

Article

Effect of Paint Process on the Performance of Modified Poplar Wood Antique

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; 03211qq@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.: +86-025-8542-7459

Abstract: Modified poplar wood is used as the substrate, based on the surface coating process and actual operation requirements of European and American furniture, and the painting process is studied. Four different paint coating methods are applied to modified poplar wood that has undergone different surface pretreatments. The gloss and adhesion of the coating system were measured. The difference in paint film performance of different paint finishes on the modified poplar with different surface pretreatments was discussed. The reasons were analyzed to establish the corresponding relationship between wood surface performance and paint film performance and obtain the best coating process parameters. The number of passes of nitrocellulose (NC) transparent primer was appropriately increasing, and the adhesion of the overall paint film was improved through the bonding between the films after sanding. NC transparent primer has the function of weakening the surface gloss. NC transparent topcoat has the effect of improving gloss. The proper use of PU sealing primer is beneficial to improve the gloss of the paint film, but excessive use will not produce any effect. The paint process of Group C is more suitable for the antique, old-fashioned process of European and American furniture from the perspective of the glossiness of the paint film.



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Keywords: modified poplar; material color modification; bottom color modification; distressing

1. Introduction

The paint process in the finishing of European and American furniture not only provides a firm protective layer on the surface of the furniture, but also an important form of load-bearing for the beautiful surface [1–3]. In the antique distressing process, the use of paint is a way of expressing the distressed effect of the coating [4–6]. It cooperates with the color layer and works together to finally make the surface of European and American furniture show the antique distressed effect [7,8]. In the production of antique painting, the bottom color modification must be prepared first, and the bottom color modification is the first overall coloring of the surface of the furniture [9]. Two coloring substances are often used, commonly known as “red water” and “yellow water” [10]. After the bottom color modification repair, the polyurethane (PU) sealing primer is applied, which can firmly fix the base color and lay a solid foundation for the entire subsequent paint job. This kind of paint is thin but harder and can form a dense film on the surface of the substrate. After polishing, the subsequent paint can adhere to the substrate well. In the actual European and American finishing antique production, nitrocellulose (NC) lacquer is also needed after finishing the sealing primer. The nitrocellulose lacquer has the characteristics of fast-drying, hard and wear-resistant, good recoatability, high gloss, good transparency, and short production cycle. Nitro-based primer and nitro-based topcoat are used in the production of antique finishing, both of which are transparent paints [11–15]. Paint is a general term, including primer and topcoat. The primer is a liquid with a certain viscosity composed of film-forming substances, fillers, solvents, and additives, while the topcoat is composed of a transparent topcoat and color essence. Generally, it is a clear, transparent

liquid with a certain brightness. As an auxiliary paint for the topcoat, the primer is the first layer of the paint system [16]. It is used to fill the paint surface, support the topcoat, and protect the front color. It has good sanding and film feel. The topcoat is the last layer of paint, which makes the product have a certain degree of gloss and good transparency.

The primary consideration for comprehensive evaluation of coating effects is the internal properties of the paint layer, including adhesion and hardness. The second is the appearance performance of the paint film, mainly color, gloss, and so on. Paint film adhesion is an intrinsic property, which refers to the bonding strength due to the interaction between the coating and the substrate. Fast-growing poplar not only has the advantages of light color, long fiber, less resin, and easy bleaching, but also has the disadvantages of soft material, poor dimensional stability, low hardness, and non-abrasion resistance. Therefore, the ultimate goal of fast-growing poplar modification is to improve practical performance, enhance its various properties, enhance its application value, and expand the scope of application. The research results of Coelho et al. [17] showed that varnish types and polishing levels significantly affect the surface quality of pine and beech, while sanding levels have little effect on the surface quality of pine and beech. Ugulino et al. [18] studied the influence of the process parameters of Peripheral planing on the coating performance and determined that the peripheral planing parameters suitable for the surface of red oak are a rake angle of 25° and a short or medium wavelength. It provides a reference for other scholars to study the influence of other planing parameters on coating performance. Ugulino et al. [19] studied the effect of particle size and feed rate on the peel adhesion of red oak surface coating properties. The results show that the impact of sand size and feed speed on pull-off adhesion is significant. Moreover, the best process parameters for red oak processing under different conditions were obtained. Effect of coating process on the performance of reversible thermochromic water-based coatings on the surface of fir was studied by Yan et al. [20]. Experiments have proved that the most critical factor affecting the color difference and gloss of the coating is the method of adding thermochromic ink. The coating process has little effect on the coating adhesion, impact resistance addition, liquid resistance, and the original performance of the coating. The effect of plasma treatment on the adhesion of water-based paint films was studied by Peng et al. [21]. The results show that plasma treatment can significantly reduce the water contact angle on the surface of the experimental material and increase its surface roughness. In addition, plasma modification is conducive to the spreading, adsorption, and adhesion of water-based coatings on the surface of the material.

In order to improve the intrinsic performance and appearance of fast-growing poplar, give full play to the performance advantages of fast-growing poplar, and explore the effective and reasonable application of modified fast-growing poplar in furniture products, the difference in paint film performance of the four different paint finishing methods on the modified poplar with different surface pretreatments is discussed. Whether the modified poplar wood is also suitable for conventional paintwork is the main aim of the research. Through the differentiated treatment of the four paint methods, a better coating method was explored through comparison.

