Effect of Resin Cleaning Process on Adhesion Strength of Water-Based Varnishes

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The purpose of this study was to determine how resin, a side compound of wood, and resin cleaning methods affect the adhesion strength of water-based varnishes. For this purpose, scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* subsp.), larch (*Larix decidua* Mill.), and spruce (*Picea abies* (L.) H. Karst.), woods with different amounts of resin in their anatomical structure were examined. Physical and chemical resin cleaning procedures were applied to the samples using acetone, cellulosic (lacquer) thinner, sodium hydroxide (NaOH), sodium hydroxide + hydrogen peroxide ($NaOH + H_2O_2$), and soft soap chemicals. Later, single-component and double-component water-based varnishes were applied to these sample surfaces. The samples were then subjected to a hot and cold-check test in accordance with the principles set forth in ASTM D 1211 (1997). In the examples, the changes in adhesion strength were examined according to TS EN ISO 4624. According to the results, resin cleaning chemicals and methods reduce the adhesion strength of water-based varnishes.

Keywords: Resin; Resin cleaning methods; Water-Based Varnishes; Cold-Check test; Adhesion strength

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INTRODUCTION

Wood is a natural continuously renewable material. Although there are many alternatives for wood, over the centuries it has never lost its importance due to its superior properties (Kaygin and Akgun 2008; Priadi and Hiziroglu 2013; Kesik and Akyıldız 2015). There are many side compounds in wood material with organic structure depending on the chemical structure. Some of these are starches, oils, tanning materials, phenolic and dyed materials, etheric oils, and resins. Wood resin is a solid or semi-fluid, thermoplastic organic material. It usually exists in coniferous trees and occurs in the middle lamella between the parenchyma cells or as a result of any injury in the wood material (Rowell *et al*. 2005).

The effect of resin on the surface treatment is greater than that of the other side compounds. As the resin in the cell wall reduces the internal surface area and plugs the pit membrane, it has negative effects in the top surface processes. In coloring processes, the paint solution cannot penetrate the depths of the wood material as the passages are clogged. Therefore, the color remains light in the resin-intensive areas. If the internal surface area of the wood material is filled with resin, then surface adhesion to the outer layer of wood becomes weak due to the decrease of the mechanical adhesion in the applied varnish layer. The disadvantage is most noticeable after the top surface processing is completed. The resin in the wood structure tends to ooze to the surface due to its thermoplastic structure because of the temperature effect in the environment. Often, it pierces the protective layer, thereby causing weakening and damage to the varnish/paint layer. In this way, the resin accumulated in the form of bud-like pitch particles is separated from the surface together with the varnish/paint layer in various forms and thus, a convenient way for water and moisture transition in the layer is opened. In order to minimize such defects, it is necessary to perform resin cleaning before the top surface treatment (Sönmez 2005).

Resin cleaning does not protect the wood. After resin cleaning, the surfaces must be covered with a protective layer such as varnish/paint in order to protect the wood material against external influences (Budakçı and Sönmez 2010; Budakçı *et al.* 2012; Budakçı and Taşçıoğlu 2013; Demirci *et al.* 2013; Kesik and Akyıldız 2015). Protective layers (paint/ varnish) have limited strength to resist external effects, and their continued integrity depends on the type and severity of the exposure. Factors such as humidity and sudden temperature changes, which cause rapid deterioration in the protective layers, lead to such problems as brightness, color change, cracking, and exfoliation. This especially reduces the life span of furniture and decoration elements made of wood materials and it affects the aesthetic value negatively (Budakçı *et al.* 2010).

One of the most complex parameters determining the long-term durability performance of the wood's protective layers, such as varnish and paint, is adhesion (Williams *et al*. 1987; Williams *et al*. 1990; Awaja *et al*. 2009). Adhesion and cohesion must be balanced for the protective layer to have a long life. This balance can deteriorate during the production phase due to errors made by producers in the formulation of the protective layer. In the layers unnecessarily thickened by the users, as a result of excessive cohesion, the surface tension coefficient increases. This, in turn, leads to cracking in the layers and reduces adhesion (Corcoran 1972; Nelson 1995; Sönmez and Budakçı 2004; Budakçı 2006; Kúdela and Liptáková 2006; Lee *et al*. 2006).

Solvents are generally preferred in paint and varnish production. Their use has been reduced by many European countries due to their damage to the environment and human health. The current legislation has accelerated the use of water-based polymers in paint and varnish production (Wicks *et al.* 2007; Chen *et al.* 2011; Pan *et al.* 2011; Ma *et al.* 2014; Dai *et al.* 2015; Saygin and Budakçı 2017). However, until now, experimental studies have not tested the relationship between resin and the performance of water-based varnish on wood.

