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Effect of Polyurethane Non-Transparent Coating Process on Paint Film Performance Applied on Modified Poplar

Qingqing Liu [1,2], Di Gao [1,2] and Wei Xu [1,2,*]

[1] Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, Nanjing Forestry University, Nanjing 210037, China; 0321lqq@njfu.edu.cn (Q.L.); gaodi@njfu.edu.cn (D.G.)
[2] College of Furnishings and Industrial Design, Nanjing Forestry University, Nanjing 210037, China
* Correspondence: xuwei@njfu.edu.cn; Tel.: +86-25-8542-7459

Abstract: Whether modified poplar can obtain a qualified or even excellent finishing effect on European and American furniture is worthy of deep study. To evaluate whether the conventional non-transparent coating process is suitable for modified poplar, a multi-level hybrid orthogonal experiment method was carried out to start research on how factors affect the paint film performance of the non-transparent coating process. The effect of experimental factors and levels on paint film performance is pointed out, and the optimal factors and levels are found. Parameter optimization of the polyurethane non-transparent finishing process based on modified poplar is carried out. An application basis was provided for the extensive use of modified poplar wood as a substrate in the European and American furniture markets. The conclusions are: (1) gloss of paint film can be improved by increasing the number of nitrocellulose (NC) lacquer transparent topcoats, (2) adhesion and thickness of paint film can be improved by polyurethane (PU) sealing primer, (3) the initial paint film's abrasion is influenced efficiently by the coating process and coating sanding. PU sealing primer has an efficient influence on the later abrasion of paint film. The effect of modified poplar surface pretreatment on the mass loss of paint film tends to be stable.

Keywords: modified poplar; coating process; non-transparent; polyurethane

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1. Introduction

The non-transparent coating process of European and American furniture is a kind of operation method characterized by full color [1]. This type of paint process is mainly based on polyurethane resin paint [2]. After multiple sprays on the wood surface, the paint film formed is thick, plump and opaque [3–5]. The non-transparent finishing does not require high-grade wood properties, especially the surface visual properties [6,7]. In standard production, some ordinary woods are also selected for spraying. Modified poplar wood has the advantages of light color, long fiber, less resin and easy bleaching. Domestic and foreign scholars' ultimate goal of modified poplar is to improve its practical performance, enhance its various properties, enhance its application value, and expand the scope of application [8–11]. Non-transparent coating pays more attention to the fullness of the paint film, the physical and chemical strength of the paint film and other properties [12,13].

Water-based polyurethane coatings are not only low-cost, safe and environmentally friendly but also have good low-temperature film-forming properties, high-temperature retack resistance, and high wear resistance, etc. [14–18]. The research results of Pan et al. [19] show that water-based polyurethane's (waterborne polyurethane, WPU) adhesion of the coating is much better than that of the acrylic resin (PA) emulsion. Chang et al. [20] paid attention to the effect of the curing process on the performance of epoxy acrylate ultraviolet (UV)/polyurethane (PU) dual-curing resins for wood coatings compared with traditional UV and polyurethane (PU) coatings. Compared with traditional UV and PU coatings, the film of dual-curing coatings is made by UV curing or the room temperature curing

process, which has excellent tensile strength, elongation at break, impact resistance and light resistance. UV/PU dual-curing coating's adhesion is better than traditional UV coatings. Ghosh et al. [21] found that polyurethane veneer can effectively maintain the luster of the wood surface to a large extent and prevent the wood from being exposed to ultraviolet rays. Pandey et al. [22] coated the modified rubberwood substrate with polyurethane transparent and opaque finishes, respectively. The study results showed that the performance of the opaque coating was better than that of the transparent coating, which may be due to the light color of the wooden substrate in the transparent coating. Liu et al. [23] compared modified poplar with mahogany, which is commonly used in European and American furniture. The results showed that modified poplar's wettability is higher than mahogany's wettability. Further research showed that change of colorants and coloring steps can reduce the difference of modified poplar and mahogany's color [24].

Modified poplar, a modification of fast-growing poplar in plantations, has been used in ordinary solid wood furniture. For European and American furniture with strict process requirements for external modeling and surface coating, the use of modified poplar wood is still under experimental research. There are still many technical problems that need to be solved [25,26]. Whether European and American furniture's extremely complex and important surface finishing processes can obtain qualified or even excellent coating effects on modified poplar wood is worthy of in-depth study [27,28].

Domestic and foreign researchers have conducted much systematic research on ordinary wood's surface coating performance [29,30], but there is little research about non-transparent finishing processes based on modified poplar. Meng et al. [31] used Nitrohydroxymethyl resin to modify poplar. Acrylic paint's wettability is better, but polyurethane coating's wettability does not change. Hao et al. [32] heat-treats modified poplar. The color change of modified, heat-treated poplar is smaller than that of untreated poplar. This research aims to evaluate whether the conventional non-transparent finishing process is suitable for modified poplar.

