coatings

MDPI

Article

Characterization of the Materials and Techniques of Red Lacquer Painting of a Horizontal Plaque Inscribed by General Feng Yü-hsiang

Liping Zheng [1,2], Liqin Wang [2,*], Xing Zhao [2], Zhoukuan Xi [3], Xianzhu Wu [1] and Xiaopan Fan [1]

[1] College of History and Society, Chongqing Normal University, Chongqing 401331, China
[2] China School of Cultural Heritage, Northwest University, Xi'an 710127, China
[3] Chongqing Bureau of Cultural Relics, Chongqing 401123, China
* Correspondence: wangliqin@nwu.edu.cn

Abstract: The "*Tian Di Chang Chun*" horizontal plaque was inscribed by General Feng Yü-hsiang in R.O.C. 25 (1936). Due to the aging of the materials and some factors in the preservation environment, the red painted layer on the surface of the plaque has shed. In this study, in order to analyse the materials and techniques used for the production of the inscribed plaques, the digital microscope system, scanning electron microscopy–energy dispersive spectroscopy (SEM-EDS), X-ray diffraction (XRD), and micro-Fourier transform infrared spectroscopy (μ-FTIR) were used to analyse the materials and techniques used on this plaque. It has been shown that the decorative layer of the plaque consists of a red Chinese lacquer film layer on the surface and a ground layer. The red lacquer film layer comprises Chinese lacquer, tung oil, and cinnabar. The materials used for the ground layer are blood putty made of a blood product, youman (flour–oil–lime mixture), and brick powder. The technique used is the SDH (San Dao Hui) layer technique in ancient buildings. This study provides physical evidence regarding the materials and techniques used in inscribed plaque relics, and also provides technical support to further protect and restore the plaque.

Keywords: painting layer; inscribed horizontal plaque; μ-FTIR; XRD; SEM

check for updates

Citation: Zheng, L.; Wang, L.; Zhao, X.; Xi, Z.; Wu, X.; Fan, X. Characterization of the Materials and Techniques of Red Lacquer Painting of a Horizontal Plaque Inscribed by General Feng Yü-hsiang. *Coatings* **2023**, *13*, 583. https://doi.org/10.3390/coatings13030583

Academic Editor: Alexander Tolstoguzov

Received: 14 February 2023
Revised: 5 March 2023
Accepted: 6 March 2023
Published: 8 March 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Lacquer objects were important ritual and daily necessities in ancient times, because lacquer film has durable, adhesive, decorative, and chemical-resistant properties. Lacquering techniques in China have a long history. In Asia, there are three species of lacquer trees: *Toxicodendron vernicifluum*, found mainly in China, Japan, and Korea; *Toxicodendron succedanea*, found mainly in Vietnam and Chinese Taiwan; and *Gluta usitata*, found mainly in Myanmar, Thailand, Cambodia, and Laos. The main components of phenol derivative of the three species of lacquer trees are urushiol, laccol, and thitsiol, respectively [1].

Obtaining information on inorganic or organic materials, and more specifically on their distribution within the stratigraphy of lacquerwares, is crucial to clarify the original technology. Scientific investigation has played an important role in the protection and restoration of ancient lacquerwares. The main techniques for the study of the binding materials of lacquerwares include Fourier transform infrared spectroscopy (FTIR) [2–4], pyrolysis–gas chromatography/mass spectrometry (Py-GC/MS) [3,5], and enzyme-linked immunosorbent assay (ELISA) [6]. Scanning electron microscopy/energy-dispersive X-ray spectrometry (SEM-EDS) [3,7,8], X-ray diffraction (XRD) [8,9], and Raman spectroscopy [8,10] are normally applied to analyse the inorganic materials present in lacquerwares.

Feng Yü-hsiang (6 November 1882–1 September 1948) was not only a famous patriotic general, but also a calligrapher. In 1936, General Feng wrote congratulations "*Tian Di Chang Chun*" (meaning 'righteousness exists forever in the heaven and earth') for a horizontal plaque inscribed for Mr. Chen's 71st birthday (Figure 1a). This plaque has a red background

and silver characters. It is 213 cm long, 73 cm high, and 5 cm thick. Lacquer painting of the plaque is on the wood surface. The upper inscription says "Inscribed by first class General of the National Revolutionary Army, commander of the sixth theatre command, vice president of the National Military Council, Feng Yü-hsiang". The lower inscription says "The 71st birthday of Mr. Chen in the 25th year of the Republic of China (1936), year bingzi in the lunar calendar in the first moon on a sunny day". This plaque shows General Feng's patriotic, compassionate, fair, and just thoughts and ideals. It has significant educational value for contemporary society.

