Coating Process Optimization and Self-Healing Performance Evaluation of Shellac Microcapsules Coated with Melamine/Rice Husk Powder

Xiaoxing Yan 1,2,* , Yan Han 2 and Taiyu Yin 2

Abstract: To explore the implication of the coating process on the comprehensive properties of water-based coating containing shellac microcapsules coated with melamine/rice husk powder on the Tilia cordata surface, the optical properties, mechanical properties, liquid resistance, aging resistance, chemical composition, and microstructure of the coating were analyzed comprehensively. After the best coating process was determined, compared with the coating without microcapsules, the self-repairing performance of the water-based coating containing shellac microcapsules coated with melamine/rice husk powder was explored via aging resistance test and scratch test. The results showed that the best comprehensive performance of the coating was obtained by three times primer, two times finish, and 6.0% shellac microcapsules coated with melamine/rice husk powder added in the primer. The coating with shellac microcapsules had significant stability, aging resistance, and self-healing performance, which can repair cracks in a certain period of time and inhibit the formation of cracks. At the core wall ratio of 0.75, the shellac which plays a role of the repair agent as the core material can effectively fill the microcracks in the coating to repair by flowing from the broken microcapsule because it can be physically cured at room temperature. The modification of waterborne coatings with shellac microcapsules coated with melamine/rice husk powder contributes the improved self-repairing properties of surface coatings containing heterogeneous natural polymer composites.

Keywords: microcapsules; melamine; rice husk powder; coating process; self-healing performance; waterborne coating

1. Introduction

Compared with traditional organic coatings, waterborne coatings on wood surfaces have the advantages of safety, innocuity, wear resistance and good chemical resistance [1–4], but it is necessary to improve the physical and mechanical properties [5–7]. Recent studies have shown that it has a broad research prospect on regulating the characteristics of coatings on a wood surface and inhibiting their defects by adding microcapsules [8–10]. Zhang et al. [11] fabricated the poly urea-formaldehyde coated epoxy microcapsules via in-situ polymerization, and the coating with microcapsules had good self-healing performance and good corrosion resistance. Cotting et al. [12] prepared poly(urea-formaldehyde-melamine) microcapsules containing epoxy resin via in-situ polymerization. It was shown that the coatings containing microcapsules achieved significant self-repairing protection effect after damage caused by artificial and mechanical stress. By in-situ polymerization, Lang et al. [13] successfully prepared a kind of self-healing coating which contained microcapsules embedded with linseed oil in the shell structure composed of poly urea-formaldehyde. Compared with the artificial epoxy resin coating, this coating showed...
excellent self-healing performance on artificial cracks. Ullah et al. [14] used oil-in-water emulsion polymerization to achieve the encapsulation of epoxy resins by encapsulating poly melamine-formaldehyde and poly urea-formaldehyde shells around emulsion epoxy droplets separately. The microcapsules also exhibited excellent self-healing properties after being added into waterborne coatings. These studies show that microcapsules can significantly improve the abilities of the coating on anti-corrosion and self-healing performance, while there are still some deficiencies on improving the mechanical properties of waterborne coatings on wooden substrates, which are problems that must be overcome in the use of waterborne coatings. In order to obtain better mechanical properties and prolong the service life of the coating, the elasticity of the coating can be enhanced by improving the polymer elasticity in the microcapsule wall. At the same time, the types and properties of adhesives in microcapsules are also very important for the self-repairing effect of microcracks [15–17].

With low price, excellent mechanical properties and thermal stability, the melamine resin is often used as wall material of microcapsules [18–20]. The rice husk powder, as a natural material, which is rich in plant fibers, has excellent toughness [21]. It can make melamine resin denser and firmer by being mixed with rice husk powder to obtain the microcapsules which have higher toughness and impermeability. It also can improve the mechanical properties of the coating on wooden substrate by extending the threshold of resistance to force and prolonging the self-healing time as a result of the good toughness of rice husk powder [22–24], as the core material, the shellac, a natural material, is green and environmentally friendly. The shellac has some excellent characteristics, such as moisture resistance, antirust, embalming, oil protection, acid resistance, and strong binding [25–27], and has been widely applied to the surface remediation of wooden crafts and precious musical instruments [28–30]. Therefore, the application of shellac microcapsule coated with melamine/rice husk powder has positive exploration significance and practical value on modification waterborne coatings on wood surface. In addition, the comprehensive properties of waterborne coating on wood surface are also affected by coating processes. Improper coating process leads to the decline of mechanical properties of the coating and initiates undesirable consequences like cracks.

In this paper, the microcapsules containing rice husk powder with a mass fraction of 5.5% were added to primer and finish, respectively. The mechanical property, optical property, and liquid resistance of waterborne coatings on the *Tilia cordata* surface were tested. The impact of the coating technology on the comprehensive performance of the waterborne coating containing microcapsule was explored by observing its surface morphology and analyzing its chemical composition. The aging resistance properties of the coating without microcapsules and the coating with microcapsules after different aging tests were compared, so as to observe the repair effect of microcapsules on the coating. The results provide a theoretical groundwork for the industrial production of high toughness self-healing functional water-based coatings.

2. Materials and Methods

2.1. Experimental Materials

Formaldehyde solution (37%, analytical purity, $M_w$: 30.03 g/mol, CAS No.: 50-00-0) was offered by Xuzhou Xingshi Chemical Co., Ltd., Xuzhou, China. Melamine (99.9%, $M_w$: 126.12 g/mol, CAS No.: 108-78-1) was offered by Shandong Shuntian Chemical Co., Ltd., Linyi, China. Shellac (Yunnan special grade II) was offered by Jinan Dahui Chemical Technology Co., Ltd., Jinan, China. The rice husk powder was (100 mesh, ground by powder machine) was provided by Lianyungang Lianfeng agricultural products Co., Ltd., Lianyungang, China. Triethanolamine (analytical purity, $M_w$: 149.19 g/mol, CAS No.: 102-71-6) and citric acid monohydrate (analytical purity, $M_w$: 210.14 g/mol, CAS No.: 5949-29-1) were provided by Sinopharm Chemical Reagent Co., Ltd., Shanghai, China. The sodium dodecyl benzene sulfonate (chemically pure, $M_w$: 348.48 g/mol, CAS No.: 25155-30-0) was offered by Changde Bickman Biotechnology Co., Ltd., Changde, China. Absolute
ethanol (99.5%, analytical purity, $M_w$: 46.07 g/mol, CAS No.: 64-17-5) was provided by Jiangsu Qiangsheng functional Chemistry Co., Ltd., Suzhou, China. The waterborne primer and waterborne finish (solid content about 30.0%, acrylic polymer as the main film-forming material) which contained water-based acrylic acid copolymer dispersion (90.0%), additive (2.0%), matting agent (2.0%) and water (6.0%), were offered by Nippon Paint Co., Ltd., Nanjing, China. *Tilia cordata* (100 mm × 65 mm × 4 mm) was offered by Weifang Hongyang Wood Industry Co., Ltd., Weifang, China.

