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Evaluation of adhesion strength of heat treated wood material using dipping and atomization methods

Daldırma ve atomizasyon yöntemleri kullanılarak ısıl işlem uygulanmış ahşap malzemenin yapışma direncinin belirlenmesi

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Abstract
The aim of this study is to evaluate the heat treated wood coating performance using dipping and atomization methods. Heat treatment temperature, treatment time, wood direction and application types were selected as independent variables while adhesion strength was determined as a dependent variable. The artificial weathering test was used to determine the performance of the surface coating applied to the heat-treated wood materials. The factors affecting the surface coating performance after the artificial weathering test were evaluated by multivariate analysis of variance (MANOVA) and pareto analysis. According to results, adhesion strength was found to be higher in both methods at 190° C temperature and 2 hours of application time. Adhesion strength in the radial direction was found to be better than the tangential direction, and it was observed that especially the dipping method created a significant interaction on the material direction and affected the adhesion strength considerably.

Özet
Bu çalışmanın amacı, daldırma ve atomizasyon yöntemlerini kullanarak ısıl işlem görmüş ahşap malzemenin yapışma direnci performansını değerlendirmektir. Isıl işlem sıcaklığı, işlem süresi, ahşap yönü ve uygulama türleri bağımsız değişkenler, yapışma mukavemeti ise bağımlı değişken olarak belirlenmiştir. Isıl işlem görmüş ahşap malzemelere uygulanan yüzey kaplamasının performansını belirlemek için yapay yaşlandırma testi kullanılmıştır. Yapay yaşlandırma testi sonrası yüzey işlem performansını etkileyen faktörler, çok yönlü varyans analizi (MANOVA) ve pareto analizi ile değerlendirilmiştir. Elde edilen sonuçlara göre 190°C sıcaklıkta ve 2 saatlik uygulama süresinde her iki yöntemde de yapışma mukavemeti daha yüksek bulunmuştur. Radyal yöndeki yapışma mukavemetinin teğetsel yönden daha iyi olduğu görülmüş ve özellikle daldırma yönteminin malzeme yönü üzerinde önemli bir etkileşim oluşturduğu ve yapışma mukavemetini önemli ölçüde etkilediği gözlemlenmiştir.

INTRODUCTION

In recent years, various methods have been used to increase the service life of wood materials. These are heat treatment, acetylation, impregnation and thermal modification (Bekhta et al. 2018a, Toker et al. 2012, Bekhta et al. 2017, We et al. 2017). Since heat treatment applications do not contain a chemical method, it is widely used in exterior applications (Boonstra and Tjeerdsma 2006, Huang et al. 2018).

The heat treatment method, which is one of the most common modification methods, offers many benefits to the wood material with both mechanical stability and extended the service life. In addition, since this method is processed according to temperature and time, some mechanical properties may decrease (Ünsal et al. 2003, Bekhta et al. 2018b, Evans et al. 1996).

In addition, in outdoor weathering conditions, these materials may cause some color changes due to factors such as UV exposure and humidity, and a decrease in durability due to abrasion. To prevent these disadvantages and especially to increase resistance, surface coating applications are applied. When the surface coating application is applied together with the heat treated samples, it provides the resistance against external weathering conditions and offers some aesthetic advantages as well.

Especially with heat treatment, varnish applications are widely used in woodworking. Such applications increase the resistance against external effects, provide an aesthetic appearance and provide resistance against wood pests (Sjökvist and Blom 2019).

The most commonly used quality properties to reveal the surface coating performance are adhesion strength, UV resistance, layer hardness, abrasion resistance and layer thickness (Keskin and Tekin 2011, Nejad and Cooper 2011, Söğütlü et al. 2016, Salca et al. 2017, Cool and Hernandez 2011, Landry et al. 2013).

The tests that allows the comparison of these performance parameters are artificial and natural weathering test methods. These methods are important tests both in determining the strength of wood material and in evaluating surface coating performance parameters.

