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Performance of Drying Oil Modified Chinese Lacquer and Its Gilding Effect

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Abstract: This study explores the modification of traditional Chinese lacquer by incorporating boiled tung oil (BTO), boiled linseed oil (BLO), and turpentine oil (TO) to enhance its properties for gold leafing applications. Current traditional lacquers are limited by slow drying times and inconsistent surface quality, making their performance suboptimal for decorative gilding. The research addresses these gaps by investigating how varying oil types and concentrations (10%, 30%, and 50%) affect the lacquer's drying time, viscosity, leveling properties, and overall gilding performance. Results indicate that TO-modified lacquer exhibits the best overall performance, showing the fastest drying time, highest glossiness, and smallest color variation, while BTO provides the smoothest surface and BLO ensures the best adhesion. These results demonstrate that the careful selection of oil type and concentration significantly improves lacquer's functionality for gold leafing, offering a more efficient and aesthetically superior alternative to unmodified lacquers. This study provides valuable insights for optimizing traditional lacquer formulations for modern applications in gilding and decorative finishes.

Keywords: Chinese lacquer; gold leafing; drying oil; viscosity; leveling properties; FTIR

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1. Introduction

Humans have been using metals to create functional and ornamental objects for over 10,000 years, with gold, silver, lead, tin, and copper being commonly found in cultural heritage artifacts [1,2]. Among these, gold is particularly valued for its excellent luster, corrosion resistance, and malleability, making it ideal for processing into thin leaves and adhered to surfaces [3,4]. Gilding allows for the conservation of gold by applying a thin layer to an object while still achieving visually appealing results [5].

In traditional Chinese gold leafing techniques, bone glue and Chinese lacquer are the primary adhesives [5,6]. Chinese lacquer, derived from the sap of the *Toxicodendron vernicifluum* (lacquer tree), offers superior adhesion and weather resistance compared to bone glue, resulting in a more durable gilding finish [7,8].

In Western gilding techniques, however, different materials and methods are employed. Animal glue, commonly referred to as mission, and the application of bolo (or bole), a clay-based material, are traditional Western methods for preparing surfaces before applying gold leaf [9,10]. These materials enhance the bonding of the gold leaf to the substrate and give the gilding its characteristic warmth and richness. Although garlic juice is occasionally mentioned in certain gilding recipes as an adhesion aid, it is not a commonly used material in most Western gilding practices [6,11]. Thus, Western techniques more often involve the use of mission or gelatin-based animal glues, combined with the use of bolo [10].

Chinese lacquer, besides being used as an adhesive for gilding, is also an excellent coating material, providing a hard, corrosion-resistant, and glossy finish [12]. However, as a natural material with a complex composition, its application is limited by specific

environmental conditions. The lacquer enzyme is only active at optimal temperature (25–35 °C) and high humidity (RH > 80%), where it catalyzes the curing process of urushiol into a durable film [13]. Additionally, the presence of allergenic compounds in Chinese lacquer can cause allergic reactions, further restricting its use [14]. To address these drawbacks, various modifications of Chinese lacquer have been explored, including repeated refining, organic silicon modification, plant oil modification, and nanoparticle addition [15–17].

Tung oil, linseed oil, and turpentine are natural, plant-derived oils traditionally used as drying agents in Chinese lacquer finishing [18]. These oils form films through oxidation, enhancing both the visual appeal and physical durability of the lacquer, which adds aesthetic value and longevity [19,20]. However, while turpentine has historically served as a drying agent, it has notable drawbacks, particularly regarding toxicity and environmental impact, limiting its suitability as a sustainable choice.

Turpentine oil (TO) specifically presents health risks due to its toxicity; prolonged exposure can lead to respiratory and skin irritation, as well as neurological symptoms like dizziness and headaches caused by its volatile organic compounds (VOCs) [21]. Additionally, TO's high volatility contributes to air pollution and can harm aquatic ecosystems if improperly disposed of. To address these issues, future research should explore green alternatives. Bio-based solvents, such as limonene, and less toxic plant-derived oils, including pine oil and methyl esters from vegetable oils, offer promising, safer substitutes with comparable performance while reducing health and environmental risks [22,23].

This study aims to enhance Chinese lacquer performance by modifying it with these plant oils, especially for gold leafing applications. It evaluates the effects of different oil types and concentrations on drying time, viscosity, leveling, and infrared spectroscopy. The modified lacquer's performance in traditional gold leafing is also tested to develop an effective, plant oil-modified Chinese lacquer suitable for gilding applications.

