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# The impact of stain removal and bleaching on the adhesion strength of water-based varnish layers in oak

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**Abstract**

The aim of this study is to determine the performance of water-based varnish adhesion on the process of stain removal, bleaching and impregnation applied to wood surfaces. In order to accomplish this objective, the selected sessile oak (*Quercus petreae* Mill.) wood samples were firstly contaminated with grease and PVAc glue, after they were cleaned. Then, the wood samples were bleached by using oxalic acid ($C_2H_2O_4$) and hydrogen peroxide ($H_2O_2$). Secondly, preprocessed specimens impregnated with imersol aqua (IA) and wood protective chemicals (WP) and together both these chemicals (IA+WP). Finally, adhesion strength performance of the wood samples were tested after they covered by single component primary resin (SCPR), double component polyurethane modified with acrylic (DCAP) and double component elastic polyurethane (DCEP). The adhesion resistance of varnish layers is determined according to ASTM 4541 principles. As a result, the oil stain removal and the protective chemical applications decreased the adhesion strength on the wood surface of water-based varnish layers. Contrary, the glue stain removal and the $C_2H_2O_4$ and $H_2O_2$ bleaching increased the adhesion strength. Also, it was determined that DCEP applications have the highest value in oak wood samples.

**Keywords:** Sessile oak, Water-based varnish, Adhesion strength, Impregnation

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## 1. Introduction

Usage of wood materials is rather widespread in every kind of furniture-decoration and architecture in contrast to other construction materials owing to its being light and quite resisting, better physical, mechanical and chemical specifications its easily applicability using less energy, having positive effects in terms of human health.

Unlike the positive effects given above, discoloration in wood materials used in industry caused by the oxidation of some chemicals and formation of heartwood at later ages or else the result of tannic wood's interaction with metals as well as knot occurrence, disease etc. are the negative impacts of the wood properties (Banks & Miller, 1982; Bauch, 1984). In drying, in addition to the use in accordance with the technique, it can minimize the negativities of the tree material caused by biotic pests with impregnation substances that will not harm the environment and human health. Disadvantages arising from color differences are solved by making the wood surface bleaching by some solutions (Edwin & Carter, 1983).

Another negative is the dirty images created on the surfaces of the wood material by glue and oil stains for different reasons during production. This unwanted situation should be cleaned with appropriate techniques before the surface treatments (Sönmez, 2005).

Especially when the elements produced from wood materials are covered with a transparent film layer, it is desired that the solid or cover plates used are compatible with color, pattern and aesthetic direction. In order to achieve this compatibility, it may be necessary to bleaching the wood material in the process of before varnishes applications (Ozdemir & Hiziroglu, 2007). After this stage, the varnishing process not only provides a beautiful appearance to the wood material but it also helps to protect the material.

The resistance properties of the varnish layers used in the top surface treatment to external factors is also important in terms of the performance of the furniture and decoration elements at the end use. The physical, chemical and mechanical effects of the varnish layers on the surface of the wood material reduce the cohesion and adhesion forces of the layer over time and reduce the expected performance of the protective layer (Sönmez & Budakçı, 2004; Sonmez et al., 2009; Yörür et al., 2010).

Becoming strong adhesion force depends on surface roughness of the material (Altun & Mermer, 2017), small molecules of the protective layers and penetration of the wood material deepths. An increase of surfaces roughness, increase the area for mechanical interlocking between coating and wood substrate (Saloni et al., 2005; Vitosytė et al., 2012; Salca, 2016).

For this reason, it is necessary that the stain removal chemicals applied for the purpose of color combination, the stain removal chemicals applied for the clean visual purpose, the impregnated chemicals applied for the protection purpose have to make a strong connection with the varnish applied to the wood material surfaces according to the usage place in order to create a beautiful image.

In this study, grease and PVAc glue for stains that may occur during production, oxalic acid ($C_2H_2O_4$) and hydrogen peroxide ($H_2O_2$) were applied as bleaching agents. Then, Imersol Aqua (IA), wood protector (WP), IA and WP consecutively were applied in the impregnation process. Finaly, primary resin (SCPR) from one-component, acrylic modified polyurethane copolymer (DCAP) and elastic polyurethane (DCEP) were used from two-component varnishes with water-based. Afterwards, single component primary resin (SCPR) and double component polyurethane copolymer modified with acrylic (DCAP) were used. Therefore, it is important to determine the adhesion resistance of water-based varnishes to the surfaces and to analyze the results and present them to furniture manufacturers in wood products treated with these chemicals.

## 2. Material and Methods

### 2.1. Wood species

Oak wood, which is widely used as indoor and outdoor decoration, furniture, doors, windows, wooden boats and wooden bridges, was chosen as the test material. These well-selected specimens were non-deficient, proper, knot-free, normally grown wood materials (without reaction wood and without decay, insect and fungal) according to the principles of TS ISO 3129 (TS ISO 3129, 2021).