### 2.2. Preparation of Microcapsule

Firstly, the 1.0 mol melamine was reacted with 3.0 mol formaldehyde in alkaline environment to form the soluble prepolymer, which could be further condensed into an insoluble cross-linked product melamine resin. According to the mass ratio of 1:2:2, the 5.0 g melamine, 10.0 g formaldehyde solution and 10.0 g deionized water were weighed and mixed in the beaker. They were fully stirred in the magnetic stirrer at the rate of 100 r/min, and the triethanolamine was slowly dropped into the above solution to control the pH value at about 9.0. After the melamine was completely dissolved, the 0.49 g rice husk powder pretreated with alkaline hydrogen peroxide and the 15.0 g deionized water were added into the mixture. The yellow liquid was obtained by stirring continuously in a constant temperature water bath at 70 °C for 30 min. The prepared solution was cooled to 20 °C and the wall material was obtained.

The 0.52 g sodium dodecylbenzene sulfonate was mixed with 51.0 g distilled water and dissolved to obtain emulsifier (mass fraction 1.0%). The shellac and ethanol were dissolved and mixed at the ratio of 1:5, the mixture was put into a centrifuge for centrifugation, and the upper clear shellac solution was taken out. According to the mass ratio of core material to wall material of 0.75, the 51.52 g of emulsifier with 1.0% concentration was slowly added into 39.84 g shellac solution at the speed of 1200 r/min. The mixed solution was stirred and emulsified at room temperature for 30 min, and a uniform core solution was obtained.

At the speed of magnetic mixer at 300 r/min, the wall material containing melamine/rice husk powder prepolymer was dripped into the core material solution. The citric acid monohydrate was dropped dropwise into the mixture to control the pH value of the solvent at about 2.5 to 3.0. Keeping it at 20 °C for reaction for 3 h, the solution was placed in a beaker for 7 d. The product was filtered after 7 d and washed with the ethanol solution and distilled water, respectively. After filtration, the product was dried in the oven for 4 h at 60 °C to obtain light yellow fluffy powder as a microcapsule sample [31].

### 2.3. Preparation of Coatings

The coating process experiment arrangement of water-based coating with microcapsules is shown in Table 1. In order to ensure that the coating with smooth surface can be obtained and the wood grain holes are closed, the best coating times of water-based coating is 2–3, and microcapsules are added in the finish or primer.

| Samples (#) | Number of Primer Coatings | Number of Finish Coatings | Coatings with Microcapsules | Microcapsule Weight (g) | Primer Coatings Weight (g) | Finish Coatings Weight (g) | Self-Healing Waterborne Coatings Weight (g) |
|------------|---------------------------|--------------------------|-----------------------------|-------------------------|-----------------------------|---------------------------|---------------------------------------------|
| 1          | 2                         | 2                        | finish                      | 0.12                    | 1.88                        | 2.0                       | 4.0                                         |
| 2          | 2                         | 3                        | finish                      | 0.12                    | 1.88                        | 2.0                       | 4.0                                         |
| 3          | 3                         | 2                        | finish                      | 0.12                    | 1.88                        | 2.0                       | 4.0                                         |
| 4          | 3                         | 3                        | finish                      | 0.12                    | 1.88                        | 2.0                       | 4.0                                         |
| 5          | 2                         | 2                        | primer                     | 0.12                    | 2.0                        | 1.88                      | 4.0                                         |
| 6          | 3                         | 2                        | primer                     | 0.12                    | 2.0                        | 1.88                      | 4.0                                         |
| 7          | 2                         | 3                        | primer                     | 0.12                    | 2.0                        | 1.88                      | 4.0                                         |
| 8          | 3                         | 3                        | primer                     | 0.12                    | 2.0                        | 1.88                      | 4.0                                         |

Preliminary experiments [32–35] showed that the comprehensive performance of the paint film was optimal when the content of rice husk powder in wall material of shellac microcapsule coated with melamine/rice husk powder was 5.5% and the optimal content
of primer or finish was 6.0%. The ingredients of microcapsules and waterborne coatings are also shown in Table 1. Take the sample with experiment No. 1 as an illustration. The 0.12 g microcapsules were mixed with 1.88 g waterborne primer. The waterborne primer containing microcapsule content of 6.0% was obtained and stirred uniformly. It was evenly coated on the surface of the *Tilia cordata* board and dried under ambient condition for 4 h. Then the dried coating was sanded with the sandpaper of 600 mesh. The primer was repeated in the same steps. Following the above process, the waterborne finish was applied twice. The prepared samples were dried at room temperature for 24 h. Samples No. 2–8 were coated in the same way. The size of the coating sample is 100 mm × 65 mm. The thickness of the dry polymer films was 60 µm.

2.4. Testing and Characterization

The chromatic aberration of the surface coating was measured with HP-2136 chromatograph (Shenzhen Threenh Technology Co., Ltd., Shenzhen, China). \( L \) indicates brightness, \( a \) indicates a red-green hue, and \( b \) indicates a yellow-blue hue. A set of data including \( L_1, a_1, \) and \( b_1 \), were output with the chromatograph at one point on the coating. Another set of data, \( L_2, a_2, \) and \( b_2 \), were measured with the chromatograph at the other point on the coating. According to the formula (1), \( \Delta L = L_1 - L_2 \) (difference in brightness), \( \Delta a = a_1 - a_2 \) (red/green difference), \( \Delta b = b_1 - b_2 \) (yellow/blue difference), chromatic aberration value \( \Delta E \) was calculated:

\[
\Delta E = \left[ (\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2 \right]^{1/2}
\]

The gloss of the coating was measured with HG 268 Smart Gloss Meter (Shenzhen Threenh Technology Co., Ltd., Shenzhen, China) by the standard GB/T 4893.6-2013 [36]. The gloss of the coating at 20°, 60° and 85° of incidence was recorded, respectively.

According to ISO 15184.1998 “Paints and varnishes—Determination of coating hardness by the pencil method” [37], the pencil hardness tester with pencil stiffness of 6B-6H (Cangzhou Jieke instrument and equipment manufacturing Co., Ltd., Cangzhou, China) was pressed down on the surface of the paint film at the angle of 45° under a load of 750 g to measure the hardness of coatings. The pencil hardness was gradually strengthened until a permanent indentation appeared on the paint film. At this time, the pencil hardness was the coating hardness.

The QFH-HG600 film scribing instrument (Dongguan Huaguo Precision Instrument Co., Ltd., Dongguan, China) was used to test the adhesion of the coating. The cutting tool was used to apply force evenly perpendicular to the coating surface, and then the cutting lines were formed on the coating. The above operations were repeated on the coating surface to form a 90° intersection with the original cutting lines to achieve a grid pattern. Then the grid was covered completely with adhesive tape, and the adhesive tape was held for a period of smooth tearing within 5 min. The coating adhesion grade was determined according to the coating breakage on the tape. There were grades of 1–5 in total, and grade 5 was the worst [38].