(1) A multi-level hybrid orthogonal experiment method was carried out to analyze the effect of experimental factors and levels on paint film performance.
(2) Several indicators were used to demonstrate factors that affect paint film's performance of non-transparent finishing process.
(3) Factors and levels that have the greatest impact on the performance of the paint film are explored to optimize the parameters of the polyurethane non-transparent coatings process applied on modified poplar wood.

2. Materials and Methods

2.1. Materials

The main components of the Didebao primer are water, oil, resin, pigment, thinner, auxiliary materials (drier, curing agent, plasticizer and moisture-proof agent) provided by Mingshida Co., Ltd. (Taian, China). The modified poplar (*Populus* L.) (sawed transversely, size 150 mm × 80 mm × 20 mm, cross section) was provided by Jiayue Wood Industry Co., Ltd. (Dezhou, China). The wood density is 0.36 g/cm^3 and the width of the annual rings is 1.54 mm. The specific steps of poplar wood modification are as follows. First, urea was dissolved in water, and antimony trioxide was dissolved in glacial acetic acid. The poplar wood modifying agent was prepared by mixing these two liquids. Then the poplar wood was processed into 150 mm × 80 mm × 20 mm pieces, according to the requirements, and then put into the modifier (liquid) under vacuum for 4 h under a pressure of 3.0 MPa. Finally, the poplar was sent to a 90 °C drying chamber for 24 h to reach an equilibrium moisture content of 8.0%. The fiber structure of poplar is loose, and the material is poor. The modified poplar not only has enhanced its mechanical strength and improved dimensional stability but also has full color. The inherent structural texture of wood can be better highlighted. It has been used to replace high-grade wood to make furniture. Polyurethane (PU) sealing primer was provided by Caideli Chemical Products Co., Ltd. (Huizhou, China), and nitrocellulose (NC) topcoat was provided by Caideli Chemical Products Co., Ltd.

(Huizhou, China). The main components of PU sealing primer were the main agent, curing agent, and diluent, with a ratio of 2–2–1.5 (solid content of 50%). Nitro lacquer is based on nitrocellulose as the main body, combined with alkyd resin or acrylic resin, rosin resin, plasticizer and mixed solvent. The 180#, 240#, 320# and 400# sandpapers were provided by Feili Co., Ltd. (Xianning, China).

2.2. Preparation of Sample

A multi-level hybrid orthogonal experiment method was carried out. Specific levels and factors are shown in Table 1. The L_{16} (4^5) orthogonal table is shown in Table 2. The specimen processing method is shown in Table 3. The spray gun "vertical gun" was used for Didebao primer, PU primer and NC topcoat. To ensure the same "coating amount" of the test piece, the spray gun air pressure was controlled to 0.5 MPa, the nozzle paint output was 200 mL/min, the spray width was 180 mm, spraying distance was 200 mm, and one spray was a "cross gun". There are three samples for each kind of finishing process (G1–G16), resulting in a total of 48 samples.

Table 1. Non-transparent coating factor level.

Levels	Factors				
	Factor 1: Didebao Primer (A)	**Factor 2: Sanding After Didebao Primer (B)**	**Factor 3: PU Sealing Primer (C)**	**Factor 4: Finishing Process (D)**	**Factor 5: Paint Film Sanding (E)**
Level 1 (I)	one time	180#	one time	once PU sealing primer + once NC topcoat	180#
Level 2 (II)	0 time	240#	0 time	once PU sealing primer + twice NC topcoat	240#
Level 3 (III)	-	320#	-	once PU sealing primer + once NC topcoat	320#
Level 4 (IV)	-	400#	-	once PU sealing primer + twice NC topcoat	400#

Note: Factor 2 refers to the first sanding after applying Didebao primer, and Factor 5 refers to the second sanding after applying the topcoat.

Table 2. Orthogonal table L16 (45).

Experiment Number	Factors				
	A	**B**	**C**	**D**	**E**
G1	1	1	1	1	1
G2	2	1	2	2	2
G3	1	1	2	3	3
G4	2	1	1	4	4
G5	1	2	2	1	2
G6	2	2	1	2	1
G7	1	2	1	3	4
G8	2	2	2	4	3
G9	2	3	1	1	3
G10	1	3	2	2	4
G11	2	3	2	3	1
G12	1	3	1	4	2
G13	2	4	2	1	4
G14	1	4	1	2	3
G15	2	4	1	3	2
G16	1	4	2	4	1

Table 3. Processing method.

