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Preparation of Melamine-Formaldehyde Resin/Rice Husk Powder Coated Epoxy Resin Microcapsules and Effects of Different Microcapsule Contents on the Properties of Waterborne Coatings on *Tilia europaea* Surface

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Abstract: With the development of economy and science and technology, people put forward higher standards for the performance of the surface coating of wood products, which requires us to carry out innovative research on the coating. In this work, a kind of microcapsule was prepared with melamine-formaldehyde resin/rice husk powder as wall material and epoxy resin as core material. The microcapsules were added to the waterborne acrylic resin coating according to the contents of 0%, 1.0%, 4.0%, 7.0%, 10.0%, 13.0%, 16.0% and 20.0% respectively, and were coated on the surface of the *Tilia europaea* boards in the form of topcoat. The effects of different contents of microcapsules on the optical properties, mechanical properties and aging resistance of the coating were explored, and the optimal content that can effectively improve the properties of the coating was analyzed. Test results indicated that when the microcapsule content is 7.0%, the comprehensive properties of the coating is optimal. At this time, the color difference of the coating is 6.96, the gloss at 60° is 13.4%, the hardness is 2H, the adhesion grade is 1, and the impact resistance is 12.0 kg·cm. After the aging test, the gloss loss rate decreases, the color difference is 5.69, and the gloss at 60° is 11.6%. The results of aging test show that the coating with epoxy microcapsules has a certain self-healing function. In this study, the microcapsules which can optimize the mechanical properties waterborne coating and prolong the service life of wood were prepared. This can meet the diverse needs of consumers, supply a theoretical reference for the preparation of functional microcapsules, and provide reference value for the functional research of the coating on wood furniture surface.

Keywords: microcapsules; waterborne coating; epoxy resin; melamine-formaldehyde resin; rice husk powder

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1. Introduction

Wood material is one of the most common materials in furniture manufacturing. It is widely loved because of its green environmental protection, good elasticity, impact resistance, rich and beautiful texture and tone, simple construction and other characteristics. However, as a natural polymer heterogeneous composite, wood materials are vulnerable to environmental impact, prone to cracking, decay, aging and other problems, which greatly limits the application and development of this green material in reality [1–8]. Painting on its surface can not only effectively protect the wood from being scratched by hard objects, isolate the direct contact between the wood and the outside world to inhibit the development of decay process, but also delay the aging problem of wood caused by long-term sunlight and greatly extend its service life [9–14].

Traditional wood coatings take organic solvents as the dispersion medium, which has high production cost and wastes energy, and will cause serious harm to the environment.

Therefore, the research, development, improvement and application of new water-based coatings have become a hot topic in recent years. Waterborne coating is a green product with water as solvent. It does not contain formaldehyde, has no irritating smell, and is environmentally friendly and safe [15–21]. However, in the process of actual use, the coating is affected by the environment and external forces, which will inevitably produce the use traces and small cracks, and shorten the service life of wood products. This poses a new challenge to improve the mechanical properties of waterborne coating. Microcapsule is a technology that completely wraps the core material with wall material to protect the chemical properties of the core material. Many studies have shown that if the microcapsules are added to the coating, when the cracks occur in the coating, the outer wall material of the microcapsule will crack, and the inner core material will slowly release to fill and repair the cracks [22–26]. It can be seen that using microcapsule technology to modify waterborne coating can not only enhance the mechanical performance of the coating, but also repair the micro cracks of the coatings and achieve the self-healing function of the coatings.

As the main component of woody organisms, the cellulose has nice mechanical properties and has been widely studied and applied in the application field of enhancing the toughness of polymers. Rice husk is rich in cellulose, which is a good raw material for wood plastic composites [27–30]. Melamine-formaldehyde resin is a kind of resin with good mechanical properties, which has the characteristics of low price and simple preparation process. Therefore, when preparing microcapsules, it is usually selected as the wall material [31–33]. Epoxy resin materials have the high chemical resistance, good adhesion, curing performance, impact resistance, and meet the requirements of environmental protection [34–36]. Using the mixture of melamine-formaldehyde resin and rice hull powder as the wall material of microcapsules can have the nice interfacial compatibility with water-based coating. Taking epoxy resin as the core material can give full play to the good performance of epoxy resin and improve the toughness of the coating.

