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Surface Hardness of Three Types Varnish Applied to Fresh and Naturally Aged Wood

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Abstract

Aim of study: This study was carried out to determine the surface hardness values of some varnishes applied to the surface of naturally aged wood material.

Material and methods: Acrylic, polyurethane and water-based varnish was applied to the surface of the experimental samples prepared from naturally aged and fresh Scots pine (*Pinus sylvestris* L.), sessile oak (*Quercus petrea* L.) and chestnut (*Castanea sativa* M.) wood materials. A total of 360 test samples, 10 for each wood type, cutting direction, age period, and varnish type were prepared then the surface hardness values of these samples were determined.

Main results: As a result of the experiments, the effect of the age period on the surface hardness of the varnish layer was found to be insignificant. The highest surface hardness value in wood material was obtained in the tangential section of oak wood and the difference between oak wood and chestnut wood was statistically insignificant. As a varnish type, the highest surface hardness value was obtained in polyurethane varnish, followed by acrylic varnish and water-based varnish, respectively. In addition, the surface hardness of the varnish layer in the tangential section of the wood material was found to be higher than that of the radial section.

Highlights: In cases where high surface hardness is required in the varnish layer, polyurethane varnish can be preferred. As a result of the experiments, water-based varnish with a low surface hardness value will be able to give a working performance compatible with wood material with a hygroscopic structure, thanks to its high elasticity. For this reason, wood with a high amount of dimensional change can be used to protect the material against external influences.

Keywords: Wood Material, Varnish, Finishing, Surface Hardness, Naturally

Taze ve Doğal Yaşlanmış Ağaç Malzemeye Uygulanan Üç Çeşit Verniğin Yüzey Sertliği

Öz

Çalışmanın amacı: Bu çalışma, doğal yaşlanmış ağaç malzeme yüzeyine uygulanan bazı verniklerin yüzey sertlik değerlerinin belirlenmesi amacı ile yapılmıştır.

Malzeme ve yöntem: Doğal yaşlanmış ve taze sarıçam (*Pinus sylvestris* L.), sapsız meşe (*Quercus petrea* L.) ve kestane (*Castanea sativa* M.) ağaç malzemeden hazırlanan deney örneklerinin yüzeyine akrilik, poliüretan ve su-bazlı vernik uygulamıştır. Her ağaç türü, kesit yönü, yaş periyodu ve vernik çeşidi için 10'ar adet olmak üzere toplam 360 adet deney örneği hazırlanmış ve yüzey sertlik değerleri belirlenmiştir.

Temel Sonuçlar: Deneyler sonucunda, yaş periyodunun vernik katmanı yüzey sertliğine etkisi önemsiz bulunmuştur. Ağaç malzemede düzeyinde en yüksek yüzey sertlik değeri meşenin teğet kesitinde elde edilmiş, meşe ve kestane arasındaki fark istatistiksel olarak anlamsız çıkmıştır. Vernik çeşidi olarak, en yüksek yüzey sertlik değeri poliüretan vernikte elde edilmiş, bunu sırası ile akrilik vernik ve su-bazlı vernik izlemiştir. Ayrıca, ağaç malzemenin teğet kesitindeki vernik katmanı yüzey sertliği radyal kesit yönünden yüksek bulunmuştur.

Araştırma vurguları: Vernik katmanında yüksek yüzey sertliği gerektiren durumlarda, poliüretan vernik tercih edilebilir. Deneyler sonucunda, yüzey sertlik değeri düşük seviyede bulunan su-bazlı vernik ise yüksek elastiklik özelliği sayesinde, higroskopik yapıya sahip olan ağaç malzeme ile uyumlu bir çalışma performansı verebilecektir. Bu nedenle, boyutsal değişim miktarı yüksek olan ağaç malzemenin harici etkilere karşı korunması için kullanılabilir.

Anahtar Kelimeler: Ağaç Malzeme, Vernik, Üstyüzey İşlemi, Yüzey Sertliği, Doğal Yaşlanmış

Introduction

The wood material is preferred due to the ease to use, low energy consumption, various colors and features, the low transmission of sound, heat and electricity (Kurtoğlu, 2000).