Number	Processing Method
G1	No Didebao primer—180# sanding paper—no PU sealing primer—once PU primer + once NC topcoat—180# sanding paper
G2	Didebao primer—180# sanding paper—PU sealing primer—once PU primer + twice NC topcoat—240# sanding paper
G3	No Didebao primer—180# sanding paper—PU sealing primer—twice PU primer + once NC topcoat—320# sanding paper
G4	Didebao primer—180# sanding paper—no PU sealing primer—twice PU primer + twice NC topcoat—400# sanding paper
G5	No Didebao primer—240# sanding paper—PU sealing primer—once PU primer + once NC topcoat—240# sanding paper
G6	Didebao primer—240# sanding paper—no PU sealing primer—once PU primer + twice NC topcoat—180# sanding paper
G7	No Didebao primer—240# sanding paper—no PU sealing primer—twice PU primer + once NC topcoat—400# sanding paper
G8	Didebao primer—240# sanding paper—PU sealing primer—twice PU primer + twice NC topcoat—320# sanding paper
G9	Didebao primer—320# sanding paper—no PU sealing primer—once PU primer + once NC topcoat—320# sanding paper
G10	Didebao primer—320# sanding paper—PU sealing primer—once PU primer + twice NC topcoat—400# sanding paper
G11	Didebao primer—320# sanding paper—PU sealing primer—twice PU primer + once NC topcoat—180# sanding paper
G12	No Didebao primer—320# sanding paper—no PU sealing primer—twice PU primer + twice NC topcoat—240# sanding paper
G13	Didebao primer—400# sanding paper—PU sealing primer—once PU primer + once NC topcoat—400# sanding paper
G14	Didebao primer—400# sanding paper—no PU sealing primer—once PU primer + twice NC topcoat—320# sanding paper
G15	Didebao primer—400# sanding paper—no PU sealing primer—twice PU primer + once NC topcoat—240# sanding paper
G16	No Didebao primer—400# sanding paper—PU sealing primer—twice PU primer + twice NC topcoat—180# sanding paper

2.3. Testing and Characterization

The gloss test equipment was the photoelectric gloss meter GZ-II (WGG60-ES4, Shanghai Precision Instrument Co., Ltd., Shanghai, China). Measurement parallel to the wood texture was carried out firstly. The gloss agent was put in a position parallel to the texture, and data were recorded after the pointer was stable. Measurement perpendicular to the wood texture was carried out. The gloss agent was put in a position perpendicular to the texture, and data were recorded after the pointer was stable. To reduce the error, each direction was measured three times. The average value was taken as the gloss value in each direction.

The measurement tools of paint film adhesion were a single blade, rigid ruler and Scotch transparent tape. To ensure the knife runs straight and the paint film is entirely cut through, a single-edged knife was used to cut the paint film along a 45° direction to the wood grain. We scribed 6 parallel lines with a spacing of 2 mm for each cut and then made six cuts along the perpendicular direction. After this was completed, a soft brush was used to gently sweep away the fine paint film debris at the cut. Scotch tape was used to stick tightly to cut a grid, and the tape was torn off quickly. A magnifying glass was used to observe and record. The peeling rate of the paint film was calculated and counted. Three places for each test piece were selected to conduct the adhesion test, and the average value was calculated.

The measuring tool of the paint film mass loss test was a paint film abrasion meter (BGD-523, Biuged Precise Instruments, Guangzhou, China). The specification of the test piece is 100 mm × 100 mm × 20 mm, with a φ = 8 mm round hole in the center. Before the test piece was worn out, an electronic balance was used to weigh and record the data. A 1000 ± 1 g weight and a roller with 400# sandpaper strips were added on the surface of the test piece. Each test piece was abraded five times, and each abrasion was 100 r. After each abrasion, a soft paper towel was used to gently wipe off the surface paint chips. Then test piece was placed on the electronic balance, and data were recorded. The result of paint film mass loss was judged by a combination of subjective observation and evaluation methods and a paint damage weighing method.

3. Results and Discussion

3.1. Glossiness of Paint Film

Table 4 is the test results of the paint film surface gloss, and Tables 5 and 6 are the range analysis result. Figure 1 is a micrograph of the cross section of the paint film. The factors that have the greatest influence on the parallel reflection gloss of the paint film are PU sealing primer, paint film sanding, paint process, Didebao primer, and Didebao primer post-sanding (as shown in Table 5). The factors that have the greatest impact on the vertical reflection gloss of the paint film and coating process parameters that are optimal for increasing the GZT (%) value are the same as the above-mentioned optimal parameters of the GZL (%) value. This shows that the factors affecting GZL (%) and GZT (%) are the same. The best finishing process parameter for increasing glossiness of paint film is "modified poplar painting Didebao primer—180# sandpaper sanding—spraying PU sealing primer—two passes of PU primer + two passes of NC topcoat—the paint film sanded with 400# sandpaper". To more intuitively show the influence of various factor levels on the glossiness of the paint film, the influence of different factors and levels on the paint film's glossiness is displayed in a chart using Origin Pro software. The result is shown in Figures 2 and 3.

Table 4. The measured value of gloss.

Glossiness	Number															
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16
GZL (%)	14.2	13.5	17.2	31.7	16.8	17	27.3	12.8	17.7	14.8	10.7	21.3	16	21.7	13.5	17
GZT (%)	15.5	13.2	18.8	33	17.8	15.2	26	13.5	18.3	15.3	14.2	23.7	16	21.7	16	15.2
GZB (%)	0.91	1.03	0.91	0.96	0.94	1.12	1.05	0.95	0.96	0.97	0.75	0.9	1	1	0.84	1.12

Table 5. Range analysis of the orthogonal experiment of paint film's gloss GZL (%).