2. Materials and Methods

2.1. Materials

Didebao primer was provided by Mingshida Co., Ltd. (Tai'an, China). The modified poplar (sawed transversely, size 150 mm × 80 mm × 20 mm, diameter section) were provided by Jiayue Wood Industry Co., Ltd. (Dezhou, China). The specific steps of poplar modification were as follows. First, the poplar wood was processed into several small pieces with a size of 150 mm × 80 mm × 20 mm. Then, a modifier for modifying poplar was prepared. The modifier was a mixture of urea dissolved in water and antimony trioxide dissolved in glacial acetic acid. Then, the poplar block was put into the modifier (liquid) for 4 h. This process must ensure that the wood chips are under a pressure of 3.0 MPa under vacuum. Finally, the modified poplar block was placed in an oven at 90 °C

for 24 h to ensure that the modified poplar reached an equilibrium moisture content of 8.0%. PU sealing primer 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 1:0.5–1:0.5–1.5 (solid content of 50%). NC transparent finish and NC transparent primer was provided by Caideli Chemical Products Co., Ltd. (Huizhou, China). Nitrolacquer is based on nitrocellulose as the main body, combined with alkyd resin or acrylic resin, rosin resin, plasticizer, and mixed solvent (solid content of 30%). Red paint water and yellow paint water were provided by Bixiang Wood Co., Ltd. (Ganzhou, China). The main components of red paint water were 4.35% disperse red 3B, 26.09% N-dimethylformamide, 34.8% cyclohexanone, 30.41% butyl acetate, and 4.35% Q22-1 nitro varnish (provided by Bixiang Wood Co., Ltd., Ganzhou, China). The main components of yellow paint were 4.48% dispersible yellow RGFL, 29.85% N-dimethylformamide, 41.79% cyclohexanone, and 23.88% butyl acetate ester. The 180 #, 240 #, 320 #, and 400 # wet/dry sandpapers were provided by Feili Co., Ltd. (Xianning, China).

2.2. Preparation of Sample

The specific preparation of samples was as follows: first, the poplar modified large plate was sanded by a wide belt sander (120 #), in which the wide side was sanded 3 times, and the narrow side was sanded 2 times. Then the 4 sides and 4 flutes were sanded by a square oscillating sander (180 #). Finally, the test piece of 150 mm × 80 mm × 20 mm was cross-cut. The temperature was 18–25 °C, and the humidity was 40–70%. To ensure the same “coating amount” of the test piece, the coating method adopted the spray gun “vertical gun”, and the spray gun air pressure was controlled to 0.5 MPa. The nozzle paint output was 200 mL/min, and the spray width was 180 mm. The spraying distance was 200 mm, and 1 spray was a “cross gun”. The modified poplar specimens were divided into 4 groups, each using 4 different paint processes, the specifications of the specimens were all 150 mm × 80 mm × 20 mm, and the surface treatment and fabrication were shown in Tables 1–4. Specimens 1–6 were mainly used to study the effect of different pretreatment methods on the coloring. To compare different angles and aspects, in the production process of specimens 1–6, the method of partition coloring was creatively adopted.

Table 1. The manufacture of specimens for Group A.

Number	Specific Description of Paint Process
A1	no Didebao primer—no sanding—bottom color modification—twice PU sealing primer—twice NC transparent finish
A2	Didebao primer—no sanding—bottom color modification—twice PU sealing primer—twice NC transparent finish
A3	Didebao primer—180 # sanding—bottom color modification—twice PU sealing primer—twice NC transparent finish
A4	Didebao primer—240 # sanding—bottom color modification—twice PU sealing primer—twice NC transparent finish
A5	Didebao primer—320 # sanding—bottom color modification—twice PU sealing primer—twice NC transparent finish
A6	Didebao primer—400 # sanding—bottom color modification—twice PU sealing primer—twice NC transparent finish

Table 2. The manufacture of specimens for Group B.

Number	Specific Description of Paint Process
B1	no Didebao primer—no sanding—bottom color modification—once PU sealing primer—once NC transparent primer—twice NC transparent finish
B2	Didebao primer—no sanding—bottom color modification—once PU sealing primer—once NC transparent primer—twice NC transparent finish
B3	Didebao primer—180 # sanding—bottom color modification—once PU sealing primer—once NC transparent primer—twice NC transparent finish
B4	Didebao primer—240 # sanding—bottom color modification—once PU sealing primer—once NC transparent primer—twice NC transparent finish
B5	Didebao primer—320 # sanding—bottom color modification—once PU sealing primer—once NC transparent primer—twice NC transparent finish
B6	Didebao primer—400 # sanding—bottom color modification—once PU sealing primer—once NC transparent primer—twice NC transparent finish

Table 3. The manufacture of specimens for Group C.

Number	Specific Description of Paint Process
C1	no Didebao primer—no sanding—bottom color modification—once PU sealing primer—twice NC transparent primer—once NC transparent finish
C2	Didebao primer—no sanding—bottom color modification—once PU sealing primer—twice NC transparent primer—once NC transparent finish
C3	Didebao primer—180 # sanding—bottom color modification—once PU sealing primer—twice NC transparent primer—once NC transparent finish
C4	Didebao primer—240 # sanding—bottom color modification—once PU sealing primer—twice NC transparent primer—once NC transparent finish
C5	Didebao primer—320 # sanding—bottom color modification—once PU sealing primer—twice NC transparent primer—once NC transparent finish
C6	Didebao primer—400 # sanding—bottom color modification—once PU sealing primer—twice NC transparent primer—once NC transparent finish

Table 4. The manufacture of specimens for Group D.