However, based on the wooden material properties which are organic, anisotropic, hygroscopic and heterogeneous; it has versatile operating characteristics depend on the cutting direction. Therefore, the wooden material is destroyed by insects and fungi. Additionally, the material is not durable in case of combustion (Budakçı, 1997).

Fading and deterioration occurs in the color of wood material exposed to outdoor conditions (Williams et al., 1990). Decompositions show different features based on the type of exposure effects. For instance, the kitchen furniture is primarily exposed to water, humidity, detergent, citric acid, oil and some chemicals found in cooking steam (Ross, 1972). Whereas the joinery, pergola and garden furniture are exposed to the sun rays, rain, dew, snow, frost, temperature differences between night and day are exposed to the effects (Ross, 1972).

The alteration of the physical and mechanical properties of the wood are derived from the changes in the chemical components in the microstructure (Fengel, 1991).

Furniture and various building elements which are constructed by made of wood should be protected from external influences. The durability of wooden products is limited, which are left open to external influences in their natural state. Usage conditions and external effects destroy and deform the wooden material over time. Therefore, the surfaces of products and structures which are constructed by wooden material should be covered with a protective layer (Söğütlü & Sönmez, 2006; Ulay & Çakıcıer, 2017; Söğütlü, 2017).

Protective layer applications are applied to different materials as liquids.

Moreover, the layer is formed on the surface after physical or chemical drying. Both the properties of the wood and surface material and the application methods can be effective in the layer performance. In this context, various technical and scientific studies have been carried out and new ones are added every day.

Liquid varnish is applied to the wood surface with various methods such as brush, sponge, roller and spray gun (Söğütlü et al., 2016). It has been reported that the varnish application method has no effect on the surface hardness value (Sönmez et al., 2004).

In the rapid aging test with xenon-arc, it was noted that by applying different varnishes of Scots pine, iroko and Anatolian chestnut, an increase in the adhesion resistance and hardness values of the varnish layer was observed at different layer thicknesses (Çakıcıer, 2007).

In a study where cellulosic, synthetic, polyurethane and polyester varnish were applied to beech and oak veneer surfaces, it was determined that the layer hardness was the highest in polyester varnish and the lowest in synthetic varnish (Sönmez, 1989).

It was determined that the application effect of the NG modification process on the surface hardness values of the beechwood samples with nano-graphene (NG) modified water-based varnish was insignificant (Pelit & Korkmaz, 2019).

Due to the effect on the hardness of the varnish layer, it seems that the varnish illumination is not efficient (Uysal et al., 1999).

The surface hardness of the varnish samples after heat treatment was observed to be lower than that of varnished untreated samples. (Çakıcıer et al., 2011).

Ageing can be defined as the irreversible change of the mechanical and physical properties of a material (Kılıç, 2019).

The aim of this study is to determine the surface hardness values of some varnishes applied to naturally aged wood material. In accordance with this purpose, the surfaces of Scotch pine, sessile oak and chestnut samples were coated with water-based, polyurethane and acrylic varnish. The experiments were carried out according to the relevant standards. This study is important in terms of developing suggestions for the conservation practices of cultural properties made of wood material, which have survived to the present day in different regions of our country.

Material and Methods

Wood Material

In this study, sessile oak (*Quercus Petrea* L.), chestnut (*Castanea sativa* M.), Scotch pine (*Pinus sylvestris* L.) were used as experimental material.

The specification of the wooden material was decided by principles in TS 2470 based on paying attention to the natural color of the timber, smooth fibers, no knots, normal growth, no reaction wood, and no fungus and insect damage.

The naturally aged wood samples were obtained from three provinces in Turkey. In this context, chestnut wood was obtained from Kocaeli province Karamürsel district, oak wood from Yozgat province Sorgun district and Scotch pine from Ankara province.

Fresh wood materials were obtained from lumber suppliers in Ankara Furniture Sites. The specimens were prepared by sawing in tangential and radial directions.

Varnish

In this study, water-based, polyurethane and acrylic varnish were used, which are frequently operated in the woodworking industry. The varnish parameters used are given in Table 1.