### 2.2. Chemicals

In the experiments, polyvinyl acetate (PVAc) adhesive provided by Dyo Company (İzmir, Turkey) and grease oil as stain removal, acetone and mild soap as stain removal, and wood preservative (WP) as for impregnation of test specimens were used. Hydrogen peroxide ($H_2O_2$) and oxalic acid ($C_2H_2O_4$) supplied by Aklar Kimya Company (Ankara, Türkiye) and Imersol Aqua (IA) supplied by Hemel were used as bleaching.

Single component primary resin (SCPR) provided from Jansen Company (Ahrweiler, Germany), double component polyurethane copolymer modified with acrylic (DCAP) and double component elastic polyurethane (DCEP) provided from Kimetsan Company (Ankara, Türkiye) used in varnishing of the test samples.

### 2.3. Preparation of test samples

Air-dried moisture test samples were kept until reaching to the equilibrium moisture (12%) in conditioning chamber according to the TS ISO 13061-1 (TS ISO 13061-1, 2021) standards. The samples were brought up to 100x100x10 mm exact measure by sanding with 100 grit sandpaper on calibrated sanding machines.

On the surfaces of the test samples prepared in exact measure were smudged through 100±10 g/m2 PVAc glue and grease oil, then the stain removal process has made by waiting 10 minutes. The remnants of glue were cut by chisel; the remnants of grease oil were wiped away as well. In order to brush the remnants of glue on the surface off, acetone was applied on the surface abundantly, after that, the stains were rubbed to the parallel to grain by using a bristle brush until removing them completely from pores. Soft soap melted in a liter water was applied on the surface in order to remove the oil stains, after that, it was removed by rubbing through a bristle brush. After making sure that the stains out, the surface was washed with plenty of warm water and after it was dried by a sponge, was made ready for other process.

In the study, two methods were used for bleaching and the company's recommendations were followed (URL-1, 2017). In the first method (oxidation effect), sodium hydroxide (NaOH) and hydrogen peroxide ($H_2O_2$) were used together. In the second method (reduction effect), oxalic acid ($C_2H_2O_4$) was used as well. In application, test specimens cleaned their dust were applied with the sponge and the bristle brush first parallel to grain, second perpendicular to grain, and then they were applied in the form of a layer again parallel to grain. The specimens completed by bleaching were allowed to dry as long as they were washed with acetic acid water in order to neutralize. Solution mixtures used for bleaching were prepared as Table 1.

Table 1. The solution mixtures used for bleaching

| Method | Stage | Used Chemicals | Amount of Application | Waiting Time |
|---|---|---|---|---|
| Oxidation | 1 | 1 liter distillate water+40 g. NaOH | 80±10 g/m$^2$ | Until drying |
| | 2 | 10 part 35% $H_2O_2$+1 part 24° ammonia | 80±10 g/m$^2$ | For 24h at 20 $^0$C |
| Reduction | 1 | 1 liter warm distillate water+50 g $C_2H_2O_4$ | 80±10 g/m$^2$ | For 24h at 20 $^0$C |

Table 2. Technical properties regarding varnishes

| Varnish species | pH | Density (g/cm³) | Viscosity (sec/DIN Cup/4mm) | The amount of solid element (%) | The amount of varnish (g/m²) |
|---|---|---|---|---|---|
| DCAP | 8.71 | 1.031 | 18 | 35 | 70 |
| DCEP | 8.90 | 1.024 | 18 | 39 | 74 |
| SCPR | 9.00 | 1.020 | 18 | 38 | 67 |

For impregnation process, three different methods were used and the company's recommendations were followed. In the first method, the immersion method was preferred in the impregnation process with Imersol Aqua (URL-2, 2017). In the second method, wood is applied to the surface of the wood material with a lacquer glaze (Dyo, 1996; URL-3, 2017). In the third method, Imersol Aqua was first applied on the same specimens dried and then a wooden shield was applied to the air-dried root.

In the varnishing of them, in accordance with ASTM D 3023 (ASTM D 3023, 2011) principles and recommendations of the manufacturer, it was performed the application on the surface in the form of filling, topcoat and two coats. According to the TS EN ISO 3251 (TS EN ISO 3251, 2012), it was applied such that DCAP 70 g/m$^2$, DCEP 74 g/m$^2$ and SCPR 67 g/m$^2$. DCAP and DCEP were applied with varnish spray gun, whereas SCPR was applied with a soft-bristled brush. In order to fix the surfaces of samples applied by the filler coat, 300 grit sandpaper was used. Technical properties regarding these varnishes was shown in Table 2.