The effects of cellulosic, polyurethane, and water-based varnishes applied to the wood material moisture on the surface adhesion strength have been investigated. The highest adhesion strength value has been found in the polyurethane varnish applied to oak wood with 8% moisture content (Sönmez *et al.* 2009). Some cellulosic, polyurethane, acrylic, and water-based varnishes have been examined to different wood species at various layer thicknesses to determine the effect on adhesion strength. The effect of wood species and varnish type is significant, but the effect of the layer thickness is insignificant on the surface adhesion strength of different varnish layers applied to wood material surfaces (Budakçı and Sönmez 2010). Water-based varnishes prepared for wood surfaces have a lower adhesion strength than solvent-based polyurethane and acrylic varnishes. Water-based varnish undergoes a visible color change, especially on oak surfaces. Alkali-based water-based varnish may interact with the tannin substance in the oak wood, causing a single-step chemical coloring, and this may be the source of the problem (Budakçı 2006). In the study by Çakıcıer (2007), single-component and double-component water-based varnishes coated with different layer thicknesses were subjected to an accelerated aging process using the xenon-arc lamp for yellow pine (*Pinus sylvestris* L.), Iroko (*Chlorophora excelsa*), and Anatolian chestnut (*Castanea sativa* Mill.), and the performance characteristics of the varnish layer were determined. In the experiments performed, adhesion to the surface and hardness values increased. In the Gezer (2009) study, water-based varnish was applied to yellow pine (*Pinus sylvestris* L.), eastern beech (*Fagus orientalis* Lipsky), and chestnut (*Castanea sativa* Mill.) subjected to heat treatment at different temperatures to see the effect of the heat treatment on varnish hardness, brightness, and adhesion to the surface. In all wood types, the double-component varnish was superior to the single-component varnish (Gezer 2009).

The aim of this study was to determine the effect of the resin in scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* subsp.), larch (*Larix decidua* Mill.), and spruce (*Picea abies* (L.) H. Karst.) on the adhesion strength of the water-based varnish layers. The effect of the resin cleaning process was investigated.

EXPERIMENTAL

Wood Materials

Scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* subsp.), larch (*Larix decidua* Mill.), and spruce (*Picea abies* (L.) H. Karst), all widely used in the furniture and decoration industry in Turkey, were preferred while preparing the samples. The samples in 12% moisture content were cut out from the wood parts of randomly selected first class knotless, crack-free wood material that exhibited smooth fiber without color and density difference. The wood samples had smooth and fresh annual rings in the sizes of 320 × 110 × 14 mm (TS 2470 1976). The samples were stored in a climate cabinet at 20 ± 2 °C temperature and 65 ± 3% relative humidity until constant weight was reached, and then adjusted to the net size of 310 × 100 × 10 mm (TS 2471 1976). After the machine operations, the wetting and sanding operations were carried out according to the finishing principles. The sanding process was performed in the calibrating sanding machine, first using 80 grit followed by 100 grit sandpaper (Fig. 1).

Fig. 1. Sample preparation

Resin Cleaning Process

Sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), and soft soap were preferred as chemically effective (saponifying) cleaners, while acetone and cellulosic (lacquer) thinner were preferred as physically effective cleaners in the resin cleaning process.

Table 1. Mixing Ratios of Resin Cleaning Chemicals

Chemical Type	Solution Ratio (%)	pH Level	Neutralization Agent	Chemical Amount to be Applied (mL/m^2)
Acetone	Package	5.6	-	100 ± 10
Cellulosic Thinner	Package	5.5	-	
NaOH	18	11.8	Distilled Water	
NaOH + H_2O_2	18	12.4	Distilled Water	
Soft Soap	18	9.0	Distilled Water	

The chemical solutions used in the resin cleaning process were prepared at the manufacturer's concentration for acetone and cellulosic thinner and at the concentration of 18% by weight (M_g) or by volume (V mL) for the others (Table 1). For those in solid state,

$$M_g = \frac{Mç.\%M/M}{\%S} \quad (1)$$

where M_g is the amount of chemical substance (g), $M_ç$ is the amount of solution intended to be prepared, %M/M is the percentage by weight of the intended solution, and %S is the impurity ratio % of the chemical substance. For liquids,

$$V_{\mathrm{ml}} = \frac{V_{\mathrm{c}}.\ \%\mathrm{V/V}}{\%\mathrm{S}.d} \quad (2)$$

where V_{ml} is the amount of chemical substance (mL), $V_ç$ is the amount of solution intended to be prepared, %V/V is the percentage by volume of the intended solution, and d is the solution density (Demir 1991).

The prepared solutions were applied to the specimens, the dusts of which were cleaned with a sponge, as 100 ± 10 mL/m^2 first parallel to the fibers, then perpendicular to the fibers, and again parallel to the fibers. While applying the NaOH + H_2O_2 solution, the solution-forming elements were applied separately, and the second solution was applied after 2 min to increase the effect of the first applied substance. After the resin cleaning, the samples were left at room temperature for 2 days to increase the effect depth of the chemicals, and then the samples were neutralized with distilled water (Fig. 2). After this procedure, the samples were stored again in the climate chamber at 20 ± 2 °C and 65 ± 3% relative humidity until reaching the constant weight.