2. Materials and Methods

2.1. Materials

The raw Chinese lacquer (CL), obtained from the Xi'an Lacquer Research Institute, originates from Ankang City in Shaanxi Province. The solid content of the raw lacquer is 78.78 ± 1.25%. Boiled tung oil (BTO), boiled linseed oil (BTO), turpentine oil (TO), and cinnabar (HgS > 99%) with a fineness of 300 mesh were procured from Tianzuofang Crafts Co., Ltd. (Liling city, China). Tinplate sheets measuring 120 mm × 50 mm × 0.28 mm and opacity testing paper were sourced from the Wood Coating Laboratory of Nanjing Forestry University.

2.2. Modification of Chinese Raw Lacquer

A total of 50 g of Chinese raw lacquer were filtered through gauze and placed into a glass beaker with a diameter of 80 mm. The beaker was then stirred using a magnetic stirrer with heating at 40 °C until the moisture content of the raw lacquer was reduced to 5%. Heating was stopped, and various proportions (10%, 30%, and 50%) of BTO, BLO, and TO were added, followed by stirring for an additional 30 min. Ten kinds of samples were coded as CL, CL-BTO10, CL-BTO30, CL-BTO50, CL-BLO10, CL-BLO30, CL-BLO50, CL-TO10, CL-TO30, and CL-TO50.

2.3. Determination of Drying Time

The drying time of the lacquer film was determined according to GB/T 1728-2020 "Determination of drying time of coating and putty films" [24]. The modified lacquer was applied to tinplate and glass slides, then placed in a constant temperature and humidity chamber at 25 °C and 80% relative humidity for drying. The drying time assessment was initially carried out using the finger touch method, where the surface drying state was judged by gently touching the surface: if it felt tacky but no lacquer adhered to the finger, it was considered surface dry. The total drying time was assessed using the cotton ball method—a cotton ball was placed on the lacquer surface, and a drying time tester was

gently placed on top. After 30 s, the tester and cotton ball were removed, and the film was left undisturbed for 5 min. If no marks from the cotton ball, loss of gloss, or removable fibers were observed, the film was deemed fully dried.

These two traditional methods for assessing lacquer film drying time are highly subjective and operator dependent, leading to potential variations in sensitivity and inconsistency. To minimize the errors introduced by subjectivity, five individuals conducted the measurements, each repeating the process three times, and the average value was taken as the final drying time.

2.4. Viscosity and Leveling Property

The viscosity performance of the lacquer was tested according to GB/T 1723-93 "Determination of viscosity of coatings" [25]. At a room temperature of 23 °C, a single-cylinder rotational viscometer was used to test the samples. Each sample was measured three times to ensure accuracy and reproducibility. The average of these three readings was taken as the final viscosity value. If the difference between any of the three measurements exceeded 3%, additional measurements were conducted to maintain consistency and reliability in the data. This approach aligns with standard practices and ensures that the reported viscosity results are precise.

The leveling performance of the lacquer was tested according to JB/T 3998-1999 "Test method for leveling characteristics of paints by draw-down method" [26]. Under constant temperature and humidity conditions, a leveling tester was used to apply the lacquer sample onto black and white hiding power paper. After scraping, the paper was kept horizontal and allowed to dry. Once the sample dried, the number of parallel bands that had flowed together on the test surface was counted. The leveling grade was determined using the leveling grade chart, where "10" indicates the best leveling performance and "0" the worst. (See Figure 1).