Table 1. The varnish properties

Varnish Type	ph	Solids Ratio (%)	Density (gr/ml) (20 ºC)	Dry Film Thickness (µm)	Viscosity (Sec. DIN cup/4mm)
Acrlyic	4.00	25-30	0,90-0.94	120	18 sec.
Polyurethane	5.71	35-40	0.93-0.97	130	18 sec.
Water-based	7.80	30-35	1.02-1.04	120	18 sec.

Preparation of Experimental Samples

Wood materials dry-air moisture value are 110×110×12 mm in the draft, and the main dimension is 100×100×10 mm. The test design was made according to the sapwood parts of the timber, wood type (3), cutting direction (2), age period (2), 1 the varnish type (3) and a total of 360 (3x2x2x3x10) test samples.

The prepared samples were kept in an environment with an average temperature of 20±2 ºC and a relative humidity of 65±5%, well ventilated and not exposed to direct sunlight, until their weight did not change. In the pre-control, the average moisture content was determined as 12% in 20 randomly selected samples.

Determination of Moisture Content

Moisture content (MC) was determined accordance with TS 2471 principles (Eq. 1):

$$MC = \frac{m_{wet} - m_{dry}}{m_{dry}} \; (100\%) \quad (1)$$

Where m_{wet} is the mass of the specimen at a given moisture content and m_{dry} is the mass of the oven-dry specimen.

Density

Density values were determined in accordance with the principles specified in TS 2472. Air-dry density (ρ_{12}) test samples were stored at 20±2 ºC and 65±5% relative humidity, and oven-dry density (ρ_{dry}) samples were stored in a ventilated drying cabinet at 103±2ºC. After waiting until their weights do not change, the mass (m) and dimensions were determined with 1% precision, and the volume (V) was calculated using the equation below (Eq. 2):

$$\rho_{12} = \frac{m_{12}}{V_{12}} \quad (2)$$

Where m_{12} is the mass of the specimen at a 12% moisture content and V_{12} is the volume of the specimen at a 12% moisture content (Eq. 3):

$$\rho_{dry} = \frac{m_{dry}}{V_{dry}} \quad (3)$$

Where m_{dry} is the mass of the ovendry specimen and V_{dry} is the volume of the ovendry specimen.

Varnishing of Test Samples

ASTM-D 3023 standard principles were employed with (ASTM D 1981). For the preparation of varnishes application, the mixing ratios were made in a way that would not adversely affect the layer performance and in line with the recommendations of the manufacturers. Viscosity measurements were made with a flow-cup with a hole diameter of 4 mm, at 20±2 ºC and 65±5% relative humidity, for 18 seconds (98-100 cp).

Filler varnish and topcoat varnish application were operated through normal cross coat application at a height of 20 cm from the sample surface. The first application was applied perpendicular to the fibers and then the second was done as parallel to the fibers with an overhead tank spray gun with an air pressure of 1-2 bar (14-28 atu) and a gun tip opening of 1.4 mm. Afterwards, each layer was left to dry for 24 hours. The dried samples were lightly sanded with 400 grit sandpaper and made suitable for the next layer, and this application was repeated for two coats of filler varnish and two coats of topcoat varnish.

Determination of Solids Content

The solid ratio (SR) of the varnishes were determined in accordance with the principles specified in TS EN ISO 3251 (TS EN ISO 2012). The varnish was placed with a dropper at a rate of 5 g on a Ø 6 cm concave watch glass, which was tared beforehand, and then it was kept in an oven at 60 ºC until it stabilized in weight. At the end of this period, the solvents were completely evaporated and the solids amount was re-weighed (Eq. 4):

$$SR = \frac{mV_{app} - E_{solv}}{mV_{app}} \ (100\%) \tag{4}$$

Where mV_{app} is the mass of the applied varnish and E_{solv} is the mass of the evaporated solvent.

Before the experiments, the dry film thickness of the varnish layer, which has fully dried on the sample surface, was determined by using a comparator capable of measuring with 5 μm precision, in accordance with ASTM D-1005-95 principles (ASTM D 2001).

Determination of Surface Hardness

The surface hardness of the samples was measured with the pendulum surface hardness tester shown in Figure 1, perpendicular to the grains and parallel to the grains, and the average of these values was recorded as the surface hardness value of 1 sample.