### 2.4. Surface adhesion resistance test

The adhesion strength of varnish layers was determined according to ASTM D 4541 (ASTM D 4541, 2009) principles. Test cylinders of Ø 20 mm were adhered to the sample surfaces which were provided with varnished and fully dried, with the help of special molds at normal room temperature (20±2 °C) and left to dry for 24 hours. Surface adhesion resistance tests were carried out by Adhesion test instrument in the laboratory of Department of Wood Products Industrial Engineering of Gazi University Faculty of Technology.

In the experiments, adhesion resistance ($X$) was calculated from the equation;

$$X = 4F/\pi d^2$$

Where, $F$: force at break (Newton), and $d$: diameter of the test cylinder (mm).

### 2.5. Assessment of data

An analysis of variance, ANOVA, was conducted ($p< 0.05$) to evaluate the effect of the stain removal process, wood species, impregnation material and varnish species on the adhesion strength values of the varnish layers. Significant differences among the average values of the adhesion strength values of the varnish layers were determined using Duncan’s multiple range test.

## 3. Results

According to variables (pretreatment (A), impregnation (B), and varnish (C)), multi variance analysis results that was made by the purpose of determining the differences between adhesion strength values in varnish layers whether is statistically significant or not, are given in Table 3. Table 3 shows that main variables A and B and interactions AxC has significantly effect on the adhesion strength of varnish layers ($p<0.05$). The Duncan test results of varnish layers’ adhesion strength values are given in Table 4 according to interactions AxC factors. Table 4 illustrates that the adhesion strength values of varnished surfaces treated by bleaching ($H_2O_2$ and $C_2H_2O_4$) with glue stain removal on DCEP experimental samples applied are the highest value. This result may be caused by the fact that to the glue stain is cleaned with acetone and the bleaching operations are carried out by $H_2O_2$ and $C_2H_2O_4$, and the excessive surfaces of the experiment become rough. It also supports our work by stating that rough surfaces are effective in increasing mechanical bonds and high adhesion resistance (Saloni et al., 2005; Vitosytė et al., 2012; Salca, 2016). Whereas those treated by oil stain removal with SCPR are the lowest. It is also seen that the oil stain removal process generally causes a decrease in the adhesion resistance values. This decrease may be due to inadequate oil stain removal applied to the test sample surfaces during pretreatment. Some knowledge from the literature also mention that some material interaction with oil effect the adhesive feature of the material and decrease the adhesion resistance (Aydın, 2004; Rudawska & Kuczmaszewski, 2006; Scholz et al., 2010; Kocaefe et al., 2015). These studies also support us.

Table 3. Multi variance analysis results of adhesion strength values of varnish layers

| Variance Source | df | Sum of Squares | Mean Square | *F*-value | *p* |
|---|---|---|---|---|---|
| Pretreatment (A) | 4 | 35.299 | 8.825 | 37.167 | <0.001 |
| Impregnation (B) | 3 | 102.265 | 34.088 | 143.569 | <0.001 |
| Varnish (C) | 2 | 52.924 | 26.462 | 111.449 | <0.001 |
| Interaction AxB | 12 | 33.008 | 2.751 | 11.585 | <0.001 |
| Interaction AxC | 8 | 6.861 | 0.858 | 3.612 | 0.001 |
| Interaction BxC | 6 | 4.191 | 0.698 | 2.942 | 0.009 |
| Interaction AxBxC | 24 | 14.657 | 0.611 | 2.572 | <0.001 |
| Error | 180 | 42.738 | 0.237 | | |
| Sum | 240 | 1753.344 | | | |

Table 4. Duncan test results of AxC interaction for adhesion resistance values

| Pretreatment (A) | Varnish (C) | | | | | |
|---|---|---|---|---|---|---|
| | SCPR | | DCAP | | DCEP | |
| | $\bar{X}$ | HG | $\bar{X}$ | HG | $\bar{X}$ | HG |
| Control | 2.09 | b | 2.48 | c | 2.82 | cd |
| Oil stain removal | 1.27 | a | 1.90 | b | 1.99 | b |
| Glue stain removal | 1.98 | b | 2.85 | cd | 3.09 | d |
| Bleaching with $H_2O_2$ | 1.92 | b | 2.78 | cd | 3.56 | d |
| Bleaching with $C_2H_20_4$ | 1.99 | b | 2.71 | c | 3.49 | d |

$\bar{X}$: *Mean adhesion resistance (N/mm$^2$), HG: Homogenous groups.*

Table 5. Duncan test results of BxC interaction for adhesion resistance values

| Impregnation (B) | Varnish (C) | | | | | |
|---|---|---|---|---|---|---|
| | SCPR | | DCAP | | DCEP | |
| | $\bar{X}$ | HG | $\bar{X}$ | HG | $\bar{X}$ | HG |
| Control | 2.40 | bc | 3.42 | de | 3.79 | f |
| WP | 1.34 | a | 1.52 | a | 2.11 | b |
| IA | 2.31 | bc | 3.13 | d | 3.55 | ef |
| IA+WP | 1.36 | a | 2.12 | b | 2.51 | c |