Levels	Factors					Comprehensive Metrics
	A	B	C	D	E	
I	150.3	76.6	164.4	64.7	58.9	
II	132.9	73.9	118.8	67.0	65.1	
III	-	64.5	-	68.7	69.4	T = 283.2
IV	-	68.2	-	82.8	89.8	
R	17.4	12.1	45.6	18.1	30.9	

Table 6. Range analysis of the orthogonal experiment of paint film's gloss GZT (%).

Levels	Factors					T Value
	A	B	C	D	E	
I	154.0	80.5	169.4	67.6	60.1	
II	139.4	72.5	124.0	65.4	70.7	
III	-	71.5	-	75.0	72.3	T = 293.4
IV	-	68.9	-	85.4	90.3	
R	14.6	11.6	45.4	20	30.2	

After brushing Didebao primer, different types of sandpaper were used to sand the surface of the material. It can be seen that GZL (%) shows a trend of first decreasing and then increasing. GZL (%) reaches the lowest value when sanding 320# sandpaper, and it reaches the highest value when sanding 180# sandpaper. Therefore, in order to obtain a good parallel gloss of the paint film, 180# sandpaper should be used to sand the surface of the Didebao primer. As the change of the combination process of the paint, the parallel gloss is showing an increasing trend. When the PU primer and the NC topcoat are applied twice, the parallel gloss of the paint film reaches the maximum. As the sandpaper model changes based on the paint film, when 400# sandpaper is used, the final parallel gloss of the paint film is the highest.

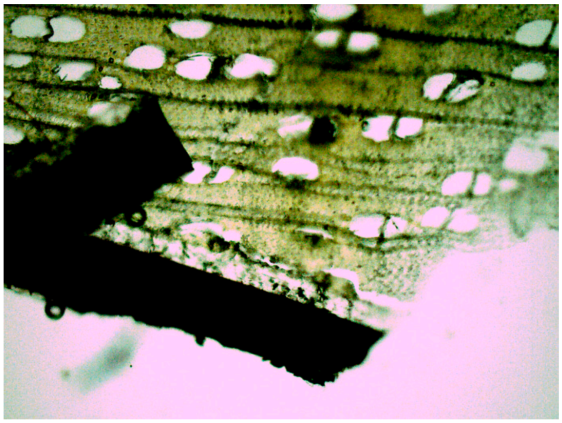


Figure 1. Micrograph of cross section of the paint film.

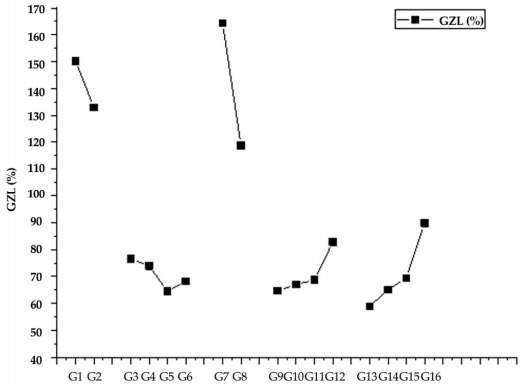


Figure 2. Change trend chart of factor and level for the effect of GZL (%).

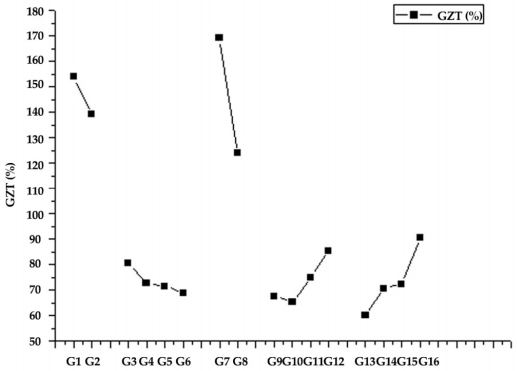


Figure 3. Change trend chart of factor and level for the effect of GZT (%).

3.2. Adhesion of Paint Film

Table 7 is the measured value of paint film adhesion, and Table 8 is the analysis of range results. It can be seen from Table 8 that the most significant factor that affects the peeling rate of the paint film is Didebao primer post-sanding. The least significant factor that affects the peeling rate of the paint film is Didebao primer. The adhesion of the paint film is negatively related to the peeling rate of the paint film, so the least level of every factor is taken as the best finishing process. The most favorable finishing process for paint film adhesion is "Didebao primer-320# sandpaper—PU sealing primer—PU primer twice and NC topcoat once—320# sandpaper".

Table 7. The measured value of adhesion of paint film.