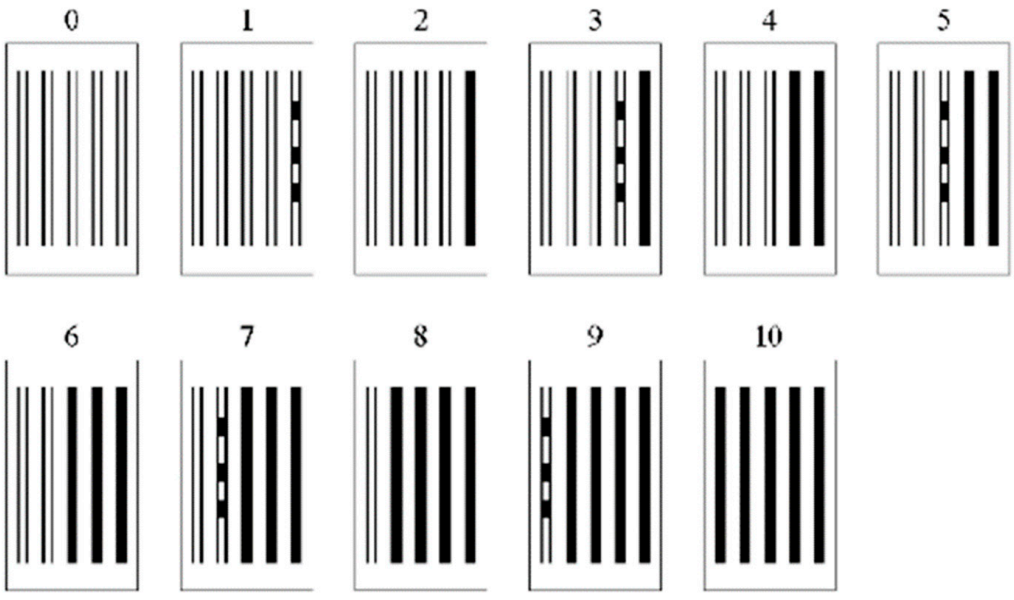

Figure 1. Leveling grade division illustration.

2.5. FTIR Investigation of Modified Chinese Lacquer

Fourier-transform infrared (FTIR) spectra were recorded for both Chinese raw lacquer and modified Chinese lacquer using an FTIR spectrometer (ALPHA, Bruker, Ettlingen, Germany) equipped with an attenuated total reflection (ATR) module. To ensure accuracy, six IR measurements were conducted per sample. The spectra were recorded within the range of 4000 to 400 cm^{-1}, at a resolution of 4.0 cm^{-1}, with a total of 24 scans for each measurement. Post-data treatments were applied to enhance the reliability of the results.

These treatments included baseline correction, normalization, and 22-point smoothing, after which the results were averaged to provide a representative spectrum for each sample.

2.6. Evaluation of Gold Leafing Effect

Acrylonitrile–Butadiene–Styrene (ABS) plastic sheets, sized 100 mm × 100 mm × 2 mm, were selected as the substrate for gold leaf application. The substrate surface was sanded with sandpaper to remove impurities and ensure a smooth, flat surface. To better enhance the color of the gold, traditional gold leaf techniques involve adding a certain amount of cinnabar powder to the adhesive [27]. In this study, Chinese lacquer and modified lacquer were mixed with cinnabar powder at a ratio of 10:0.625 and evenly applied to the substrate surface. The coated substrates were placed in a constant temperature and humidity chamber at 25 °C and 80% relative humidity for drying. Once the lacquer film reached a surface-dry state, gold leaf was applied to the surface. A cotton ball was gently used to press the gold leaf to ensure close adhesion. After the lacquer film fully dried, a cotton ball was used to gently brush the surface, resulting in a finished gold leaf sample. Roughness, glossiness, color, and adhesion were selected as the basic methods for evaluating the gilding effect.

2.6.1. Roughness

Roughness was tested according to GB/T 1031-1995 "Surface Roughness Parameters and Their Values" [28] using a Surface Roughness Meter (JB-1C, Shanghai Taiming Optical Instrument Co., Ltd., Shanghai, China). The roughness of the surface of all gilded samples was measured. After calibrating the equipment, the sampling length was set to 2.5 mm, and the measurement segment was set to 4, with a total measurement length of 50 mm. To avoid errors, four points were measured on each sample, with two measurements taken per point, resulting in a total of eight measurements per sample. The average of these eight measurements was taken as the roughness value of the tested sample. R_a represents the arithmetic mean deviation of the profile, R_q represents the root mean square deviation of the profile, and R_t represents the total height of the profile.

2.6.2. Glossiness

The HG60 Economic Gloss Meter (Shenzhen Three NH Technology Co., Ltd., Shenzhen, China) was used to measure surface glossiness. After calibrating the equipment, the glossiness of all gilded samples was measured at a 60° incident angle. Four measurement areas of 2 mm × 4 mm were selected on each sample, and each area was measured twice. The average of these eight measurements was taken as the glossiness value of the tested sample.

2.6.3. Color Measurement

A NH310 Portable Colorimeter (Shenzhen Three NH Technology Co., Ltd., Shenzhen, China) was used to measure the color of all gilded samples. The measurements were taken using a D65 standard light source and a 10° standard observer. Reflectance percentages were collected at 10 nm intervals within the visible spectrum (400–700 nm) and converted to the CIELAB color system. The color coordinates before and after treatment were expressed as lightness L* (ranging from 0 for black to 100 for white), redness a* (ranging from negative for green to positive for red on the green–red axis), and yellowness b* (ranging from negative for blue to positive for yellow on the blue–yellow axis). The color difference between the modified and unmodified Chinese lacquer gilded samples was calculated using the following equation:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

where ΔL, Δa, and Δb represent the differences in L, a, and b values before and after modification, respectively. Lower ΔE values correspond to smaller color differences.

