

Article

UV Ageing Behavior of Chinese Lacquer Coatings on 3D-Printed PLA Substrates

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Abstract

Chinese lacquerware is valued for its distinctive gloss, hardness, and durability. In this study, three layers of natural lacquer were applied to 3D-printed PLA substrates and exposed to UVA-340 accelerated aging for 25 days. The lacquer film gradually became lighter in color, with the lightness value increasing from 30.69 to 44.69. At the same time, gloss decreased from 59.37 to 48.28 GU, while surface roughness increased significantly, with Ra rising from 2.11 to 10.07 μm . Pencil hardness declined from H to 5B, indicating a reduction in surface strength. FTIR results showed partial oxidation of phenolic hydroxyl groups, whereas the aromatic backbone and aliphatic side chains remained largely unchanged. These results suggest that UV aging mainly causes surface photo-oxidation, leading to fading, gloss loss, roughening, and reduced durability of the lacquer coating. SEM images showed that the lacquer surface changed gradually during UV exposure. In the first few days of aging, small cracks started to appear on the surface, along with a bit of powdering. As UV exposure continued, the cracks gradually became larger and began to spread. By the final stage, many of them linked up into a network, but the overall damage slowed down compared to earlier stages. Overall, the process moved through a quick initial change, then a period of crack growth, and finally a more stable phase. These results help make it clearer how UV light affects lacquer coatings on polymer-based materials.

Keywords: Chinese lacquerware; 3D-printed PLA; UV aging; photodegradation; surface characterization

1. Introduction

Chinese lacquerware has a history of several thousand years and is widely considered an important part of China's traditional craftsmanship and cultural heritage [1,2]. Natural lacquer has long served as the main coating material for lacquerware. When applied to wooden substrates, it not only improves the appearance of objects but also provides good protection and durability [3,4]. Because of its high gloss, hardness, and resistance to environmental damage, natural lacquer has been widely used in furniture, ceremonial objects, and cultural artifacts [5,6]. Preserving lacquerware is therefore important not only for protecting cultural heritage, but also for understanding traditional making techniques and historical material technologies.

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Although natural lacquer performs well overall, it is still sensitive to long-term ultraviolet exposure. UV radiation can lead to gloss loss, surface roughening, microcracks, and changes in chemical structure, all of which gradually weaken its protective performance [7,8]. Most previous studies have focused on lacquer films on traditional wooden substrates, while research on coatings applied to modern polymer materials is still relatively limited. Polylactic acid (PLA), a common material in additive manufacturing, has attracted attention due to its biodegradability, easy processing, and ability to form complex structures. Combining natural lacquer with 3D-printed PLA substrates offers a new way to reproduce traditional lacquerware and also opens up more possibilities for research and cultural heritage protection [9].

Compared with traditional wood substrates, which often suffer from moisture fluctuation, anisotropic swelling, biological degradation, and structural heterogeneity, PLA offers a more geometrically stable and reproducible platform for coating evaluation. However, PLA surfaces are chemically inert, exhibit relatively low surface energy, and are highly sensitive to UV-induced degradation, which may affect coating adhesion and long-term stability. These differences make PLA a fundamentally distinct substrate compared with traditional wood, requiring specific investigation into lacquer–polymer interfacial behavior [10,11].

The adhesion mechanism between natural lacquer and PLA substrates is expected to involve multiple interactions, including hydrogen bonding between urushiol phenolic hydroxyl groups and PLA carbonyl groups ($C=O \cdots H-O$), as well as micro-mechanical interlocking induced by the layer-by-layer morphology generated during 3D printing. In addition, UV irradiation may promote surface oxidation of both lacquer and PLA, further enhancing interfacial crosslinking and thus modifying coating stability during aging [12].

Compared with traditional manufacturing methods, 3D printing allows better control over sample size, structure, and surface features, making it easier to prepare consistent specimens for coating testing. This improves the reliability and repeatability of aging experiments. The advantages of additive manufacturing include controllable surface roughness (determined by 0.2 mm layer height), high structural reproducibility, and reduced variability compared with natural wood substrates, which often exhibit significant anatomical heterogeneity. These features make 3D-printed PLA an effective platform for standardized evaluation of coating degradation behavior [9].

The combination of natural lacquer and additive manufacturing is a practical link between traditional craftsmanship and modern engineering, and it creates new opportunities in product design, heritage restoration, and cultural innovation [13,14]. This study bridges traditional lacquer technology with additive manufacturing, enabling controlled evaluation of UV degradation on standardized polymeric substrates.

In this study, natural lacquer coatings on 3D-printed PLA substrates were exposed to accelerated UV aging. Changes in color, gloss, surface morphology, mechanical properties, and chemical structure were systematically analyzed to better understand how the lacquer film degrades under UV light and to provide useful reference data for future preservation and material applications.