In this work, the melamine-formaldehyde resin/rice husk powder coated epoxy resin microcapsules were prepared by situ-polymerization. The selected paint is waterborne acrylic resin paint, and the selected base material is *Tilia europaea* boards. The microcapsules were not added to the primer, but were added to the topcoat according to different contents [37]. The micro morphology, chemical composition, optical properties, mechanical properties and aging resistance of the coatings were tested and characterized, and the effect of microcapsule content on the performance of waterborne coating is explored, which provides a certain theoretical basis for the performance optimization of water-based coating applicable to the surface of wood substrate.

2. Experimental Materials and Methods

2.1. Experimental Materials

The materials used in this work are shown in Table 1. The wood base material is *Tilia europaea* boards, and the size is 60 mm × 80 mm × 5 mm. The topcoat and primer are Nippon waterborne acrylic paint.

Table 1. List of experimental materials.

Material	Molecular Formula	M_W (g/mol)	CAS No.	Concentration	Producer
Tilia europaea	-	-	-	-	Shanghai Jiangda Economic and Trade Co., Ltd., Shanghai, China
waterborne acrylic resin	-	-	9003-01-4	-	Jiangsu Changjiang Paint Co., Ltd., Nanjing, China
100 mesh rice husk powder	-	-	-	-	Xi'an Ruihe Bioengineering Technology Co., Ltd., Xi'an, China

Table 1. *Cont.*

Material	Molecular Formula	M_W (g/mol)	CAS No.	Concentration	Producer
hydrogen peroxide	H_2O_2	34.00	7722-84-1	5.0%	Shandong Xiekang Medical Technology Co., Ltd., Shandong, China
sodium hydroxide	NaOH	40.00	1310-73-2	-	Xilong Science Co., Ltd., Shantou, China
bisphenol A epoxy resin	$C_{21}H_{24}O_4$	340.41	25085-99-8	-	Nantong Xingchen Synthetic Material Co., Ltd., Nantong, China
T-31 curing agent	-	-	-	-	Nantong Xingchen Synthetic Material Co., Ltd., Nantong, China
melamine	$C_3H_6N_6$	126.12	108-78-1	99.8%	Nantong Xingchen Synthetic Material Co., Ltd., Nantong, China
formaldehyde solution	CH_2O	30.03	50-00-0	37.0%	Xilong Science Co., Ltd., Shantou, China
triethanolamine	$C_6H_{15}NO_3$	149.19	102-71-6	99.9%	Guangzhou Jieya Chemical Co., Ltd., Guangzhou, China
benzyl alcohol	C_7H_8O	108.14	100-51-6	99.9%	Xilong Science Co., Ltd., Shantou, China
sodium dodecyl benzene sulfonate	$C_{18}H_{29}NaO_3S$	348.48	25155-30-0	99.9%	Tianjin Zhiyuan Chemical Reagent Co., Ltd., Tianjin, China
citric acid monohydrate	$C_6H_{10}O_8$	210.14	5949-29-1	99.9%	Xilong Science Co., Ltd., Shantou, China
n-octanol	$C_8H_{18}O$	130.29	111-87-5	99.9%	Xilong Science Co., Ltd., Shantou, China
ethyl acetate	$C_4H_8O_2$	88.11	141-78-6	99.9%	Nanjing Chemical Reagent Co., Ltd., Nanjing, China
anhydrous ethanol	C_2H_6O	46.07	64-17-5	99.9%	Wuxi Zhanwang Chemical Reagent Co., Ltd., Tianjin, China

2.2. Preparation Method of the Epoxy Resin Microcapsules

The microcapsules prepared in this test take melamine-formaldehyde resin/rice husk powder as the wall material and epoxy resin as the core material. The preparation process is as follows:

(1) Preparation of rice husk powder: the 10.0 g of the 100 mesh rice husk powder was weighed, and the hydrogen peroxide was poured in a ratio of 1:20 by volume of solid-liquid. The aqueous sodium hydroxide solution was slowly poured in until the pH of the solution was 11.5. The obtained solution was placed in a constant temperature water bath at 70 °C for 24 h, then placed in a centrifuge for centrifugation, and the clarified liquid on it was poured out. The remaining substances were poured back into a beaker and dried in baking oven at 60 °C for 3 h. As shown in Figure 1, the dried rice husk powder was ground in the grinder to reduce the particle size to the micron level, which can better cover the core material.

Figure 1. Pretreated rice husk powder.

(2) Preparation of wall material: the 5.0 g of melamine, the 10.0 g of 37.0% formaldehyde and the 10.0 g of water were added to the beaker, and the 1.0 g of pretreated rice husk powder was added, and then mixed evenly. The triethanolamine was slowly added until the pH value was adjusted to 8.59. The obtained solution was placed in a 70 °C constant temperature magnetic stirrer and reacted at 800 r/min speed. When the solution became transparent, the 15.0 g of water was added, and the prepolymer was obtained after reaction for 30 min.

(3) Preparation of core material: the 1.0 g epoxy resin and the 1.0 g benzyl alcohol as diluent were weighed and stirred until fully mixed. The 100.0 g water and 1.0 g sodium dodecyl benzene sulfonate powder were weighed to another beaker, which was stirred evenly to become an emulsifier solution. The diluted epoxy resin solution was poured in, which was fully stirred evenly and then put into a 60 °C constant temperature magnetic stirrer at a speed of 1200 r/min. After 30 min, the n-octanol was dripped for defoaming. The obtained solution was the core material solution.

(4) Microencapsulation: the wall material was slowly poured to the core material, and the citric acid monohydrate was added one by one at the speed of 300 r/min. After being stirred until completely dissolved, the pH test paper was used to test the pH value until the value was 2.5–3.0. Then the temperature was slowly raised to 70 °C, and the reaction lasted for 3 h. The resulting substance was filtered by suction and then put into a drying oven at 80 °C for 4 h and then ground. As shown in Figure 2, the obtained powder were the prepared microcapsules, which were light yellow white.

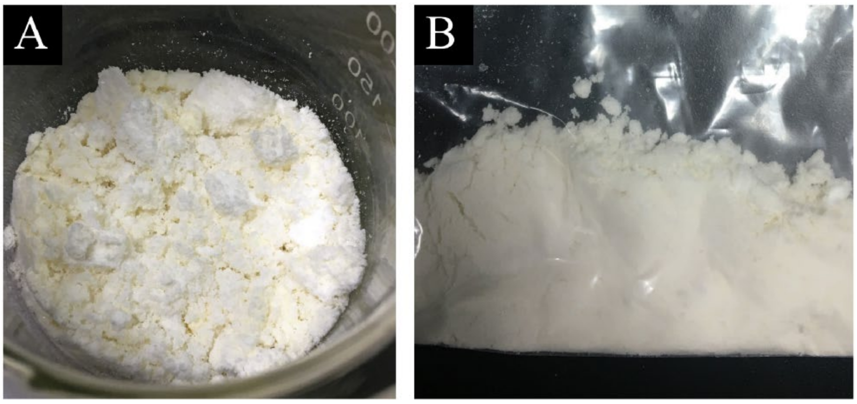

Figure 2. Macro morphology of the microcapsules: (**A**) the microcapsules before grinding, (**B**) the microcapsules after grinding.