The impact resistance of the coating was measured by the QCJ coating impact tester (Jinan Ruima Testing Machine Manufacturing Co., Ltd., Jinan, China). The coated wood plate was placed on the impact tester to ensure that the steel ball in the center of the impact part could be lifted for a certain height to make the steel ball strike the wood board by free-falling method. Whether the coating was damaged was observed. The maximum height which made coating damage was recorded as the impact strength [39].

The elongation at break of the coating was measured by the universal mechanical testing machine (Xieqiang Instrument Manufacturing Co., Ltd., Shanghai, China) [40] and calculated according to the calculation Formula (2). In the formula (2), \( L_0 \) is the original marking distance of the sample, \( L \) is the length of the coating when the sample is broken:

\[
e = \frac{L - L_0}{L_0} \times 100\%
\]
The 15% sodium chloride solution (self-made), 70% ethanol solution (Qingdao Heino innover Disinfection Technology Co., Ltd., Qingdao, China), detergent which contained fatty alcohol ethylene oxide of mass fraction of 25% and water of mass fraction of 75% (Shanghai White Cat Co., Ltd., Shanghai, China) and red ink (Shanghai Fine Cultural Products Co., Ltd., Shanghai, China) were used to test the liquid resistance of the waterborne coating [41]. The surface of the coating was wiped clean. Then, the filter paper soaked with the solution was tiled on the four areas on the coating surface. After being placed in the sealed tank and standing for 48 h, the filter paper was withdrawn. Then the residual reagent on the coating was sucked dry with paper and standing for 16 h. The surface damage and impression of the test area were observed, and then the color difference and gloss were measured.

The appearance of microcapsules was observed by the Quanta-200 scanning electron microscope (FEI Co., Ltd., Hillsboro, OR, USA). The chemical composition of microcapsules and coatings were gauged by VERTEX 80 V infrared spectrum analyzer (Germany Bruker Co., Ltd., Karlsruhe, Germany). The specific test parameters included the test range of 4000–500 cm$^{-1}$, the time of scanning test of 16 s and the resolution of 4 cm$^{-1}$. The microcapsule powder and KBr were mixed and crushed for tablet pressing. The sample was placed on the test bench, and the infrared spectrum was obtained through the computer analysis connected with the equipment.

The aging test was carried out in the oven at 120 °C, 160 °C, and ultraviolet (UV) weather resistance test chamber (Dongguan Jiedong Experimental Equipment Co., Ltd., Dongguan, China), respectively. The UV region was considered as 290–400 nm, and the illumination level was 0.08 W/cm$^2$. The distance of the light source from the surface of the coatings was about 15 cm. The chromatic aberration and light loss rate of the coating were tested every 8 h in the oven for 40 h. The damages of the coating surfaces containing microcapsule addition of 0.0% and 6.0% under different high temperature aging were compared. The samples were placed in the UV weather resistance test chamber for 200 h, and tested and recorded every 40 h. During the aging process of the coating, the loss of light of the coating was also an evaluation method to detect the aging degree of the coating. The Formula (3) for calculating the light loss rate (G) is the following:

$$G = \frac{A - B}{A} \times 100\%$$ (3)

In the Formula (3), $A$ is the measured value of gloss before aging test, and $B$ is the measured value of gloss after aging test.

For scratch testing, the coating was scratch with a thin blade, and then the scratch changes at 1 d, 3 d, 7 d and 14 d were observed by Zeiss Axio scope A1 biological microscope (OM, Zeiss optical instruments International Trade Co., Ltd., Shanghai, China).

The rough test was tested by fine roughness tester J8-4C (Shanghai Taiming Optical Instrument Co., Ltd., Shanghai, China). The coated wood board was placed on the test bench, and the probe was moved to contact the wood board. After adjusting the probe position to ensure its stability at coordinate 0, the roughness was detected and recorded. All the tests were repeated four times, and the error was within 5.0%.

3. Results and Discussion

3.1. Analysis of Microcapsule Morphology and Composition

The SEM morphology of microcapsules with and without rice husk powder was analyzed as shown in Figure 1. Compared with Figure 1A, the microcapsules with rice husk powder content of 5.5%, which was showed in Figure 1B, had little agglomeration, good morphology, and uniform particle size. In Figure 2, the absorption peak at 1547 cm$^{-1}$ belongs to -NH- stretching vibration peak, which is the characteristic peak of melamine resin. Compared with the microcapsules without rice husk powder, the infrared spectrum of the microcapsules with rice husk powder in the wall material split at 1157 cm$^{-1}$, and the peak type changes. It can be inferred that this peak is affected by the C-H vibration
of aromatic core and the C-O-C antisymmetric “bridge” stretching vibration peak in rice husk powder, and it can be judged that the wall material of microcapsule contains cellulose. The absorption peaks at other positions of microcapsules with 5.5% rice husk powder in the infrared spectra are consistent with the microcapsules without rice husk powder. The chemical composition of the microcapsules has not changed, so it can be concluded that the microcapsules are successfully prepared.

![Figure 1](image1.png)  
**Figure 1.** SEM morphology of microcapsules: (A) without rice husk powder and (B) with rice husk powder.

![Figure 2](image2.png)  
**Figure 2.** Infrared spectrum of microcapsules with and without rice husk powder.

3.2. Influence of Coating Processes on the Performances of Waterborne Coatings Containing Microcapsules

3.2.1. Influence of Coating Processes on Optical Performances of Waterborne Coatings with Microcapsules

The influence of coating processes on chromatic aberration of waterborne coatings containing microcapsules is shown in Table 2. The difference between waterborne coatings prepared by different coating processes is not significant. However, on the whole, the
chromatic aberration of coatings is relatively minimum when microcapsules are added to the primer. When microcapsules are added into the finish, the chromatic aberration of the coating is slightly larger than that of the primer. Because microcapsules are particles, which affect the uniformity of the coating, the chromatic aberration of the paint film is enhanced. Table 3 and Figure 3 show the chromatic aberration analysis of orthogonal experiment. The greater the range, the more significant the influence of this factor. By comparing the range value, the influence of number of finish coatings on chromatic aberration of paint film is the most obvious, and the influence of number of primer coatings on chromatic aberration of paint film is the least.

Table 2. Influence of coating processes on chromatic aberration of waterborne coating containing microcapsules.

| Samples (#) | L1  | a1  | b1  | L2  | a2  | b2  | △L  | △a  | △b  | △E  |
|-------------|-----|-----|-----|-----|-----|-----|------|------|------|------|
| 1           | 75.0| 12.4| 24.0| 74.7| 12.0| 23.1| −0.3 | −0.4 | −0.9 | 1.0  |
| 2           | 72.5| 12.0| 24.7| 74.4| 12.5| 22.2| 1.9  | 0.5  | −2.5 | 3.2  |
| 3           | 67.5| 17.6| 28.1| 66.0| 17.6| 27.7| −1.5 | 0    | −0.4 | 1.5  |
| 4           | 68.2| 16.0| 25.8| 67.7| 15.3| 24.6| −0.5 | −0.7 | −1.2 | 1.5  |
| 5           | 69.3| 15.6| 29.1| 68.8| 15.2| 28.1| −0.5 | −0.4 | −1.0 | 1.2  |
| 6           | 67.2| 15.0| 28.2| 67.8| 15.3| 28.8| 0.6  | 0.3  | 0.6  | 0.9  |
| 7           | 69.5| 14.2| 27.6| 70.4| 14.2| 26.9| 0.9  | 0    | −0.7 | 1.1  |
| 8           | 69.2| 13.4| 28.5| 70.4| 13.5| 28.0| 1.2  | 0.1  | −0.5 | 1.3  |