2. Materials and Methods

2.1. Materials

Polylactic acid PLA with the chemical formula $C_3H_4O_2$ was used as the 3D printing substrate, and polyvinyl alcohol PVA C_2H_4O was used as the water-soluble support material. Both PLA and PVA filaments were purchased from Ultimaker (Makerbot Method series, Ultimaker, Utrecht, The Netherlands), with a diameter of 1.75 mm. The PLA filament is pure white, while the PVA filament is a light transparent yellow.

Chinese lacquer was provided by Longtou National Lacquer Company (Nanjing, China). It appears as a milky liquid with a distinct acidic smell and gradually darkens from a light tone to a brownish color when exposed to air. The solid content of the lacquer was determined using the gravimetric method, in which the lacquer was dried at 105 °C until constant mass. The solid content was calculated as follows: Solid content (%) = (dry mass/initial mass) × 100%, and was measured to be 71.97%.

2.2. Specimen Preparation

In this study, 3D-printed polylactic acid PLA panels were used as the substrates. A total of 30 samples were prepared, each with a size of 70 mm × 70 mm × 5 mm. The specimens were made using a Makerbot Method 3D printer (Ultimaker, The Netherlands). The printing parameters were determined based on preliminary optimization tests, literature reports, and manufacturer recommendations, and included a printing speed of 50 mm/s, a layer height of 0.2 mm, an infill density of 40%, and a nozzle temperature of 205 °C. The slicing process was performed using Makerbot Print software (version 5.0). After printing, the samples were placed in water to dissolve the PVA support material. Once the supports were fully removed, the specimens were taken out and left at room temperature, about 25 °C, for 24 h to make sure they were completely dry and stable.

After substrate preparation, natural lacquer with a solid content of 71.97% was applied to the PLA surface using a 50 µm wire-wound coating rod (Shanghai Chengyi Instrument Co., Ltd., Shanghai, China). Due to the relatively low surface energy of PLA, which limits wetting and adhesion, a multilayer coating strategy was adopted to enhance interfacial coverage, while lacquer penetration was mainly confined to surface roughness valleys. The coated specimens were then cured in a controlled environment at 25 °C and 80% relative humidity. Drying was assessed by a simple touch test. A surface that felt slightly tacky but did not stick to the finger was regarded as surface-dry, while a completely non-tacky surface indicated full curing.

After the first layer had fully dried, the same procedure was repeated to apply two additional layers. The three-layer coating system was used to improve film uniformity and overall stability. The final coating thickness was measured by cross-sectional SEM analysis (n = 5 measurements per specimen) and was determined to be 150 ± 4.6 µm (mean ± standard deviation). Before UV aging tests, all specimens were stored at room temperature for conditioning and subsequent characterization.

2.3. Accelerated Photodegradation

The accelerated UV aging test was carried out following ISO 4892-3:2016 “Plastics—Methods of exposure to laboratory light sources—Part 3: Fluorescent UV lamps” [15], which is commonly used to simulate and evaluate the weathering behavior of polymers and coatings under controlled laboratory conditions. The UVA-340 lamps (Q8/UV3, Kunshan Hongzhan Instrument Co., Ltd, Suzhou, China) were selected because their emission spectrum closely matches the short-wavelength region (295–365 nm) of natural sunlight UV radiation, providing a reliable simulation of outdoor UV exposure responsible for photochemical degradation.

The lacquer-coated specimens were placed in a Hongzhan Q8 UV aging chamber equipped with UVA-340 nm lamps. The test conditions were set at 40 °C, with a distance of 300 mm between the samples and the light source, an irradiance of 0.76 ± 0.08 W/m², and a relative humidity of 60%.

The whole aging test lasted for 25 days. Samples were taken out and evaluated every 5 days. At each time point, five parallel specimens were tested, and another five unaged samples were kept as the control group, giving a total of 30 specimens for the experiment.

2.4. Characterization Methods

The color of the lacquer coatings was measured using a CR-400 chroma meter Konica Minolta, Tokyo, Japan following ASTM D2244-16 “Standard Practice for Calculation of Color Differences from Instrumentally Measured Color Coordinates” [16]. At each aging stage, five specimens were randomly selected for testing, and four points were measured on each specimen, giving a total of $n = 20$ measurements per group. The L^* , a^* , and b^* values were recorded, and the average values were used to track the color change during UV aging.

The gloss of the lacquer films was measured according to ISO 2813:2014 [17] (Paints and varnishes—Determination of gloss value at 20° , 60° , and 85°) using a WG60 Glossmeter Shanghai Modern Environmental Engineering Technology Co., Ltd., Shanghai, China. Four positions at the corners of each of the five specimens were tested, resulting in 20 measurements per group. The final gloss value was taken as the average.