2.6.4. Adhesion

The adhesion of the lacquer film was tested according to GB/T 9286-2021/ISO 2409:2007 "Paints and Varnishes—Cross-cut Test" [29]. A tool with 11 sharp blades was used to make parallel cuts on the lacquer film sample, with each cut being 10–20 mm long and spaced 1 mm apart, cutting through the entire depth of the lacquer film. Then, perpendicular cuts of the same type were made over the initial cuts, forming a grid of small squares. A 25 mm wide semi-transparent pressure-sensitive tape was applied over the entire grid and then quickly pulled off. The number of remaining squares on the lacquer surface was compared to the adhesion classification chart in Table 1 to determine the gold leaf adhesion strength, with "0" being the best and "5" being the worst.

Table 1. Adhesion grade division illustration.

Adhesion Grade	Illustration	Schematic Diagram
0	The edges of the cuts are completely smooth, and none of the squares in the lattice have detached.	
1	Small flakes of the coating have detached at the intersections of the cuts, affecting no more than 5% of the cross-cut area.	
2	The coating has flaked along the edges and/or at the intersections of the cuts, affecting a cross-cut area greater than 5% but not exceeding 15%.	
3	The coating has flaked along the edges of the cuts, either partly or wholly in large ribbons, and/or it has flaked partly or wholly on different parts of the squares, affecting a cross-cut area greater than 15% but not exceeding 35%.	
4	The coating has flaked along the edges of the cuts in large ribbons, and/or some squares have detached partly or wholly, affecting a cross-cut area greater than 35% but not exceeding 65%.	
5	The coating exhibits flaking to an extent that exceeds the criteria of classification 4 and cannot be classified.	—

2.7. Statistical Analysis

The gilding effect using modified and unmodified lacquer as adhesives was evaluated for statistical significance by analyzing the measured data for roughness, glossiness, color difference, and adhesion. An analysis of variance (ANOVA) was conducted using SPSS software (IBM Corp., IBM SPSS Statistics for Windows, v. 25, Armonk, NY, USA) with

a significance level set at 0.05. A two-way ANOVA was performed, including "oil type" and "oil addition amount" as independent factors, as well as their interaction "oil type*oil addition amount".

To assess the homogeneity of variances, Levene's test was conducted, and to check for the normal distribution of the data, the Shapiro–Wilk test was performed. These two tests are prerequisites for conducting a two-way ANOVA. At a significance level of $\alpha = 0.05$, Fisher's protected least significant difference (LSD) test was used to distinguish between treatment means.

3. Results

3.1. Determination of Drying Time

The surface drying time and total drying time of the adhesive used for gold leaf application significantly impact the quality of the gilding. Figure 2 illustrates the surface and total drying times for unmodified and modified Chinese lacquer. The unmodified Chinese lacquer has surface and total drying times of 17.9 h and 42.1 h, respectively. As shown in the Figure 2, the drying times of Chinese lacquer modified with different types of drying oils vary with different modifier concentrations. CL-BTO's surface drying time significantly decreases at 10% and 30% modifier concentrations but increases substantially at 50%. CL-BLO's surface drying time decreases at 10% but gradually increases at 30% and 50%. CL-TO's surface drying time consistently decreases with increasing modifier concentration, reaching its lowest at 50%. For total drying time, CL-BTO shows a significant decrease at 10% and 30% but a notable increase at 50%. CL-BLO's total drying time decreases at 10% and increases at 30% and 50%. CL-TO's total drying time consistently decreases with increasing modifier concentration, reaching its lowest at 50%. This indicates that CL-TO may be more sensitive and efficient with the modifier compared to the other two types. Overall, the percentage of modifier has a significant impact on the drying times of different types, and selections should be made and optimized based on specific circumstances.