Fig. 2. Resin cleaning procedure

Varnish

After resin cleaning, the sample surfaces were varnished using Aquacoll brand FX 6150 coating (acrylic), FX 7680 single-component (acrylic aliphatic polyurethane), and FX 980 double-component (aliphatic polyurethane) water-based bright varnishes (Dual Paint Varnish Ind. Trade Co. Ltd., Istanbul, Turkey). The solid material ratio and manufacturer's recommendations were decisive in determining the amount of varnish to be applied to the surface. Some properties of varnishes are given in Table 2.

Table 2. Properties of Varnishes Used in Experiments

Varnish type	Solid Amount (%)	pH Level	Application Viscosity (sn-dincup/4mm)	Varnish Amount to be Applied (g/m^2)	Gun Tip Clearance (mm)	Air Pressure (bar)
Primer	20	8.83	11	100	1.8	3
Single-component	43.5	8.37	175	300	1.8	3
Double-component	38	7.70	136	300	1.8	4

The samples were varnished in accordance with ASTM D 3023 (2011) and the manufacturer's recommendations. The varnish was made with a spray gun as FX 7680 single-component and FX 980 double-component varnish application on FX 6150 primer varnish. After the application of the primer coating, the surfaces were sanded slightly with 220 grit sandpaper using a sanding pad on a smooth surface, and the final coating of the varnish application was performed after the dusts were cleaned. The time interval between the coatings was 24 h. The amount of varnish applied was determined by weighing with 0.01 g precision analytical balance (Fig. 3).

Fig. 3. Varnish application

Fig. 4. Determining dry film thickness

Air pressure and gun tip clearance were adjusted according to the manufacturer's recommendations and the spray gun was moved 20 to 25 cm above the sample surface perpendicular and parallel to the surface at the same speed. This prevented the formation of faulty layers or differences in the amounts of applied varnish (Budakçı 2006).

Dry Film Thickness

The dry film thickness of the varnished specimens was determined with non-destructive ultrasonic measurement according to ASTM D 6132 (2013) using a PosiTector-200 instrument (DeFelsko Corporation, Ogdensburg, NY, USA) (Fig. 4). Measurements were also taken on scanning electron microscope (SEM) images to check the reliability of the test (Fig. 5). The arithmetic mean of the dry film thickness measurements of the varnishes is given in Table 3.

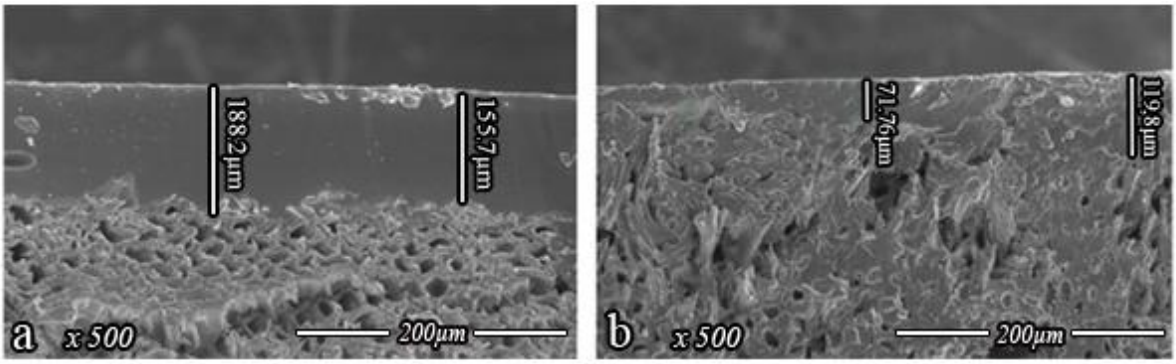

Fig. 5. Layer thickness in the SEM images (a) Single-component (b) Double-component

Table 3. Average Dry Film Thicknesses (µm)

Layer Thickness	Varnish Type	
	Single-Component	Double-Component
Primer + Final Coating	170 ± 10	100 ± 10

Fig. 6. Hot-cold test procedure

Hot-Cold Test

Samples, which had been varnished and thoroughly dried, were first stored in a drying-oven for 1 h at 50 ± 5 °C temperature according to ASTM D 1211 (1997), conditioned for 1 h in laboratory conditions, and then left for 1 h in a deep freezer at -20 ± 2 °C. This process was repeated 20 times (Fig. 6).

Adhesion Strength Test

In the study, the adhesion strength of the varnish layers was determined according to TS EN ISO 4624 (2016) in the UTEST 7012 model 50 kN universal test machine (Utest, Ankara, Turkey). At normal room temperature, pull-off test cylinders of Ø 20 mm were attached to the fully dried sample surfaces covered with a protective layer (Fig. 7). The excess glue that started to gel was cleaned with the help of a spatula and left to dry for 1 week. In the study, 404 plastic steel adhesive with high adhesive strength but without any solvent effect on double-component epoxy resin varnish layers was used as 150 ± 10 g/m^2 according to TS EN ISO 4624 (2016).