$\bar{X}$: *Mean adhesion resistance (N/mm$^2$), HG: Homogenous groups.*

The adhesion resistance values of the varnishes at the BxC interaction level are given in Table 5. Table 5 shows that, the adhesion strength values of DCEP applications are highest in control (non-impregnated) sample surfaces, and SCPR applications on wood protector (WP) and imersol aqua+wood protector (IA+WP) sample surfaces have the lowest adhesion resistance values of SCPR applications. It is also seen that impregnation with WP generally causes a decrease in adhesion strength values. This decrease may be due to the oil compounds present in the WP. From the literature they mention that impregnation application with varnishes samples causes the decrease of adhesion resistance (Özpak, 2006). Thus this supports our studies.

The adhesion resistance values of the varnishes at the AxBxC interaction level are given in Table 6. The adhesion strength values of the SCPR coated test specimens were impaired by $C_2H_2O_4$ bleaching and impregnated with IA, and the adhesion strength value of the test specimens coated with DCAP was highest when the adhesion strength value was highest in Table 6. It is possible to claim that when the lowest and highest values of adhesion strength are determined in the test samples bleaching with $C_2H_2O_4$, the bleaching operations have no effect on adhesion strength. However, the test samples in which the bleaching and the WP is applied have the lowest of the adhesion strength values. The oil compounds contained in the WP have an effect on adhesion resistance. These results also show us from the literature that some material with oil interaction leads to decrease adhesion resistance (Aydın, 2004; Rudawska & Kuczmaszewski, 2006).

Table 6. Duncan test results of AxBxC interaction for adhesion resistance values

| Pretreatment (A) | Impregnation (B) | Varnish (C) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SCPR | | DCAP | | DCEP | |
| | | $\bar{X}$ | HG | $\bar{X}$ | HG | $\bar{X}$ | HG |
| Control | Control | 2.41 | g-l | 3.28 | m-p | 4.11 | r-y |
| | WP | 1.54 | a-f | 1.56 | a-f | 1.95 | b-h |
| | IA | 2.44 | g-l | 3.61 | n-t | 3.22 | l-o |
| | IA+WP | 1.98 | b-h | 1.50 | a-e | 2.04 | c-i |
| Oil Stain Removal | Control | 1.44 | a-e | 2.12 | c-i | 1.33 | a-c |
| | WP | 1.16 | ab | 1.62 | a-g | 2.40 | g-l |
| | IA | 1.35 | a-c | 1.99 | b-h | 1.89 | b-h |
| | IA+WP | 1.17 | ab | 1.91 | b-h | 2.36 | f-k |
| Glue Stain Removal | Control | 2.66 | h-m | 4.12 | r-y | 4.41 | u-y |
| | WP | 1.38 | a-d | 1.48 | a-e | 2.05 | c-i |
| | IA | 2.54 | h-m | 3.33 | m-r | 3.68 | o-u |
| | IA+WP | 1.36 | a-c | 2.51 | h-m | 2.25 | e-k |
| Bleaching with $H_2O_2$ | Control | 2.56 | h-m | 3.55 | n-t | 4.81 | vy |
| | WP | 1.49 | a-e | 1.98 | b-h | 2.22 | d-j |
| | IA | 2.67 | h-m | 3.27 | m-p | 4.17 | s-y |
| | IA+WP | 1.00 | ab | 2.34 | f-k | 3.07 | k-o |
| Bleaching with $C_2H_2O_4$ | Control | 2.97 | j-o | 4.05 | p-v | 4.32 | t-y |
| | WP | 1.14 | ab | 0.97 | a | 1.97 | b-h |
| | IA | 2.57 | h-m | 3.47 | n-s | 4.84 | y |
| | IA+WP | 1.30 | a-c | 2.37 | f-k | 2.86 | i-n |

*$\bar{X}$: Mean adhesion resistance (N/mm$^2$), HG: Homogenous groups.*

## 4. Conclusion

In this study, the performances of water-based varnish were discussed after the surface adhesion strength tests, which are applied on the surface of wood material processed such as oil stain removal, glue stain removal and bleaching. Based on the results, there is a little decrease in the adhesion strength of the wood material on which the process of stain removal and bleaching was applied. The bleaching made on the oak wood did not reduce the adhesion strength of water-based varnishes, but on the contrary increased to some extent. It is believed that the recessed structure of the test sample surfaces during the bleaching has an effect on adhesion of water-based varnishes to the surface of the wood materials. The brightness, color change and the adhesion strength of the water-based varnishes needs to be searched more. The water-based varnishes of DCEP and DCAP were recommended based on its adhesion feature, the method of varnishing and drying time.

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**Conflict of interest**

The authors declare that there is no conflict of interest.

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