Table 3. Analysis results of the orthogonal experiment.

| Samples (#) | Number of Primer Coatings | Number of Finish Coatings | Coatings with Microcapsules | △E  |
|-------------|---------------------------|---------------------------|-----------------------------|------|
| 1           | 2                         | 2                         | finish                      | 1.0  |
| 7           | 2                         | 3                         | primer                      | 1.1  |
| 6           | 3                         | 2                         | primer                      | 0.9  |
| 4           | 3                         | 3                         | finish                      | 1.5  |
| Mean 1      | 1.050                     | 0.950                     | 1.250                       |      |
| Mean 2      | 1.200                     | 1.300                     | 1.000                       |      |
| Range       | 0.150                     | 0.350                     | 0.250                       |      |

The influence of coating processes on the gloss of waterborne coatings containing microcapsules was gauged at the incident angle of 20°, 60°, and 85°, respectively. According to the Table 4, the gloss of the coatings No. 5–8 is better than that of the coatings No. 1–4. It indicates that the gloss of the coating under the process of “microcapsule added to the primer” is higher than the gloss of the coating under the process of “microcapsules added to the finish”. This is because the finish, which is on the upper layer, mainly determines the surface morphology of the coating. Under the process of “microcapsule added to the finish”, the particle numbers in the finish are increased, and it will increase the surface roughness of the coating, strengthen the diffuse reflection of light, and reduce the gloss of the coating. Compared with the coatings No. 5–8, it is found that the coatings No. 6 and No. 8 have the high gloss. The coatings No. 6 and 8 have more than one primer application compared to samples No. 5 and 7. It is inferred that the increase in the number of primer applications can have leveled the distribution of microcapsules over the primer. Hence, it can obtain a higher gloss by applying finish on the flatter primer. Taken together, the coating gloss is high via the coating processes of three times of primer and microcapsule added into the primer.
Figure 3. Main effects plot of number of primer coatings, number of finish coatings, and coatings with microcapsules.

Table 4. Influence of coating processes on gloss of water-based coating containing microcapsules.

| Samples (#) | Gloss of 20° (%) | Gloss of 60° (%) | Gloss of 85° (%) |
|------------|------------------|------------------|------------------|
| 1          | 3.5              | 10.7             | 4.2              |
| 2          | 5.9              | 14.3             | 5.0              |
| 3          | 3.5              | 11.9             | 3.5              |
| 4          | 5.5              | 15.5             | 6.7              |
| 5          | 22.0             | 42.8             | 48.9             |
| 6          | 19.3             | 43.0             | 55.4             |
| 7          | 15.7             | 35.1             | 37.3             |
| 8          | 19.3             | 52.3             | 55.5             |

3.2.2. Influence of Coating Processes on Mechanical Performances of Waterborne Coatings Containing Microcapsules

The effect of coating processes on mechanical performances of waterborne coatings containing microcapsules is shown in Table 5. The adhesion and hardness test results differed insignificantly. The factors indistinctively affecting the results depend on whether the microcapsules are mixed into the primer or the finish. Because the microcapsules increased the roughness and hardness of the coatings, the adhesion of the samples with microcapsule added in the finish slightly decreased and the hardness slightly enhanced. The values of impact resistance of samples No. 1–4 were all 5 kg·cm, which were lower than the values of samples No. 5–8. It indicated that the coating process of “microcapsule added into the primer” led to the high impact resistance, in which the primers of samples No. 6 and No. 8 were coated three times so that the coating impact resistance was better. According to the data of elongation at break, it can be analyzed that the elongation at break of the waterborne coating with microcapsules is improved, because the microcapsules contain rice husk powder cellulose, which can improve the mechanical properties of the coating and enhance the toughness of the coating. According to the Table 5, it showed that the elongation at break of the waterborne coating with primer containing microcapsules was higher, and the toughness of sample No.6 was better. The mechanical performances of the coating by the coating processes of three times of primer, two times of finish, and microcapsules added to the primer, are the best in Table 5. At this time, the adhesion of the coating is 0, the hardness is 4H, the impact resistance is 10 kg·cm and the elongation at break is 30.90%.
Table 5. Influence of coating processes on mechanical performances of waterborne coating containing microcapsules.

| Samples (#) | Adhesion | Hardness | Impact Resistance (kg cm) | Elongation at Break (%) |
|-------------|----------|----------|---------------------------|-------------------------|
| 1           | 1        | 5H       | 5                         | 10.42                   |
| 2           | 1        | 5H       | 5                         | 19.70                   |
| 3           | 0        | 4H       | 5                         | 22.56                   |
| 4           | 1        | 5H       | 5                         | 24.46                   |
| 5           | 0        | 4H       | 7                         | 18.48                   |
| 6           | 0        | 4H       | 10                        | 30.90                   |
| 7           | 0        | 4H       | 7                         | 26.82                   |
| 8           | 0        | 4H       | 10                        | 18.97                   |

3.2.3. Influence of Coating Processes on Liquid Resistance of Waterborne Coatings Containing Microcapsules

The liquid resistance of waterborne coatings prepared by different coating processes was tested, and the results were shown in Table 6. It was not observed that there were obvious traces on the surface after liquid resistance tests of NaCl solution, ethanol solution, and detergent. There was no obvious difference according to the chromatic aberration. However, there were obvious red traces in the area soaked with red ink. The change of chromatic aberration of the coating with the primer containing microcapsules is relatively small. This is because the texture of the finish without microcapsules is more uniform. It formed a dense and protective layer to isolate the red ink from microcapsules and wood, resulting in less chromatic aberration change. The change of liquid resistance gloss is shown in Table 7. It was illustrated that the gloss changes were not obvious after the four solutions were tested for the liquid resistance test.

