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Research Article

Effects of Ash (*Fraxinus exelsior* L.) Veneer Surface Form and Spray Gun Inclination Angle on Color and Gloss Values of Polyurethane Coatings

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Abstract: In this study, polyurethane paint and varnish were applied to the surfaces of test samples prepared from ash (*Fraxinus exelsior* L.) veneer with different surface forms at 45° and 90° angles. The objective was to determine the changes in gloss and color values resulting from the application of these polyurethane coatings. In order to achieve this objective, samples were prepared by bonding ash veneer with two different surface characteristics (smooth and band sawn) onto MDF, and these were selected as test samples. Polyurethane paint-varnishes were applied to test sample surfaces and the resulting changes in gloss and total color (ΔE) were evaluated following accelerated UV ageing. The methodology employed for the UV ageing tests, gloss tests and color tests applied to the test samples was in accordance with the relevant standards. The findings of the research indicate that the type of protective layer and veneer surface form are effective factors influencing gloss and ΔE values. The gloss values were found to be high in varnishes applied to smooth veneer surfaces, while the total color change values were determined to be low in protective layers applied to traced veneer.

Keywords: ash veneer surface form; polyurethane paint-varnish; total color change; gloss; UV aging

Poliüretan Kaplamaların Renk ve Parlaklık Değerleri Üzerine Dişbudak Kaplama Yüzey Formu ve Sprey Boya Tabancası Eğim Açısının Etkileri

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Öz: Bu çalışmada, farklı yüzey formlarındaki dişbudak (*Fraxinus exelsior* L.) kaplamalardan hazırlanan deney örneklerinin yüzeylerine 45° ve 90° açılarda poliüretan boya ve vernik uygulanmış daha sonra parlaklık ve renk değerlerindeki değişimlerin belirlenmesi amaçlanmıştır. Bu amaçla, iki farklı yüzeye (düz ve şerit izli) sahip dişbudak kaplamaların MDF üzerine yapıştırılması ile hazırlanan örnekler deney numunesi olarak tercih edilmiştir. Deney örnek yüzeylerine poliüretan boya-vernikler uygulanmış ve hızlandırılmış UV yaşlandırma etkisi altında parlaklık ve toplam renk değişimi (ΔE) test edilmiştir. Deney örneklerine uygulanan UV yaşlandırma testleri, parlaklık testleri ve renk testleri ilgili standartlara göre belirlenmiştir. Araştırma sonuçlarına göre, koruyucu katman tipi ve kaplama yüzey formu, parlaklık ve ΔE değerlerinde etkili bulunmuştur. Düz kaplama yüzeylerine uygulanan verniklerde parlaklık değerleri yüksek, izli kaplama yüzeylerine uygulanan koruyucu katmanlarda ise toplam renk değişimi değerleri düşük belirlenmiştir.

Anahtar Kelimeler: dişbudak kaplama yüzey formu; poliüretan boya-vernik; toplam renk değişimi; parlaklık

1. Introduction

In order to circumvent the potential drawbacks associated with the inherent characteristics of wood, alternative materials (MDF, particle board, etc.) have been developed and coated with varying thicknesses of surface layers that emulate the appearance of natural wood. In addition to smooth-form veneer, veneer with motifs and linear scratches on their surfaces are now widely used in furniture and decoration projects where aesthetic appeal and quality are desired. An investigation into the extent to which these applications of veneer affect the performance of paint and varnish (the protective layer) could provide a new perspective for the sector.

It is of great importance to apply protective layers that are appropriate for the task at hand in order to extend the lifespan of wooden furniture and decorative elements. The discrepancy in application methods may result in the manifestation of defects in the brightness and color properties of the protective layer surfaces. The majority of manufacturing companies have advised that the angle of inclination of the gun with respect to the surface of the workpiece should be maintained at 90 degrees in order to optimize the performance of the protective layer. However, the angle of application of the protective layer often varies depending on the skill of the practitioner, and it is hypothesized that this change may result in the furniture surface gloss and color appearing defective.