Group	Source	Detect 1	Detect 2	Detect 3	Mean
G1	Paint film off rate	11%	17%	12%	13.3%
	Rating	2	3	2	2
G2	Paint film off rate	5%	8%	10%	7.7%
	Rating	2	2	2	2
G3	Paint film off rate	24%	24%	21%	23.0%
	Rating	3	3	3	3
G4	Paint film off rate	3%	4%	5%	4%
	Rating	1	1	1	1
G5	Paint film off rate	9%	3%	3%	5%
	Rating	2	1	1	1
G6	Paint film off rate	44%	84%	34%	54.0%
	Rating	4	5	2	4
G7	Paint film off rate	2%	1%	1%	1.3%
	Rating	1	1	1	1
G8	Paint film off rate	20%	52%	80%	50.6%
	Rating	3	4	5	4
G9	Paint film off rate	0.5%	5%	0.5%	2%
	Rating	1	1	1	1
G10	Paint film off rate	4%	10%	6%	6.7%
	Rating	1	2	2	2
G11	Paint film off rate	10%	0%	8%	6.0%
	Rating	2	0	2	2
G12	Paint film off rate	1%	36%	0%	12.3%
	Rating	1	4	0	2
G13	Paint film off rate	2%	48%	76%	42%
	Rating	1	4	5	4
G14	Paint film off rate	13%	4%	2%	6.3%
	Rating	3	1	1	2
G15	Paint film off rate	0%	12%	40%	17.3%
	Rating	0	2	4	3
G16	Paint film off rate	5%	10%	0%	5%
	Rating	1	2	0	1

Table 8. Range analysis of the orthogonal experiment of paint film's spalling rate.

Levels	Factors					T Value
	A	B	C	D	E	
I	100.7	102.3	129.6	79.5	70.5	T = 266.9
II	166.2	67	137.3	71.5	64.1	
III	-	27	-	58.2	51.4	
IV	-	70.6	-	57.7	80.9	
R	65.5	76.2	7.7	21.8	29.5	

Orthogonal experiment analysis results show that different factors and levels will impact the adhesion of the paint film. The following will focus on analyzing the influence of various factors on the process of adhesion of the paint film. In order to facilitate the analysis, the relevant data are summarized and presented in the form of graphs, as shown in Figure 4. From the experimental results, whether modified poplar wood is coated with Didebao primer has a greater impact on adhesion. Paint film adhesion is greatly improved by applying the Didebao primer.

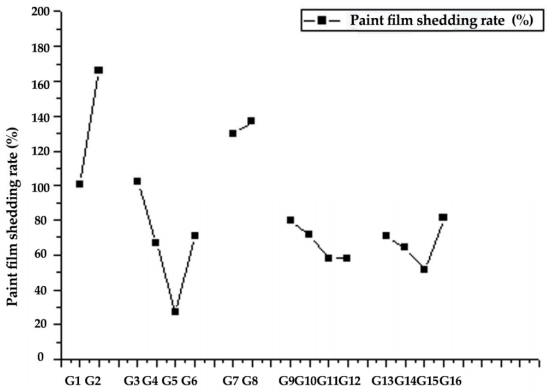


Figure 4. Change trends of factors and levels for the effect of adhesion of paint film.

Whether the modified poplar substrate is coated with Didebao primer, the paint film sanded with 320# sandpaper has the lowest peeling rate. As the type of sandpaper increases, the peeling rate shows a trend of first decreasing and then increasing. Adhesion of paint film is not always positive for surface roughness. Proper surface roughness contributes to the adhesion of paint film [33]. In addition, the peeling rate of the paint film is 76.2, which is the largest among all the factors. It can be seen that surface roughness has the most significant effect on the adhesion of the paint film [24,34]. In the non-transparent process, the PU sealing primer and sandpaper polish are mainly used to make the material surface flat enough. It can pave the way for the adhesion between the paint films in the subsequent painting process. The experimental results show that spraying PU sealing primer reduces the paint film's peeling rate and improves the paint film's adhesion to a certain extent. However, the range of each level is small, indicating that this factor does not greatly influence the adhesion of the paint film. This is because the surface pretreatment in the early stage has made the surface of the modified poplar wood obtain conditions suitable for the adhesion of the paint film.

There are four types of paint technology, which are mainly the combinations of the number of passes of PU primer and NC nitro topcoat. It can be seen from the trend graph that the peeling rate of the paint film after spraying the PU primer twice is significantly lower than the peeling rate of the paint film only spraying the PU white primer once. The PU primer is thicker, the paint film has high hardness and fullness, and the paint film has good sandability. Spraying twice is more conducive to the adhesion of the paint film. The primary function of the NC topcoat is covering, the paint film is thin and the standability is poor. Multiple sprays of NC topcoat have little effect on the adhesion of the paint film.

Sanding between paint films is an important process. Sanding can make the paint film obtain a certain rough surface, which is more conducive to combining the upper paint film. As the type of sandpaper increases, the peeling rate of the paint film decreases first and then increases. The peeling rate is the smallest when sanding with 320# sandpaper. This shows that proper sanding can effectively increase the adhesion between coatings, thereby increasing the overall paint film adhesion.