Pencil hardness was tested following ASTM D3363-20 “Standard Test Method for Film Hardness by Pencil Test” using a BY Pencil Hardness Tester Shanghai Pushen Chemical Machinery Co., Ltd., Shanghai, China [18]. Pencils from 6H to 6B were used and mounted on the tester. Starting from the softer end 6B, each pencil was drawn across the coating surface until a visible scratch appeared. The hardest pencil that did not leave a scratch was recorded as the coating hardness. Five specimens were tested for each group.

Surface roughness was measured according to ISO 4287:1997 [19]—Geometrical product specifications (GPS)—Surface texture: Profile method—Terms, definitions and surface texture parameters using a TR110 Surface Roughness Tester (Wenzhou Jingcheng Metrology Equipment Co., Ltd., Wenzhou, China). The parameters R_a , R_q , and R_t were measured at four different points on each of five specimens, giving a total of 20 data points per group.

Surface morphology was observed using a Quanta 200 Environmental Scanning Electron Microscope ESEM from Thermo Fisher Scientific in Hillsboro, ON, USA. Before SEM analysis, the samples were cut into small pieces measuring 2 mm by 2 mm with a thickness less than 0.5 mm, fixed on conductive adhesive tape, and coated with a thin layer of gold to improve conductivity. Images were collected at an accelerating voltage of 6 kV.

Chemical structure changes of the lacquer coatings during aging were analyzed using a Nicolet iS50 ATR-FTIR (Attenuated Total Reflectance Fourier Transform Infrared) spectrometer from Thermo Fisher Scientific in Waltham, MA, USA. The measurement range was 500 to 4000 cm^{-1} , with 32 scans per sample and a spectral resolution of 4 cm^{-1} . ATR mode was selected to ensure surface-sensitive detection and to minimize the contribution from the non-degraded inner layer of the coating.

All quantitative measurements, including color L^* , a^* , b^* , gloss, and surface roughness R_a , R_q , R_t , followed the same sampling strategy, with $n = 20$ data points per group (five specimens $\times$ four measurement points per specimen). Data were expressed as mean $\pm$ standard deviation. Statistical differences among aging intervals were evaluated using one-way analysis of variance (ANOVA) followed by Tukey’s HSD post-hoc test, with significance defined as $p < 0.05$.

3. Results and Discussion

3.1. Physical Changes of Lacquer Coatings During UV Aging

The physical properties of natural lacquer coatings on 3D-printed PLA substrates were clearly influenced by UVA-340 accelerated aging, as shown in Table 1. Over the 25-day UV exposure period, obvious changes were observed in color, gloss, surface roughness, and pencil hardness, which indicates a gradual degradation of the lacquer film. All tests were conducted on five specimens, with four measurement points on each specimen to keep the results reliable.

The brightness value (L^*) increased noticeably with time, rising from 30.69 on day 0 to 44.69 on day 25, with $p < 0.001$. This shows that the coating surface gradually became lighter. The main reason is related to UV-induced photochemical reactions, such as oxidation of phenolic structures and partial chain breakage [20,21]. The chromaticity values a^* and b^* changed less, but still showed statistically significant differences ($p = 0.013$ and 0.036), indicating slight shifts in hue. The rapid increase in L^* during the first 5 days, as evident from the steep initial slope of the ΔE curve in Figure 1, highlights that early-stage photodegradation predominantly affects the surface layer, consistent with previous reports on natural lacquer films [22,23].

Table 1. Physical changes of natural lacquer coatings on 3D-printed PLA substrates during UVA-340 accelerated aging (mean $\pm$ standard deviation, $n = 5$ specimens $\times$ 4 measurement points per specimen). Different letters within the same column indicate statistically significant differences among aging times (one-way ANOVA, $p < 0.05$).