Table 6. Influence of coating processes on liquid resistant chromatic aberration of waterborne coating containing microcapsules.

| Samples (#) | Liquid Resistant Chromatic Aberration |
|-------------|--------------------------------------|
|             | NaCl | Ethanol | Detergent | Red Ink |
| 1           | 3.04 | 2.12    | 2.75      | 45.21   |
| 2           | 2.57 | 1.85    | 3.06      | 40.15   |
| 3           | 2.10 | 2.25    | 1.95      | 43.02   |
| 4           | 3.99 | 2.56    | 2.18      | 39.12   |
| 5           | 1.93 | 1.40    | 2.67      | 34.79   |
| 6           | 1.88 | 1.24    | 1.83      | 35.31   |
| 7           | 1.32 | 1.88    | 1.81      | 36.25   |
| 8           | 1.88 | 1.59    | 1.24      | 37.43   |

Table 7. Influence of coating processes on liquid resistant gloss of waterborne coating containing microcapsules.

| Samples (#) | Liquid Resistant Gloss(%) |
|-------------|---------------------------|
|             | NaCl | Ethanol | Detergent | Red Ink |
| 1           | 11.2 | 9.9     | 7.6       | 9.9     |
| 2           | 8.4  | 8.8     | 8.5       | 10.0    |
| 3           | 12.7 | 13.5    | 12.9      | 12.7    |
| 4           | 11.4 | 12.8    | 10.3      | 12.4    |
| 5           | 32.3 | 35.2    | 33.0      | 34.8    |
| 6           | 38.2 | 37.5    | 35.6      | 37.1    |
| 7           | 29.7 | 28.7    | 25.4      | 28.9    |
| 8           | 44.7 | 45.8    | 43.8      | 44.8    |
The effect of coating processes on liquid resistant grade is shown in Table 8. All samples had good liquid resistance after being soaked with colorless liquid, which was grade 1. There was no obvious trace on the surface. However, there was difference in the liquid resistance grade after red ink infiltration. In addition, compared with the coating process of microcapsules added in the finish, the coating process of microcapsules added in the primer impacted the liquid resistance in a more remarkable way. The liquid resistance of coatings prepared by the coating process of a microcapsule added into the primer is better.

Table 8. Effect of coating processes on liquid resistant grade of waterborne coating containing microcapsules.

| Samples (#) | NaCl | Ethanol | Detergent | Red Ink |
|------------|------|---------|-----------|---------|
| 1          | 1    | 1       | 1         | 3       |
| 2          | 1    | 1       | 1         | 3       |
| 3          | 1    | 1       | 1         | 3       |
| 4          | 1    | 1       | 1         | 3       |
| 5          | 1    | 1       | 1         | 3       |
| 6          | 1    | 1       | 1         | 2       |
| 7          | 1    | 1       | 1         | 2       |
| 8          | 1    | 1       | 1         | 2       |

3.2.4. Analysis of Microstructure and Infrared Spectrum of Coatings

The optical property, mechanical property, and liquid resistance tests showed that the coating fabricated by the coating processes of three times of primer and two times of finish, microcapsule added into the primer, which was sample 6, had good performance. The roughness of the coating prepared by “three times of primer and two times of finish, no microcapsules” is 0.644 μm. The roughness of coating with 6.0% microcapsules in the primer (sample No. 6) is 0.936 μm. The SEM images of these two coatings are compared in Figure 4. It indicates that under the same coating process conditions, which are three times of primer and two times of finish, the waterborne coating without microcapsules is smoother than the waterborne coating with microcapsules in the primer. However, the surface of the coating coated with two times of finish after the three times of primer containing microcapsules is also relatively smooth and has less particles.

![Figure 4. SEM of the coating prepared by coating process on three times of primer and two times of finish: (A) without microcapsules and (B) with microcapsules in the primer.](image)

As shown in Figure 5, it can be observed that for the coating with the microcapsules added into the primer by the method of three times of primer and two times of finish, the characteristic absorption peaks of methyl and methylene are at 2943 cm⁻¹ and 2875 cm⁻¹, the strong and sharp absorption peak is -OH at 1731 cm⁻¹, and the characteristic absorption peak of carbon oxygen single bond in ester group is at 1166 cm⁻¹. Because the microcapsules do not change the chemical composition of the coating, the spectra of the two
coatings are relatively similar. In order to better visualize the change of polymer film with the microcapsules, Figure S1 shows the infrared spectrum of paint film with microcapsules and microcapsules alone.

![Infrared spectrum of paint film](image)

**Figure 5.** Infrared spectrum of paint film on three times of primer and two times of finish.

### 3.3. Aging Resistance Test of Waterborne Coating with Shellac Microcapsule Coated with Melamine/Rice Husk Powder

From the above results, when shellac microcapsules coated with melamine/rice husk powder are mixed to the waterborne paint primer, the coating process of “three times of primer and two times of finish, microcapsule added into the primer” is better. The aging resistance test results of waterborne coatings without microcapsules and that with 6.0% microcapsule were analyzed. As shown in Figure 6, when the aging time was 8 h–40 h in the oven at 120 °C, the chromatic aberration of the coating with 6.0% microcapsule increased from 2.77 to 2.94, and that of the coating without microcapsule increased from 3.18 to 5.06. As shown in Figure 7, the chromatic aberration of the coating with 6.0% microcapsules increased from 19.70 to 30.51, and that of the coating without microcapsules increased from 24.06 to 40.07 when the aging time was 8 h–40 h in the oven at 160 °C. As shown in Figure 8, with the aging time in the UV climate resistance test chamber increased from 40 h to 200 h, the chromatic aberration of the coating with 6.0% microcapsules increased from 3.25 to 6.92, and the chromatic aberration of the coating without microcapsules increased from 5.44 to 10.44. It illustrated that during the aging process, the chromatic aberration of the coating would gradually increase with the aging time. Based on the two different high-temperature aging processes, the chromatic aberration of the coating without microcapsule increases more than that of the coating with microcapsules. This is because the wood itself will carbonize to change the chromatic aberration in the high temperature environment. In addition, the microcapsules will break and release the core material from the milky yellow microcapsule during the aging process, increasing the protection of the coating on the wood surface. Therefore, the chromatic aberration is changed indistinctively.
protection of the coating on the wood surface. Therefore, the chromatic aberration is influenced by the temperature environment. In addition, the microcapsules will break and release the core material from the milky yellow microcapsule during the aging process, increasing the light loss rate. It is because the wood itself will carbonize to change the chromatic aberration in the high-temperature environment. As shown in Figure 7, the chromatic aberration of the coating with 6.0% microcapsule was 3.25 to 6.92, and the chromatic aberration of the coating without microcapsules increased from 5.44 to 10.44. It illustrated that during the aging process, the chromatic aberration of the coating would gradually increase with the aging time. Based on the two different high-temperature aging processes, the chromatic aberration of the coating with microcapsules increased from 5.44 to 10.44. It illustrated that during the aging process, the chromatic aberration of the coating without microcapsules did not have this ability.

When the coating was at 120 °C, as shown in Figure 9, the light loss rate of the coating without microcapsule reached 19.65% for 40 h, and that of the coating with microcapsule addition of 6.0% was 2.13% for 40 h. It indicates that the gloss of the paint film decreases only slightly. As shown in Figure 10, when the coating was at 160 °C, the light loss rate of the coating without microcapsules reached 45.85% for 40 h, and the light loss rate of the coating with 6.0% microcapsules reached 16.63% for 40 h. As shown in Figure 11, when the coating was at 160 °C and UV climate resistance test chamber, with the too-high aging strength, the microcapsules distributed in the coating broke under stress after the cracks occurred. The repair agent, as the core material, flowed to the crack to inhibit the generation of crack. This made the light loss rate of the coating surface increase slowly, while the coating without microcapsules did not have this ability.

Figure 6. Influence of time on chromatic aberration of coating under 120 °C aging test.

Figure 7. Influence of time on chromatic aberration of coating under 160 °C aging test.