Fig. 7. Attaching the pull-off test cylinders to sample surfaces using mold

The varnish layer on the pull-off test cylinder attached surfaces was cut to the wood material surface with a cutter (Fig. 8).

Fig. 8. Cutting the pull-off test cylinder circumference to the layer

Fig. 9. Adhesion strength test procedure

The prepared specimens were pulled from the cylinders adhered to the surface in UTEST 7012 tester, and the force at breaking was recorded (Fig. 9). Care was taken to increase the tensile stress according to TS EN ISO 4624 (2016) at a constant speed not exceeding 1 MPa/s and to complete the test within 90 s.

During the tests, adhesion strength *(X)* was computed according to Eq. 3,

$$X = 4F / \pi.d^2 \qquad \text{(MPa)} \qquad (3)$$

where F is the rupture force (N) and d is the diameter of the experiment cylinder (mm).

Scanning Electron Microscopy

To determine the effects of the wood type, varnish type, aging, and resin cleaning chemicals on the adhesion performance, SEM images were taken of the wood material, and the varnish interface and measurements were made on the dry film layer. To obtain clearer images for this purpose, 5 mm × 5 mm × 5 mm samples in groups of twelve were coated with gold metal using the Denton Vacuum Desk V (Denton, Moorestown, NJ, USA). The coated specimens were placed on the FEI Quanta FEG 250 SEM (FEI Company, Hillsboro, OR, USA) in such a way that measurements were taken from the section edge. Microscopic images were taken using the low-vacuum method.

Statistical Analysis

Samples that had been varnished after the resin cleaning process but had not been exposed to the hot-cold test (control) were compared to those that had been exposed to hot-cold. The MSTAT-C 2.1 statistical package program (Michigan State University, Lansing, USA) was used in the evaluations, and as a result of "ANOVA" tests of multivariate analysis, the effects of the factors “the wood type, varnish type, aging, and resin cleaning chemicals” on the adhesion strength values and the interactions between these factors were determined. Comparisons were made using the Duncan’s Multiple Range Test (DMRT) and least significant difference (LSD) critical values, and the factors causing the difference were examined.

RESULTS AND DISCUSSION

Table 4 shows the average adhesion values obtained to determine how the resin cleaning process affects the layer performance of water-based varnishes.

The adhesion strength values were different according to the wood type, varnish type, aging, and resin cleaning chemicals. Analysis of variance (ANOVA) was performed to determine which factor the difference arose from and the results are given in Table 5.

According to the analysis of variance, AC interaction is meaningless, CD interaction is not significant, and other factors and interactions are significant ($p \leq 0.05$). The DMRT comparison results at the wood type level using LSD critical value are given in Table 6.

At the wood type level, the value of adhesion strength was highest in the black pine and lowest in the spruce. Particularly, pieces of spruce wood were broken off (Fig. 10). This may be due to the fact that the molecular cohesion of the spruce material was lower than the adhesion established between the varnish molecules and the wood material. The cohesion of softwood materials is low (Sönmez *et al.* 2009; Budakçı and Sönmez 2010).

Table 4. Arithmetic Mean Values of Adhesion Strength Measurements (MPa)

Wood	Varnish	Aging	Chemicals											
			Acetone		Cellulosic Thinner		NaOH		$NaOH+H_2O_2$		Soft Soap		Control	
			$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
Scots Pine	SC	WHC	3.434	0.336	2.530	0.465	1.743	0.449	1.793	0.509	2.243	0.371	2.255	0.576
		HC	3.248	0.452	2.650	0.649	1.890	0.330	2.118	0.441	2.962	0.695	2.702	0.409
	DC	WHC	1.828	0.411	1.600	0.101	1.528	0.429	1.825	0.038	1.55	0.261	2.078	0.386
		HC	1.507	0.062	1.803	0.053	2.058	0.451	1.945	0.300	1.683	0.223	1.778	0.211
Black Pine	SC	WHC	2.542	0.586	2.557	0.569	2.140	0.308	2.277	0.719	2.397	0.455	2.527	0.446
		HC	3.150	0.447	2.190	0.308	2.940	0.366	2.598	0.201	2.589	0.329	3.430	0.382
	DC	WHC	1.747	0.138	1.747	0.029	1.819	0.293	1.852	0.229	2.010	0.064	1.668	0.186
		HC	2.073	0.229	1.732	0.095	1.462	0.202	1.850	0.426	1.892	0.408	1.580	0.263
Larch	SC	WHC	2.008	0.324	2.400	0.598	1.718	0.267	1.700	0.333	2.538	0.732	2.022	0.312
		HC	2.819	0.699	2.373	0.472	1.522	0.384	2.008	0.025	1.892	0.396	2.333	0.393
	DC	WHC	1.237	0.245	1.515	0.217	1250	0.343	1.332	0.247	1.192	0.253	1.452	0.121
		HC	1.268	0.373	1.912	0.294	1.332	0.251	1.607	0.261	1.360	0.200	1.520	0.437
Spruce	SC	WHC	2.457	0.263	2.022	0.209	1.260	0.177	1.320	0.362	1.753	0.170	1.678	0.316
		HC	2.310	0.339	1.878	0.276	1.513	0.339	1.542	0.258	1.458	0.220	2.025	0.431
	DC	WHC	1.297	0.221	1.213	0.133	1.362	0.138	0.880	0.096	1.233	0.216	1.748	0.366
		HC	1.337	0.201	1.357	0.228	1.390	0.247	1.232	0.239	1.483	0.217	1.432	0.168