Aging Time (Days)	Color Parameters			Gloss (GU)	Roughness (μm)			Hard- ness
	L^*	A^*	B^*		R_a	R_t	R_q	
0	30.69 ^e $\pm$ 0.94	0.61 ^b $\pm$ 0.27	0.58 ^b $\pm$ 0.24	59.37 ^a $\pm$ 3.91	2.11 ^e $\pm$ 0.09	2.60 ^e $\pm$ 0.09	10.48 ^e $\pm$ 0.54	H
5	36.07 ^d $\pm$ 1.34	0.59 ^b $\pm$ 0.10	0.61 ^b $\pm$ 0.18	56.48 ^b $\pm$ 2.22	4.92 ^d $\pm$ 0.16	5.43 ^d $\pm$ 0.18	15.79 ^d $\pm$ 0.65	B
10	39.00 ^c $\pm$ 1.01	0.71 ^{ab} $\pm$ 0.29	0.74 ^{ab} $\pm$ 0.29	54.25 ^c $\pm$ 1.93	6.75 ^c $\pm$ 0.24	7.18 ^c $\pm$ 0.26	18.99 ^c $\pm$ 0.78	3B
15	41.79 ^b $\pm$ 1.13	0.81 ^a $\pm$ 0.25	0.77 ^{ab} $\pm$ 0.23	51.22 ^d $\pm$ 2.08	8.36 ^b $\pm$ 0.32	8.82 ^b $\pm$ 0.33	21.54 ^b $\pm$ 0.89	4B
20	44.68 ^a $\pm$ 1.11	0.83 ^a $\pm$ 0.28	0.81 ^a $\pm$ 0.24	48.32 ^e $\pm$ 1.97	10.04 ^a $\pm$ 0.32	10.57 ^a $\pm$ 0.34	24.29 ^a $\pm$ 0.81	5B
25	44.69 ^a $\pm$ 1.10	0.86 ^a $\pm$ 0.26	0.84 ^a $\pm$ 0.29	48.28 ^e $\pm$ 1.96	10.07 ^a $\pm$ 0.31	10.61 ^a $\pm$ 0.34	24.31 ^a $\pm$ 0.50	5B
<i>p</i> values	<0.001	0.013	0.036	<0.001	<0.001	<0.001	<0.001	-

Gloss measurements revealed a steady decline from 59.37 GU to 48.28 GU over 25 days ($p < 0.001$). The most pronounced decrease occurred during the initial 10 days, corresponding to rapid surface evolution. This is closely associated with increased surface roughness and the formation of surface morphology defects such as microcracks and particulate debris, which reduce specular reflection [22,23]. Beyond 15 days, the rate of gloss loss slowed, indicating the possible formation of a thin layer of photoproducts on the surface, which may partially protect underlying material from further degradation [24,25].

Surface roughness parameters R_a , R_q , and R_t all showed a clear increasing trend throughout the aging process, with statistically significant differences ($p < 0.001$). Specifically, R_a increased from 2.11 μm to 10.07 μm , R_q from 2.60 μm to 10.61 μm , and R_t from 10.48 μm to 24.31 μm . These results indicate progressive deterioration of the coating surface, accompanied by microcrack formation and surface particulate debris accumulation. The increase was rapid in the early stage (0–5 days), corresponding to intense photochemical reactions, while the later stage (15–25 days) showed a gradual deceleration, suggesting partial stabilization of the surface layer.

The pencil hardness of the lacquer coatings decreased from H to 5B over 25 days, indicating a clear reduction in mechanical strength caused by UV irradiation. The most significant drop occurred during the first 0–5 days, showing that the surface structure was quickly weakened at the early stage. From 15–25 days, the rate of decrease became slower, which is likely related to continuous oxidation and gradual breakdown of the polymer network of the lacquer [26]. The results demonstrate a staged degradation process characterized by rapid initial changes followed by gradual deceleration rather than “leveling off” behavior.

Quadratic fitting of color (ΔE), gloss, and roughness changes (Figure 1) further confirms a staged degradation process. In the early stage from 0 to 5 days, ΔE and R_a increased quite quickly while gloss dropped sharply, showing that strong photochemical reactions and surface damage were taking place. In the middle stage from 5 to 15 days, the changes

became slower, which suggests that relatively stable oxidized surface layers were starting to form. In the late stage from 15 to 25 days, the trends tended to level off a bit, reflecting the development of crosslinked networks and some degree of surface stabilization.

Overall, the results from Table 1 and Figure 1 show that natural lacquer coatings on 3D-printed PLA substrates follow a typical staged photodegradation process. There are rapid changes at the beginning in color and surface properties, and then a slower, more gradual evolution over time. These results clearly indicate that UV exposure leads to chemical oxidation, polymer chain scission, and physical surface degradation at the same time. This also highlights the need for protective approaches such as UV-blocking coatings to improve the service life of lacquer-coated PLA substrates under long-term sunlight exposure [7,27].