Figure 1. Pendulum surface hardness tester (Erichsen)

The device determines the surface hardness with the oscillations of two balls with a hardness of 65±5 HRC and a diameter of 5±0.0005 mm and pendulum contacting the sample surface. For this purpose, two types of pendulum are used and the starting and stopping points of the swing differ according to the pendulum type. Oscillations from 60 to 30 in the Köning pendulum and from 120 to 40 in the Persoz pendulum are counted. In principle, there is more oscillation on hard surfaces and less oscillation on soft surfaces. Before the measurements, the pendulum hardness tester was calibrated as 100 oscillations in 40 seconds with the calibrating glass in accordance with the principles specified in ASTM D-4366 (ASTM, 2016).

Köning pendulum and measuring method were used in the measurements. Each pass of the pendulum in front of the photocell is counted as 1 oscillation with an automatic counter. In principle, higher oscillation occurs on hard surfaces and lower oscillation occurs on soft surfaces (Örs et al., 2002).

Statistical Analysis

Multiple variances (MANOVA) were used to determine the difference between the surface hardness values which were obtained from 10 numbers samples in a total of 360 tests within the wood species (3), the direction of intersection (2), age period (2) and varnish type (3). When the difference between the groups was significant, the Duncan test was performed and the mean values were ranked according to the smallest significant difference (LSD).

Results and Discussion

Within the scope of the experiments, the solid ratio of the varnishes, the dry film thicknesses measured on the sample surfaces, the arithmetic mean of the density values of the wood types are given in Table 2, and the arithmetic averages of the surface hardness values are given in Table 3.

Table 2. Solid ratio and dry film thickness of varnishes-Density of wood types.

Varnish type	Solids Ratio (%)		Dry Film Thickness (μm)
	Filler varnish	Top coat varnish	
Water-based	35	35	120
Polyurethane	40	40	130
Acrylic	25	30	120

Age period	The arithmetic mean of the Density of wood types (g/cm^3)					
	Scotch pine		Oak		Chestnut	
	A-D	O-D	A-D	O-D	A-D	O-D
F	0.55	0.51	0.77	0.73	0.62	0.58
NA	0.48	0.46	0.70	0.66	0.58	0.54

F: Fresh NA: Naturally aged A-D: Air dry O-D: Oven-dry

Table 3. Surface hardness values (Number of oscillations).

Wood Type-Age Period	Water-based				Polyurethane				Acrylic			
	R		T		R		T		R		T	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
F. Scotch pine	22.7	3.56	22.6	3.86	62.8	5.96	63.5	6.69	46.4	3.31	50.6	5.56
NA. Scotch pine	23.9	3.90	24.6	2.17	62.2	3.97	61.4	3.63	48.1	3.70	49.4	4.90
F. Oak	29.2	2.62	26.2	1.62	60.6	5.04	71.6	3.31	54.4	4.12	57.4	2.95
NA. Oak	28.2	1.87	29.7	2.11	69.1	6.77	67.3	8.30	58.9	2.38	59.1	2.56
F. Chestnut	25.8	1.69	26.9	0.99	67	5.54	70.2	2.57	53.7	2.67	55	3.74
NA. Chestnut	27.8	1.69	28.5	2.80	67.6	5.39	67.8	5.39	54.3	3.16	58.3	3.30

$\bar{X}$: Arithmetic mean; s: Standard deviation; F: Fresh; NA: Naturally aged; R: Radial; T: Tangential

The Table 3 shows that the surface hardness values each wood type, age period, cutting direction, varnish type are different. The variance analysis were used to determine the factors had an effect on surface hardness given in Table 4.

Table 4. Variance analysis results regarding the effect of wood type, age period, cutting direction and varnish type.