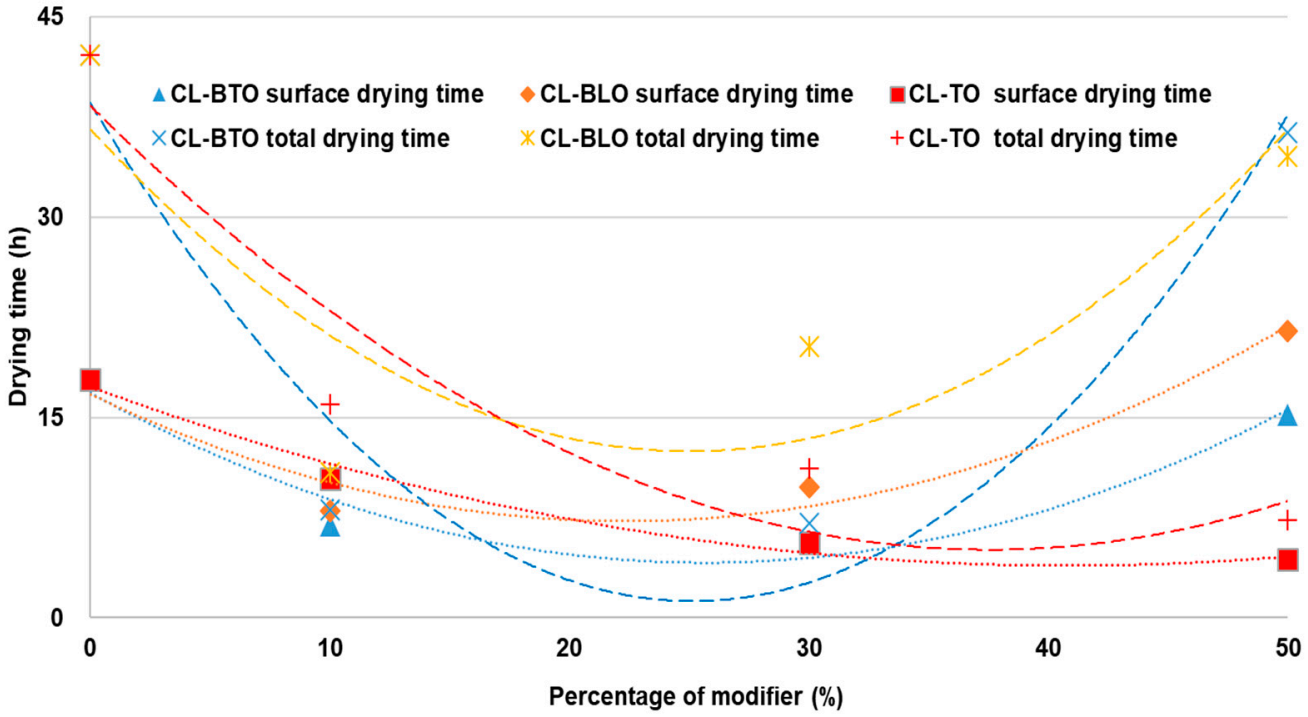

Figure 2. The surface drying and total drying time of unmodified and modified Chinese lacquer.

3.2. Viscosity and Leveling Property

Viscosity and leveling properties are crucial factors that affect the uniformity of adhesive and coating application. The viscosity and leveling grade of the Chinese lacquer are affected by the type and concentration of the modifier (Table 2). For CL-BTO, the viscosity decreases from 12,860 mPa·s at 10% to 11,220 mPa·s at 50%, with a corresponding leveling grade improvement from one to 2–3. For CL-BLO, the viscosity varies irregularly, increasing from 10,040 mPa·s at 10% to 12,600 mPa·s at 30%, and then decreasing to 11,740 mPa·s at 50%, with leveling grades of 4–5 at 10%, improving to one at 30%, and stabilizing at two at 50%. CL-TO shows a significant decrease in viscosity from 9060 mPa·s at 10% to 1140 mPa·s at 50%, with an improvement in leveling grade from 6–7 at 10% to 9–10 at 50%. The visual aspect of the lacquer is influenced by these properties, as lower viscosity and higher leveling grades generally result in a smoother and more aesthetically pleasing finish. Overall, the percentage of the modifier significantly impacts the drying times, viscosity, and leveling properties of different types, and selections should be made and optimized based on specific circumstances to achieve the desired visual and functional outcomes.

Table 2. Viscosity and leveling grades of unmodified and modified Chinese lacquer.