3.3. Paint Film Mass Loss

Table 9 shows the results of the paint film mass loss test, and Table 10 shows the range analysis results. The factor that has the most significant influence on the total paint film

damage is the type of paint combination (Table 10). The least influential factor is whether to use the Didebao primer. Since the total paint film mass loss is more significant, the wear of the paint film is greater, and the thickness is worse. Therefore, the level corresponding to the minor paint film mass loss among the various factors is taken as the optimal level. Therefore, the optimal process parameter for increasing the paint film mass loss of the paint film is "brushing the Didebao primer—using 320# sandpaper to sand the surface—spraying PU sealing primer—spraying PU primer twice and NC topcoat once + 320# sandpaper for paint coating". In order to analyze the influence of these factors on the paint film mass loss and find out the law, OriginPro 8.0 (2014, Originlab, Northampton, MA, USA) software was used to graphically process the total paint film mass loss value corresponding to each level in Table 10. The results are shown in Figure 5.

Table 9. Measurement of paint film mass loss.

Number	0–100 g/r	100–200 g/r	200–300 g/r	300–400 g/r	400–500 g/r	Total Paint Film Mass Loss g/r
G1	0.041	0.083	0.052	0.052	0.061	0.289
G2	0.047	0.062	0.066	0.065	0.065	0.305
G3	0.035	0.046	0.061	0.053	0.047	0.242
G4	0.050	0.055	0.067	0.065	0.069	0.306
G5	0.050	0.067	0.062	0.066	0.064	0.309
G6	0.033	0.056	0.053	0.047	0.063	0.252
G7	0.045	0.062	0.065	0.059	0.063	0.294
G8	0.040	0.043	0.058	0.066	0.059	0.266
G9	0.052	0.061	0.066	0.061	0.067	0.307
G10	0.030	0.062	0.063	0.064	0.062	0.281
G11	0.039	0.050	0.056	0.053	0.057	0.255
G12	0.044	0.063	0.061	0.050	0.057	0.275
G13	0.047	0.055	0.065	0.068	0.061	0.296
G14	0.049	0.064	0.059	0.057	0.059	0.288
G15	0.056	0.062	0.065	0.050	0.049	0.282
G16	0.027	0.060	0.053	0.061	0.067	0.268

Table 10. Range analysis of the orthogonal experiment of total paint film mass loss.

Levels	Factors					T Value
	A	B	C	D	E	
I	2.246	1.142	2.222	1.201	1.171	
II	2.269	1.121	2.293	1.126	1.064	
III	-	1.118	-	1.073	1.103	T = 266.9
IV	-	1.134	-	1.115	1.177	
R	0.023	0.024	0.071	0.128	0.113	

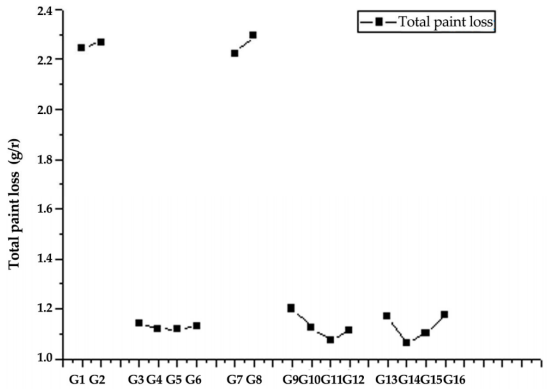


Figure 5. Change trend chart of factor and level for the effect of adhesion of paint film.

Using Didebao primer in the pretreatment stage contributes to the paint film thickness. Total paint film mass loss shows a trend of first decrease and then increase as sandpaper type increases, indicating that the treatment of modified poplar wood in the pretreatment stage has a specific impact on the paint film mass loss. The spread of the paint film on the substrate surface with good performance can strengthen the paint by alleviating the internal

stress of the paint film to a certain extent. PU sealing primer acts as an intermediate medium between the modified poplar wood pretreatment surface and the paint coating, which can seal and fill the wood surface and improve the adhesion of the paint film. Therefore, the sealing primer is used to reduce the mass loss of the paint film. Two passes of PU primer and one pass of NC topcoat will give the paint film the least mass loss. Reducing the number of passes of PU white primer and increasing the number of NC topcoats is not conducive to the mass loss of the paint film. It is necessary to polish the previous topcoat when increasing the NC topcoat. However, the NC transparent topcoat is thin, leading to the lower PU primer being polished. The overall paint film thickness will decrease. The influence of the sanding method of the paint film on the paint film mass loss shows a trend of first decreasing and then increasing in Figure 5, indicating that the paint film surface with appropriate roughness is beneficial to the combination of the different paint films. The internal stress of the overall coating will be reduced, and the mass loss will be reduced.

The above discussion is based on the total paint film mass loss after 500 r abrasion of the paint film. In the actual measurement, the weight is divided five times. If the orthogonal experiment is carried out for each time the paint film mass loss is analyzed, the degree of influence of various factors will be found. In other words, the influences of the coating process on paint film mass loss at the beginning and paint film mass loss at the later stage are different. In order to explore their differences, the orthogonal range of various factors at different stages is counted, and Table 11 is obtained.