Factors	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	P ≤0.05
Wood Type (WT)	2	1 026.32	513.16	29.9909	0.0000*
Age Period (AP)	1	14.40	14.40	0.842	NS
WT x AP	2	706.05	353.03	20.632	0.0000*
Cutting Direction (CD)	1	816.01	816.01	47.691	0.0000*
WT x CD	2	271.41	135.70	7.931	0.0004*
AP x CD	1	494.68	494.68	28.911	0.0000*
WT x AP x CD	2	378.54	189.27	11.062	0.0000*
Varnish Type (VT)	2	86 530.55	43 265.28	2 528.581	0.0000*
WT x VT	4	1 743.73	435.93	25.478	0.0000*
AP x VT	2	393.12	196.56	11.488	0.0000*
WT x AP x VT	4	683.83	170.96	9.991	0.0000*
CD x VT	2	146.74	73.37	4.288	0.0145*
WT x CD x VT	4	1 207.04	301.76	17.636	0.0000*
AP x CD x VT	2	202.11	101.05	5.906	0.0030*
WT x AP x CD x VT	4	1 308.08	327.02	19.112	0.0000*
Error	324	5 543.80	17.11		
Total	359	101 466.40			

**: The difference is significant at 0.05; NS: Nonsignificant*

Wood species, cutting direction, varnish type and their interactions were found to be statistically significant on surface hardness values, while the effect of age period was insignificant (α=0.05). Comparisons were done using the Duncan test to the statistically significant interactions. The wood type and cutting direction comparison results are given in Table 5.

Table 5. Comparison results for the wood type and cutting direction.

Wood Type						Cutting Direction			
Scotch Pine		Oak		Chestnut		R		T	
$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
47.1	B**	51.0	A*	50.2	A	47.9	B**	50.9	A*
LSD ± 1.05						LSD ± 0.86			

$\bar{X}$: Arithmetic mean, HG: Homogeneity group, *: The highest surface hardness, **: The Lowest surface hardness

The highest surface hardness value in terms of wood species was obtained in oak and chestnut wood. On the other hand, low surface hardness value was obtained in pine. The difference in surface hardness value between oak and chestnut was found to be statistically insignificant. High surface hardness values were obtained in the tangential direction and lower in the radial direction at the level of the cutting direction.

The Duncan test comparison results at the level of wood type-cutting direction are given in Table 6.

Table 6. Comparison results for the wood type-cutting direction (LSD ± 1.49).

Scotch Pine				Oak				Chestnut			
R		T		R		T		R		T	
$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
44.4	D**	49.8	BC	50.1	BC	51.9	A*	49.4	C	51.2	AB

In the wood type-cutting direction interaction, the highest surface hardness value was obtained in the tangential section of oak wood, and the lowest in the radial cutting of Scots pine. Comparison results of wood type-age period are given in Table 7

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Table 7. Comparison results for the wood type-age period (LSD ± 1.49).

Age Period of Wood	Wood Type					
	Scotch Pine		Oak		Chestnut	
	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
Fresh	49.2	B	49.9	B	49.8	B
Naturally aged	44.9	C**	52.1	A*	50.7	AB

The highest surface hardness value was obtained in naturally oak, but the lowest was acquired in natural Scotch pine. The difference between the hardness values of fresh Scotch pine, fresh oak and fresh chestnut was found to be statistically insignificant. Comparison results of age period-cutting direction are given in Table 8.

Table 8. Comparison results for the age period-cutting direction (LSD ± 1.21).

Age Period / Cutting Direction							
Fresh				Naturally aged			
Radial		Tangential		Radial		Tangential	
$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
47.0	C**	52.3	A*	48.9	B	49.6	B

The surface hardness value was determined at the age period-cutting direction level, in the tangential cutting directions of the fresh wood, but the lowest was in the radial cutting directions of the fresh wood. Comparison results of wood type-age period-cutting direction are given in Table 9.

Table 9. Comparison results for the wood type-age period-cutting direction (LSD ± 2.1)

Age Period of Wood	Wood Type / Cutting Direction											
	Scotch Pine				Oak				Chestnut			
	R		T		R		T		R		T	
	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
Fresh	44.0	E**	54.5	A*	48.1	D	51.7	B	48.8	CD	50.7	BC
Naturally aged	44.7	E	45.1	E	52.1	B	52.0	B	49.9	BCD	51.5	B

The surface hardness value was found to be highest in the fresh scotch pine-tangential cutting direction but the lowest was in the fresh-scotch pine-radial cutting direction at the wood species-age period-varnish type level. The Duncan test comparison results at the level of varnish type, wood type-varnish type are given in Table 10.