$\bar{x}$: Arithmetic mean, S: Standard deviation, SC: Single-component varnish, DC: Double-component varnish, WHC: Without hot-cold test, HC: With hot-cold test

Table 5. Results of Analysis of Variance Analysis of Adhesion Strength

Factors	Degrees of Freedom	Sum of Squares	Mean Square	*F* Value	Level of Significance ($p \le 0.05$)
Wood Type (A)	3	42.028	14.009	107.2807	0.0000*
Varnish Type (B)	1	66.115	66.115	506.3002	0.0000*
Interaction (AB)	3	3.509	1.170	8.9576	0.0000*
Aging (C)	1	3.133	3.133	23.9924	0.0000*
Interaction (AC)	3	0.550	0.183	1.4027	0.2413
Interaction (BC)	1	0.917	0.917	7.0238	0.0083*
Interaction (ABC)	3	2.258	0.753	5.7631	0.0007*
Chemicals (D)	5	14.642	2.928	22.4252	0.0000*
Interaction (AD)	15	4.368	0.291	2.2298	0.0051*
Interaction (BD)	5	12.711	2.542	19.4677	0.0000*
Interaction (ABD)	15	8.700	0.580	4.4414	0.0000*
Interaction (CD)	5	0.486	0.097	0.7438	ns**
Interaction (ACD)	15	4.280	0.285	2.1851	0.0062*
Interaction (BCD)	5	2.558	0.512	3.9175	0.0017*
Interaction (ABCD)	15	3.692	0.246	1.8846	0.0226*
Error	480	62.681	0.131		

***:** Significant **: Not significant

Table 6. The DMRT Comparison Results at the Wood Type (MPa)

Wood Type							
Scots Pine		**Black Pine**		**Larch**		**Spruce**	
$\bar{x}$	***HG***	$\bar{x}$	***HG***	$\bar{x}$	***HG***	$\bar{x}$	***HG***
2.115	B	2.224	A*	1.764	C	1.549	D
LSD ± 0.08381							

$\bar{x}$: Arithmetic mean, ***HG*****:** Homogeneity group, *: Highest adhesion value

Fig. 10. Breakage from the spruce samples after adhesion strength experiment

The DMRT comparison results at the varnish type level are given in Table 7. In the varnish type level, the highest adhesion value was obtained in the single-component varnish and the lowest in the double-component varnish. The fact that the single-component varnish had high adhesion strength may be due to its acrylic resin modification, which is different from the double-component varnish. The adhesion of the varnishes prepared with polyurethane and acrylic resin is high (Sönmez *et al.* 2009; Budakçı and Sönmez 2010; Budakçı and Taşçıoğlu 2013; Söğütlü *et al.* 2016). This study is consistent with the literature.

Table 7. DMRT Comparison Results of the Varnish Type (MPa)

Varnish Type			
Single-Component Varnish		**Double-Component Varnish**	
$\bar{x}$	***HG***	$\bar{x}$	***HG***
2.252	A*	1.574	B
LSD ± 0.05927			

$\bar{x}$: Arithmetic mean, ***HG*****:** Homogeneity group, *: Highest adhesion value.