Number	Specific Description of Paint Process
D1	no Didebao primer—no sanding—bottom color modification—3 times NC transparent primer—once NC transparent finish
D2	Didebao primer—no sanding—bottom color modification—3 times NC transparent primer—once NC transparent finish
D3	Didebao primer—180 # sanding—bottom color modification—3 times NC transparent primer—once NC transparent finish
D4	Didebao primer—240 # sanding—bottom color modification—3 times NC transparent primer—once NC transparent finish
D5	Didebao primer—320 # sanding—bottom color modification—3 times NC transparent primer—once NC transparent finish
D6	Didebao primer—400 # sanding—bottom color modification—3 times NC transparent primer—once NC transparent finish

Group A: after the first coat of PU sealing primer was sprayed, it was placed in the drying room for more than 12 h, 320 # sandpaper was used for hand sanding, and then conducted the second coat of PU primer. After spraying the first pass of NC topcoat, it was placed in a 60 °C dust-free drying room for more than 3 h, hand sanded with 400 # sandpaper, and then the second pass of NC topcoat spraying was carried out.

Group B: after spraying the PU sealing primer for the first time, it was placed in the drying room for more than 12 h, 320 # sandpaper was used for hand sanding, and then the NC primer was sprayed. As for the drying room for more than 3 h, 320 # sandpaper was used for hand sanding. Then, the NC topcoat was sprayed, it was placed in a 60 °C dust-free drying room for more than 3 h, hand sanded with 400 # sandpaper, and then the second NC topcoat spraying was carried out.

Group C: after spraying the PU sealing primer for the first time, it was placed in the drying room for more than 12 h, 320 # sandpaper was used for hand sanding, and then the NC primer was sprayed. As for 60 °C drying room for more than 3 h, 320 # sandpaper was used for hand sanding, and then the second coat of NC primer was carried out. After it was dried at 60 °C for more than 3 h, the NC topcoat was sprayed.

Group D: after each spraying of the NC primer, it needed at least 3 h to dry at 60 °C, and 320 # sandpaper was used to polish by hand before next spraying.

2.3. Testing and Characterization

The measuring equipment for the glossiness test of paint film was the photoelectric gloss meter GZ-II. The zero points of the meter should be calibrated before use. Firstly, the power was turned on, then the selector switch was pulled to 140%, and the machine needed to be warmed up for 10 min. Secondly, the probe was placed on the surface of the experimental material that needed to be measured, and 3 places were found at random to measure, and the average value was taken. It should be noted that if the gloss was lower than 70%, the switch was turned to 70%, re-calibration, and the test was performed. The measurement method was as follows: first, the wood texture was measured parallel. The gloss agent was put parallel to the texture. After the pointer was stable, the data were read and recorded. Then, the measurement was performed perpendicular to the wood texture. The gloss agent was placed in a position perpendicular to the texture, and the data were read and recorded after the pointer was stabilized. Each direction was measured 3 times to reduce the error, and the average value was taken as the gloss value in each direction. The test results of each group of specimens are shown in Tables 5–8.

Measuring equipment of test and analysis of paint film adhesion was a combination tool for blade adhesion test. In this experiment, a single blade with stronger operability was mainly used for the cutting experiment of the paint film. The blade with a thinner blade was primarily used; a rigid ruler was used for straight cutting, and the distance between the cutting lines was controlled. Adhesive scotch tape was used for the adhesion and tearing of the paint film after cutting. The measurement method was as follows: a single-edged blade was used to cut the paint film along a 45° direction to the wood grain. When cutting, it must be guided by a ruler to ensure a straight knife. The blade should be penetrated into the substrate to ensure that the paint film was completely cut through. Six parallel cuts with a spacing of 2 mm were made for each cut, and then 6 cuts along the perpendicular direction were made. After the cut was completed, a soft brush was used to sweep away the paint film debris gently. The scotch tape was used along the line closely to adhere to the cut grid in the direction of the cut mark, and the tape was torn off quickly. A magnifying glass was used to observe and record, and the peeling rate of the paint film was calculated and counted. Three places were selected for each test piece to conduct the adhesion test and calculate the average value [22]. The measurement results are shown in Tables 9–12. There was a peeling paint film on the transparent tape. The tape with the paint film was attached to the transparent plastic sheet to facilitate statistics and observation, as shown in Figure 1.



Figure 1. Transparent adhesive tape with paint film (Group B).

3. Results and Discussion

3.1. Glossiness of Paint Film

The glossiness test results of each group's specimens are shown in Tables 5–8. The vertical incident glossiness (GZT) (%) of the A3–A6 specimens have no obvious rising and falling trend. The parallel incident glossiness (GZL) (%) value of the B3–B6 specimens gradually increased. The GZT (%) value of the B3–B6 specimens gradually increased. The GZT (%) value of C3–C6 specimens gradually decreased. The GZL (%) value of the D3–D6 specimens gradually increased. The GZT (%) value of the D3–D6 specimens gradually increased. The above analysis was an intuitive description of the gloss value of the paint film of each group of specimens, but the relationship between them was not clear. The GZL (%) and GZT (%) of each group of specimens are shown in Figures 2 and 3.

Table 5. The measured value of gloss for Group A.

Number		A1	A2	A3	A4	A5	A6
GZL (%)	Value	36.5	30.5	37.5	27.0	35.0	25.0
		33.5	30.0	36.5	27.5	34.0	24.5
		34.5	29.5	35.5	28.5	33.5	25.5
	Mean	34.8	30.0	36.5	27.7	34.2	25.0
Range		3.0	1.0	2.0	1.5	1.5	1.0
GZT (%)	Value	35.5	29.5	35.0	26.0	37.5	26.0
		36.0	31.0	33.5	26.5	37.5	25.5
		36.0	30.5	33.0	26.5	36.0	26.5
	Mean	35.8	30.3	33.8	26.3	37.0	26.0
Range		0.5	1.5	2.0	0.5	1.5	1.0
GZL/GZT	GZB	0.97	0.99	1.08	1.05	0.92	0.96

Table 6. The measured value of gloss for Group B.