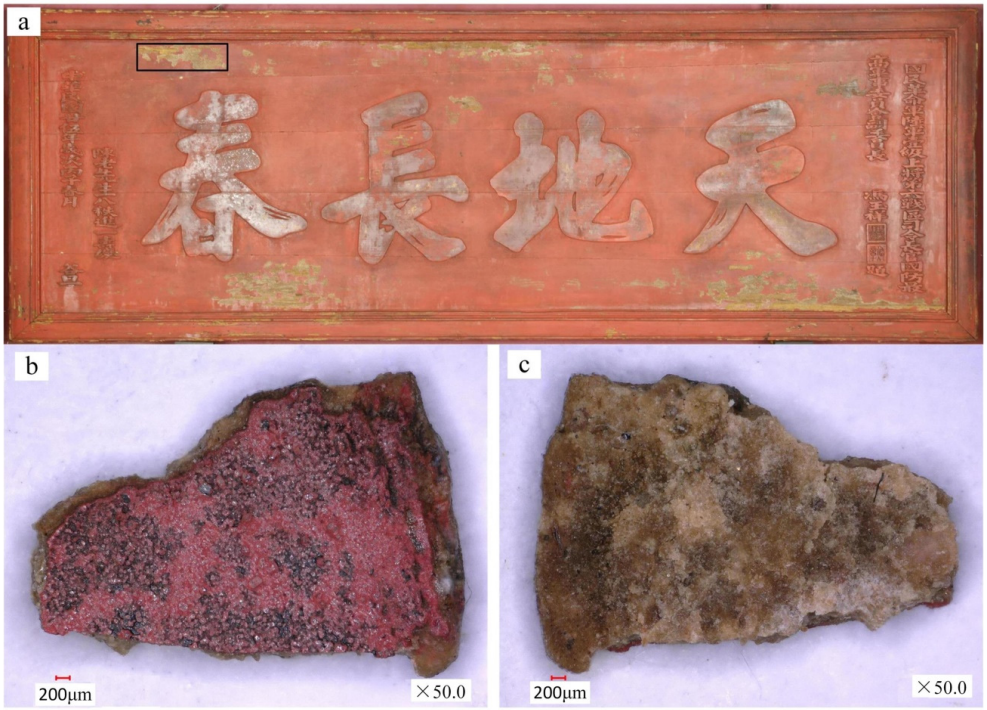


Figure 1. (**a**) "*Tian Di Chang Chun*" horizontal plaque (inscribed by General Feng Yü-hsiang). Collected by Chongqing Bayu Mingbian Cultural Art Museum. Photographer: Shen Lin (Three Gorges Museum). (**b**) Front side of the experimental sample. (**c**) Back side of the experimental sample.

In the period of the Republic of China, the economy was depressed and people's living conditions were dire. The lacquerware techniques declined. However, this birthday horizontal plaque inscribed by General Feng Yü-hsiang was so perfectly formed. This shows its preciousness and reflects people's respect and love for General Feng Yü-hsiang. Due to the natural aging of the materials and factors in the preservation environments, the red painted layer on the surface of the plaque has severely shed. It must be restored using the original materials and technical processes. Therefore, identifying the materials and techniques used is extremely important in the protection and restoration of artifacts.

According to the literature, the decoration of inscribed horizontal plaques belongs to the lacquering craft [11]. Artifacts that also belong to the lacquering craft include coloured drawings in ancient buildings, lacquerware, etc., whose materials and techniques have been explored [12–14]. However, there are no reports on scientific studies focusing on the materials and techniques for inscribed horizontal plaques. In this study, a digital microscope system, SEM-EDS, μ-FTIR, and XRD were used to analyse the materials and techniques used on this plaque to provide new evidence for the traditional techniques used on inscribed horizontal plaques and references for the further protection and restoration of inscribed plaque artifacts.

2. Materials and Methods

2.1. Samples

The shed samples from the surface of the plaque are broken into many pieces with different sizes and irregular shapes. The largest piece is approximately 1.2 × 1.0 × 0.1 cm^3, and the smallest piece is approximately 0.9 × 0.4 × 0.1 cm^3. The samples were taken from the position of rectangle in Figure 1a. The front side (on the surface of the plaque) of the experimental sample is red (Figure 1b), with large black particles, and its back side is earth-brown with a small amount of white matter (Figure 1c).

2.2. Optical Microscopy

A VHX-6000 digital microscope (Keyence, Osaka, Japan) was used for the microscopic observation of the surface and cross section of the sample. The microscope was configured using a VHX-6020 Camera CMOS sensor unit, VH-Z20T ultrasmall 20× to 200× zoom lens, automatic z-axis resolution of 1 μm, and electric XY stage.

2.3. Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy

A FEI Quanta 450 FEG scanning electron microscope and X-MaxN50 energy-dispersive X-ray analyser (FEI, Hillsboro, OR, USA) were used to observe the microscopic morphology and cross section of the sample.

2.4. Microattenuated Total Reflection Fourier Transform Infrared Spectroscopy

A LUMOS FT-IR microscope (Bruker, Bremen, Germany) was used for the nondestructive identification of organic substances in the microareas of the sample. The spectral range was 4000–600 cm^{-1} and the spectral resolution was 4 cm^{-1} with 16 times scanning and 8× magnification. The diameter of the crystal (germanium) tip for attenuated total reflection (ATR) was 100 μm. The measured microarea could be adjusted within the 100–10 μm length range. OPUS7.5, which was installed in the microscope by default, was used for baseline correction. Origin2020 was used to plot the infrared spectra.

2.5. X-ray Diffraction

A Smartlab X-ray diffractometer with a rotating target (Rigaku, Tokyo, Japan) was used for the nondestructive phase analyses of the microareas of the sample. The maximum power output of the diffractometer was 9 kW. The rotating target was made with copper and the XY space sample stage was equipped with microarea optical components. The test conditions were as follows: scanning range 5°–90°; angle interval 0.01; scanning speed 10; voltage 40 kV; current 150 mA.

2.6. Experimental Methods

Analyses of the front and back sides of the sample: The sample was placed on the stage in order to conduct nondestructive microscopic observation and analyses on micromorphology and composition using the digital microscope, SEM-EDS, XRD, and μ-FTIR.

Analyses of the cross section of the sample: The sample needed to be embedded in resin. To carry this out, approximately 0.5 × 0.4 × 0.1 cm^3 of the sample was vertically embedded in the middle of epoxy AB glue (Shanghai Naibo corporation, Shanghai, China) to solidify it at 25 °C for 3–4 h. Then, 200, 800, 3000, and 7000 grit sandpaper, as well as 12,000 grit sandpaper, were used to polish it, in that order. Finally, the digital microscope, SEM-EDS, and μ-FTIR were used to conduct microscopic observations and analyses on micromorphology and composition for the above resin-embedded sample.

3. Results and Discussion

3.1. Analyses by Digital Microscope and SEM-EDS

From SEM micromorphology of the red surface layer (Figure 2a, 600× magnification), it was seen that the particles are fine, but there are a large number of cracks, which indicates that the coloured decoration surface has undergone a certain degree of aging. The cross

sections from SEM (Figure 2b, 100× magnification) and the digital microscope analyses (Figure 2c, 200× magnification) show that there are four layers. The first, second, and third layers are ground layers. This means that there are three putty layers whose colour is earth-brown with different shades of darkness. The fourth layer is the red surface layer.