In addition to their aesthetic properties, the gloss and color properties of protective layers are effective in influencing customers' furniture selection and preference (Salca and Cismaru, 2010; Cakicier et al., 2011; Bekhta et al., 2014; Slabejova et al., 2016; Salca et al., 2016; Şahin et al., 2024). An increase in color change (Loganina et al., 2017) and a decrease in the gloss effect are to be avoided. Indeed, the majority of companies market protective layers that they produce in numerous gloss levels and a vast array of color tones, thereby enhancing the economic value of the products to which they are applied. The ability of protective layers to withstand various effects is crucial for the durability of wooden elements in their end-use environment (Yürekli, 1995). While it is desirable for urethane paints and varnishes used in outdoor areas to demonstrate resistance to heat and ultraviolet (UV) radiation (Yürekli, 1995), the impact of fluorescent lighting and solar radiation on items used indoors should not be overlooked.

The ageing process plays an important role in determining the lifespan and durability of paints (Holzhausen et al., 2002). Aging processes can be conducted under both natural and artificial conditions; however, accelerated aging devices are frequently utilized to reduce the time required for the process (Çakıcıer, 2007). Ultraviolet (UV) radiation is a primary factor in both aging devices and the natural environment, causing damage to wood and particularly affecting color (Jančovičová et al., 2007; Gürleyen, 2021; Temiz, 2005) and gloss values (Budakçı, 2006).

A number of studies have demonstrated that the aging process has a detrimental impact on the color values of UV-cured varnishes (Çavuş, 2021). Similarly, the aging process has been shown to reduce gloss values in cellulosic, polyurethane and acrylic varnishes (Sönmez and Kesik, 1999). The color properties of shellac polish, teak oil and liquid paraffin are adversely affected (Söğütlü and Sönmez, 2006). Furthermore, fluctuations in gloss values increase and decrease depending on the ageing period in different varnishes (Gorman and Feist, 1989; Ulay, 2023; Kılıç and Söğütlü, 2020; Salca et al., 2021). The efficacy of protective layers is not solely contingent upon the aging effect. The anatomical structure of the wood (Moya et al., 2017), the preparation stages of the wood material for surface treatments, the quality of the protective layer, surface form to which a protective layer is applied Kesik, 2009), content of the protective layer (Aygül et al., 2024; Calovi and Rossi, 2024), the pigment ratio (Aykan et al., 2022; Song et al., 2024; Zhang et al., 2024), modification of the protective layer (Deng et al., 2024; Miklečić et al., 2024; Wang et al., 2024) and molecular sizes (Khorshidi et al., 2024), the application method (Alvarenga et al., 2024) of the protective layer, the application location of the protective layer and the skill of the personnel performing the application (Loganina et al., 2024) are significant factors in determining the color and gloss values.

The objective of this study is to ascertain the impact of the marks on the veneer surfaces, the spray gun inclination angle and the accelerated UV ageing process on the gloss and color properties of polyurethane paint-varnish layers. It is hypothesized that the formation of decorative images and the development of mechanical bonds will be enhanced by the traces created on the veneer surface during the painting and varnishing process. It is therefore important to determine the gloss and color properties of the protective layers in coated works with different surfaces.

2. Experimental

2.1. Material

In the study, two types of ash (*Fraxinus exelsior* L.) veneer (smooth and band sawn) were selected as the test material, as they represent the surface forms most commonly used in the woodworking industry. The veneers were affixed to the medium-density fibreboard (MDF) using a hot press and a urea-formaldehyde adhesive. All preparatory stages of the test samples were conducted at Axis Furniture (İstanbul/Türkiye).

Polyurethane varnish (Devilux) and polyurethane paint (Polchem) were preferred for protective layer applications.

2.2. Preparation of Test Samples

In the study, two types of ash veneer, namely smooth and band sawn, were adhered to MDF using a hot press, resulting in the production of 384 test samples [(paint and varnish) x2, (45° and 90°) x2, (smooth and band sawn) x2, (control and UV) x2, (sample number=24)] (Figure 1). In order to make the UV ageing process practical, the test samples were prepared in the dimensions of 10x32x1 cm. The initial step involved the application of polyurethane primer to the test samples. This was followed by the application of topcoat polyurethane varnish and paint, with a spray gun inclination angle of 45 and 90 degrees, respectively. Polyurethane varnish and paint were applied in accordance with the manufacturer's recommendations and 125gr/m² on the surfaces. Prior to each measurement, the test samples were acclimatized at a temperature of 20 ± 2°C and a relative humidity of 50 ± 5%.