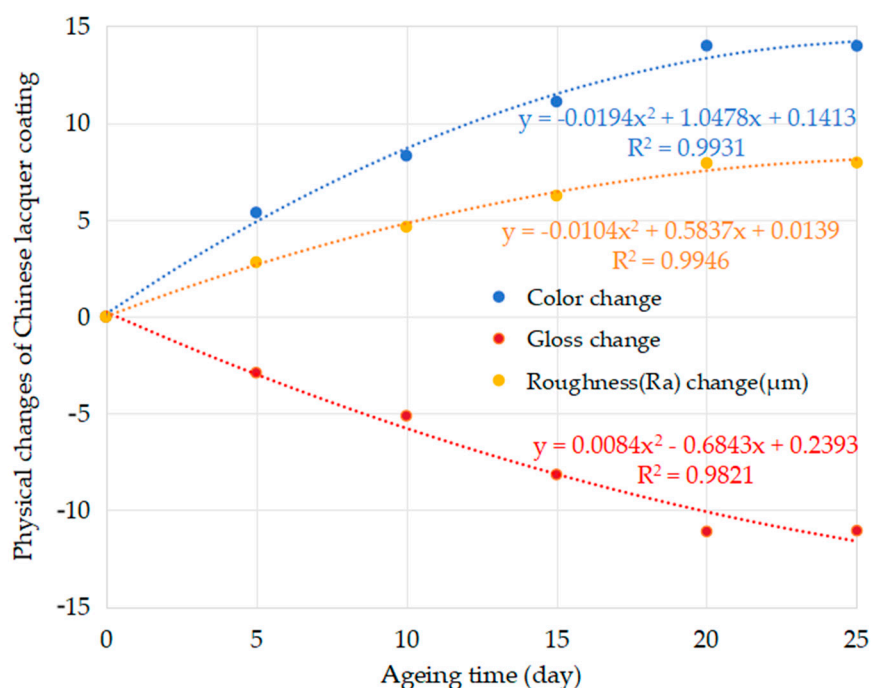


Figure 1. Trends of color, gloss, and roughness (Ra) during UV aging.

3.2. Chemical Changes of Lacquer Coatings During UV Aging

FTIR analysis was carried out to examine the chemical changes of natural lacquer coatings on 3D-printed PLA substrates during UVA-340 accelerated aging (Figure 2). The spectra give a clear picture of how different functional groups evolve over time, as well as the stability of the polymer backbone and the gradual formation of oxidative cross-linked structures within the lacquer film.

The broad band around 3350 cm^{-1} (–OH stretching) showed a slight decrease with increasing UV exposure time. This indicates that phenolic hydroxyl groups in urushiol undergo limited oxidation and hydrogen-bond rearrangement during aging, rather than significant consumption as previously assumed. The relatively stable OH signal suggests that hydroxyl groups are less directly involved in the primary photodegradation pathway [14,28].

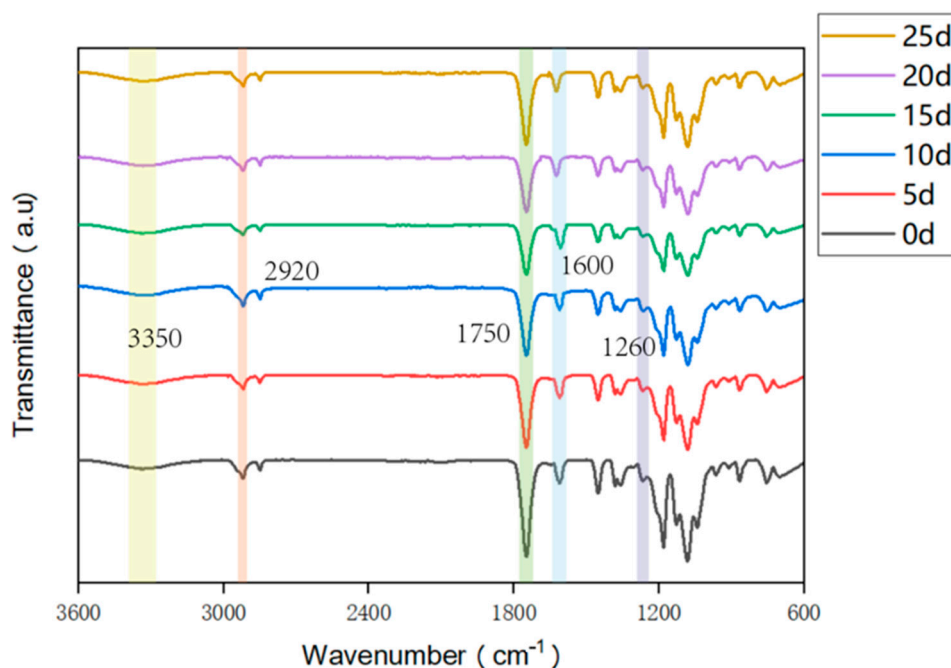


Figure 2. FTIR spectra of natural lacquer coatings on 3D-printed PLA substrates during UVA-340 accelerated aging.

The peak near 2920 cm^{-1} , corresponding to aliphatic $-\text{CH}_2-$ stretching, remained essentially stable throughout the aging process. This suggests that the long hydrocarbon side chains in urushiol are relatively stable under UV exposure. Because of this stability, the coating can better maintain its hydrophobicity and flexibility, and it may also help slow down the appearance of surface cracks and powdering seen in the physical tests [29].