Number		B1	B2	B3	B4	B5	B6
GZL (%)	Value	34.5	34.5	34.5	38.5	39.5	41.0
		36.5	36.5	35.5	35.0	38.5	39.5
		36.0	33.5	36.5	37.5	36.5	39.5
	Mean	35.7	34.8	35.5	37.0	38.5	40.0
	Range	2.0	3.0	0.5	3.5	6.0	1.5
GZT (%)	Value	39.5	36.0	38.5	39.5	40.0	40.0
		36.0	31.5	32.5	37.5	37.5	40.5
		37.5	32.0	36.5	38.0	39.5	41.0
	Mean	37.7	33.2	35.8	38.3	39.5	40.5
	Range	3.5	4.5	6.0	2.0	3.5	1.0
GZL/GZT	GZB	0.95	1.05	0.99	0.97	1.04	0.99

Table 7. The measured value of gloss for Group C.

Number		C1	C2	C3	C4	C5	C6
GZL (%)	Value	28.5	24.0	40.0	36.0	22.0	18.0
		25.5	25.0	42.0	35.5	22.0	21.5
		26.5	24.5	37.5	35.0	23.5	22.5
	Mean	27.2	24.5	39.8	35.5	22.5	20.7
	Range	2.0	1.0	4.5	1.0	1.5	4.5
GZT (%)	Value	35.0	27.5	46.0	42.5	22.5	20.5
		22.5	25.5	40.0	40.0	21.5	19.0
		34.5	35.5	48.5	42.0	21.0	21.5
	Mean	30.7	29.5	44.8	41.5	22.5	20.3
	Range	12.5	10.0	8.5	2.5	7.0	2.5
GZL/GZT	GZB	0.89	0.83	0.89	0.86	1.14	1.02

Table 8. The measured value of gloss for Group D.

Number		D1	D2	D3	D4	D5	D6
GZL (%)	Value	28.0	36.5	40.0	35.5	40.0	38.5
		28.5	37.5	37.5	38.5	37.5	40.5
		26.5	35.5	34.5	40.0	39.0	39.5
	Mean	27.7	36.5	37.3	38	38.5	39.5
	Range	2.0	0.0	5.5	4.5	6.0	3.5
GZT (%)	Value	30.5	33.5	36.5	38.0	36.5	41.5
		33.0	34.5	35.0	38.5	38.5	38.5
		30.5	35.5	34.5	35.5	39.0	35.5
	Mean	31.3	34.5	35.3	37.3	38.0	38.5
	Range	2.5	9.0	2.0	2.0	2.0	6.0
GZL/GZT	GZB	0.88	0.97	1.06	0.99	1.01	0.96

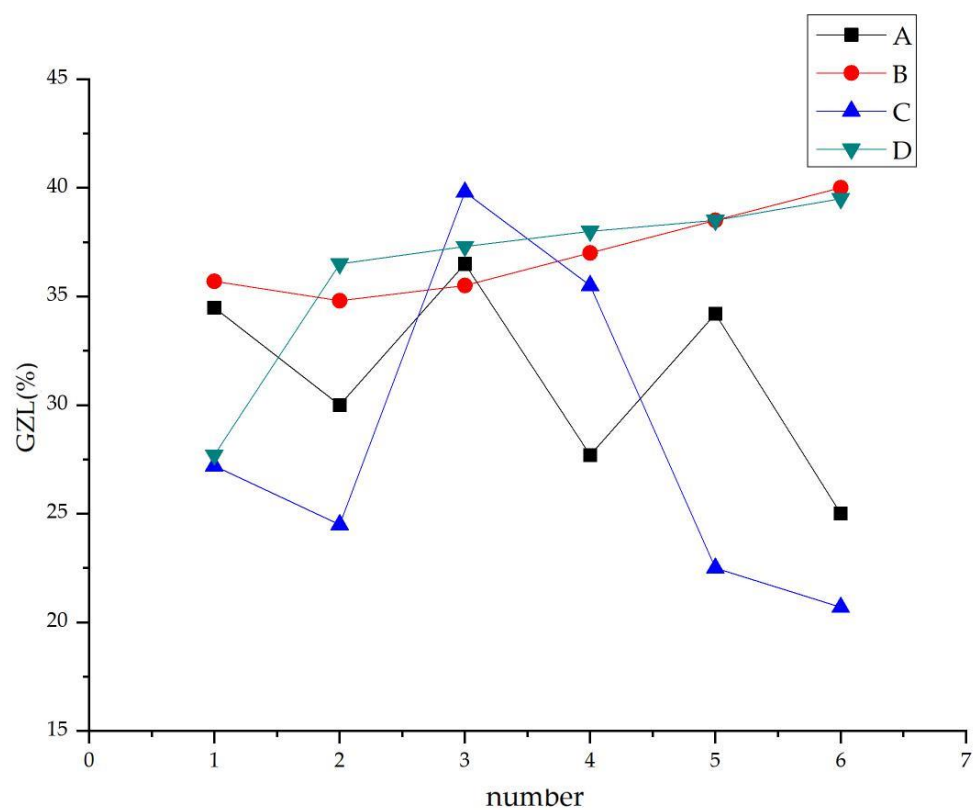


Figure 2. GZL of test pieces of each group.