2.3. Preparation of the Coatings

The 600 mesh sandpaper was used to gently polish the *Tilia europaea* boards to remove burrs, the brushes were used to remove debris, and the rags were used to wipe dirt off the wood surface to make the wood surface smooth and clean. The corresponding weights of microcapsules and coatings are shown in Table 2. The microcapsules were added to the topcoat, and the microcapsules were not added to the primer. The microcapsules in the topcoat were 0%, 1.0%, 4.0%, 7.0%, 10.0%, 13.0%, 16.0% and 20.0% respectively. First, the film preparer was used to apply the primer evenly on the surface of the boards. After drying at room temperature for 12 h, the 800 mesh sandpaper was used to polish carefully. Then the boards were coated for the second time, and then dried in the oven at 30 °C for 24 h, and the sandpaper was used to polish it again. After the primer was coated, the topcoat with microcapsules was evenly painted on the surface of the boards twice, and the coating process was the same as that of the primer. The thickness of the coating was 60 µm.

Table 2. Experimental material list.

Content of Microcapsules (%)	Weight of Microcapsules (g)	Weight of Primer (g)	Weight of Topcoat (g)
0	0	3.00	3.00
1.0	0.03	3.00	2.97
4.0	0.12	3.00	2.88
7.0	0.21	3.00	2.79
10.0	0.30	3.00	2.70
13.0	0.39	3.00	2.61
16.0	0.48	3.00	2.52
20.0	0.60	3.00	2.40

2.4. Testing and Characterization

The test instruments used in this paper are shown in Table 3. The micro morphology of the coating was analyzed by scanning electron microscope. Infrared spectroscopy was used to analyze the coating.

According to the standard of GB/T 11186.3-1989 [38], a portable colorimeter was used to test the color difference of the coatings. First, the colorimeter was calibrated, the test hole was aligned with the plate to be tested, and two groups of the values of L^*, a^* and b^* were recorded. The L^* indicates brightness, and a positive value indicates that the surface color of the measured object is bright. The a^* indicates the change of color from red to green, and a positive value indicates that the color is red. The b^* indicates the change of color from yellow to blue, and a positive value indicates that the surface color of the tested object is yellow. The first group of data tested was recorded as L_1^*, a_1^*, b_1^*. The second group of data tested was recorded as L_2^*, a_2^*, b_2^*. The color difference was represented by ΔE, calculated by the Formula (1). In this formula, $\Delta a^* = a_2^* - a_1^*$, $\Delta L^* = L_2^* - L_1^*$, $\Delta b^* = b_2^* - b_1^*$.

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (1)$$

As a surface optical property of an object, the gloss depends on the specular reflection ability of the object surface. According to the standard of GB/T 4893.4-2013 [39], the gloss meter was used to record the gloss of the coatings at three different angles of 20°, 60° and 85°. The gloss loss of the coatings with microcapsules was calculated compared with that without microcapsules at an incident angle of 60°. The G_0 is the coating without microcapsules, the G_1 is the coating with microcapsules, and the G_L is the light loss rate. The light loss rate was calculated according to the Formula (2).

$$G_L = (G_0 - G_1)/G_0 \times 100\% \quad (2)$$

According to the standard of GB/T 6739-2006 [40], the hardness of the paint film was tested with a portable paint film hardness tester. The wooden rod part of the pencil top was cut off, and the pencil lead was exposed for about 3 mm and placed for use. The boards were placed flat on the console, and the pencil was at an angle of 45° to the surface of the boards. The pencil was pushed on the surface of the paint film, and the pencil hardness that cut the surface of the paint film was the surface hardness of the paint film. By repeating the above experiments, the surface hardness of the paint films with different microcapsule content was measured respectively.

The adhesion of the paint film was tested with a paint film gridding instrument according to the standard of GB/T 9286-1998 [41]. The tooth pitch of this instrument is 2 mm. The board was placed on the operating platform, and the handle of the scriber was held so that the knife was perpendicular to the surface of the board, and then the surface was cut with uniform force and fixed speed. After that, the board was rotated by 90°, and the previous operation was repeated at the cut previously, so that a mesh pattern appeared on the surface. All cuts in this operation should penetrate the coating. After that, the adhesive tape with a width of 25.0 mm and an adhesion of 10 ± 1 N was pasted on the whole grid, and then it was gently torn off. The adhesion was judged on the basis of the peeling off of the coatings. The adhesion grade of the coating was divided into 0, 1, 2, 3, 4 and 5 from high to low. The falling off areas of the paint film correspond to 5.0%, 15.0%, 35.0%, 55.0% and more than 60.0% respectively. The higher the grade, the worse the adhesion of the paint film.