In natural weathering test, coated or uncoated wood materials are exposed to natural weather conditions and some properties such as color change and chemical change are followed. Although the residue is the same in the artificial weathering method, it is tried to simulate the weather conditions in this method**.**

coating applications on wooden materials are applied by many methods. However, these methods are generally evaluated under two main headings as contact and atomization methods.

Commonly used contact methods are brushing, dipping, immersion vacuum and roller systems. In addition, commonly used non-contact methods are conventional, low pressure pneumatic atomization (HVLP), hydraulic atomization, and powder coating spray application (Bulian and Graystone 2009, Sulaiman et al. 2011).

In this study, varnish was applied to the woodwork by using both dipping and atomization methods. An artificial weathering test is used to evaluate their performance. The input parameters of the study are heat treatment temperature, application time, material direction and application type. The output parameter, on the other hand, is the determination of adhesion strength, which is a crucial quality characteristic.

MATERIAL AND METHOD

Material

Scots pine (*Pinus sylvestris* L.) sapwood lumbers were selected because of that used in many woodworking areas. These specimens were conditioned in climate at (20 ± 2) ºC and (65 ± 1) % relative humidity (RH) until they reach an equilibrium moisture content. Mean of density values was as 318 kg/m^3.

These samples were provided according to the principles specified in ASTM D-358. Special attention was paid to choose the wood material supplied from logs without knots, no buckling, and no growth defects. These specimens were chosen due to having a wide range of uses in exterior applications. Dimensions of the specimens were determined as 21 mm (radial) × 120 mm (tangential) × 1000 mm (longitudinal). These specimens were conditioned in climate at (20 ± 2) ◦C and (65 ± 1)% relative humidity (RH) until they reach an equilibrium moisture content. After the samples reached equilibrium moisture, the heat treatment process was applied in a controlled manner. After reaching the equilibrium humidity, heat treatment was applied to the wood samples at different temperatures and times. Temperature conditions were selected as 190 ° C and 212 ° C while duration times were used as 2 and 3 hours.

METHOD

Atomization and Dipping Methods

After these process, water-based varnish, materials of which were supplied by AkzoNobel (Istanbul, Turkey), was used to the specimens. The varnishing was carrird out according to ASTMD 3023 (2017) principles and application instructions. This process was created in three stages, namely, primer, filling, and topcoat. This process was applied from a distance of 18–28 cm with a spray gun with a bottom chamber nozzle of 1.7–2.1 mm and air pressure of 2–2.3 bar. At the primer application, the prepared samples were sanded with 80 and 150 numbered sandpaper. After this process was completed, approximately 150 g/m^2 of varnish was applied to the samples. At the filling and topcoat varnish application, after these samples were kept at 20 ^{0} C and % 65 relative humidity for 4 hours, the samples were intermediate sanded with a grit size of 220. Approximately, 130 g/m^2 filling varnish and 150 g/m^2 topcoat varnish were applied to the samples.

The wood material is completely immersed in a tank full of surface treatment agent and left for about 6-8 minutes. After the dipping process, the wood material is kept on the tank for 2-3 minutes and the excess on the surface allow the product to flow into the tank. After this process, it should dry for at least 24 hours to apply varnish on the wood. After the drying and sanding process were completed.

Determination of Adhesion Strength

Adhesion test applied to evaluate coating performance is one of the most crucial quality characteristics. Because this test affects the resistance and durability of the wood surface coating performance. In this work, this performance was applied with according to EN ISO 4624-2016. A PosiTest-AT adhesion tester and pull-off test method were applied to determine the adhesion strength of the samples. In order to evaluate the adhesion strength, 20 mm diameter with dollies were bonded to wood surfaces using two-component silane-epoxy resin. This application was carried out at room conditions (20 ° C and 40% RH). Dolies adhered to the wood samples were measured using an automatic type of Positest equipment.