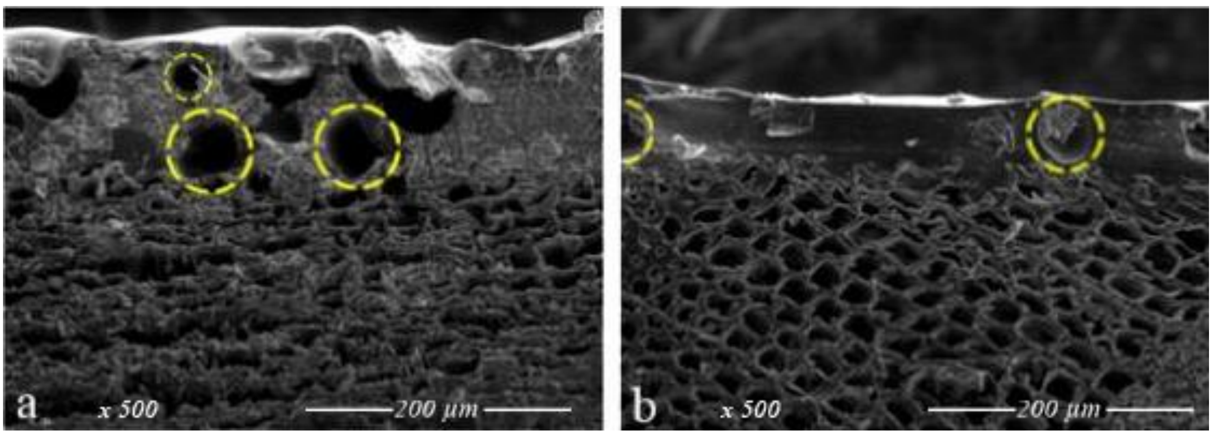

Fig. 11. a) Spruce control sample, b) Larch control sample

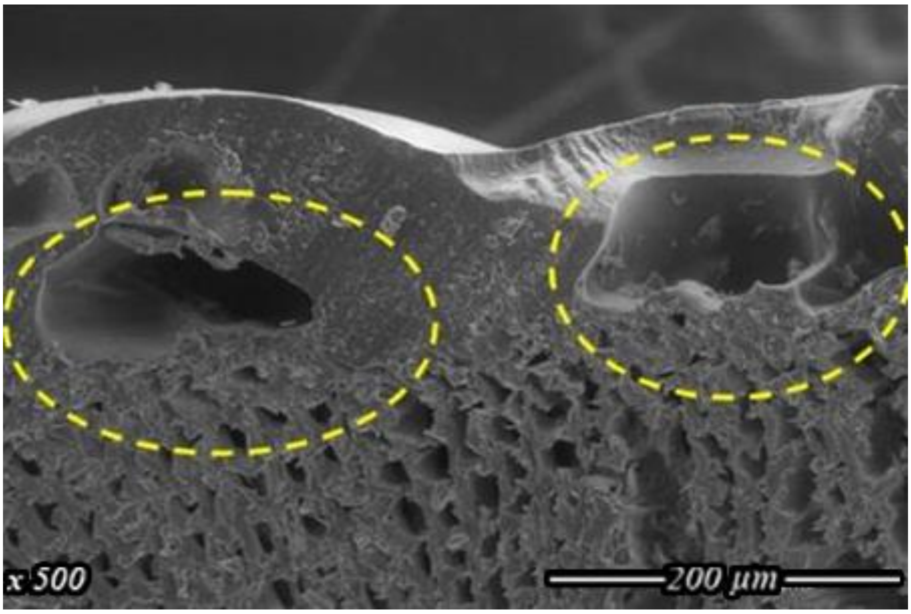

Fig. 12. SEM image of scots pine

Defects appeared in double-component water-based varnish layers. Roughening was particularly observed on the surfaces of the control samples of the double-component varnish-applied spruce and larch types without the resin cleaning process. The SEM images showed that this roughness occurred due to air bubbles in the varnish layer (Fig. 11). This effect likely happened during the drying reaction when the resin contained in the wood material interacted with the double-component varnish.

A similar situation was observed on the surfaces of the samples of yellow pine treated with the double-component varnish after the resin cleaning with NaOH (Fig. 12). This is thought to be caused by the effect of NaOH on the double-component water-based varnish layer even though the neutralization process had been carried out.

Air bubbles were also detected in the double-component varnish-applied black pine samples after the resin cleaning process with NaOH + H_2O_2 (Fig. 13). The bubble formation might have occurred due to the high pH value (12.4) of NaOH + H_2O_2, its strong chemical resin cleaning solution feature, and its interacting with the double-component varnish layer.