Impact resistance of paint film refers to the ability of the paint film applied to wood to deform rapidly without cracking under the action of high-speed gravity. According to the standard of GB/T 1732-1993 [42], the paint film impactor tester was used to test the impact resistance of the film. After the impact block was raised to a certain height, it falls freely to impact the specimen. The surface of the coatings was observed for cracks and spalling, and the maximum height without cracking was the impact strength.

According to the standard of GB/T 1740-2007 [43], the aging test in this paper was to create a simulated environment to accelerate the aging of the boards. The coated wood boards were placed in a 120 °C electric blast drying oven for high-temperature aging test, and the coating surface was observed after 12 h. The effect of microcapsules on the high temperature aging resistance of the coating was analyzed.

Table 3. Experimental instrument list.

Instrument	Model	Producer
constant temperature heating magnetic stirrer	DF-101Z	Zhengzhou Tengyue Instrument Equipment Co., Ltd., Zhengzhou, China
four side film applicator	BEVS1803	Guangzhou Keyu New Material Technology Co., Ltd., Guangzhou, China
scanning electron microscope (SEM)	Quanta-200	FEI Company, Hillsboro, OR, USA
Fourier transform infrared spectrometer (FTIR)	VERTEX 80V	Germany Bruker Co., Ltd., Karlsruhe, Germany
portable colorimeter	SC-10	Shanghai Hechen Energy Technology Co., Ltd., Shanghai, China
gloss meter	X-rite ci60	Shenzhen Laite Instrument Equipment Co., Ltd., Shenzhen, China
portable paint film hardness tester	QHQ-A	Aikosi Electronic Technology Co., Ltd., Changzhou, China
paint film gridding instrument	QFH-A	Aikosi Electronic Technology Co., Ltd., Changzhou, China
paint film impactor tester	BEVS1601	Guangzhou Xinyi laboratory equipment Co., Ltd., Guangzhou, China
electric blast drying oven	DHG-9031A	Shanghai Jinghong Experimental Equipment Co., Ltd., Shanghai, China

3. Results and Discussion

3.1. Morphology Analysis of the Microcapsules and Coatings

Figure 3 shows the SEM morphology of microcapsules. The prepared microcapsules are well coated, spherical and uniform in particle size, about 5–7 μm. Figure 4 shows the SEM morphology of the coatings with different content of the microcapsules on the wood substrate. The surface of the coating without microcapsules is smooth and flat, and the surface smoothness of the coating with a small amount of microcapsules is second. With the increase of microcapsule content, the agglomeration in the coating increases. When the content reaches 13.0%, the agglomeration is obvious and the surface becomes uneven. This is because microcapsules are granular. With the increase of content, microcapsules cannot be evenly distributed in the paint, so the particles agglomerate when coated on wood.

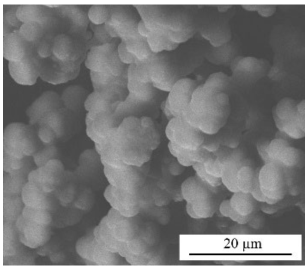

Figure 3. Morphology of the microcapsules.