	CL	CL-BTO			CL-BLO			CL-TO		
		10%	**30%**	**50%**	**10%**	**30%**	**50%**	**10%**	**30%**	**50%**
Viscosity (mPa·s)	12,860	12,020	11,220	10,040	12,600	11,740	9060	4950	2620	1140
Leveling grade	1	2–3	2–3	4–5	1	2	2	6–7	8–10	9–10
Visual aspect										

3.3. FTIR Investigation of Modified Chinese Lacquer

FTIR spectra are a common and important tool for investigating the chemical composition of coatings and adhesives [30,31]. These spectra allow the identification of chemical characteristics through the absorption peaks of functional groups. Figure 3 compares the FTIR spectra of unmodified Chinese lacquer with those of Chinese lacquer modified by adding 50% of different types of drying oils. The FTIR spectra highlight the chemical changes before and after modification. The unmodified Chinese lacquer shows an absorption peak at 3400 cm^{-1}, corresponding to the νOH vibration mode associated with the hydroxyl group on the catechol ring [32,33]. The shoulder at 3016 cm^{-1}, assigned to the νCH=CH vibration of the side chain, diminishes. Additionally, there are symmetric and asymmetric methylene peaks at 2920 cm^{-1} and 2855 cm^{-1}, respectively; a benzene ring's skeletal vibration absorption peak at 1597 cm^{-1}; a phenol C-O stretching vibration absorption peak at 1275 cm^{-1}; a benzene ring C-H in-plane bending vibration absorption peak at 1070 cm^{-1}; and a conjugated triene absorption peak at 985 cm^{-1}. However, with the addition of 50% drying oils, the functional groups of the Chinese lacquer undergo significant changes. Firstly, the free hydroxyl peak at 3400 cm^{-1} sharply decreases, and the absorption peak at 3016 cm^{-1} almost disappears. The characteristic peaks in the fingerprint region also change, mainly due to the influence of the primary chemical components of the drying oils [34,35].

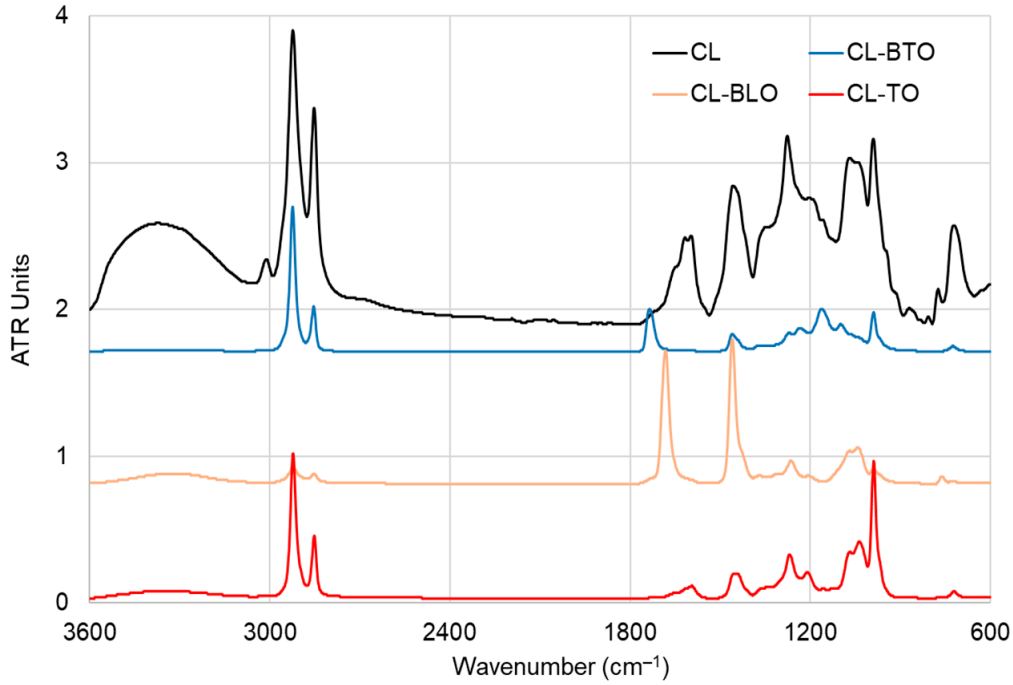

Figure 3. The surface drying and total drying time of unmodified and modified Chinese lacquer.