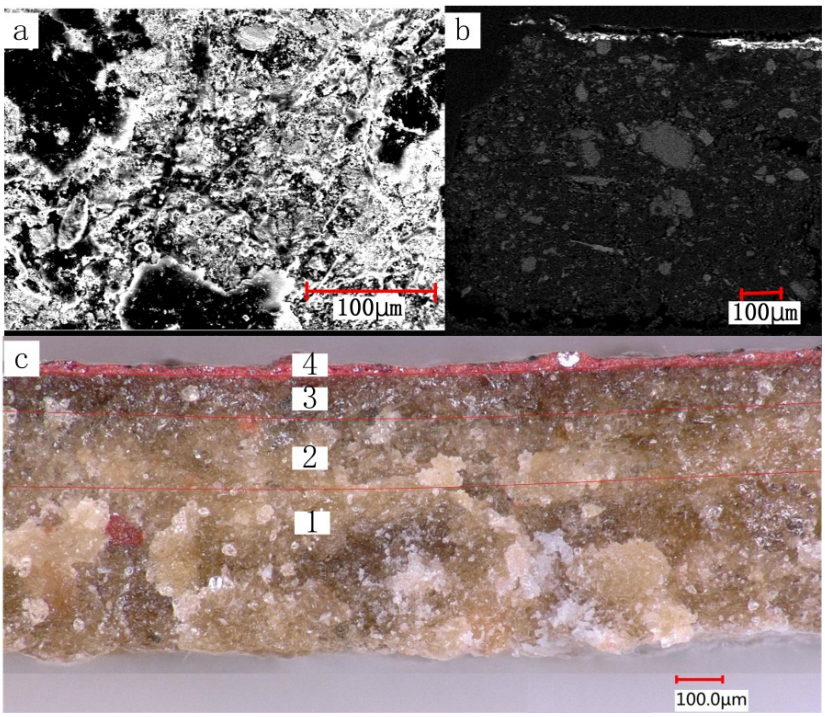


Figure 2. Results of the micromorphology and the cross section analyses: (**a**) SEM secondary electron image of the surface layer. (**b**) Backscattered electron image for the cross section. (**c**) Digital microscopic image for the cross section.

In terms of the graininess of each layer, the first and second layers are coarser, the third layer is finer, and the fourth layer (surface layer with red colour) is the finest. This shows that the ground layer was applied three times using materials of increasingly finer particle sizes from the ground to the surface layer, and the red surface layer contains red pigment of extremely fine particulate matters. In terms of the thickness of each layer, the first layer is relatively thick, approximately 330 μm; the second layer is approximately 150 μm; the third layer is approximately 140 μm; and the fourth layer is approximately 40 μm. This indicates that the thickness of the applied materials gets increasingly thinner. From the cross-sectional view, the sample is curved in the horizontal direction, confirming that its decorative layer of the plaque has warped.

The EDS result for the red surface layer is shown in Figure 3. The contents of C and O are relatively high (weight % of 32.33% and 14.42%, respectively), and the total content of C and O is 46.75%. By deduction, it may contain organic substances. The content of S is 8.75%, and the content of Hg is very high (43.36%). The total contents of S and Hg is 52.11%. By deduction, the red pigment may be cinnabar. In addition, the content of Ca is 1.24%.

3.2. XRD Analysis

To identify the inorganic substances in the plaque, XRD analysis was conducted on its surface and ground layer. The X-ray diffraction diagram (Figure 4) of the red surface layer shows that the diffraction peaks at 2θ of 27°(vs), 29°(s), 32°(vs), 39°(w), 45°(s), 46°(w), 47°(m), 53°(m), 54°(m), 56°(m), 59°(w), 60°(w), 66°(w), 71°(w), 73°(w), and 76°(w) belong to cinnabar (HgS, Figure 4, JCPD:99-0031). The diffraction peaks of the samples match

those of cinnabar well, which shows that the cinnabar used has a good crystal form and high purity.

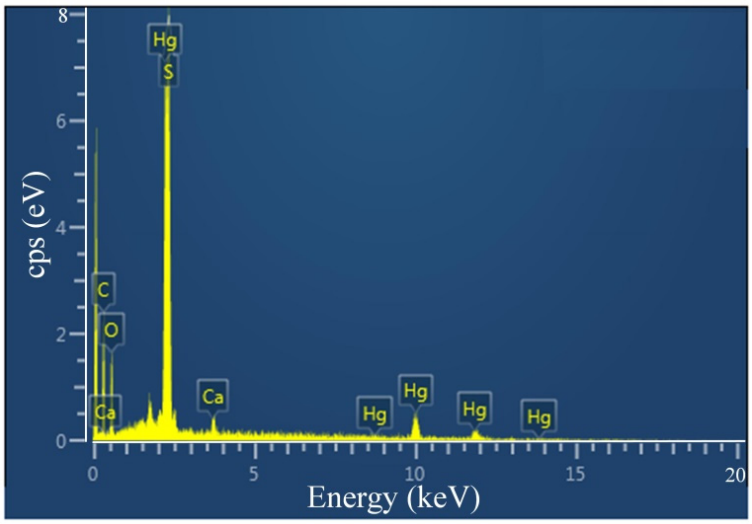


Figure 3. EDS result for the surface layer.