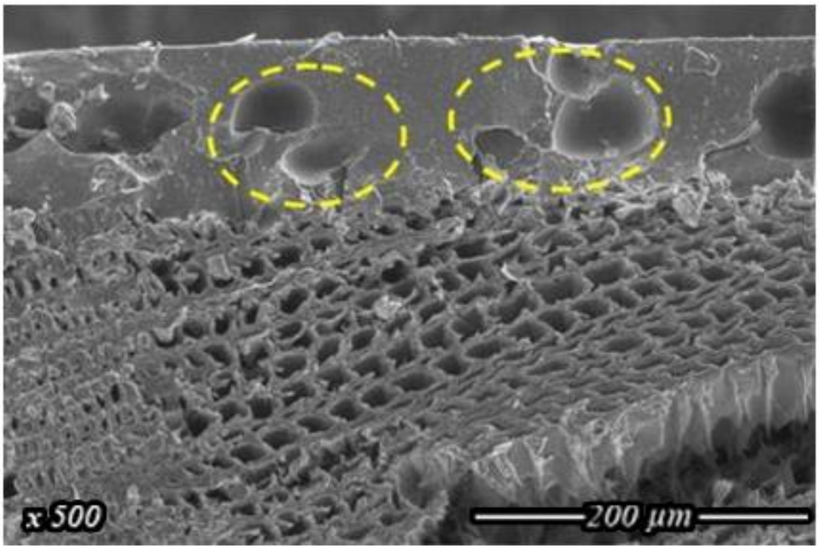

Fig. 13. SEM image of black pine

Table 8. The DMRT Comparison Results of Aging

Aging			
Hot-cold Test Not Conducted		**Hot-cold Test Conducted**	
$\bar{x}$	***HG***	$\bar{x}$	***HG***
1.839	B	1.987	A*
LSD ± 0.05927			

$\bar{x}$: Arithmetic mean, ***HG*:** Homogeneity group, *: Highest adhesion value.

The DMRT comparison results at the aging level are given in Table 8. At the aging factor level, the highest value of adhesion strength was determined in the samples with the hot-cold test and the lowest in the samples without the hot-cold test. The hot-cold method applied in this study did not adversely affect the adhesion strength of the water-based varnish layers used in the research. As the accelerated aging time increases, adhesion strength decreases and the preservation of transparent varnish layers on the surface of wood materials is not sufficient (Black *et al.* 1979). However, the water-based varnishes used in this study were subjected to 20 repetitions of the hot-cold test and thus had sufficient layer performance, which may have been effective in high adhesion strength.

The DMRT comparison results with regard to the resin cleaning chemicals are given in Table 9. At the level of resin cleaning chemicals, the highest adhesion strength value was obtained in the samples resin-cleaned with acetone, while the lowest adhesion strength value was obtained in the samples resin-cleaned with NaOH and NaOH + H_2O_2. Acetone is an active solvent with real solvent properties and evaporates without residue. It might have played an important role in cleaning resin wood materials and might have been effective in achieving high adhesion strength. Even though the neutralization process had been carried out after the resin cleaning process with NaOH and NaOH + H_2O_2 solutions, the residues of the chemicals left on the surface interacted with the varnish layer, thus decreasing the adhesion strength. These chemicals, also used as decolorizing agents, decrease the adhesion of varnish layers (Atar 1999). The results in this study are consistent with the literature.

Table 9. The DMRT Comparison Results at the Resin Cleaning Chemicals

Resin Cleaning Chemicals											
Acetone		**Cellulosic Thinner**		**NaOH**		**NaOH +H_2O_2**		**Soft Soap**		**Control**	
$\bar{x}$	***HG***	$\bar{x}$	***HG***	$\bar{x}$	***HG***	$\bar{x}$	***HG***	$\bar{x}$	***HG***	$\bar{x}$	***HG***
2.141	A*	2.005	B	1.685	D	1.742	D	1.890	C	2.014	B
LSD ± 0.1027											

$\bar{x}$: Arithmetic mean, ***HG*:** Homogeneity group, *: Highest adhesion value.

The results of DMRT comparisons made at the level of interaction of wood type-varnish type-aging-resin cleaning chemicals are given in Table 10 in order to see the results of the single comparisons collectively.

At the level of interaction of the wood species-varnish-type-aging-resin cleaning chemicals, the highest value of adhesion strength was obtained in the scots pine, for which the single-component varnish was applied after the resin-cleaning process with acetone and the hot-cold test was not performed on it. A similar result was also obtained in the black pine on which the hot-cold test was conducted after applying the single-component varnish. The lowest adhesion strength value was obtained in the larch, the double-component varnish was applied to this larch after the resin-cleaning process with soft soap and the hot-cold test was not performed on it.

Table 10. The DMRT Comparison Results for Interaction of Wood Type-Varnish Type-Aging-Resin Cleaning Chemicals