3.4. Evaluation of Gold Leafing Effect

The experimental results presented in Table 3 indicate significant influences of oil type and oil addition amount on the surface properties of modified Chinese lacquer, as assessed through *p* values calculated using Fisher's Protected LSD test at the 0.05 significance level. The *p* values for the factor "Oil type" are all below 0.0001 across different measurements, highlighting the highly significant effect of the oil type on lacquer properties. Boiled tung oil (BTO) modified Chinese lacquer produces the smoothest surface, with a roughness average (Ra) of 0.522 μm, while turpentine oil (TO) results in the roughest surface (Ra = 1.290 μm) but achieves the highest glossiness at 62.36%. This indicates a trade-off between glossiness and smoothness, depending on the oil selected. In terms of color difference, TO exhibits the smallest color difference (ΔE = 9.14), suggesting it preserves color better than BTO (ΔE = 13.00) and boiled linseed oil (BLO) (ΔE = 11.53), which is crucial for applications like gold leafing where color fidelity is essential. The *p* values associated with oil addition amounts also indicate significant effects, with values below 0.0001 for roughness and glossiness, and 0.001 for color changes, reflecting how varying the proportion of oil alters lacquer properties. As the oil addition amount increases, glossiness rises (e.g., 64.37% at 50% oil addition); however, this increase also leads to greater roughness, suggesting that while higher oil content can enhance aesthetic features like glossiness, it may compromise surface smoothness. The interaction term "Oil type × Oil addition amount" shows a *p* value less than 0.0001 for most measurements, indicating that the combined effect of oil type and addition level significantly influences lacquer properties. For instance, while TO exhibits high glossiness, its roughness is markedly affected by oil addition, suggesting that performance varies with the amount used. Adhesion values indicate that while BLO has the highest adhesion at 2.92, there is no significant difference between BTO and TO, with a *p* value of 0.545, suggesting that adhesion might be more closely tied to the oil type than its concentration. Overall, the statistical analysis demonstrates that both the type of oil and the amount added play critical roles in determining the physical properties of the lacquer, influencing surface roughness, glossiness, color fidelity, and adhesion. Thus, when formulating the modified lacquer for applications such as gold leafing, it is essential to balance achieving a desirable aesthetic finish (high glossiness) with maintaining surface smoothness (low roughness). Further research should explore the optimization of oil types and concentrations to enhance performance while mitigating any adverse effects on the

lacquer's mechanical properties, guiding future formulations to ensure that both aesthetic and functional attributes are considered in the lacquer application processes.

Table 3. Gold leafing effect of unmodified and modified Chinese lacquer.

	Roughness [1]			Glossiness(%)	Color Changes				Adhesion
	R_a (μm)	R_q (μm)	R_t (μm)		ΔL	Δa	Δb	ΔE	
CL	1.348	1.648	8.778	45.78	-	-	-	0	3
Oil type									
BTO	0.522 ^{b}	0.667 ^{b}	5.191 ^{c}	52.15 ^{c}	−2.35 ^{a}	4.65 ^{a}	11.59 ^{a}	13.00 ^{a}	2.83 ^{a}
BLO	1.091 ^{a}	1.329 ^{a}	8.590 ^{b}	57.91 ^{b}	−1.51 ^{a}	3.46 ^{b}	10.84 ^{a}	11.53 ^{a}	2.92 ^{a}
TO	1.290 ^{a}	1.627 ^{a}	11.658 ^{a}	62.36 ^{a}	−1.24 ^{a}	3.39 ^{b}	6.41 ^{b}	9.14 ^{b}	2.75 ^{a}
Oil addition amount									
10%	0.653 ^{b}	0.822 ^{b}	5.919 ^{b}	46.98 ^{c}	−2.94 ^{a}	4.14 ^{a}	8.62 ^{a}	11.14 ^{ab}	2.67 ^{a}
30%	1.239 ^{a}	1.538 ^{a}	10.251 ^{a}	61.07 ^{b}	−1.84 ^{a}	4.16 ^{a}	9.14 ^{a}	12.21 ^{a}	2.83 ^{a}
50%	1.011 ^{a}	1.263 ^{a}	9.270 ^{a}	64.37 ^{a}	−3.09 ^{a}	3.19 ^{b}	11.08 ^{a}	10.33 ^{b}	3.00 ^{a}
					p Values [2]				
Oil type	<0.0001	<0.0001	<0.0001	<0.0001	0.262	<0.0001	0.001	<0.0001	0.857
Oil addition amount	<0.0001	<0.0001	0.001	<0.0001	0.003	0.005	0.161	0.058	0.545
Oil type × Oil addition amount [3]	<0.0001	<0.0001	<0.0001	<0.0001	0.006	0.006	0.022	0.001	0.551

Note: [1.] Mean values of the "roughness" followed by the same small superscript letters (a, b and c) within a group are not significantly different based on Fisher's Protected LSD test at the 0.05 significance level. [2.] The *p* value indicates the significance of the different influencing factors. A smaller *p* value indicates stronger significance. The *p* values < 0.05 were significant, and *p* values > 0.05 were not significant. [3.] "Oil type × Oil addition amount" is the influence of the interaction between applied oil type and oil addition amount.