Table 11. Measurement of paint film mass loss.

Number of Revolutions	Factors				
	A	B	C	D	E
0–100 r	0.029	0.032	0.029	0.064	0.032
100–200 r	0.023	0.032	0.025	0.066	0.024
200–300 r	0.020	0.025	0.010	0.034	0.028
300–400 r	0.027	0.036	0.030	0.030	0.021
400–500 r	0.028	0.026	0.047	0.009	0.010

With the increase in the number of wear revolutions, the orthogonal range of the paint type continues to decrease. It shows that type of paint has a more significant influence on the mass loss firstly, but as the wear continues, the degree of this effect weakens. Because the first part of the abrasion is the surface paint film, the impact will decrease when the surface paint film is worn out. The effect of sanding of the paint film after paint finishing on the mass loss also shows an increasing trend. The internal influence mechanism is consistent with the type of paint.

In contrast to this, the impact of PU sealing primer on the mass loss of the paint film is increasing because PU sealing primer acts as an intermediate layer. When the paint film is worn too much, PU sealing primer will be resistant to the paint film. As for whether to paint the Didebao primer, the data in the table do not show a certain pattern, and it is probably maintained at the same level, indicating that the effect of the Didebao primer on the mass loss of the paint film is relatively stable.

4. Conclusions

Modified poplar has been used to gradually replace slow-growing wood for its characteristics of rich resources and strong adaptability. This research tried to explore the effect of European and American furniture's painting process applied on modified poplar. An application basis was provided for the extensive use of modified poplar wood as a substrate in the European and American furniture markets. The main conclusions are drawn as follows:

(1) Increasing the number of passes of NC transparent topcoat can increase the gloss of the paint film. The gloss of the paint film is the highest when 400# sandpaper is used for the sanding of the paint film.

(2) Spraying PU sealing primer is beneficial to improve the adhesion of the paint film. The use of two-pass PU primer, one-pass NC topcoat, and 320# sandpaper for inter-film sanding is the most effective way to enhance the overall paint film adhesion. When the modified poplar wood surface is pretreated, the base is painted with Didebao primer and 240# sandpaper is used for sanding, the paint film adhesion improvement is significant.

(3) When the modified poplar wood surface is pretreated, the bottom is painted with Didebao, and 240# sandpaper is used for sanding. The mass loss of the paint film will be reduced mostly. Spraying PU sealing primer is beneficial for reducing the mass loss of the paint film. The use of two-pass PU white primer, one-pass NC transparent topcoat, and 320# sandpaper for inter-film sanding can enhance the overall wear resistance of the paint film. The painting process and coating sanding have a greater impact on the abrasion of the initial paint film. The PU sealing primer has a greater impact on the later abrasion of the paint film. The effect of modified poplar surface pretreatment on the paint film mass loss tends to be stable.

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References

1. Yan, X.; Li, W.; Han, Y.; Yin, T. Preparation of melamine/rice husk powder coated shellac microcapsules and effect of different rice husk powder content in wall material on properties of wood waterborne primer. *Polymers* **2022**, *14*, 72. [CrossRef]
2. Tao, Y.; Yan, X.; Chang, Y. Effect of coating process on mechanical, optical, and self-healing properties of waterborne coating on Basswood surface with MF-coated shellac core microcapsule. *Polymers* **2021**, *13*, 4228. [CrossRef] [PubMed]
3. Salca, E.A.; Krystofiak, T.; Lis, B. Evaluation of selected properties of alder wood as functions of sanding and coating. *Coatings* **2017**, *7*, 176. [CrossRef]
4. Paula, M.H.; Mesquita, R.R.S.; Costa, M.D.; Goncalez, J.C.; Ananias, R.A.; Janin, G. Effect of applying finishing products and sanding on the surface of marupa wood. *Maderas. Cienc. Tecnol.* **2020**, *22*, 45–54. [CrossRef]
5. Hernandez, R.E.; Cool, J. Evaluation of three surfacing methods on paper birch wood in relation to water- and solvent-borne coating performance. *Wood Fiber Sci.* **2008**, *40*, 459–469.
6. Yan, X.; Zhao, W.; Wang, L. Mechanism of thermochromic and self-repairing of waterborne wood coatings by synergistic action of waterborne acrylic microcapsules and fluorane microcapsules. *Polymers* **2022**, *14*, 56. [CrossRef]
7. Yan, X.; Huang, N. Effects of three different types of aloin on optical, mechanical, and antibacterial properties of waterborne coating on Tilia europaea surface. *Coatings* **2021**, *11*, 1537. [CrossRef]
8. Yan, X.X. Effect of different color paste on properties of fluorine resin/aluminum infrared low emissivity coating. *Coatings* **2020**, *10*, 70. [CrossRef]
9. Yan, X.X.; Chang, Y.J. Investigation of waterborne thermochromic topcoat film with color-changing microcapsules on Chinese fir surface. *Prog. Org. Coat.* **2019**, *136*, 105262. [CrossRef]
10. Cakicier, N.; Korkut, S.; Korkut, D.S. Varnish layer hardness, scratch resistance, and golssiness of various wood species as affected by heat treatment. *Bioresources* **2011**, *6*, 1648–1658.
11. Yan, X.X.; Peng, W.W. Effect of microcapsules of a waterborne core material on the properties of a waterborne primer coating on a wooden surface. *Coatings* **2021**, *11*, 657. [CrossRef]
12. Xu, M. Effects of surface roughness and wood grain on the friction coefficient of wooden materials for wood–wood frictional pair. *Tribol. Trans.* **2014**, *57*, 871–878.
13. Li, J. Discussion on the factors affecting the abrasion resistance of paint film. *Shanghai Paint* **2004**, *5*, 34–35.
14. Li, L.H. Adhesion of wooden material polyurethane paint film. *J. Northeast. For. Univ.* **2002**, *30*, 94–96.
15. Kong, X. Research on Influencing Factors of Adhesion of Polyurethane Acrylic Waterborne Wood Coatings. *Paint Ind.* **2010**, *40*, 37–40.
16. Keskin, H.; Atar, M.; Korkut, S.; Tekin, A. Scratch resistance of cellulosic, synthetic, polyurethane, waterborne, and acid-hardening varnishes used on woods. *Ind. Crops Prod.* **2010**, *31*, 219–224. [CrossRef]