Figure 8. Influence of time on chromatic aberration of coating under UV weather resistance test.
the coating without microcapsules reached 45.85% for 40 h, and the light loss rate of the coating with 6.0% microcapsules reached 16.63% for 40 h. As shown in Figure 11, when the coating was in the UV weather resistance test, the light loss rate of the coating without microcapsule was 19.21% for 40 h, and the light loss rate of the coating with microcapsule addition of 6.0% was 3.80% for 40 h. The results show that the light loss rate of the coating increased with the increase of aging time. During the aging process in the oven at 120 °C, the light loss rate decreased slightly from 24 h to 32 h. It may be because the microcapsule breaks caused by the micro crack on the coating surface, and the outflow of core material has the excellent repair effect on the coating. At this time, the repair effect was higher than the aging cracking strength of the coating, which reduced the gloss loss of the coating. After 32 h, the aging strength was still increasing, while the number of microcapsules with the repair effect in the coating decreased, resulting in the gradual decrease of overall repair strength and the increase of light loss rate. During the aging process in the oven at 160 °C and UV climate resistance test chamber, with the too-high aging strength, the microcapsules could also improve the aging resistance of the coating. The plant fiber, which is the composition in the microcapsule wall material, enhanced the toughness of the coating, fundamentally reducing the generation of cracks in the coating during the aging process. The microcapsules distributed in the coating broke under stress after the cracks occurred. The repair agent, as the core material, flowed to the crack to inhibit the generation of crack. This made the light loss rate of the coating surface increase slowly, while the coating without microcapsules did not have this ability.

Figure 9. Influence of time on light loss rate of coating at 120 °C in oven.

Figure 10. Influence of time on light loss rate of coating at 160 °C in oven.
Figure 9. Influence of time on light loss rate of coating at 120 °C in oven.

Figure 10. Influence of time on light loss rate of coating at 160 °C in oven.

Figure 11. Effect of time on light loss rate of coating in UV weather resistance test.

The SEM images of the coatings without microcapsules and with 6.0% microcapsules in which wall material contained 5.5% rice husk powder after aging test in the oven at 120 °C, at 160 °C and UV weather resistance test chamber are shown in Figures 12–14. It can be seen that the coating on the wood surface without microcapsules is obviously damaged after the aging test (Figures 12A, 13A and 14A). There are damages and cracks, and the maximum crack size is close to 40–50 μm. The coating with 6.0% microcapsules is not easy to crack in the aging process (Figures 12B, 13B and 14B). It may be that the waterborne coating with 6.0% microcapsules has the better elongation at break, good toughness and strong environmental adaptability. Even if the microcracks occur in the high-temperature environment, the microcracks will cause the microcapsule wall in the coating to break, and the core material will flow out and solidify at the crack, so as to inhibit or reduce the expansion of cracks and damage. However, the coating without microcapsules is prone to produce the cracks, and the cracks will continue to expand under the continuous action of environmental factors. It is directly proved that microcapsules can improve the aging resistance and thermal stability of waterborne coatings.

Figure 11. Effect of time on light loss rate of coating in UV weather resistance test.

Figure 12. SEM images of coating without and with microcapsules after aging at 120 °C in oven: (A) without microcapsules, (B) with 6.0% microcapsules.

Figure 13. SEM images of coating without and with microcapsules after aging at 160 °C in oven: (A) without microcapsules, (B) with 6.0% microcapsules.

Figure 14. SEM images of coating without and with microcapsules after aging in UV weather resistance test: (A) without microcapsules, (B) with 6.0% microcapsules.
The change of chemical composition of waterborne coatings without microcapsules before and after aging tests can be observed in Figure 15. The characteristic absorption peaks of methyl and methylene are at 2943 cm⁻¹ and 2875 cm⁻¹. The characteristic absorption peak of -OH is at 1731 cm⁻¹, and the characteristic absorption peak of carbon oxygen single bond in ester group is at 1166 cm⁻¹. The chemical composition of the waterborne coating before and after aging does not change, indicating that the aging test will not cause chemical reaction of the coating. Figure 16 is the infrared spectrum of the coating with 6.0% microcapsule before and after aging. It is observed that the characteristic peak positions are basically the same and the chemical composition has no change, indicating that there is no chemical reaction before and after the aging resistance test of the coating with 6.0% microcapsules.

The SEM images of the coatings without microcapsules and with 6.0% microcapsules after aging at 160 °C in oven: (A) without microcapsules, (B) with 6.0% microcapsules.

The SEM images of the coatings without microcapsules and with 6.0% microcapsules after aging in UV weather resistance test: (A) without microcapsules, (B) with 6.0% microcapsules.

Figure 13. SEM images of coating without and with microcapsules after aging at 160 °C in oven: (A) without microcapsules, (B) with 6.0% microcapsules.

Figure 14. SEM images of coating without and with microcapsules after aging in UV weather resistance test: (A) without microcapsules, (B) with 6.0% microcapsules.

Figure 15. Infrared spectrogram of coating without microcapsules before and after aging.
The change of chemical composition of waterborne coatings without microcapsules before and after aging tests can be observed in Figure 15. The characteristic absorption peaks of methyl and methylene are at 2943 cm$^{-1}$ and 2875 cm$^{-1}$. The characteristic absorption peak of -OH is at 1731 cm$^{-1}$, and the characteristic absorption peak of carbon oxygen single bond in ester group is at 1166 cm$^{-1}$. The chemical composition of the waterborne coating before and after aging does not change, indicating that the aging test will not cause chemical reaction of the coating. Figure 16 is the infrared spectrum of the coating with 6.0% microcapsule before and after aging. It is observed that the characteristic peak positions are basically the same and the chemical composition has no change, indicating that there is no chemical reaction before and after the aging resistance test of the coating with 6.0% microcapsules.

The stability and aging resistance of shellac microcapsules coated with 6.0% melamine/rice husk powder were compared with those without microcapsules. The results show that the composition of the coating does not change under any aging condition. In the aging test, the chromatic aberration of the coating will gradually increase with time. The chromatic aberration and light loss rate of the coating without microcapsule change more than that with microcapsule. The coatings without microcapsules have the large size damage, while the coatings with 6.0% microcapsules have much less damage in diameter and quantity. It indicates that the addition of microcapsules will make the coating have better stability and aging resistance. The coating with 6.0% microcapsule has good stability and aging resistance, indicating that a melamine/rice husk powder coated shellac microcapsule can inhibit the generation of microcracks and repair the coating to a certain extent.