Table 10. Comparison results for the varnish type, wood type-varnish type

Varnish type			Varnish type	Wood Type (LSD ± 1.82)					
				Scotch Pine		Oak		Chestnut	
	$\bar{X}$	*HG*		$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
Water based	28.7	C**	Water based	30.5	F	28.3	G	27.3	G**
Polyurethane	65.9	A*	Polyurethane	62.5	B	67.2	A	68.2	A*
Acrylic	53.7	B	Acrylic	48.3	E	57.5	C	55.3	D
LSD ± 1.05									

The surface hardness value was found at the wood type-varnish type level, the highest in chestnut-polyurethane varnish, but the lowest was in chestnut-water-based varnish.

The Duncan test comparison results at the level of age period-varnish type, cutting direction-varnish type are given in Table 11.

Table 11. Comparison results for the age period-varnish type, cutting direction-varnish type

Age Period	Varnish Type						Cutting Direction						
	W-B		PU		Ac			W-B		PU		Ac	
	$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*		$\bar{X}$	*HG*	$\bar{X}$	*HG*	$\bar{X}$	*HG*
F	26.8	F**	64.9	B	52.6	D	Radial	26.3	F**	64.9	B	52.6	D
NA	31.1	E	67.0	A*	54.8	C	Tangential	31.1	E	67.0	A*	54.8	C
	LSD ± 1.49							LSD ± 1.49					

The surface hardness value was found at the age period-varnish type level, the polyurethane varnish in naturally aged wood species, while the lowest was in water-based varnish.

The surface hardness value was found at the cutting direction-varnish type level, the highest hardness value was found in the tangential direction-polyurethane varnish, but the lowest was in the radial direction-water-based varnish.

The Duncan test comparison results at the level of wood type-age period-varnish type are given in Table 12.

Table 12. Comparison results for the wood type-age period-varnish type (LSD ± 2.57)

Age Period of Wood	Varnish Type					
	Water based		Polyurethane		Acrylic	
	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*
Fresh Scotch Pine	36.7	F	63.2	B	47.9	E
Naturally Aged Scotch Pine	24.3	H**	61.8	B	48.8	E
Fresh Oak	27.7	G	66.1	A	55.9	D
Naturally Aged Oak	29.0	G	68.2	A	59.0	C
Fresh Chestnut	26.4	GH	68.6	A*	54.4	D
Naturally Aged Chestnut	28.2	G	67.7	A	56.3	D

The surface hardness value was found at the wood species-age period-varnish type level, the highest surface hardness value was found in the fresh chestnut-polyurethane varnish, but the lowest was in naturally scotch pine-water-based varnish. The Duncan test comparison results at the level of cutting wood type-cutting direction-varnish type are given in Table 13.

Table 13. Comparison results for the wood type-cutting direction-varnish type (LSD ± 2.57).

Varnish Type	Wood Type / Cutting Direction											
	Scotch Pine				Oak				Chestnut			
	R		T		R		T		R		T	
	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*
Water based	23.3	I**	37.6	G	28.7	H	28.0	H	26.8	H	27.7	H
Polyurethane	62.5	C	62.5	C	64.9	BC	69.5	A*	67.3	AB	69.0	A
Acrylic	47.3	F	49.4	F	56.7	DE	58.3	D	54.0	E	56.7	DE

The surface hardness value was found at the level of wood type-cutting direction-varnish type, the highest surface hardness value was found in the tangential direction of oak-acrylic varnish, whereas the lowest was found in Scotch pine-radial direction-water-based varnish.

The Duncan test comparison results at the level of age period-cutting direction-varnish type are given in Table 14.

Table 14. Duncan test for the age period-cutting direction-varnish type (LSD ± 2.1)

Age Period of Wood	Varnish Type / Cutting Direction											
	Water Based				Polyurethane				Acrylic			
	R		T		R		T		R		T	
	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*	$\overline{X}$	*HG*
Fresh	25.9	G**	34.6	F	63.5	C	68.4	A*	51.5	E	53.9	D
Naturally aged	26.6	G	27.6	G	66.3	B	65.5	BC	53.8	D	55.6	D

The highest surface hardness value was found in the fresh wood species-radial cutting direction-polyurethane varnish, but the lowest was in the fresh wood types-radial cutting direction-water-based varnish. The Duncan test comparison results at the level of wood type-age period-cutting direction-varnish type are given in Figure 2 (LSD ± 3.64).