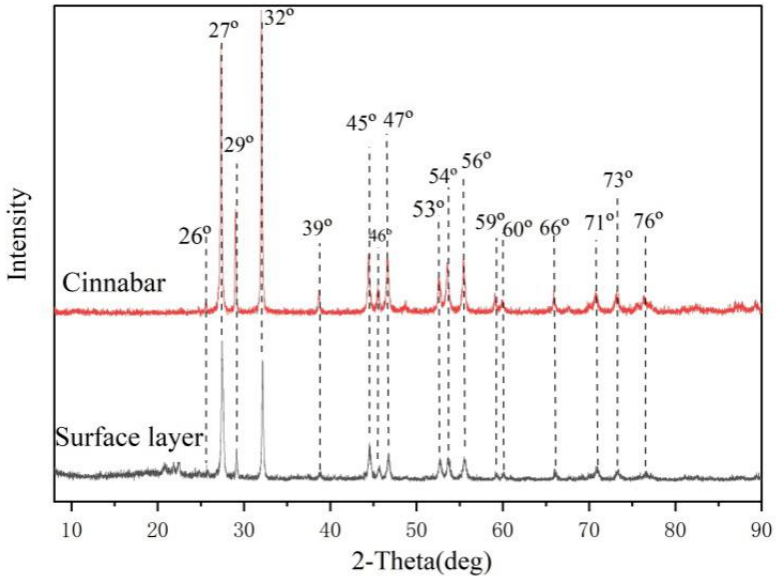


Figure 4. The XRD diffractogram of the surface layer and cinnabar.

As shown in Figure 5, the diffraction peaks of the ground layer almost match the diffraction peaks of brick powder [15] at 2θ of 21°(s), 26°(vs), 28°(s), 36°(w), 39°(w), 41°(w), 42°(w), 45°(m), 50°(m), 55°(w), 60°(w), and 68°(w). This shows that the ground layer contains brick powder. The diffraction peaks at 21°, 26°, 36°, 39°, 41°, 42°, 45°, 50°, 55°, 60°, and 68° are attributed to the gismondine phase ($CaAl_2Si_2O_8{\cdot}4H_2O$, JCPD:20–0452). The peak at 28° is attributed to the albite phase ($Na(AlSi_3O_8)$, JCPD:84–0752) [15]. The diffraction peaks of the ground layer at 2θ of 29° and 48° are not found in the diagram of brick powder. They may be from calcite ($CaCO_3$, Figure 5, JCPD:05-0586), which may form in the reaction between $Ca(OH)_2$ and CO_2 [15], and the weak diffraction peaks represent its low content.

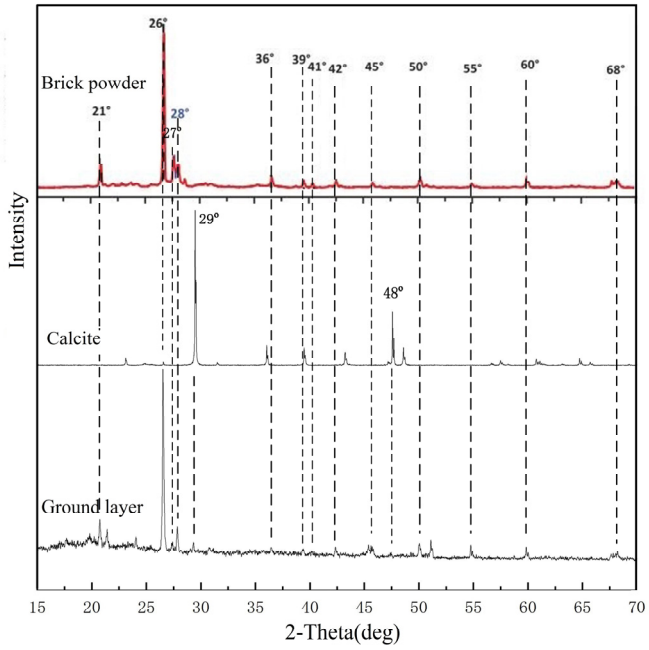


Figure 5. XRD diffractogram of brick powder, calcite, and ground layer.

3.3. μ-FTIR Analysis

The μ-FTIR analyses of the red surface and ground layer of the sample were carried out to identify the organic substances. The μ-FTIR result of the red surface layer compared with those of raw tung oil [15], boiled tung oil, and the current Chinese lacquer [16] (Figure 6) shows the following: the absorption peak of the sample at 3296 cm^{-1} belongs to the stretching vibration of OH [17]. The absorption peaks at 2921 and 2850 cm^{-1} belong to the asymmetric stretching vibration and symmetric stretching vibration of methylene-branch ($-CH_2$) [18]. The absorption peak at 1723 cm^{-1} belongs to the stretching vibration of C=O [19]. The strong absorption peak at 1651 cm^{-1} belongs to the C=C stretching vibration of benzene rings [20]. The absorption peak at 1542 cm^{-1} belongs to the stretching vibration of C=O. The absorption peak at 1459 cm^{-1} belongs to the asymmetric deformation vibration of CH_3. The absorption peak at 1253 cm^{-1} belongs to the stretching vibration of C-O. The absorption peak at 1075 cm^{-1} belongs to the stretching vibration of C-O and C-C. The absorption peaks at 990 cm^{-1} and 965 cm^{-1} belong to the wagging vibration of C-H conjugated double bonds. The weak absorption peak at 727 cm^{-1} belongs to the rocking vibration of CH_2.

The μ-FTIR analysis of the red surface layer shows that the absorption peaks exist at wavenumbers of 3296, 2921, 2850, 1651, 1459, 1278, and 1075 cm^{-1}, deducing that there is Chinese lacquer. The absorption peaks also exist at 2921, 2850, 1723, 1542, 1459, 1253, 990, 965, and 727 cm^{-1}, deducing that there is tung oil, which is a traditional material in the Bashu region of China. The weak absorption peak at 1542 cm^{-1} is the peak that differentiates raw from boiled tung oil. This may be caused by the stretching vibration of C=O under C=C conjugation after the oxidation of tung oil. The absorption peak of the sample at 1723 cm^{-1} being stronger than that at 1651 cm^{-1} is a typical characteristic of tung oil being added to Chinese lacquer [21]. The absorption peak of tung oil at 1741 cm^{-1} and the absorption peak of Chinese lacquer at 1625 cm^{-1} affect each other, moving the absorption peaks of the sample to 1723 and 1651 cm^{-1}. The absorption peak of Chinese lacquer at 3428 cm^{-1} moves to 3296 cm^{-1} under the influence of the absorption peaks of tung oil at 2921 and 2850 cm^{-1}. Therefore, the red surface layer is a lacquer film layer containing Chinese lacquer and boiled tung oil.

