[15] Özşahin, Ş., Singer, H., "Prediction of Wood's Surface Roughness and Adhesion Resistance with Artificial Neural Network", ***Journal of Polytechnic***, 22 (4), 889-900, (2019).

[16] Aykaç, S., Sofuoğlu, S. D., "Investigation of the Effect of Varnish Types on the Surface Properties of Bamboo Wood Material", ***Journal of Polytechnic***, 24 (4), 1353-1363, (2021).

[17] Atar M., Keskin H., Yavuzcan H.G., "Varnish Layer Hardness of Oriental Beech (*Fagus Orientalist* L.) Wood as Affected by Impregnation and Color Bleaching", ***Journal of Coatings Technology***, 1(3): 219-224, (2004).

[18] Atar M., Çolakoğlu M. H., "Surface Adhesion Strength of Varnishes in Impregnated Woods", ***Journal of Applied Science***, 9(22): 4066-4070, (2009).

[19] Kılıç, K., Söğütlü, C., "Determination of the Gloss Values of Some Varnishes Applied on the Natural Aged Wood", ***Journal of Polytechnic***, 23 (4), 1423-1431, (2020).

[20] TS 2470, "Sampling Methods for Physical and Mechanical Experiments in Wood", (1976).

[21] TS 2471, "Determination of Moisture Amount for Physical and Mechanical Experiments in Wood", (1976).

[12] TS 2472, "Determination of Unit Weight for Physical and Mechanical Experiments in Wood", (1976).

[23] ASTM D 3023, "Determination of Resistance of Factory Applied Coatings on Wood Products of Stain and Reagents", (1981).

[24] TS EN ISO 3251, "Determination of Non-Volatile Matter in Paints and Varnishes, Paints, Varnishes and Binders", (2012).

[25] ASTM D 1005, ‘‘Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers", (2001).

[26] TS EN 24624, "Paints and Varnishes-Tension Test", (1996).

[27] ASTM D 4541, "Standard test method for pull-off strength of coatings using portable adhesion testers", (1995).

[28] TS EN ISO 4624, "Paints and Varnishes-Tension test for adhesion", (2016).

[29] TS EN 311, "Wood-based boards-Surface strength Test method", (2005).

[30] Söğütlü, C., Nzokou, P., Koc, I., Tutgun, R., Döngel, N, "The effects of surface roughness on varnish adhesion strength of wood materials". ***Journal of Coatings Technology and Research***, 13(5), 863-870, (2016).

[31] Yakın, M, "Determination of Hardness, Gloss and Adhesion Strength of Water Based Varnishes", ***M. Sc. Thesis***, Gazi University Institute of Science and Technology, (2001).

[32] Bayram M, "The Effect of Wood Material Moisture Content to Adhesion Strength of Varnishes", ***M. Sc. Thesis***, Gazi University, Institute of Science and Technology, Turkey (2004).