A significant decrease in the carbonyl peak around 1750 cm^{-1} was observed, indicating active participation of ester-related groups in degradation reactions. In addition, the C–O stretching band near 1260 cm^{-1} also exhibited a notable reduction, demonstrating that C–O bonds are directly involved in the UV-induced degradation process. These results confirm that C=O and C–O functional groups are the primary reactive sites during photodegradation [30].

The aromatic C=C vibration near 1600 cm^{-1} remained almost unchanged, indicating that the aromatic backbone of urushiol is relatively stable under UV exposure [27].

Based on these observations, the photodegradation mechanism is mainly attributed to UV-induced photolysis of C–O bonds, followed by radical formation and subsequent oxidation of urushiol side chains. The cleavage of C–O bonds generates reactive intermediates that further promote crosslinking and partial network restructuring, rather than purely enzymatic or hydroxyl-driven reactions. This mechanism differs fundamentally from lactase-catalyzed enzymatic crosslinking and better explains the observed decrease in C–O and C=O signals [31].

The FTIR data indicate that while UV exposure induces significant changes in carbonyl and C–O related groups, the aromatic core structure remains largely intact. Progressive radical-driven oxidation and partial crosslinking contribute to the formation of a more stable surface network, which helps slow down later-stage physical degradation. These findings provide a molecular-level explanation for the observed trends in color, gloss, roughness, and hardness during the 25-day aging process.

3.3. Surface Morphology of Lacquer Coatings During UV Aging

The surface morphology of natural lacquer coatings on 3D-printed PLA substrates under UVA-340 accelerated aging was observed using SEM and digital imaging (Figure 3). Before aging, the coating exhibited a smooth and dense surface, consistent with high gloss and low roughness values. After 5 days of UV exposure, initial microcrack formation,

localized pits, and surface particulate debris were observed, indicating early-stage photochemical degradation [32].

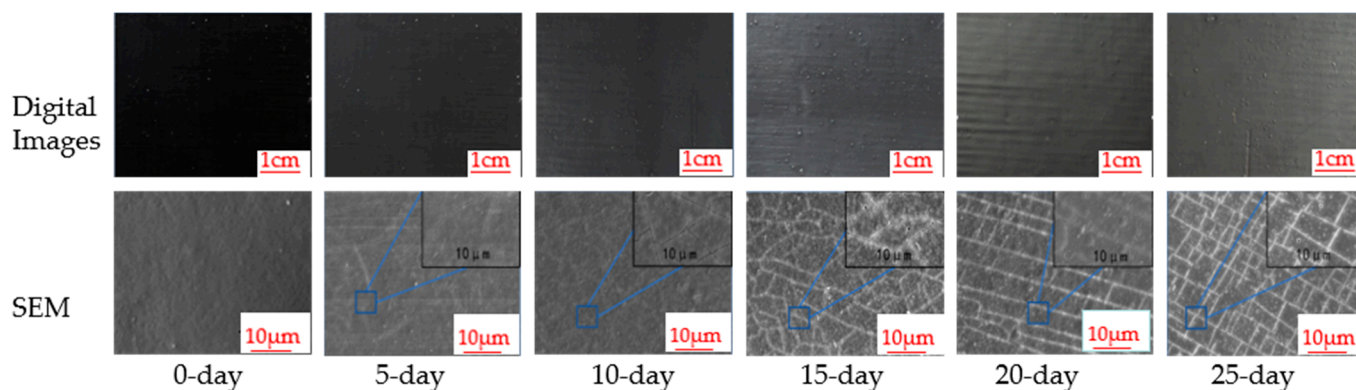


Figure 3. SEM and digital imaging of natural lacquer coatings on 3D-printed PLA substrates at different aging times under UVA-340 irradiation.

As aging continued to 10–15 days, the surface changes became more obvious. The number of cracks increased and they gradually grew and spread, while more protrusions and void-like structures appeared. The build-up of white powder together with the expanding cracks suggests that this stage corresponds to intermediate degradation, where oxidative crosslinking takes place in the urushiol side chains. This explanation is also supported by FTIR results (Figure 2). The trends in roughness and hardness during this period are consistent with SEM observations, showing that chemical reactions and physical damage occur at the same time [33,34].

In the late stage to 15–25 days, the coating surface exhibited extensive interconnected cracks, obvious voids, and widespread powdering, indicating severe structural damage and partial delamination. Although the defects continued to develop, changes in color, gloss, and roughness became more gradual, suggesting that crosslinked structures and degradation products partially stabilized the surface. Overall, the results show a clear staged aging process: rapid changes in the first 0–5 days, structural expansion and oxidation during 10–15 days, and severe deterioration in 15–25 days [5]. Importantly, by using 3D-printed PLA substrates, the present study benefits from a highly controllable and reproducible surface structure, which reduces the inherent variability of natural wood and enables more consistent evaluation of UV-induced degradation behavior in lacquer coatings. This advantage of additive manufacturing provides a more standardized platform for systematically analyzing lacquer aging mechanisms under controlled conditions.