Figure 1. Test Samples

2.3. Surface Gloss Measurement

The gloss measurements were determined in accordance with the requirements set forth in TS EN ISO 2813 (2014). In determining the gloss of paint and varnish layers, the 20°, 60° and 85° angles are employed. However, the 60° angle (Salca et al., 2021) is predominantly utilized for the determination of surface gloss in wood materials. Gloss measurements of varnish and painted surfaces were conducted with a gloss meter (Gloss-meter) at a 60° angle and parallel to the fibers (Figure 2).

Figure 2. Gloss meter measuring device.

2.4. Color Measurement

The Minolta CR-231 color measuring device, which is a tristimulus colorimeter, was employed in the color measurement process (Figure 3).

Figure 3. MINOLTA CR-231 color measurement device.

The color measurements were determined in accordance with the requirements of TS EN ISO 11664-6 (2022). The total color change (ΔE) of the samples prepared for the experiments by acclimatization at a temperature of 20±2°C and a relative humidity of 50±5% was determined both before and after the accelerated ageing process. In the CIE L*a*b* color system (Figure 4), the differences in colors and their locations are determined according to the color coordinates L*, a*, b*. Here, L* indicates the black-white axis, a* the red-green axis and b* the yellow-blue axis. ΔL* is the difference in light, Δa* and Δb* are the difference in colors.

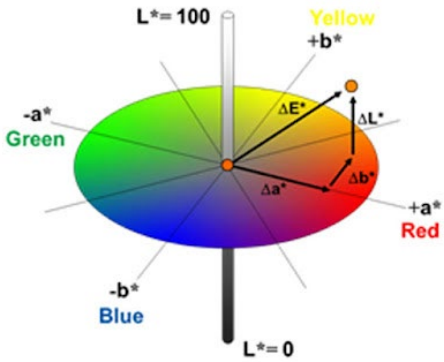

Figure 4. CIE L*a*b* color system (URL 1).

Total color change (ΔE*); was calculated using the equation.

$$\Delta E^* = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)2]1/2 \quad 1$$

It is desirable to have a low color change value in protective layers exposed to any effect. Light difference (ΔL*), a difference (Δa*), b difference (Δb*); were calculated using the equation.

$$\Delta L^* = L^*2 - L^*1,\ \Delta a^* = a^*2 - a^*1,\ \Delta b^* = b^*2 - b^*1 \quad 2$$

2.5. Accelerated UV Aging Process

The test samples to which ash veneer was glued were subjected to an accelerated ageing process by the application of paint-varnish. Subsequent to this, gloss and color tests were performed on the surfaces of the samples.

The test samples were safeguarded from the effects of heat and light between the test processes. The accelerated UV ageing tests were conducted in accordance with the requirements set forth in TS EN ISO 16474-3 (2021). The samples were subjected to an accelerated UV ageing process for a period of 24 hours in an environment where eight UVA 340 lamps were placed and the temperature was maintained at 55±2 °C (Figure 5).

Figure 5. Atlas UV 2000 Aging Device.

2.6. Evaluation of Data

In order to ascertain the color and gloss properties of the test samples processed with the marks applied to the veneer, gun inclination angle, protective layers and the losses caused by the UV ageing effect, statistical analyses were conducted using the SPSS package program with data obtained before and after ageing. Multiple variance analyses were performed to determine the factor effects of the obtained data, and in cases where a significant difference was identified between the groups, the Duncan test (Homogeneity Group) was applied to each factor.

3. Findings and Discussion

3.1. Determination of Gloss

The gloss values of the test samples that were treated with polyurethane paint-varnish are presented in Table 1.