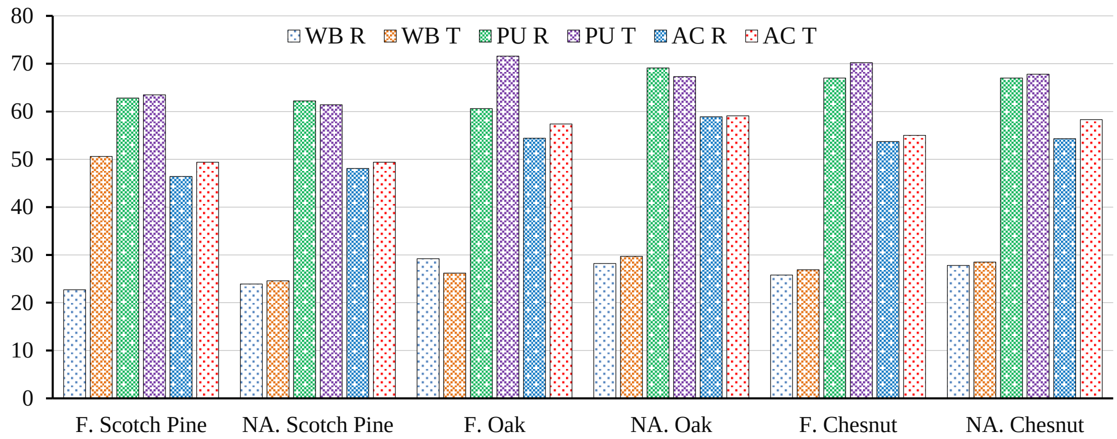

Figure 2. Comparison results for the wood type-age period-cutting direction-varnish type
WB R: Water Based-Radial; WB T: Water Based-Tangential; PU R: Polyurethane-Radial; PU T: Polyurethane-Tangential; AC R: Acrylic-Radial; AC T: Acrylic- Tangential, F: Fresh; NA: Natural Aged

Surface hardness value, wood type-age period-cutting direction-varnish type level; the highest was obtained in the fresh oak tangential direction-polyurethane varnish, but the lowest was obtained in the fresh scotch pine-radial direction-water-based varnish.

Conclusion

Density values were determined for the wood types in the research as 0.50 g/cm3 in Scots pine, 0.72 g/cm3 in oak and 0.58 g/cm3 in chestnut. The varnish dry film thicknesses measured on the sample surfaces were 120 µm in scots Pine, 130 µm in oak and 120 µm in chestnut.

The highest surface hardness at the wood material was in oak (50.87) whereas the statistical difference between sessile oak and chestnut was insignificant. At the level of cutting direction, the tangential direction (50.94) gave a higher surface hardness value.

As a result of the comparisons for the wood species-cutting direction level, the highest surface hardness value was obtained in the oak-tangentially (51.88). When evaluated of the varnish type effect independently, the wood material density value is effective in surface hardness values.

There is no statistically significant difference between the naturally aged wood material and the fresh wood material in terms of surface hardness. However, at the wood species-age period level, naturally aged sessile oak provided the highest surface hardness value (52.05), while naturally aged Scotch pine presented the lowest surface hardness value.

The highest hardness value was found in the fresh scotch pine-tangentially (54.50) at the level of wood species-age period-cutting direction.

In conclusion, tangential cut oak and chestnut woods can be preferred in applications where surface hardness is desired. In addition, since there is no statistical difference between fresh and naturally aged wood materials; it can be said that the natural ageing of the wood material does not pose a disadvantage in terms of surface treatments.

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: K.K; Investigation: K.K, C.S.; Material and Methodology: K.K., C.S.; Supervision: K.K.; Visualization: K.K., C.S.; Writing-Original Draft: K.K.; Writing-review & Editing: K.K.; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

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