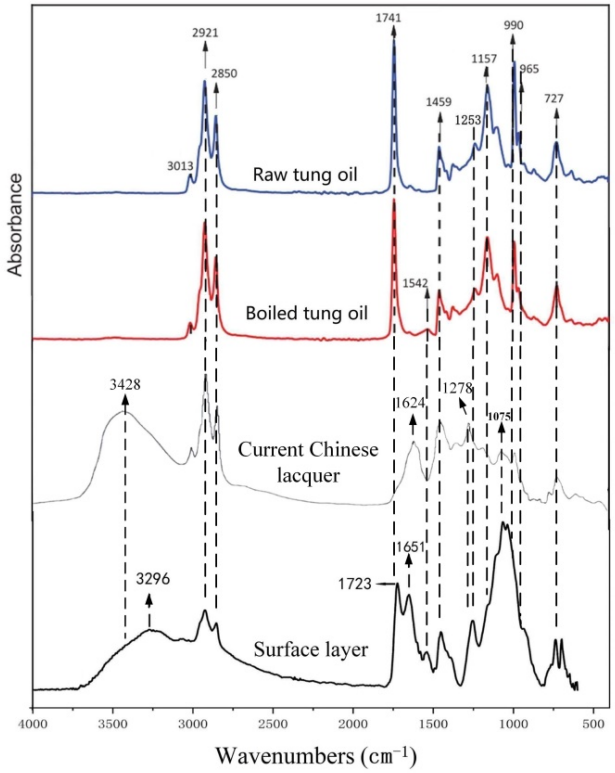


Figure 6. The infrared spectra of raw tung oil, boiled tung oil, the current Chinese lacquer, and the surface layer.

The infrared spectra of the ground layer of the sample, youman, and a blood product (meaning 'animal blood') [15] are shown in Figure 7. The main component of blood is protein. The wide absorption peaks at 3343–3147 cm^{-1} belong to the stretching vibration of the N-H in protein. The absorption peak at 1630 cm^{-1} belongs to the stretching vibration of C=O in amide bonds. The absorption peak at 1514 cm^{-1} belongs to the deformation vibration of C-N. Comparing the infrared spectra of the sample, youman, and blood, it is deduced that the absorption peaks of the infrared spectra of the ground layer at 2921, 2850, 1741, 1542, 1459, 1157, and 990 cm^{-1} belong to youman, which consists of flour, lime water, and boiled tung oil [15]. In the youman component, lime water absorbs CO_2 from the air to form calcite, which is consistent with XRD results. The absorption peaks at 3296, 1630, and 1514 cm^{-1} belong to the blood product, which is usually added to the ground layers of coloured drawings in ancient Chinese buildings to increase intensity. In summary, the ground layer may contain the blood product and youman.

Significantly, Figure 7 also shows that the absorption peak of the ground layer around 1000 cm^{-1}, is of the higher intensity. The peak around 1000 cm^{-1} is typical of a silicate [22]. The higher intensity of the peak around 1000 cm^{-1} indicates that the ground layer was likely added powdered brick, which is consistent with the XRD result.

3.4. Analyses of the Coloured Decoration Materials and Techniques

From the analysis results above, the decoration layers of the horizontal plaque inscribed by General Feng Yü-hsiang include a Chinese lacquer film layer and a ground layer. The Chinese lacquer film layer is on the surface of the plaque and it is red. Its cementitious material is a mixture of Chinese lacquer and tung oil. Its pigment is high-purity cinnabar, whose particles are fine and crystal forms are good. The ground layer is made of the blood-product putty made of blood, youman, and brick powder. The putty particles used during the first two times are coarser. Fine-particle putty was applied at the last time. The particles are fine, and were applied evenly and thinly to flatten the surface in preparation for the application of the red lacquer film.

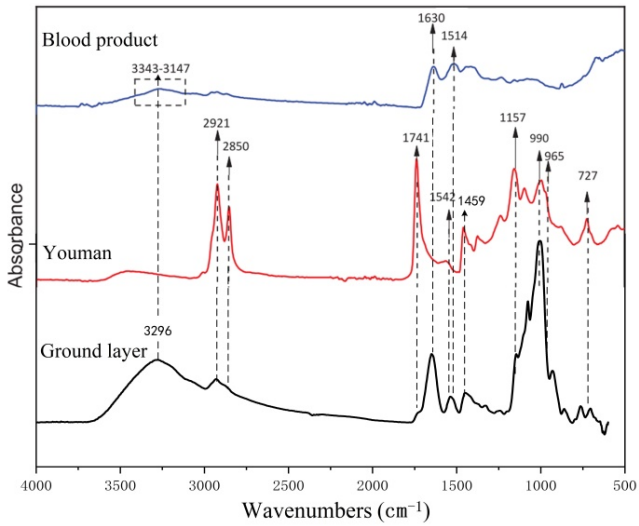


Figure 7. The infrared spectra of the blood product, youman, and the ground layer.