3.4. Self-Repairing Performance Test of Water-Based Coating Containing Microcapsules

The results of scratch test of waterborne coating are shown in Figure 17. The scratch size on the first day of coating was 30.67 µm. The scratch size after 3 days was 20.73 µm. The addition of microcapsules has a certain repair effect on the cracks of the coating. The scratch size on 7 days was 20.42 µm. The repair speed began to slow down, and the scratch size was 22.57 µm on the 14th day. It shows that the effective time of self-healing property of microcapsules is about 7 days. When the external force makes the water-based coating crack, it also can make the microcapsules in the coating break. The shellac solution which contains shellac and solvent ethanol flows from the damaged microcapsule to the crack under the action of siphon. The solvent ethanol in shellac solution is easy to volatilize at room temperature. After the solvent volatilizes, shellac physically solidifies at room temperature, which can fill the microcracks, so as to reduce the cracks of waterborne coating to a certain extent. The cured core material no longer therefore has a self-healing ability, and the scratch will continue to expand under the action of environmental factors.
The addition of microcapsules has a certain repair effect on the cracks of the coating. The scratch size on the first day of coating was $30.67 \mu \text{m}$. The self-repairing mechanism is that shellac can flow into the gap of microcracks and repair the coating to a certain extent. The cured core material no longer has a self-healing ability, and the scratch size decreased from $30.67 \mu \text{m}$ to $20.42 \mu \text{m}$ after 7 days. The self-repairing mechanism is that shellac can flow into the gap of microcracks after the microcapsules break and be physically cured at room temperature to fill the gap. The results provide an important technical groundwork for improving the self-repairing performance of water-based coatings on the *Tilia cordata* surface. Research on the mechanism of bonding between shellac and acrylic resin—including bonding mechanism, adhesive force, and influencing factors—will be further explored in the future.

**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10.3390/app11188373/s1, Figure S1: Coating Process Optimization and Self-healing Performance Evaluation of Shellac Microcapsules Coated with Melamine/Rice Husk Powder.

**Author Contributions:** Conceptualization, X.Y.; methodology, X.Y.; validation, X.Y.; resources, X.Y.; data curation, X.Y.; writing-original draft preparation, X.Y.; supervision, X.Y.; data analysis, Y.H.; investigation, Y.H.; writing-review and editing, T.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** This project was partly supported by the Natural Science Foundation of Jiangsu Province (BK20201386).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

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

*Figure 17.* Scratch test diagram of waterborne coating: (A) 1 day, (B) 3 days, (C) 7 days, (D) 14 days.

4. Conclusions

The waterborne coating prepared by the best coating process of “three times of primer, two times of finish, and microcapsule which contained 5.5% rice husk powder in wall material added into the primer” had the better comprehensive properties. The chromatic aberration of the coating surface was small, which was 0.90, and the gloss was high, which was 55.4%. The cellulose in rice husk powder contained in the wall material could improve the mechanical properties of the coating to achieve good hardness and elongation at the break of the coating. The hardness was 4H and the elongation at break was 30.9%. The shellac microcapsule coated with melamine/rice husk powder could improve the stability and aging resistance. The scratch test illustrated that the waterborne coating had improved on the self-healing ability, and the scratch size decreased from $30.67 \mu \text{m}$ to $20.42 \mu \text{m}$ after 7 days. The self-repairing mechanism is that shellac can flow into the gap of microcracks after the microcapsules break and be physically cured at room temperature to fill the gap. The results provide an important technical groundwork for improving the self-repairing performance of water-based coatings on the *Tilia cordata* surface. Research on the mechanism of bonding between shellac and acrylic resin—including bonding mechanism, adhesive force, and influencing factors—will be further explored in the future.
References

1. Agnol, L.D.; Dias, F.T.G.; Ornaghi, H.L.; Sangermano, M.; Bianchi, O. UV-curable waterborne polyurethane coatings: A state-of-the-art and recent advances review. Prog. Org. Coat. 2021, 154, 106156. [CrossRef]
2. Xu, W.; Fang, X.Y.; Han, J.T.; Wu, Z.H.; Zhang, J.L. Effect of coating thickness on sound absorption property of four wood species commonly used for piano soundboards. Wood Fiber Sci. 2020, 52, 28–43. [CrossRef]
3. Liu, Q.Q.; Gao, D.; Xu, W. Influence of the bottom color modification and material color modification process on the per-for-mance of modified Poplar. Coatings 2021, 11, 660. [CrossRef]
4. Liu, Y.; Hu, J.; Wu, Z. Fabrication of coatings with structural color on a wood surface. Coatings 2020, 10, 32. [CrossRef]
5. Wu, Y.; Zhang, H.Q.; Yang, L.C.; Wang, S.Q.; Meng, Y.J. Understanding the effect of extractives on the mechanical properties of the waterborne coating on wood surface by nanoindentation 3D mapping. J. Mater. Sci. 2021, 56, 1401–1412. [CrossRef]
6. Liu, Q.Q.; Gao, D.; Xu, W. Effect of sanding processes on the surface properties of modified Poplar coated by primer compared with Mahogany. Coatings 2020, 10, 856. [CrossRef]
7. Wu, S.S.; Tao, X.; Xu, W. Thermal conductivity of Poplar wood veneer impregnated with graphene/polyvinyl alcohol. Forests 2021, 12, 777. [CrossRef]
8. Yan, X.X.; Peng, W.W. Preparation of microcapsules of urea formaldehyde resin coated waterborne coatings and their effect on properties of wood crackle coating. Coatings 2020, 10, 764. [CrossRef]
9. Liu, Y. Self-assembly of poly(styrene-methyl methacrylate-acrylic acid) (P(St-MMA-AA)) colloidal microspheres on wood surface by thermal-assisted gravity deposition. Wood Sci. Technol. 2021, 55, 403–417. [CrossRef]
10. Liu, Y.; Hu, J. Investigation of polystyrene-based microspheres from different copolymers and their structural color coatings on wood surface. Coatings 2021, 11, 14. [CrossRef]
11. Zhang, C.; Wang, H.R.; Zhou, Q.X. Preparation and characterization of microcapsules based self-healing coatings containing epoxy ester as healing agent. Prog. Org. Coat. 2018, 125, 403–410. [CrossRef]
12. Cotting, F.; Koebusch, A.; Aoki, I.V. Epoxy self-healing coating by encapsulated epoxy ester resin in poly (urea-formaldehyde-melamine) microcapsules. Front. Mater. 2019, 6, 314. [CrossRef]
13. Lang, S.N.; Zhou, Q.X. Synthesis and characterization of poly(urea-formaldehyde) microcapsules containing linseed oil for self-healing coating development. Prog. Org. Coat. 2017, 105, 99–110. [CrossRef]
14. Ullah, H.; Qureshi, K.S.; Khan, U.; Zaffar, M.; Yang, Y.J.; Rabat, N.E.; Khan, M.I.; Saqib, S.; Mukhtar, A.; Ullah, S.; et al. Self-healing epoxy coating synthesis by embedment of metal 2-methyl imidazole and acetylacetone complexes with microcapsules. Chemosphere 2021, 285, 131492. [PubMed]
15. Wang, Q.P.; Cao, J.Z.; Liu, X.E.; Yang, S.M.; Jiang, M.L. Self-healing coatings for inhibiting corrosion of ferrous metals exposed to preservative-treated bamboo. J. Wood Sci. 2020, 66, 18. [CrossRef]
16. Wang, Q.P.; Cao, J.Z.; Jiang, M.L. Self-healing coating to reduce isothiazolinone (MCI/MI) leaching from preservative-treated bamboo. Bioresources 2020, 15, 1904–1914.
17. Yan, X.X.; Tao, Y.; Qian, X.Y. Preparation and optimization of waterborne acrylic core microcapsules for waterborne wood coatings and comparison with epoxy resin core. Polymers 2020, 12, 2366. [CrossRef] [PubMed]
18. Jiang, W.J.; Zhou, G.; Wang, C.M.; Xue, Y.F.; Niu, C.X. Synthesis and self-healing properties of composite microcapsule based on sodium alginate/melamine-phenol-formaldehyde resin. Constr. Build. Mater. 2021, 271, 121541. [CrossRef]
19. Arukalam, I.O.; Madu, I.O.; Ishidi, E.Y. High performance characteristics of Lupinus arboreus gum extract as self-healing and corrosion inhibition agent in epoxy-based coating. Prog. Org. Coat. 2021, 151, 106095. [CrossRef]
20. Du, G.H.; Hu, J.F.; Zhou, J.H.; Wang, G.W.; Guan, S.L.; Liu, H.L.; Geng, M.; Lu, C.; Ming, Y.Q.; Qu, J.Q. The study on the mechanical properties of PU/MF double shell self-healing microcapsules. Chin. J. Chem. Eng. 2020, 28, 1459–1473. [CrossRef]
21. Hafid, H.S.; Omar, F.N.; Zhu, J.Y.; Wakisaka, M. Enhanced crystallinity and thermal properties of cellulose from rice husk using acid hydrolysis treatment. Carbohydr. Polym. 2021, 260, 117789. [CrossRef]
22. Chen, C.; Guo, W.H.; Zhou, Y.L.; Xiao, P.C.; Li, Y.F.; Wang, J.K. Curing behavior and properties of rice husk/melamine formaldehyde composite. Bioresources 2018, 13, 327–339. [CrossRef]
23. Zhang, G.X.; Zhang, Y.Y.; Chen, C.; Guo, W.H. Improved interfacial bonding of melamine formaldehyde/rice husk composites using poly(vinyl alcohol) modification. Nanosci. Nanotechnol. Lett. 2017, 9, 2088–2094. [CrossRef]
24. Hassan, A.F.; Alafid, F.; Hrdina, R. Preparation of melamine formaldehyde/nanozeolite Y composite based on nanosilica extracted from rice husks by sol-gel method: Adsorption of lead (II) ion. J. Sol-Gel Sci. Technol. 2020, 95, 211–222. [CrossRef]
25. Ma, J.J.; Zhou, Z.Q.; Li, K.; Li, K.; Liu, L.X.; Zhang, W.W.; Xu, J.; Tu, X.H.; Du, L.Q.; Zhang, H. Novel edible coating based on shellac and tannic acid for prolonging postharvest shelf life and improving overall quality of mango. Food Chem. 2021, 354, 129510. [CrossRef] [PubMed]
26. Yuan, Y.; He, N.; Xue, Q.R.; Guo, Q.Y.; Dong, L.Y.; Haruna, M.H.; Zhang, X.; Li, B.; Li, L. Shellac: A promising natural polymer in the food industry. Trends Food Sci. Technol. 2021, 109, 139–153. [CrossRef]
27. Liu, M.; Tu, X.W.; Liu, X.Y.; Wu, Z.H.; Lv, J.F.; Varodi, A.M. A comparative study on the effects of linseed oil and shellac treatment on the hygroscopicity, dimensional stability, and color changes of Chinese Ash Wood. Bioresources 2020, 15, 8085–8092. [CrossRef]
28. Simunkova, K.; Panek, M.; Zeidler, A. Comparison of selected properties of shellac varnish for restoration and polyurethane varnish for reconstruction of historical artefacts. Coatings 2018, 8, 119. [CrossRef]
29. Poli, T.; Chiantore, O.; Nervo, M.; Piccirillo, A. Mid-IR fiber-optic reflectance spectroscopy for identifying the finish on wooden furniture. *Anal. Bioanal. Chem.* **2011**, *400*, 1161–1171. [CrossRef]