17. Amrifan, S.M. Mathematical Modelling of Surface Roughness on Tropical Wood Machining Using Response Surface Methodology. *Appl. Mech. Mater.* **2015**, *815*, 313–317.
18. Alvarez, J.O.; Schechter, D.S. Application of wettability alteration in the exploitation of unconventional liquid resources. *Pet. Explor. Dev. Online* **2016**, *43*, 832–840. [CrossRef]
19. Pan, H.X.; Chen, D. Waterborne Polyurethane Coating and its New Applications in Plush Finishing. *Text. Res. J.* **2009**, *79*, 687–693.
20. Chang, C.W.; Lu, K.T. Epoxy acrylate UV/PU dual-cured wood coatings. *J. Appl. Polym. Sci.* **2010**, *115*, 2197–2202. [CrossRef]
21. Ghosh, M.; Gupta, S.; Kumar, V.S.K. Studies on the loss of gloss of shellac and polyurethane finishes exposed to UV. *Maderas-Cienc. Tecnol.* **2015**, *17*, 39–44. [CrossRef]
22. Pandey, K.K.; Srinivas, K. Performance of polyurethane coatings on acetylated and benzoylated rubberwood. *Eur. J. Wood Wood Prod.* **2015**, *73*, 111–120. [CrossRef]
23. Liu, Q.Q.; Gao, D.; Xu, W. Effect of sanding processes on the surface properties of modifified poplar coated by primer compared with mahogany. *Coatings* **2020**, *10*, 856. [CrossRef]
24. Liu, Q.Q.; Gao, D.; Xu, W. Inflfluence of the Bottom Color Modifification and Material Color Modifification Process on the Performance of Modifified Poplar. *Coatings* **2021**, *11*, 660. [CrossRef]
25. Wang, N. *Research on Surface Properties and Transparent Finishing of Useful Modified Fast-Growing Poplar*; Beijing Forestry University: Beijing, China, 2013.
26. Zhou, T.T. *Study on the Treatment and Coating Performance of the Metal Base of the Material*; Nanjing Forestry University: Nanjing, China, 2011.
27. Ayrilmis, N.; Candan, Z. Effect of sanding on surface properties of medium density fiberboard. *Drv. Ind.* **2010**, *61*, 175–181.
28. Faust, T.D.; Rice, J.T. Effect of venner surface roughness on gluebond quality in southern pine olywood. *For. Prod. J.* **1986**, *35*, 57–62.
29. Maziar, S.M. Wettability and swelling of acetylated and furfurylated wood analyzed by multicycle Wilhelmy plate method. *Holzforschung* **2016**, *70*, 69–77.
30. Silje, R. Fracture mechanical testing of adhesion of organic coatings on aluminium. *Mater. Sci. Forum* **2016**, *519*, 655–666.
31. Meng, S. *Study on Finishing and Aging Properties of Hydroxymethyl Resin Modified Wood*; Northeast Forestry University: Harbin, China, 2014.
32. Hao, D.E. *Study on Ultra-High Temperature Heat Treatment of Poplar Wood*; Nanjing Forestry University: Nanjing, China, 2008.
33. Li, R.; Alizadeh, A.; Shang, W. Adhesion of liquid droplets to rough surfaces. *Phys. Rev. E* **2010**, *82*, 4. [CrossRef]
34. Liu, D.L.; Martin, J.; Burnham, N.A. Which Fractal Parameter Contributes Most to Adhesion? *J. Adhes. Sci. Technol.* **2010**, *24*, 2383–2396. [CrossRef]