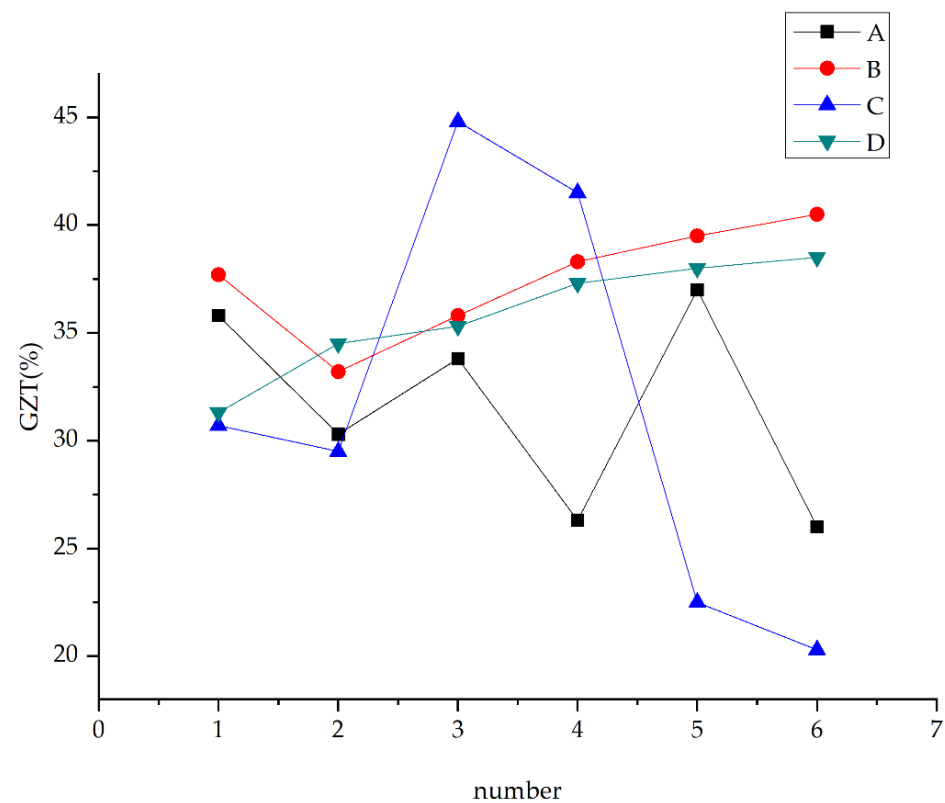


Figure 3. GZT of test pieces of each group.

The scatter curves of the two graphs seem complicated, but there are some regular features. Now the chart was divided into three parts for analysis. The first part is the No. 1 to No. 2 specimens, the second part is the No. 2 to No. 3 specimens, and the third part is the No. 3 to No. 6 specimens. The reason for this classification is that the difference between No. 1 and No. 2 specimens is whether the Didebao primer is painted in the pretreatment stage, and the difference between the No. 2 and No. 3 specimens is whether the Didebao primer is polished after the pretreatment stage. The model of sandpaper used for sanding of No. 3 to No. 6 was gradually increasing.

First, the first part of the broken line was analyzed, that is, the gloss value of the No. 1 and No. 2 specimens. The GZL (%) and GZT (%) of the paint films of Group A, Group B, and Group C, all had a downward trend, and only the value of Group D appeared to have an upward trend. The second part of the broken line was the gloss value of No. 2 and No. 3 specimens, the paint film GZL (%) and GZT (%) of Group A, Group B, Group C, and Group D had an upward trend. Finally, there was the third part of the broken line. The gloss value of Group A had no evident change in trend. The GZL (%) and GZT (%) values of the paint film of groups B and D were on the rise, and the GZL (%) and GZT (%) values of Group C showed a downward trend. From Figures 2 and 3, we can also see that the GZL (%) value and substitution of the paint film appeared in the Group C specimens.

The difference in the pretreatment stage between No. 1 and No. 2 specimens was that the No. 1 sample had not undergone any treatment, while the No. 2 sample was coated with a layer of Didebao on its surface. The common point of Group A, Group B, and Group C was that they all used PU sealing primer as the first paint, while the first spray paint of the modified poplar wood specimen of Group D was NC transparent primer. The role of PU sealing primer, as the name suggests, is to play a sealing role on the surface of the material because PU paint has high fullness, good permeability, hard paint layer, and can well fill small gaps in the wood. However, the fullness of the NC transparent primer is not high, and the paint layer is relatively thin, which cannot play a good sealing effect on the surface of the material. Therefore, after the A, B, and C groups were repainted and sprayed on the surface with good sealing properties, the swarf effect of Didebao had little effect on the surface, and the surface gloss increased. In contrast, the paint film of the Group B specimens was thinner and the surface was rougher, the swarfing effect of the Didebao cannot be ignored, thus the surface gloss was reduced. Thus, it can be seen that the PU sealing primer was beneficial to improve the gloss of the modified poplar surface paint film.

The No. 2 specimen was only painted with the Didebao without sanding. After the No. 3 specimen was painted with the Didebao, it was sanded with 180 # sandpaper, which shows that the overall surface roughness of the No. 3 specimen was less than the No. 2 specimen. The GZL (%) and GZT (%) of No. 3 specimens in Group A, Group B, Group C, and Group D were greater than those of the No. 2 specimens. The above analysis indicates that the surface roughness of modified poplar has a certain effect on the paint film's gloss, but the specific impact is still unclear.