4. Discussion

The surface drying time and total drying time of the adhesive used for gold leaf application have a significant impact on the quality of gilding. The surface drying time for unmodified lacquer is 17.9 h, and the total drying time is 42.1 h. Lacquers modified with different types of drying oils exhibit varying drying times depending on the concentration of the modifier. The fitted curves of drying time versus modifier concentration, as shown in Figure 2, are generally similar, with the fitting formulas and correlation coefficients (R^2) provided in Table 4. A comparison of different modifiers indicates that CL-TO may be more sensitive and effective than the other two types of modifiers. Overall, the proportion of the modifier has a significant effect on drying time and should be optimized based on specific requirements. This observation aligns with previous research, which suggests that the type and amount of oil added can alter the drying dynamics, thereby influencing the surface finish and overall quality of the coating [14].

Table 4. Viscosity and leveling grades of unmodified and modified Chinese lacquer.

Drying Time	Modified CL	Fitting Formula	R^2
Surface drying	CL-BTO	$y = 0.0193x^2 - 0.992x + 16.842$	0.9395
	CL-BLO	$y = 0.0191x^2 - 0.8523x + 16.735$	0.9357
	CL-TO	$y = 0.008x^2 - 0.6562x + 17.284$	0.9812
Total drying	CL-BTO	$y = 0.059x^2 - 2.9673x + 38.543$	0.9227
	CL-BLO	$y = 0.0386x^2 - 1.9312x + 36.598$	0.6815
	CL-TO	$y = 0.0236x^2 - 1.7711x + 38.339$	0.8813

Similarly, the type and amount of oil used significantly impact surface properties, such as roughness, glossiness, and color difference. For example, BTO produces the smoothest surface (Ra = 0.522) but has the lowest glossiness (52.15), whereas TO results in the roughest

surface (Ra = 1.290) and the highest glossiness (62.36). BLO falls between these extremes. Higher oil addition amounts generally increase glossiness but also contribute to increased roughness. The impact of oil type on color difference is also notable, with TO showing the smallest color difference (ΔE = 9.14), which suggests better color stability compared to BTO and BLO. These results corroborate findings from earlier studies that have shown how different oils can lead to varying aesthetic and mechanical properties, further underlining the importance of the careful selection and optimization of oil type and concentration [36].

Moreover, viscosity and leveling properties, which are crucial for achieving uniform adhesive and coating application, are significantly affected by the type and concentration of the modifier. For instance, CL-BTO shows a decrease in viscosity and improvement in leveling grade with increasing oil concentration, while CL-TO exhibits the most pronounced decrease in viscosity, leading to a smoother finish. These properties are essential in determining the final surface quality and overall effectiveness of the gold leaf application. The changes observed in FTIR spectra with the addition of drying oils also indicate chemical modifications, particularly a decrease in the free hydroxyl peak, which highlights the interactions between the oils and the lacquer, as noted in similar studies [13,37].

In summary, the experimental results demonstrate that both the type of oil and its concentration play a critical role in determining the drying time, surface properties, and overall quality of the gold leafing effect. The findings emphasize the need for a balanced approach, considering factors such as roughness, glossiness, color difference, and drying time, to achieve optimal outcomes in surface treatments. These insights are consistent with previous research and provide a more nuanced understanding of how oil modifiers influence lacquer performance, guiding future applications and optimizations in similar contexts.

5. Conclusions

This study aimed to optimize the performance of Chinese lacquer for gold leafing by modifying it with different types of plant oils (boiled tung oil, boiled linseed oil, and turpentine) at varying concentrations. The results demonstrated that the choice of oil type and its concentration significantly influenced the lacquer's surface properties, drying times, viscosity, and leveling characteristics. Turpentine oil (TO) emerged as the most effective modifier, providing a balanced combination of high glossiness, low color variation, and efficient drying times, making it a promising option for achieving optimal gold leafing outcomes. Boiled tung oil (BTO) produced the smoothest surface but had the lowest glossiness, while boiled linseed oil (BLO) offered a middle ground in terms of surface roughness and glossiness. These findings underscore the importance of carefully selecting and optimizing oil modifiers in Chinese lacquer to achieve desired visual and functional results in gold leafing applications.

Author Contributions: W.W. and Q.W. analyzed the data and wrote this manuscript. W.W. gave valuable suggestions on the experiments and manuscript. C.Z., X.L. and W.W. modified the manuscript in detail. All authors have read and agreed to the published version of the manuscript.

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