Table 1. Gloss values of the test samples

Protective Layer	Spray Gun Tilt Angle	Veneer Surface Form	Aging Status	Mean	Std. Dev.	N
Varnish	*45*	*Smooth*	*Control*	21,5958	9,82944	24
			UV	18,9667	8,38791	24
		Band sawn	*Control*	12,9792	4,8779	24
			UV	12,8792	5,0086	24
	90	*Smooth*	*Control*	19,925	10,05793	24
			UV	19,525	9,59834	24
		Band sawn	*Control*	11,8417	4,64813	24
			UV	11,5667	4,26774	24
Paint	*45*	*Smooth*	*Control*	18,7333	9,78773	24
			UV	18,2125	8,87734	24
		Band sawn	*Control*	9,675	2,59987	24
			UV	9,8333	2,80398	24
	90	*Smooth*	*Control*	18	9,84722	24
			UV	16,6208	8,06932	24
		Band sawn	*Control*	9,75	3,28435	24
			UV	9,7375	3,50736	24

The objective of the variance analysis was to ascertain whether the discrepancy in gloss values between the protective layers of the test samples to which polyurethane paint-varnish was applied was statistically significant, taking into account the variables pertaining to the veneer surface, spray gun inclination angle, protective layer type and ageing status. The results of this analysis are presented in Table 2.

Table 2. Multiple variance analysis regarding the surface gloss values of the protective layers

Variance source	Degrees of freedom	Sum of squares	Mean squares	F Account	Severity level % 5
Factor A	1	525,470	525,470	10,211	,002*
Factor B	1	52,363	52,363	1,018	,314
Factor C	1	6013,500	6013,500	116,857	,000*
Factor D	1	39,913	39,913	,776	,379
*Interaction A*B*	1	2,220	2,220	,043	,836
*Interaction A*C*	1	4,996	4,996	,097	,756
*Interaction A*D*	1	4,084	4,084	,079	,778
*Interaction B*C*	1	1,402	1,402	,027	,869
*Interaction B*D*	1	1,576	1,576	,031	,861
*Interaction C*D*	1	33,135	33,135	,644	,423
*Interaction A*B*C*	1	19,893	19,893	,387	,534
*Interaction A*B*D*	1	14,260	14,260	,277	,599
*Interaction A*C*D*	1	,555	,555	,011	,917
*Interaction B*C*D*	1	4,420	4,420	,086	,770
*Interaction A*B*C*D*	1	14,338	14,338	,279	,598
Mistake	368	18937,337	51,460		
Total	384	111955,5			

Factor-A= Protective layer type, Factor-B = Spray Gun inclination angle, Factor-C= Veneer surface form, Factor-D= Accelerated UV aging process, *: Significant (according to $\alpha = 0.05$)

As evidenced in Table 2, the primary variables, namely the protective layer type and veneer surface forms, exert a discernible influence on the surface gloss of the test samples. No other interactions were found to be effective in influencing the surface gloss. The results of the Homogeneity Group (HG) test, which was conducted to determine the group that creates a difference in the variables of the protective layer type and veneer surface forms that are effective on the surface gloss, are presented in Table 3.

Table 3. Surface gloss values of test samples at the level of veneer surface form and protective layer type, homogeneity group test

Glossiness		X	HG	n
Veneer Surface Form	*Smooth*	18,94*	A	96
	Band sawn	11,03	B	96
Protective Layer Type	*Varnish*	16,16*	A	192
	Paint	13,82	B	192

X: Arithmetic mean, HG: Homogeneity group, *: Highest gloss value

As illustrated in Table 3, the highest gloss value was observed in samples with a smooth veneer surface (18.94), while the lowest was noted in samples with a scarred veneer surface (11.03). In comparison, the highest gloss value was recorded in varnished samples (16.16), while the lowest was observed in painted samples (13.82). It was established that the veneer-scarred surface form resulted in a reduction in gloss values. This may be attributed to the wavy structure created by the traces on the veneer surfaces. It is anticipated that the gloss values will be low on surfaces with traces. The existing literature indicates that gloss values are typically high on varnished surfaces, and this result is corroborated by the present study (Khorshidi et al., 2024; Zhang et al., 2024). Additionally, the effect of UV aging on gloss values tends to decrease. In Yakin's study, a similar situation was discussed as application differentiation (Yakın, 2001).