After the No. 3 to No. 6 specimens were painted with Didebao, they were sanded with different kinds of sandpaper. Liu et al. [23] found that the depth parameters of surface roughness of modified poplar decreased with the increase of the number of sanding paper, and the density parameter of surface roughness (S_m , the average spacing of micro unevenness of contour) decreased at first and then increased, the surface wettability also decreased first and then increased. There was no apparent regularity in the glossiness of the paint film of No. 3 to No. 6 specimens in Group A. This is because Group A had been coated with PU sealing primer twice thus that the surface properties of modified poplar wood had little effect on the glossiness of the paint film. Moreover, the gloss of the paint film was greatly affected by other factors. The gloss of No. 3 to No. 6 specimens in Group B and Group D gradually increased, indicating that the gloss of the paint film was affected by the surface roughness properties of modified poplar wood with these two paint processes, and there was a positive correlation. The gloss of the paint film under the painting process

of Group C was unique and showed a decreasing trend. By comparing the painting process of Group B and Group C, it can be seen that Group B was coated with NC primer once, NC transparent finish twice, and Group C was coated with NC primer twice, NC transparent finish once. Because NC primer has better light-shielding performance, the smoother the surface of the material, the better the light-shielding effect of NC primer, which reduces the gloss of the paint film. Although Group D used the NC primer three times, it did not affect the PU sealing. The paint film was thinner, and the gloss of the paint film was primarily dominated by the roughness of the material [24].

From this, the following conclusions were drawn: the surface gloss of the paint film was affected by the surface roughness of the modified poplar wood, and the way and extent of the effect were restricted by the painting process. The proper use of PU sealing primer can improve the surface properties of the material, thereby increasing the gloss of the paint film, but excessive use will not produce any effect. NC transparent primer has the function of weakening the surface gloss. When the surface roughness and wettability of the modified poplar wood is better, the weakening effect is more obvious. NC transparent topcoat has the effect of improving gloss, but the effect of repeated use is not obvious. Since the antique distressing process has a controllable and low level of gloss on the surface of the paint film, the painting process of Group C is more suitable for the antique distressing process of European and American furniture from the perspective of the gloss of the paint film.

3.2. Test and Analysis of Paint Film Adhesion

Tables 9–12 show the measured values of paint film's adhesion for Groups A–D.

Table 9. The measured value of adhesion of paint film for Group A.

A1	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	0%	2%	3%	1.6%
Rating	0	1	1	1
A2	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	0%	0%	0%	0%
Rating	0	0	0	0
A3	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	0%	0%	0%	0%
Rating	0	0	0	0
A4	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	0%	0%	0%	0%
Rating	0	0	0	0
A5	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	0%	0%	0%	0%
Rating	0	0	0	0
C6	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	0%	2%	2%	2.0%
Rating	0	1	1	1

Table 10. The measured value of adhesion of paint film for Group B.

B1	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	92%	6%	65%	54.3%
Rating	5	2	5	4
B2	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	10%	11%	16%	12.3%
Rating	2	2	3	2
B3	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	10%	10%	8%	9.3%
Rating	2	2	2	2
B4	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	9%	9%	8%	8.7%
Rating	2	2	2	2
B5	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	15%	7%	8%	10.0%
Rating	3	2	2	2
B6	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	5%	8%	7%	9.7%
Rating	1	2	2	2

Table 11. The measured value of adhesion of paint film for Group C.

C1	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	12%	16%	18%	15.3%
Rating	2	3	3	3
C2	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	8%	9%	8%	8.7%
Rating	2	2	2	2
C3	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	3%	0%	4%	2.3%
Rating	1	0	4	1
C4	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	1%	0%	0%	0.3%
Rating	1	0	0	1
C5	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	5%	4%	3%	4.0%
Rating	1	1	1	1
C6	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	6%	7%	4%	5.7%
Rating	2	2	1	2

Table 12. The measured value of adhesion of paint film for Group D.

D1	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	100%	2%	20%	40.6%
Rating	5	1	3	4
D2	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	4%	8%	8%	10.0%
Rating	1	2	2	2
D3	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	8%	5%	8%	7.0%
Rating	2	2	2	2
D4	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	7%	6%	5%	6.0%
Rating	2	2	2	2
D5	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	9%	7%	5%	7.7%
Rating	2	2	2	2
D6	Detect 1	Detect 2	Detect 3	Mean
Paint Film off Rate	10%	9%	6%	8.3%
Rating	2	2	2	2

The above results are now summarized in simple data for further research (Table 13). After the modified poplar of Group A was painted, the paint film peeling rate was generally not high, the minimum was 0, the maximum was 2% of the No. 6 specimen, and the difference was 2%. After the modified poplar of Group B was painted, the maximum peeling rate was 54.3% of the No. 1 specimen, and the minimum was 8.6% of the No. 4 specimen, and the difference was 45.7%. Among the test pieces of Group C, the paint film peeling rate of No. 1 specimen was the largest, which was 15.3%, and the smallest was 4% of No. 4 specimen, and the difference was 11.3%. Among the specimens of Group D, the maximum paint film peeling rate was still No. 1 piece, which was 40.6%, and the minimum paint film peeling rate was also No. 4 piece, which was 7.6%, with a difference of 33%. The above analysis shows that, except for Group A, the maximum paint film peeling rate appeared in the No. 1 specimen, while the minimum paint film peeling rate occurred in the No. 4 specimen in the four groups.