4. Conclusions

This study systematically investigated the UV aging behavior of natural lacquer coatings on 3D-printed PLA substrates under UVA-340 accelerated conditions, focusing on physical properties, chemical structure, and surface morphology evolution. The main novelty lies in integrating traditional natural lacquer with additive-manufactured PLA substrates, providing a highly controllable and reproducible platform for evaluating coating degradation behavior. Results indicate that UV aging induces a staged degradation process dominated by surface photochemical reactions. In the early stage (0–5 days), rapid increases in L^* and surface roughness, together with a sharp decline in gloss and hardness, reflect intense surface photodegradation. In the intermediate stage (5–15 days), crack propagation and oxidative reactions dominate, leading to progressive structural deterioration. In the late stage (15–25 days), although severe damage such as interconnected

cracks and powdering occurs, the degradation rate gradually slows due to partial stabilization of crosslinked photoproducts. ATR-FTIR analysis shows limited changes in hydroxyl groups, while significant reductions in C=O and C–O bands indicate that UV-induced photolysis and radical-driven oxidation are the main degradation pathways. SEM observations confirm progressive surface failure from initial microcracks to a highly fragmented network structure. Importantly, the use of 3D printing reduces substrate variability compared with natural wood, improving experimental repeatability and enabling more reliable evaluation of lacquer degradation mechanisms. Limitations include the absence of long-term natural weathering data and interfacial adhesion analysis between lacquer and PLA. Future work should address long-term environmental exposure and interface optimization strategies.

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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.
2. Zhu, Z.; Qin, Y.; Guo, Z.; Cai, S.; Lin, P.; Wang, X.; Yang, J. Shedding new light on lacquering crafts from the Northern Wei Dynasty (386–534 CE) by revisiting the lacquer screen from Sima Jinlong’s Tomb. *J. Cult. Herit.* **2025**, *71*, 309–319.
3. Wu, M.; Zhang, B.; Jiang, L.; Wu, J.; Sun, G. 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.
4. Song, X.; Yang, Y.; Yang, R.; Shafi, M. Keeping watch on intangible cultural heritage: Live transmission and sustainable development of Chinese lacquer art. *Sustainability* **2019**, *11*, 3868.
5. Liu, L.; Wu, H.; Liu, W.; Gong, D.; Zhu, Z. Lacquering craft of Qing Dynasty lacquered wooden coffins excavated from Shanxi, China—A technical study. *J. Cult. Herit.* **2016**, *20*, 676–681.
6. Wang, N.; Zhang, T.; Min, J.; Li, G.; Ding, Y.; Liu, J.; Lei, Y. Analytical investigation into materials and technique: Carved lacquer decorated panel from Fuwangge in the Forbidden City of Qianlong Period, Qing Dynasty. *J. Archaeol. Sci. Rep.* **2018**, *17*, 529–537.
7. Yao, K.; Tian, J.; Huang, P. Urushiol-Based Antimicrobial Coatings for Lacquer Art Applications: A Review of Mechanisms, Durability, and Safety. *Coatings* **2026**, *16*, 198.
8. Lu, R.; Kamiya, Y.; Kumamoto, T.; Honda, T.; Miyakoshi, T. Deterioration of surface structure of lacquer films due to ultraviolet irradiation. *Surf. Interface Anal.* **2006**, *38*, 1311–1315.
9. Xie, Y.; Feng, Y.; Olarescu, A.; Chen, Y.; Liu, X. Effects of 3D Printing Parameters on the Coating Performance of Chinese Lacquer on PLA Substrates. *Coatings* **2025**, *15*, 1222.
10. Soares, J.B.; Finamor, J.; Silva, F.P.; Roldo, L.; Cândido, L.H. Analysis of the influence of polylactic acid (PLA) colour on FDM 3D printing temperature and part finishing. *Rapid Prototyp. J.* **2018**, *24*, 1305–1316.