Weathering Test

An artificial weathering test was applied to evaluate the adhesion strength performances of heat-treated samples. 48 samples were prepared with dimensions of 140 × 75 × 5 mm^3. These samples were exposed to artificial weathering tests according to the principles of TS EN ISO 16474-3 standard (Atlas UV 2000, Atlas Material Testing Technology IL USA). This application was carried out in the UV tester (8-340 UV-A lamps, BPT 40–110 ◦C, 104–230 ◦F, BST 40–120 ◦C, 104–248 ◦F, Single deck). Test application and control periods were determined as one cycle (6 h), interim check (500 h), and test duration (727 h).

2^k Factorial Design

Experimental design (2^k) is widely used to investigate the factors affecting the output of the process. This method reveals the relationship between dependent and independent parameters by reducing the experimental cost. It also investigates the interactions between the parameters. Therefore, it offers advantages over the classical experimental design. In present study, treatment temperature, time, direction and application were determined to independent factors. The number of experiment repetitions was determined as 3.The factors coded as (-1) and (+1) are given in Table 1.

Table 1. Process parameters

Symbol	Parameters	Unit	Level (-1)	Level (+1)
A	Application type	-	Atomization	Dipping
B	Direction	-	Tangential	Radial
C	Temperature	° C	190	212
D	Time	h	2	3

RESULTS

Results of MANOVA

2^4 factorial design was used to evaluate the effective factors. Main effect, interaction effect, MANOVA and Pareto plot were used together to investigate the effects of the determined four factors on wood coating adhesion strength. The factors of A, B, C, D and AB were effective factors on the wood coating adhesion strength.

Table 2. MANOVA results for adhesion strength after weathering test

Source	DF	SS	MS	F	P
Model	15	26.8774	1.79183	16.16	0.000ª
Linear	4	18.4776	4.61939	41.67	0.000ª
A-Application type	1	0.8480	0.84801	7.65	0.009ª
B-Direction	1	8.6700	8.67000	78.22	0.008ª
C-Temperature	1	5.3734	5.37341	48.48	0.000ª
D-Time	1	3.5861	3.58613	32.35	0.000ª
2-Way Interaction	6	7.9582	1.32636	11.97	0.000ª
AB	1	7.3164	7.31641	66.00	0.000ª
AC	1	0.0133	0.01333	0.12	0.731
AD	1	0.0721	0.07208	0.65	0.426
BC	1	0.1610	0.16101	1.45	0.237
BD	1	0.3201	0.32013	2.89	0.099
CD	1	0.0752	0.07521	0.68	0.416
3-Way Interaction	4	0.4321	0.10802	0.97	0.435
ABC	1	0.1200	0.12000	1.08	0.306
ABD	1	0.0030	0.00301	0.03	0.870
ACD	1	0.3072	0.30720	2.77	0.106
BCD	1	0.0019	0.00188	0.02	0.897
4-Way Interaction	1	0.0096	0.00963	0.09	0.770
ABCD	1	0.0096	0.00963	0.09	0.770
Error	32	3.5471	0.11085		
Total	47	30.424			

DF: Degree of Freedom; *SS*: Sum of Square; *MS*: Mean of Square; *F*: *F*-value; P: *P*-value

(a) is indicate the important parameters.

Evaluation of Main Effects and Pareto Plot

Figures 1 and 2 show the main and pareto effects on adhesion strength. It is seen that the A, B, C, D and AB factors are statistically significant at the 5% significance level. In addition, these results are supported by analysis of variance. When Pareto analysis was evaluated, it was seen that while the direction was the greatest effect on adhesion strength, the least effect was seen as the application type. However, when the interaction (AB) between them was evaluated, it was seen that it has a significant effect on the adhesion strength.