3.2. Total Color Change (ΔE) Determination

ΔE values of the test samples applied with polyurethane paint-varnish are given in Table 4.

Table 4. ΔE values of the test samples

Protective Layer	Spray Gun Tilt Angle	Veneer Surface Form	Mean	Std. Dev.	N
Varnish	*45*	*Smooth*	15,6629	3,70425	24
		Band sawn	16,5854	2,62157	24
	90	*Smooth*	16,3483	3,28109	24
		Band sawn	19,8338	10,28516	24
Paint	*45*	*Smooth*	1,6192	0,48468	24
		Band sawn	2,1254	1,08297	24
	90	*Smooth*	1,5675	0,64946	24
		Band sawn	1,5446	0,58018	24

The objective of the variance analysis was to ascertain whether the discrepancy in the ΔE values of the protective layers of the test samples to which polyurethane paint-varnish was applied was significant according to the veneer surface form, spray gun inclination angle and protective layer type variables. The results of this analysis are presented in Table 5.

Table 5. Multiple variance analysis regarding the ΔE values of the protective layers

Variance source	Degrees of freedom	Sum of squares	Mean squares	F Account	Severity level % 5
Factor A	1	11373,98	11373,98	653,159	0*
Factor B	1	32,695	32,695	1,878	0,172
Factor C	1	71,773	71,773	4,122	0,044*
*Interaction A*B*	1	62,552	62,552	3,592	0,06
*Interaction A*C*	1	46,207	46,207	2,653	0,105
*Interaction B*C*	1	12,408	12,408	0,713	0,4
*Interaction A*B*C*	1	28,683	28,683	1,647	0,201
Mistake	184	3204,137	17,414		
Total	192	31836,87			

Factor-A= Protective Layer type, Factor-B= Spray Gun inclination angle, Factor-C= Veneer surface form, *: Significant (according to $\alpha = 0.05$)

As evidenced in Table 5, the primary variables, namely the protective layer type and veneer surface forms, exert a discernible influence on the ΔE of the test samples. It can be concluded those other interactions are not effective on ΔE. The results of the Homogeneity Group (HG) test, which was conducted to determine which group creates a difference in the variables of the protective layer type and veneer surface forms that are effective on ΔE, are presented in Table 6.

Table 6. ΔE values of test samples at the level of veneer surface form and protective layer type, homogeneity group test

Total Color Change (ΔE)		X	HG	n
Veneer Surface Form	*Smooth*	8,79	B	96
	Band sawn	10,02*	A	96
Protective Layer Type	*Varnish*	17,10*	A	96
	Paint	1,71	B	96

According to Table 6, the ΔE value was determined as the highest (10.02) in samples with a Band sawn surface form, the lowest (8.79) in samples with a Smooth veneer surface form, the highest (17.1) in varnished samples, and the lowest (1.71) in painted samples. It was determined that the traced veneer surface form increased the ΔE values, and this may be due to the shadowy and wavy (Kesik, 2009) structure created by the traces on the veneer surfaces. It is an expected result that ΔE values are high in varnishes (Yalınkılıç and Sönmez, and low in paints. Most studies in the literature support this result (Khorshidi et al., 2024). Additionally, the effect of UV aging on ΔE values tends to decrease (Kesik, 2009).

4. Results and Recommendations

This study examines the impact of UV ageing on the gloss and color of polyurethane varnish and paints applied to ash veneer veneers with varying surface forms and gun inclination angles, specifically 45 and 90 degrees. The lowest gloss value was observed in ash veneer veneers with traced surface forms and in surfaces treated with polyurethane paint. The lowest ΔE value was observed in ash veneer veneers with smooth surface forms and on surfaces treated with polyurethane paint.

The findings of this study indicate that the selection of a protective coating is a crucial aspect in areas subjected to UV radiation. However, it is important to note that the use of a protective coating should not necessarily result in the expectation of high gloss levels on the surface.

Further studies investigating the performance characteristics of diverse protective layers with varying application techniques may offer valuable insights to the scientific community.

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