In the lacquer film layer of this plaque, Chinese lacquer is the adhesive, tung oil is the auxiliary agent, and cinnabar is the colour pigment. Therefore, the technique is a form of a coloured-lacquering technique. Since ancient times, the lacquering technique, including the coloured-lacquering technique, has developed into a self-contained material technology. (i) Chinese lacquer is a good natural resin adhesive, as expressed in the idiom "like glue and lacquer". Chinese lacquer has strong fusion capability and permeability. Using this property, Chinese lacquer is mixed with pigment to be applied onto objects. During the process of Chinese lacquer's solidification into film, its urushiol, laccase, polysaccharide, glycoprotein, water, and other components undergo complicated biocatalytic oxidation polymerization [23]. The formed Chinese lacquer film has good resistance to water, heat, acid, alkali, and corrosion, and has other properties such as antibacterial properties. It is both gorgeous and protective. (ii) Tung oil is an excellent dry vegetable oil with fast-drying, lustrous, and heat- and corrosion-resistant properties. Regardless of how Chinese lacquer is made, it cannot be as transparent as water. It also forms a film slowly and takes a long time to dry and change colour. Therefore, the addition of tung oil is beneficial to the transparency of Chinese lacquer. In addition, the Chinese lacquer modified by tung oil has a good air-drying property and flexibility, and makes the painting process smooth [24]. It also enhances the lustrous effect of the Chinese lacquer film on the surface, giving a better painting effect. For example, objects painted with red Chinese lacquer combined with tung oil look more festive. Once Chinese lacquer and tung oil are mixed, the mechanisms of polymerization and oxidation reactions of the mixture change. The oxidation degree of tung oil decreases while its net structure increases [25]. However, the firmness of the Chinese lacquer–tung oil mixture is not as good as Chinese lacquer alone. The paint falls off easily if only tung oil is used to make the paint [26]. (iii) Cinnabar is a common red pigment with a bright red colour. In a long period of Chinese history, cinnabar was the first choice for red pigment. Ancient people believed that it was spiritual and could ward off evil. According to traditional Chinese medicine records throughout Chinese dynasties, cinnabar is believed to have the functions of clearing the heart, calming, improving eyesight, and acting as an insect repellent and an antiseptic [27].

The ground layer of this plaque contains youman, a blood product, and brick powder. The substances containing blood products in ground layers in coloured drawings in ancient Chinese buildings are usually referred to as blood putty. Its techniques include a ground layer with linen or cotton and a ground layer without fabric materials. As there is no linen or cotton in the ground layer of this plaque and the ground layer was applied three times, the ground layer technique belongs to the SDH (San Dao Hui, that is, the ground layer applied three times) technique without fabric materials, one of the typical blood put-

ties [28]. The ground layer of this plaque is an inorganic–organic composite that is similar to sticky rice–lime mortar used in ancient Chinese city walls, water facilities, tombs, etc. [29]. (i) The blood is usually made of pig blood, cow blood, sheep blood, etc. Among these blood products, the blood products fermented from pig blood have the best quality. The blood products made of cow and sheep blood, which are slightly less viscous, have comparatively lower quality. Generally, cow blood is used for halal ground layers. The blood products have high fibrin content [30]. (ii) Brick powder is the powder for bricks. The ancient Chinese used local clay to make bricks. Bricks are made of an inorganic silicate material with stable chemical properties. They are a common construction material for building houses, city walls, water facilities, towers, bridges, dams, wells, mausoleums, etc. [31]. (iii) The scientific principle for using blood putty is that during the fermentation of pig blood, the fibrin reacts with the calcium ions in brick powder. Carboxylation in biochemistry happens. The gel that is formed exhibits an amphiphilic property, where its hydrophobicity causes it to combine well with tung oil, while its hydrophilicity causes it to combine well with pigment [32]. The use of blood putty on the ground layer not only protects the wood from corrosion, but it is also good for keeping the coloured surface layer flat and beautiful.

The Chinese lacquer, blood product, tung oil, cinnabar, and bricks used for this plaque have a long history of application in China. Natural Chinese lacquer is one of the earliest polymer materials used by humankind. It can be traced back to the Neolithic Age. At the Kuahuqiao site in Xiaoshan, Zhejiang, 8000 years ago, early humans used natural Chinese lacquer as a coating and an adhesive for boats and pottery [33]. The use of blood and tung oil on ancient lacquerware can be traced back to the Warring States period. In the coloured surface layer of the ear cup lacquerware unearthed from the Chu Tomb in Jiuliandun, Zaoyang, Hubei, a mixture of tung oil, linseed oil, and perilla seed oil was found, and blood was found in the bottom Chinese lacquer layer [34]. Cinnabar first appeared in the coloured potteries in the Neolithic period. It was found in many places at the Dadiwan site in Qin'an, Gansu, dating to about 7000 years ago. A Chinese lacquer bowl was found in the third cultural layer of the Hemudu site of the Neolithic Age in Yuyao, Zhejiang, 6600 $\pm$ 300 years ago. A layer of red paint on the outside of the bowl was identified to contain cinnabar and Chinese lacquer [35,36]. Brick is the fundamental material for ancient Chinese buildings. Archaeological excavations confirmed that the earliest bricks discovered so far were unearthed at the Yangshao cultural Xinjie site, Lantian, Shaanxi [37].

From historical documents, the earliest handicraft book "*Zhou Li·Kaogong Ji*" (in the Spring and Autumn Period and the Warring States Period) recorded that the metal spoon that was used to pour (scoop) wine in ancient worship ceremonies for mountains and rivers was decorated with turquoise on the outside and red Chinese lacquer on the inside [38]. The "*Han Fei Zi·Shi Guo*" by Han Fei, a thinker at the end of the Warring States Period, recorded, "Yu made sacrificial artifacts with black Chinese lacquer on the outside and red Chinese lacquer on the inside" [39]. Together with the red wooden Chinese lacquer bowl unearthed from the Hemudu site, it can be seen that red is one of the most traditional colours of the Chinese lacquering technique. The only surviving ancient Chinese lacquer technique book in China, "*Xiu Shi Lu*" (by Huang Cheng in the Ming Dynasty, and annotated by Yang Ming in the Ming Dynasty), clearly recorded the use of pig blood, brick powder, and manshui (also known as youman) as the Chinese lacquer ground layer materials [40]. It can be deduced that the lacquering process of lacquerware was last fixed in the Ming Dynasty. Experiments have confirmed that the oil decorations on the pillars of the Bogda Khan Palace Museum in Mongolia in the Qing Dynasty used the one-linen–five-putty ground layer technique, where the red pigment was cinnabar, and linen fibre was used in the ground layer together with flour, blood, and brick powder [41].