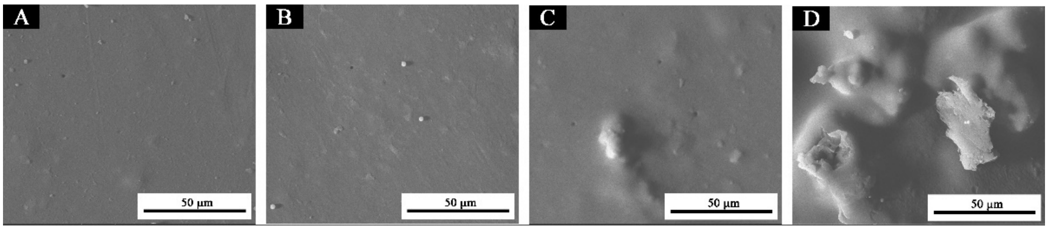

Figure 4. Morphology of the coatings with different content of the microcapsules: (**A**) 0%, (**B**) 1.0%, (**C**) 7.0%, (**D**) 13.0%.

3.2. Infrared Spectrum Analysis of the Microcapsules and Coatings

Figure 5 is the infrared spectrum of the microcapsules and coatings added with different content of the microcapsules. The peaks at 1148 and 862 cm^{-1} represent the vibration peaks of C–O and O–H in aqueous acrylic acid respectively. The peak at 1726 cm^{-1} represents the characteristic peak of C=O in aqueous acrylic acid. These characteristic peaks are found in both the waterborne coating without microcapsules and the waterborne coatings with microcapsules, but they are not found in the microcapsules.

The vibration peak of C–N in melamine-formaldehyde resin appears at 1344 cm^{-1}, and the bending vibration peak of triazine ring in melamine-formaldehyde polycondensation system appears at 813 cm^{-1}. These peaks are characteristic peaks of melamine-formaldehyde resin, which exist in the microcapsules and the waterborne coatings with microcapsules, proving that the wall material in the microcapsules have not been damaged. The peak at 3418 cm^{-1} is the vibration peak of N–H in melamine-formaldehyde resin. Because the microcapsule content is small, this peak is not obvious in the coatings. At 2872 cm^{-1}, it is the characteristic absorption peak of $–CH_2$ of polyether amine, and at 939 cm^{-1}, it is the stretching vibration peak of C–O–C of ether bond. These are the characteristic peaks of epoxy resin, which exist in microcapsules and coatings with microcapsules, proving that the core material in microcapsules has not been damaged. These peaks proved that there was no chemical reaction between the wall and core materials of microcapsules, and the microcapsules were successfully prepared. The microcapsules have no chemical reaction with the waterborne coating, and exist in the waterborne coating.

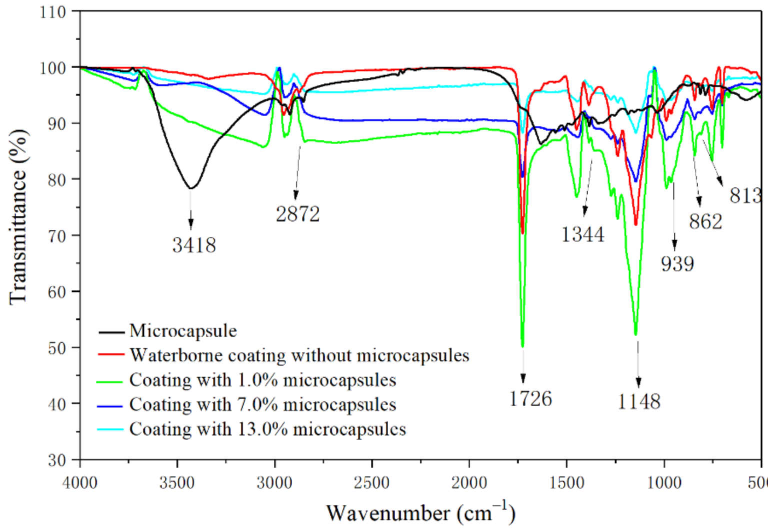

Figure 5. FTIR image of the microcapsules and coatings.