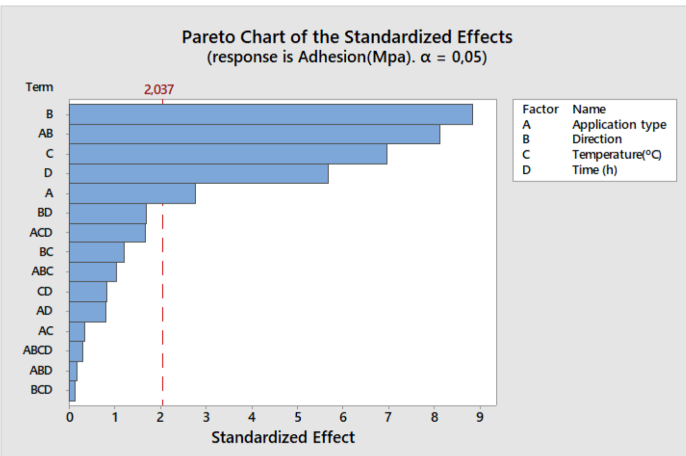


Figure 1. Pareto chart for the effective factors

When the main effect graph was evaluated, it is seen that the dipping method gives better results than the atomization method. In addition, it was observed that the adhesion strength was higher at lower temperature and time. At the same time, tangential direction to formation was found to be better in the radial direction.

Evaluation of Interaction Effects

Interaction graphs are used to investigate the effect of one factor on other factors. According to the Pareto and MANOVA results, it was found that there was an interaction between the application type and the direction of the wood material. As can be seen in Figure 3, when the type of atomization application and the direction of the wood material were considered together, it is seen that there was little effect on the adhesion strength. However, when the dipping method and material direction were evaluated together, the adhesion strength results in the radial direction were found to be better than the tangential direction.

Validation of The Model

In the investigation of the assumption of normality, normal probability histograms were determined by forming. In Figure 4a, the difference between the estimated value and the actual value forms a straight line. In Figure 4b, the distribution of these values is similar to the normal distribution. In Figures 4c and 4d, these values do not form a pattern. Therefore, it can be concluded that the data fit a normal distribution.

CONCLUSION

The 2^4 experimental design approach was applied to evaluate the effective factors. Input variables were selected as temperature, time, direction and application type while adhesion strength was selected as output variable. Interactions and main variable effects were highly effective on adhesion strength. The main and interaction plots were used in the investigation of adhesion resistance and all factors were found to be effective. It was also seen that the interaction between the type of apply and the direction of wood was quite effective. These results were in verified with MANOVA and Pareto analysis.