4. Conclusions

SEM-EDS, XRD, μ-FTIR, and other technologies were used to analyse the materials and techniques of the "*Tian Di Chang Chun*" horizontal plaque inscribed by the patriotic General Feng Yü-hsiang. Results show that this plaque has a red Chinese lacquer film layer

on the surface and a ground layer. The red lacquer layer is made of a mixture of Chinese lacquer and tung oil. The red pigment consists of fine particles of cinnabar. The ground layer was applied three times using blood putty made of a blood product, youman, and brick powder. The particles in the first two applications of putty are coarser. The particles in the last application are fine, even, and thin. The ground layer of the plaque has no linen or cotton. It used the SDH technique in the ground layers without fabric materials, commonly used in ancient buildings. In the future, more research should be focused on the protection of plaques.

Author Contributions: L.Z.: investigation, data curation, writing—original draft, writing—review and editing. L.W.: Writing—review and supervision. X.Z.: visualization. Z.X.: resources, investigation. X.W. and X.F.: investigation. All authors have read and agreed to the published version of the manuscript.

Funding: This research was founded by the National Social Science Foundation of China (17XKG002) and the National Natural Science Foundation of China (52203126).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Guangrui Liu and his staff of Chongqing Bayu Famous Plaque Culture and Art Museum) for the provision of the samples in the investigation.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sung, M.; Jung, J.; Lu, R.; Miyakoshi, T. Study of historical Chinese lacquer culture and technology—Analysis of Chinese Qin-Han dynasty lacquerware. *J. Cult. Herit.* **2016**, *21*, 889–893. [CrossRef]
2. Koochakzaei, A.; Nemati, B.A.; Jelodarian, B.B. Identification of Coatings on Persian Lacquer Papier Mache Penboxes by Fourier Transform Infrared Spectroscopy and Luminescence Imaging. *Heritage* **2021**, *4*, 1962–1969. [CrossRef]
3. Karpova, E.; Nefedov, A.; Mamatyuk, V.; Polosmak, N.; Kundo, L. Multi-analytical approach (SEM-EDS, FTIR, Py-GC/MS) to characterize the lacquer objects from Xiongnu burial complex (Noin-Ula, Mongolia). *Microchem. J.* **2017**, *130*, 336–344. [CrossRef]
4. Martin de Fonjaudran, C.; Nevin, A.; Piqué, F.; Cather, S. Stratigraphic analysis of organic materials in wall painting samples using micro-FTIR attenuated total reflectance and a novel sample preparation technique. *Anal. Bioanal. Chem.* **2008**, *392*, 77–86. [CrossRef] [PubMed]
5. Tamburini, D.; Bonaduce, I.; Ribechini, E.; Gallego, C.; Perez-Arantegui, J. Challenges in the data analysis of Asian lacquers from museum objects by pyrolysis gas chromatography/mass spectrometry. *J. Anal. Appl. Pyrol.* **2020**, *151*, 104905. [CrossRef]
6. Zhai, K.R.; Sun, G.P.; Zheng, Y.F.; Wu, M.; Zhang, B.J.; Zhu, L.G.; Hu, Q. The earliest lacquerwares of China were discovered at Jingtoushan site in the Yangtze. *Archaeometry* **2022**, *64*, 218–226. [CrossRef]
7. Kalinina, K.B.; Nikolaev, N.N.; Michri, M.V. Study of Lacquer Objects and Their Fragments from the Orgoyton and Ilmovaya Pad Burial Grounds. *Nanobiotechnol. Rep.* **2021**, *16*, 638–645. [CrossRef]
8. Hussein, A.M.; Madkour, F.S.; Afifi, H.M.; Abdel-Ghani, M.; Abd Elfatah, M. Comprehensive study of an ancient Egyptian foot case cartonnage using Raman, ESEM-EDS, XRD and FTIR. *Vib. Spectrosc.* **2020**, *106*, 102987. [CrossRef]
9. Teri, G.; Fu, P.; Han, K.Z.; Li, J.X.; Li, Y.L.; Jia, Z.H.; Wang, Y.J.; Li, Y.H. Color paintings of Taiping Heavenly Kingdom royal residence: An analytical study. *Coatings* **2022**, *12*, 1880. [CrossRef]
10. Li, T.; Xie, Y.F.; Yang, Y.M.; Wang, C.S.; Fang, X.Y.; Shi, J.L.; He, Q.J. Pigment identification and decoration analysis of a 5th century Chinese lacquer painting screen: A micro-Raman and FTIR study. *J. Raman Spectrosc.* **2009**, *40*, 1911–1918. [CrossRef]
11. Bian, J.Y. *Chinese Ancient Architecture Painting*; China Building Materials Industry Press: Beijing, China, 2013; pp. 50–55.
12. Chen, E.X.; Zhang, B.J.; Zhao, F.; Wang, C. Pigments and binding media of polychrome relics from the central hall of Longju temple in Sichuan. *China Herit. Sci.* **2019**, *7*, 45–83. [CrossRef]
13. Rao, H.Y.; Li, B.; Yang, Y.M.; Ma, Q.L.; Wang, C.S. Pro-teomic identification of organic additives in the mortars of ancient Chinese wooden buildings. *Anal. Methods* **2015**, *7*, 143–149. [CrossRef]
14. Hao, X.Y.; Schilling, M.R.; Wang, X.; Khanjian, H.; Heginbotham, A.; Han, J.; Stephanie, A.; Wu, X.J.; Beisong, F.; Hua, T. Use of THM-PY-GC/MS technique to characterize complex, multilayered Chinese lacquer. *J. Anal. Appl. Pyrol.* **2019**, *140*, 339–348. [CrossRef]
15. Qin, P.F.; Yi, D.Q.; Meng, Q.; Sun, A.J.; Sun, J.Q. Study and restoration of the Yi Ma Wu Hui layer of the ancient coating on the Putuo Zongcheng Temple. *Int. J. Archit. Herit.* **2020**, *5*, 1–15. [CrossRef]