Firstly, the effect of the surface pretreatment performance of modified poplar wood on the adhesion of the paint film was analyzed. Specimens 1–6 were divided into two parts to consider. From part 1 to part 2, the paint film peeling rate of the four groups decreased, indicating that the surface paint film adhesion of the No. 2 specimen after finishing the Didebao primer was significantly improved. This is because the surface roughness and surface activity of the No. 2 specimen was increased, and Didebao improves the penetration of the paint and strengthens the bond with the paint molecules, and the adhesion of the paint film is naturally increased. The surface roughness and depth of specimens No. 2 to No. 6 continued to decrease, the roughness density first decreased and then increased, and the surface wettability also first decreased and then increased. It can be seen from Figure 4 that in addition to Group A, the paint film shedding rate of the specimens of Group B, Group C, and Group D showed a trend of first decreasing and then increasing from No. 2 specimen to No. 6 specimen, and all reached the minimum at the position of the No. 4 specimen. This is consistent with the trend of the surface roughness and compactness of the modified poplar and the wettability of the contact angle between water and glycerol. It means that the smoother the surface of the modified poplar wood, the greater the adhesion of the paint film. Appropriate surface roughness is conducive to the enhancement of paint film adhesion. In addition, the superior wettability and strong activity of the material surface are also conducive to the combination of paint film and material. When the surface

of the modified poplar is too rough, the paint molecules cannot penetrate into the tiny pores and combine with it. Some wood fibers with larger peaks may pierce the paint film, causing the paint film surface to be uneven and blistering. It will have a great impact on the adhesion of the paint film. When the surface is too smooth, the contact area between the oil molecules and the material will be reduced, which is not conducive to the improvement of the adhesion of the paint film. Therefore, proper roughening of the modified poplar wood treated with Didebao can make the paint film better adhere to the material's surface. On the other hand, the surface activity of the modified poplar also has a great influence on the adhesion of the paint film. If the paint coating is to be spread on the material to form a paint film, its surface free energy cannot be greater than the surface free energy of the material. Increasing the surface free energy of the material and reducing the surface tension are effective methods to improve the adhesion of the paint film.

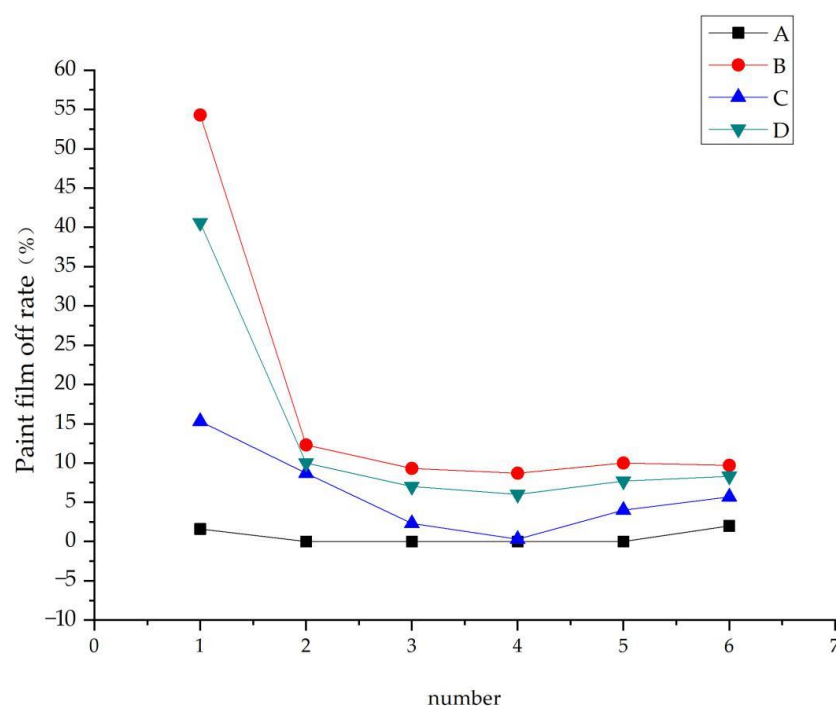


Figure 4. Paint film off rate of each group.

In order to make the results more intuitive, the data were processed through the software OriginPro 8.0, and the results of different paint processes on the adhesion of the paint film are shown in Figure 4.

Table 13. The measured value of adhesion of paint film for groups.

Number	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6
Group A	1.6%	0.0%	0.0%	0.0%	0.0%	2.0%
Group B	54.3%	12.3%	9.3%	8.6%	10.0%	9.6%
Group C	15.3%	8.6%	2.3%	0.3%	4.0%	5.3%
Group D	40.6%	10.0%	7.0%	6.0%	7.6%	8.3%

It can be seen from Figure 4 that the curves of Group B are at the top, Group D and Group C are at the bottom, and the curves of Group A are at the bottom. This shows that the paint film peeling rate of the A paint process was the lowest, and the paint film adhesion was the best, followed by the paint film adhesion of Group C, the paint film adhesion of the Group D was the second, and the paint film adhesion was the worst in Group B. The surface of modified poplar wood specimens of Group A was sprayed with PU sealing

primer twice and then with NC transparent topcoat twice. Because the PU sealing primer is thicker and has a good bond with the material treated by Didebao primer, the paint film adhesion has obvious advantages compared with the other three groups, although the twice NC transparent topcoat does not adhere well to the upper layer. The painting process of the modified poplar wood specimens of Group C and the modified poplar wood specimens of Group B are compared. The two groups both use PU sealing primer. The difference is that the follow-up process of Group C is two passes of NC transparent primer and one pass of NC Transparent topcoat, and the follow-up process of Group B is one pass of NC clear primer and two passes of NC clear topcoat. The solid content of the NC primer is higher than that of the topcoat, and the sanding performance of the primer is better. The primer can produce a good bonding force after sanding, and the function of the topcoat is mainly surface protection and improvement. The bonding force between the topcoats after sanding was relatively poor. Therefore, the paint film adhesion of Group C was greater than that of Group B. In the same way, although Group D did not have PU sealing primer as the first paint, it was coated with NC primer three times, and the bonding between the primers was sanded, thus the adhesion performance of the overall paint film was improved. Compared with adding PU sealing paint and NC primer once of Group B, Group D has advantages.