11. Avinc, O.; Khoddami, A.; Hasani, H. A mathematical model to compare the handle of PLA and PET knitted fabrics after different finishing steps. *Fibers Polym.* **2011**, *12*, 405–413.
12. Chen, Y.; Liu, X.; Feng, X. Applications and prospects of 3D printing technology in lacquerware production. *China For. Prod. Ind.* **2024**, *61*, 77. 10.19531/j.issn1001-5299.202405013 (In Chinese).
13. Hou, J.; Wang, T.; Wang, Y.; Feng, X.; Liu, X. Research on the rapid curing mechanism and technology of Chinese lacquer. *Polymers* **2025**, *17*, 1596.
14. Bai, W.; Zhuo, D.; Xiao, X.; Xie, J.; Lin, J. Conductive, mechanical, and chemical resistance properties of polyurushiol/multi-walled carbon nanotube composite coatings. *Polym. Compos.* **2012**, *33*, 711–715.
15. ISO 4892-3:2016; Plastics—Methods of Exposure to Laboratory Light Sources—Part 3: Fluorescent UV lamps. International Organization for Standardization: Geneva, Switzerland, 2016.
16. ASTM D2244-16; Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates. ASTM International: West Conshohocken, PA, USA, 2016.
17. ISO 2813:2014; Paints and Varnishes—Determination of Gloss Value at 20°, 60° and 85°. International Organization for Standardization: Geneva, Switzerland, 2014.
18. ASTM D3363-20; Standard Test Method for Film Hardness by Pencil Test. ASTM International: West Conshohocken, PA, USA, 2020.
19. ISO 4287:1997; Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Terms, Definitions and Surface Texture Parameters. International Organization for Standardization: Geneva, Switzerland, 1997.
20. Nechifor, M. Factors influencing the photochemical behavior of multicomponent polymeric materials. In *Photochemical Behavior of Multicomponent Polymeric-Based Materials*; Springer: Cham, Switzerland, 2016; pp. 21–65.
21. Weigl-Kuska, M.; Kandelbauer, A.; Hansmann, C.; Müller, U. Wood—From natural color patterns toward naturally altered color impressions. In *Handbook of Natural Colorants*, 2nd ed.; Wiley: Hoboken, NJ, USA, 2023; pp. 469–505.
22. Liu, W.; Liu, X.; Lv, J. Comparative study on UV degradation of black Chinese lacquers with different additives. *Materials* **2023**, *16*, 5607.
23. Liu, M.; Wang, Z.; Varodi, A.M.; Liu, X. The influence of natural light aging on the surface properties of colored Chinese lacquer coatings. *Coatings* **2025**, *15*, 1229.
24. Hebner, T.S.; Maurer-Jones, M.A. Characterizing microplastic size and morphology of photodegraded polymers placed in simulated moving water conditions. *Environ. Sci. Process. Impacts* **2020**, *22*, 398–407.
25. Gaylarde, C.C.; Morton, L.H.G.; Loh, K.; Shirakawa, M.A. Biodeterioration of external architectural paint films—A review. *Int. Biodeterior. Biodegrad.* **2011**, *65*, 1189–1198.
26. Francis, R.; Sasikumar, S.; Gopalan, G.P. Synthesis, structure, and properties of biopolymers (natural and synthetic). In *Polymer Composites*; Wiley-VCH: Weinheim, Germany, 2013; pp. 11–107.
27. Zheng, Y.; Xin, X.; Yang, Q.; Zhang, Z.; Zhou, Z.; Ma, Y. Exploring the Development of Photoresists in Lacquer under the Background of Global Carbon Neutrality: A Mini Review. *Coatings* **2024**, *14*, 994. <https://doi.org/10.3390/coatings14080994>.
28. Anzai, K.; Lu, R.; Phuc, B.T.; Miyakoshi, T. Development and characterization of laccol lacquer blended with urushiol lacquer. *Int. J. Polym. Anal. Charact.* **2014**, *19*, 130–140.
29. Zheng, B.; Bai, W.; Chen, J.; Jian, R.; Yang, K.; Lin, Q.; Xu, Y. Inorganic salts as effective additive for adjusting the curing of natural oriental lacquer. *Prog. Org. Coat.* **2021**, *161*, 106494.
30. Hong, J.H.; Park, M.Y.; Kim, H.K.; Choi, J.O. UV-degradation chemistry of oriental lacquer coating containing hindered amine light stabilizer. *Bull. Korean Chem. Soc.* **2000**, *21*, 61–64.
31. Lee, H.B.; Jeon, J.G.; Lee, H.; Lim, J.A.; Lee, M.W. Enhancing structural stability of bio-inspired alumina coatings on CFRP for improved stab resistance using lacquer and adhesive. *Funct. Compos. Struct.* **2026**, *8*, 15004.
32. Zanoaga, M.; Tanasa, F. Photochemical behavior of synthetic polymeric multicomponent materials composites and nanocomposites. In *Photochemical Behavior of Multicomponent Polymeric-Based Materials*; Springer: Cham, Switzerland, 2016; pp. 109–164.
33. Van Acker, J.; Van den Bulcke, J.; Forsthuber, B.; Grüll, G. Wood preservation and wood finishing. In *Springer Handbook of Wood Science and Technology*; Springer: Cham, Switzerland, 2023; pp. 793–871.
34. Ainali, N.M.; Bikiaris, D.N.; Lambropoulou, D.A. Physicochemical alterations on UV aged polymers leading to microplastics formation: A multi-tiered study of polyester, polycarbonate and polyamide. *Polym. Degrad. Stab.* **2024**, *222*, 110692.

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