16. He, L.; Wang, N.; Liang, J.Y.; Li, H.X. The effect of hematite and malachite to the aging of tung oil and Chinese lacquer. *Herit. Museum* **2009**, *6*, 269–275.
17. Xia, J.R.; Xu, Y.L.; Lin, J.H. UV-induced polymerization of urushiol, II: Effects of hydrogenation degree of urushiol on surface morphology. *Prog. Org. Coat.* **2010**, *67*, 365–369. [CrossRef]
18. Zheng, J.B.; Shan, W.F.; Zhang, W.; Guo, S.Q. Infrared spectra of ancient lacquer objects. *J. Fudan Univ. (Nat. Sci.)* **1992**, *31*, 345–349.
19. Jin, P.J.; Hu, Y.L.; Ke, Z.B. Characterization of lacquer films from the middle and late Chinese warring states period 476-221BC. *Microsc. Res. Techniq.* **2017**, *80*, 1344–1350. [CrossRef]
20. Schönemann, A.; Edwards, H.M.G. Raman and FTIR microspectroscopic study of the alteration of Chinese tung oil and related drying oils during ageing. *Anal. Bioanal. Chem.* **2011**, *400*, 1173–1180. [CrossRef] [PubMed]
21. He, Z.B.; Qian, J.; Qu, L.J.; Yan, N.; Yi, S.L. Effects of tung oil treatment on wood hygroscopicity, dimensional stability and thermostability. *Ind. Crop. Prod.* **2019**, *140*, 111647. [CrossRef]
22. Zhu, Y.; Li, Y.Z.; Ding, H.R.; Lu, A.H.; Li, Y.; Ji, X.; Zhang, Y.L.; Wang, C.Q. Vibrational and structural insight into silicate minerals by mid-infrared absorption and emission spectroscopies. *Phys. Chem. Miner.* **2022**, *49*, 6. [CrossRef]
23. Kumanotani, J. Enzyme catalyzed durable and authentic oriental lacquer: A natural microgelprintable coating by polysaccharide–glycoprotein–phenolic lipid complexes. *Prog. Org. Coat.* **1998**, *34*, 135–146. [CrossRef]
24. Li, Y.; Wang, X.S.; Ren, Y.H.; Zhang, T.T.; Zhang, J.N. Detection methods for the tung oil doped in lacquer. *Sci. Tech. Vision.* **2017**, *11*, 16–17.
25. Tamburini, D.; Sardi, D.; Spepi, A.; Duce, C.; Tine, M.R. Colombini, M.P.; Bonaduce, I. An investigation into the curing of urushi and tung oil films by thermoanalytical and mass spectrometric techniques. *Polym. Degrad. Stabil.* **2016**, *134*, 251–264. [CrossRef]
26. Wang, S.X. Overview of lacquering in ancient Chinese. *Cult. Relics* **1979**, *3*, 49–55.
27. Hu, A.H. A brief review of the history of cinnabar since the 20th century. *J. Hubei Univ. Chin. Med.* **2013**, *15*, 40–41.
28. Lu, H.L. *Technology and Construction of Ancient Architecture Oil Decoration*; China Construction Industry Press: Beijing, China, 2012; pp. 11–32.
29. Yang, F.W.; Zhang, B.J.; Ma, Q.L. Study of sticky rice-lime mortar technology for the restoration of historical masonry construction. *Accounts Chem. Res.* **2010**, *43*, 936. [CrossRef]
30. Shi, D.B.; Fu, W.G.; He, H.B.; Liu, Z.J.; Zhang, X.M.; Dong, Z.H.; Wang, Y.Q. The physical properties and biocompatibility of pig fibrin materials. *Chin. J. Exp. Surg.* **2009**, *26*, 1735–1736.
31. Lu, X.J. Introduction to application of brick in ancient times. *Brick-Tile* **2017**, *5*, 90–94.
32. Hu, D.D.; Li, Y.H.; Li, J. Some scientific information in technical process of colored drawing on Chinese ancient building. *Herit. Museum* **2009**, *6*, 443–458.
33. Wu, M.; Zhang, B.J.; Jiang, L.P.; Wu, J.; Sun, G.P. Natural lacquer was used as a coating and an adhesive 8000 years ago, by early humans at Kuahuqiao, determined by ELISA. *J. Archaeol. Sci.* **2018**, *100*, 80–87. [CrossRef]
34. Fu, Y.C.; Chen, Z.F.; Zhou, S.L.; Wei, S.Y. Comparative study of the materials and lacquering techniques of the lacquer objects from Warring States Period China. *J. Archaeol. Sci.* **2020**, *114*, 105060. [CrossRef]
35. Zhou, G.X. Cinnabar in China and its development in function. *Dunhuang Res.* **2010**, *2*, 51–59.
36. Chen, Y.S.; Xie, Y.L.; Lu, H.; Zheng, Y.M.; Jin, X.R.; He, Y.H. Studies on analysis and identification of prehistoric Chinese lacquer. *Sci. Conserv. Archaeol.* **1995**, *7*, 12–19.
37. Yang, Y.Z.; Shao, J.; Di, N. The excavation of the Xinjie site in Lantian county, Shaanxi Province. *Archaeol. Cult. Relics* **2014**, *4*, 3–23.
38. Wen, R.J. *Kao Gong Ji (Introduction to Chinese Classics)*; China International Broadcasting Press: Beijing, China, 2011; p. 219.
39. Han, F. Han Fei Zi–Shi Guo. The End of the Warring States Period. Available online: http://www.guoxue.com/book/hanfeizi/0010.htm (accessed on 16 August 2020).
40. Wang, S.X. *Explanation of Xiu Shi Lu: A Study on the Traditional Chinese Lacquer Craft*; Cultural Relics Publishing House: Beijing, China, 1998; pp. 5, 171.
41. Zhou, W.H.; Wang, L.Q.; Fan, X.L.; Yi, Y.; Ma, T. Study on the making techniques and materials of the oil-painting samples from a column in Bogda Khan Palace Museum. *J. Inner Mongolia Univ.* **2010**, *41*, 522–526.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.