30. Weththimuni, M.L.; Milanese, C.; Licchelli, M.; Malagodi, M. Improving the protective properties of shellac-based varnishes by functionalized nanoparticles. *Coatings* **2021**, *11*, 419. [CrossRef]

31. Yan, X.X.; Chang, Y.J. Effect of MF-coated epoxy resin microcapsules on properties of waterborne wood coating on Basswood. *Coatings* **2020**, *10*, 785. [CrossRef]

32. Qiao, J.; Zhao, D.; Zhao, Y.Y.; Lu, W.; Li, M.M.; Hu, X.M.; Liang, Y.T.; Tian, F.C.; Ju, S.; Yan, B.R. Preparation and characteristics of sustained-release microcapsule-based inhibitory foam with high foaming ratio. *Fuel* **2021**, *302*, 121219. [CrossRef]

33. Ouarga, A.; Noukrati, H.; Iraola-Arregui, I.; Elaissari, A.; Barroug, A.; Ben Youcef, H. Development of anti-corrosion coating based on phosphorylated ethyl cellulose microcapsules. *Prog. Org. Coat.* **2020**, *148*, 105885. [CrossRef]

34. Chen, K.L.; Xu, C.Y.; Zhou, J.L.; Zhao, R.Y.; Gao, Q.; Wang, C.X. Multifunctional fabric coatings with slow-releasing fragrance and UV resistant properties from ethyl cellulose/silica hybrid microcapsules. *Carbohyd. Polym.* **2020**, *232*, 115821. [CrossRef] [PubMed]

35. Yan, X.X.; Zhao, W.T.; Qian, X.Y. Effect of water-based emulsion core microcapsules on aging resistance and self-repairing properties of water-based coatings on Linden. *Appl. Sci. (Basel)* **2021**, *11*, 4662. [CrossRef]

36. GB/T 4893. 6-2013 Test of Surface Coatings of Furniture—Part 6: Determination of Gloss Value; Standardization Administration of the People’s Republic of China: Beijing, China, 2013; pp. 1–12. (In Chinese)

37. ISO 15184-1998 Paints and Varnishes—Determination of Coating Hardness by the Pencil Method; International Organization for Standardization: Geneva, Switzerland, 1998; pp. 1–7.

38. GB/T 4893. 4-2013 Test of Surface Coatings of Furniture—Part 4: Determination of Adhesion—Cross Cut; Standardization Administration of the People’s Republic of China: Beijing, China, 2013; pp. 1–12. (In Chinese)

39. GB/T 4893. 9-2013 Test of Surface Coatings of Furniture—Part 9: Determination of Resistance to Impact; Standardization Administration of the People’s Republic of China: Beijing, China, 2013; pp. 1–12. (In Chinese)

40. BS EN 15977-2011 Rubber or Plastic Coated Fabrics. Mechanical Properties. Determination of the Elongation under Load and the Residual Deformation; British Standards Institution: London, UK, 2011; pp. 1–12.

41. GB/T 4893. 1-2021, Test of Surface Coatings of Furniture—Part 1: Determination of Surface Resistance to Cold Liquids; Standardization Administration of the People’s Republic of China: Beijing, China, 2021; pp. 1–12. (In Chinese)