It can be concluded that when PU sealing primer is used as the first primer, its thick, hard, and highly permeable characteristics lay a good foundation for the overall paint process. The number of passes of NC transparent primer was appropriately increasing, and the adhesion of the overall paint film was improved through the bonding between the films after sanding. NC transparent finish does not have much effect on improving the adhesion of the paint film. PU sealing primer is used as the first primer. Its thick, hard, and highly permeable characteristics lay a good foundation for the overall paint process. When the number of passes of NC transparent primer was appropriately increasing, the adhesion of the overall paint film is improved through the bonding between the films after sanding. The NC transparent finish has little effect on improving the adhesion of the paint film.

The results of GZT, GZL, and adhesion tests were assessed in terms of the statistical significance of the different finishing processes and sandpaper model for the coating [25]. The non-repeated two-way analysis of variance (ANOVA) method was used for significance analysis. The analysis of variance at a significance level of 0.05 was performed to detect significant differences in coating properties.

Tables 14–16 show the significant difference analysis of different finishing processes and sandpaper model. In Tables 14–16, SS refers to the sum of squares of the sample data, d_f is the degree of freedom, MS is the ratio of SS to d_f , and MS refers to the average sum of squares of the sample data. F is the value of the F statistic, which is a coefficient indicating correlation. The P-value was used to determine whether a factor was significant. F_{crit} represents the F value of the corresponding significance level [26]. When F_{crit} is greater than F, there is no difference between the two sets of data. The criterion for judging the significance of the difference is that if $0.01 < P_{value} < 0.05$, the difference was significant. If $P_{value} \leq 0.01$, the difference was very significant. If $P_{value} > 0.05$, there was no difference.

Table 14. Significance analysis of GZT.

Difference Source	SS	d_f	MS	F	P _{value}	F _{crit}
Finishing Processes	107.37	5.00	21.47	0.57	0.72	2.90
Sandpaper Model	165.58	3.00	55.19	1.47	0.26	3.29
Error	564.97	15.00	37.66	-	-	-
Total	837.92	23.00	-	-	-	-

Table 15. Significance analysis of GZL.

Difference Source	SS	d _f	MS	F	P _{value}	F _{crit}
Finishing Processes	114.28	5.00	22.86	0.88	0.52	2.90
Sandpaper Model	299.02	3.00	99.67	3.82	0.03	3.29
Error	391.79	15.00	26.12	-	-	-
Total	805.09	23.00	-	-	-	-

Table 16. Significance analysis of adhesion.

Difference Source	SS	d _f	MS	F	P _{value}	F _{crit}
Finishing Processes	0.17	5.00	0.03	5.15	0.00	2.90
Sandpaper Model	0.10	3.00	0.03	5.05	0.00	3.29
Error	0.10	15.00	0.00	-	-	-
Total	0.37	23.00	-	-	-	-

The results of significance analysis of adhesion obtained by the above methods were that $F > F_{crit}$ and $P_{value} < 0.01$. It shows that there was a very significant difference between the measured data in adhesion. The results of significance analysis of GZL under different sandpaper models obtained by the above methods were that $F > F_{crit}$ and $P_{value} < 0.05$. It shows that there was a significant difference between the measured data in GZL under different sandpaper models. The results of significance analysis of GZT and results of significance analysis of GZL under different finishing processes obtained by the above methods were that $F < F_{crit}$ and $P_{value} > 0.05$. It shows that there was no significant difference between the measured data in GZT. The above results show that the sanding model had a significant impact on GZL, the coating process had no significant impact on GZL, and the sanding model and coating process had no significant impact on GZT. Different coating processes and sandpaper models have a significant impact on the paint film shedding rate. This is because different coating processes and sandpaper models will affect the firmness of the paint film and the substrate, thereby affecting the paint film shedding rate.

4. Conclusions

The surface gloss of the paint film is affected by the surface roughness of the modified poplar wood, and the way and extent of the effect is restricted by the paint process. The proper use of PU sealing primer is beneficial to improve the gloss of the paint film by improving the surface properties of the material, but excessive use will not produce any effect. NC transparent primer has the function of weakening the surface gloss. The sanding model has a significant impact on GZL. When the surface roughness and wettability of the modified poplar wood are better, the weakening effect is more obvious. NC transparent finish has the effect of improving gloss, but the effect of repeated use is not obvious. Since the antique distressing process requires the glossiness of the paint film surface to be controllable and at a low level, the paint process of Group C is more suitable for antique distressing of European and American furniture from the perspective of the glossiness of the paint film craft. PU sealing primer is used as the first primer. Its thick, hard, and highly permeable characteristics lay a good foundation for the overall paint process. When the number of passes of NC transparent primer was appropriately increasing, the adhesion of the overall paint film was improved through the bonding between the films after sanding. The NC transparent finish had little effect on improving the adhesion of the paint film.

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