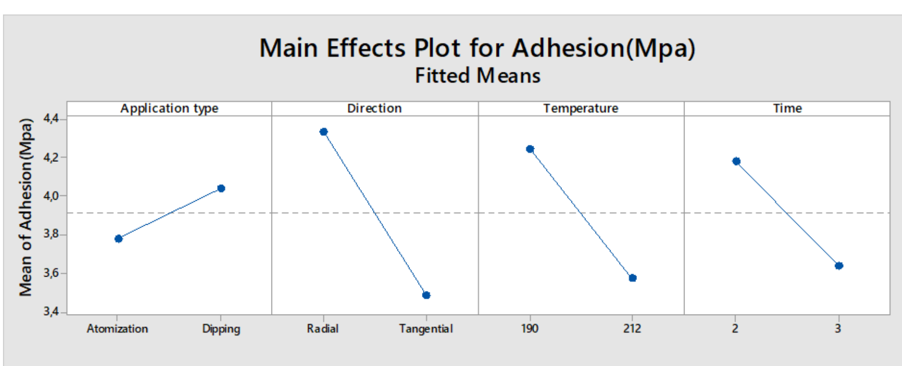


Figure 2. Main effect plot of adhesion strength

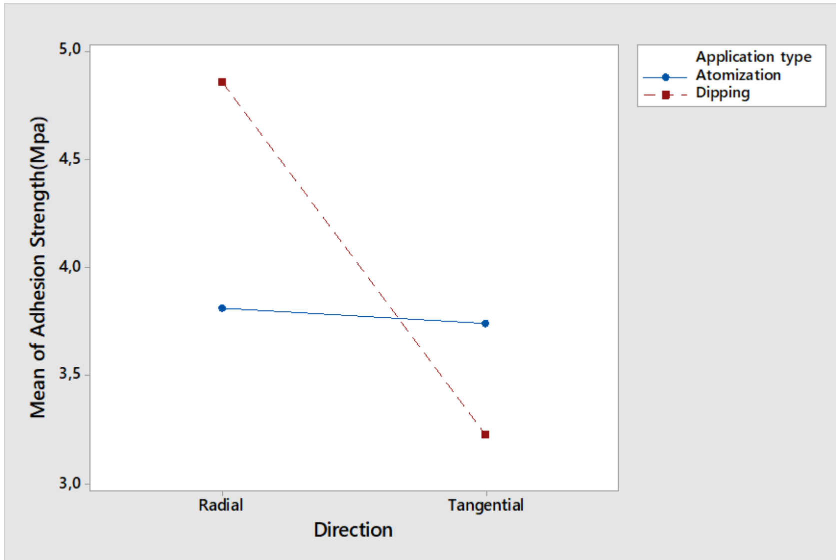
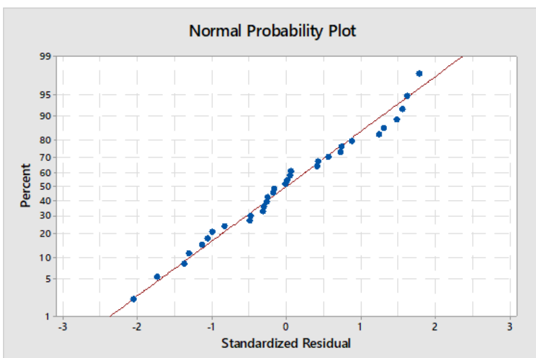
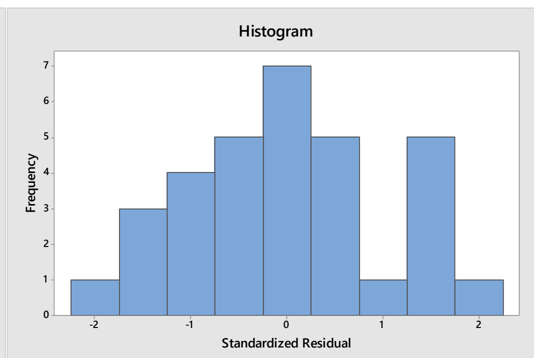


Figure 3. Interaction between application type and direction

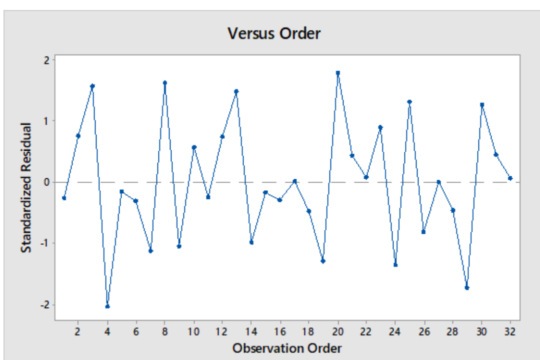
(a)



(b)



(c)



(d)

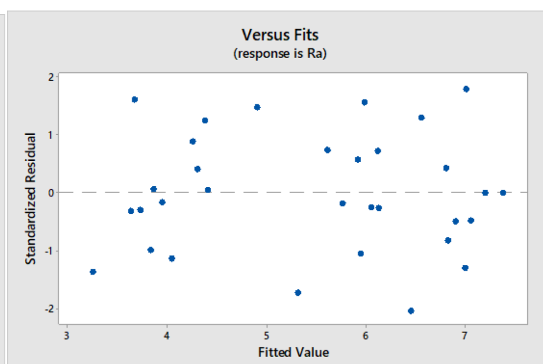


Figure 5 (a) Normal probability plot for standardized residuals; **(b)** histogram of standardized residuals; **(c)** versus order for standardized residuals; **(d)** versus fits for standardize residuals

When the main effect graph was evaluated, it is seen that the dipping method gives better results than the atomization method. In addition, it was observed that the adhesion strength was higher at lower temperatures and times. Radial direction to formation was found to be better in the tangential direction. The validated results of the model were supported by real data and it was seen that it showed a normal distribution.

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