Factor WVAR**		Hot-cold Test Not Conducted											
		Acetone		Cellulosic Thinner		NaOH		$NaOH+H_2O_2$		Soft Soap		Control	
		$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*
Scots Pine	SC	3.434	**A***	2.530	DEFGHIJK	1.743	RSTUVWXYZ[\]^_`abc	1.793	PQRSTUVWXYZ[\]^_`	2.243	HIJKLMNOPQRS	2.255	HIJKLMNOPQR
	DC	1.828	OPQRSTUVWXYZ[\]^_	1.600	UVWXYZ[\]^_`abcd	1.528	WXYZ[\]^_`abcd	1.825	OPQRSTUVWXYZ[\]^_	1.550	VWXYZ[\]^_`abcd	2.078	JKLMNOPQRSTUV
Black Pine	SC	2.542	DEFGHIJ	2.557	DEFGHIJ	2.140	IJKLMNOPQRST	2.277	HIJKLMNOPQ	2.397	FGHIJKLM	2.527	DEFGHIJK
	DC	1.747	RSTUVWXYZ[\]^_`ab	1.747	RSTUVWXYZ[\]^_`ab	1.819	OPQRSTUVWXYZ[\]^_	1.852	OPQRSTUVWXYZ[\]^	2.010	LMNOPQRSTUVWXY	1.668	TUVWXYZ[\]^_`abcd
Larch	SC	2.008	LMNOPQRSTUVWXY	2.400	FGHIJKLM	1.718	STUVWXYZ[\]^_`abcd	1.700	TUVWXYZ[\]^_`abcd	2.538	DEFGHIJ	2.022	KLMNOPQRSTUVWX
	DC	1.237	bcde	1.513	XYZ[\]^_`abcd	1.250	abcde	1.332	^_`abcde	1.192	de	1.452	Z[\]^_`abcd
Spruce	SC	2.457	EFGHIJKL	2.022	KLMNOPQRSTUVWX	1.260	abcde	1.320	^_`abcde	1.753	RSTUVWXYZ[\]^_`ab	1.678	TUVWXYZ[\]^_`abcd
	DC	1.297	_`abcde	1.213	cde	1.362	\]^_`abcde	0.880	e	1.233	bcde	1.748	RSTUVWXYZ[\]^_`ab

Table 10. (Continued) The DMRT Comparison Results for Interaction of Wood Type-Varnish Type-Aging-Resin Cleaning Chemicals

Factor WVAR**		Hot-cold Test Conducted											
		Acetone		Cellulosic Thinner		NaOH		$NaOH+H_2O_2$		Soft Soap		Control	
		$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*
Scots Pine	SC	3.248	AB	2.650	DEFGH	1.890	MNOPQRSTUVWXYZ[\	2.118	IJKLMNOPQRSTU	2.962	BCD	2.702	CDEFGH
	DC	1.507	XYZ[\]^_`abcd	1.803	PQRSTUVWXYZ[\]^_	2.058	JKLMNOPQRSTUVW	1.945	LMNOPQRSTUVWXYZ	1.683	TUVWXYZ[\]^_`abcd	1.778	QRSTUVWXYZ[\]^_`a
Black Pine	SC	3.150	ABC	2.790	BCDEFG	2.940	BCDE	2.598	DEFGHI	2.589	DEFGHI	3.430	**A***
	DC	2.073	JKLMNOPQRSTUV	1.732	RSTUVWXYZ[\]^_`abc	1.462	Z[\]^_`abcd	1.850	OPQRSTUVWXYZ[\]^	1.892	MNOPQRSTUVWXYZ[\	1.580	VWXYZ[\]^_`abcd
Larch	SC	2.819	BCDEF	2.373	FGHIJKLMN	1.552	VWXYZ[\]^_`abcd	2.008	LMNOPQRSTUVWXY	1.892	MNOPQRSTUVWXYZ[\	2.333	FGHIJKLMNO
	DC	1.268	`abcde	1.912	MNOPQRSTUVWXYZ[	1.332	^_`abcde	1.607	UVWXYZ[\]^_`abcd	1.360	\]^_`abcde	1.520	XYZ[\]^_`abcd
Spruce	SC	2.310	GHIJKLMNOP	1.878	NOPQRSTUVWXYZ[\]	1.513	XYZ[\]^_`abcd	1.542	WXYZ[\]^_`abcd	1.458	Z[\]^_`abcd	2.025	KLMNOPQRSTUVWX
	DC	1.337	^_`abcde	1.357	]^_`abcde	1.390	[\]^_`abcd	1.232	bcde	1.483	YZ[\]^_`abcd	1.432	Z[\]^_`abcd
LSD ± 0.4106													

$\bar{x}$: Arithmetic mean, *HG*: Homogeneity group, *: Highest adhesion value; **:W: Wood type, V: Varnish type, A: Aging, R: Resin cleaning chemicals, SC: Single-component varnish, DC: Double-component

CONCLUSIONS

1. This study evaluated how the resin cleaning processes affect the physical and chemical properties of scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra subsp*.), larch (*Larix decidua* Mill.), and spruce (*Picea abies* (L.) H. Karst.) woods with different amounts of resin in their anatomical structure. The effects on the adhesion strength of single-component and double-component water-based varnishes were examined. Although acetone might have been effective in achieving high adhesion strength, the resin cleaning chemicals and methods generally reduced the adhesion strength of water-based varnishes.
2. A higher adhesion strength was obtained in the single-component water-based varnish than the double-component varnish.
3. Although neutralization was carried out after the chemical resin cleaning with NaOH and NaOH + H_2O_2 solutions, residues of the remaining chemicals on the surface interacted with the varnish layers, reducing the adhesion strength.
4. The adhesion strength test results after the hot-cold test in the study showed that the water-based varnishes used had adequate layer performance.
5. As a result, it is advisable to use acetone, a physical resin cleaner, in the water-based varnish layers requiring high adhesion strength when using resinous wood in the woodwork and furniture industry.

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