3.3. Effect of Microcapsule Content on Optical Properties of the Coatings

The chromaticity value and color difference of the coatings with different content of the microcapsules on the wood substrate are shown in Table 4 and Figure 6. It can be seen that the color difference of the coating without microcapsules is small. The color difference of the coatings added with the microcapsules gradually increases with the increase of content, showing an upward trend. When the microcapsule content is 0%–7.0%, the color difference increases significantly. When the microcapsule content is 7.0%–13.0%, the change of color difference is relatively gentle, which is lower than 8.0. When the microcapsule content is 20.0%, the color difference reaches the maximum. This is because the microcapsule itself is a light yellowish powder, which will affect the color of the coating when added to the coating. When the content is too high, the microcapsules are unevenly distributed in the coating, resulting in a large color difference.

The effect of microcapsules with different content on the gloss of the coatings is shown in Table 5 and Figure 7. With the increase of microcapsule content, the gloss of the coatings gradually decreases and the gloss loss rate gradually increases. When the microcapsule content is 0%–4.0%, the gloss is high. When the microcapsule content is 4.0%–10.0%, the gloss of the coating decreases significantly. When the content of microcapsules is 13.0%–20.0%, the decrease of the gloss tends to be gentle. This is because the smoothness and roughness of the coating surface will affect the gloss of the coating. When there are more microcapsules in the coating, the microcapsule particles will reduce the surface flatness of the coating, thereby reducing the light reflection ability of the coating, so the gloss of the coating will decrease and the light loss rate will increase.

Table 4. Chromaticity value and color difference of the coatings with different microcapsule content.

Microcapsules Content (%)	L_1*	a_1*	b_1*	L_2*	a_2*	b_2*	ΔL*	Δa*	Δb*	ΔE*
0	61.90	15.62	41.82	62.61	15.5	41.44	0.71	0.12	0.38	0.81
1.0	53.41	14.34	40.97	55.12	12.67	38.09	1.71	1.67	2.88	3.74
4.0	55.30	12.15	34.35	57.92	9.81	36.77	2.62	2.34	2.42	4.27
7.0	43.32	15.14	35.38	37.45	18.82	34.69	5.87	3.68	0.69	6.96
10.0	42.74	7.56	37.59	37.18	11.77	36.76	5.56	4.21	0.83	7.02
13.0	38.11	9.59	25.66	31.49	6.38	22.77	6.62	3.21	2.89	7.90
16.0	39.26	16.2	19.10	30.84	13.05	23.22	8.42	3.18	4.12	9.90
20.0	21.68	11.15	12.10	12.7	14.61	17.02	8.98	3.46	4.92	10.81

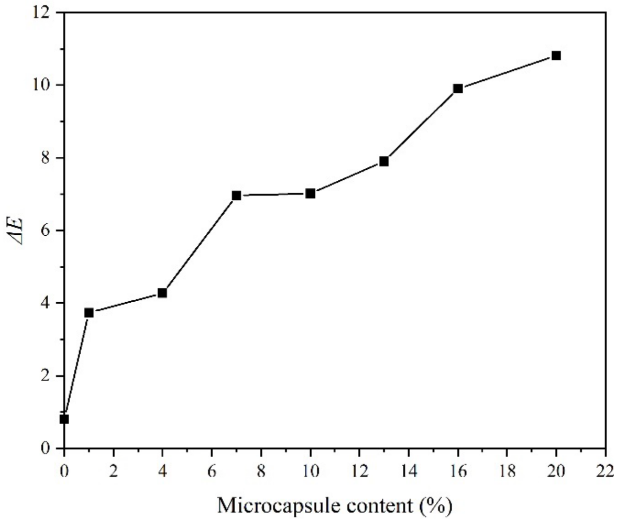

Figure 6. Effect of the microcapsule content on color difference of the coatings.

Table 5. Gloss of the coatings with different microcapsule content.

Microcapsules Content (%)	20°	60°	85°	Light Loss Rate (%)
0	7.2	31.2	48.5	-
1.0	6.5	23.3	28.1	25.32
4.0	3.6	14.7	6.4	52.88
7.0	3.1	13.4	6.0	57.05
10.0	1.6	7.4	4.4	76.28
13.0	1.4	3.1	2.7	90.06
16.0	1.6	3.0	2.5	90.38
20.0	1.4	2.7	2.3	91.35

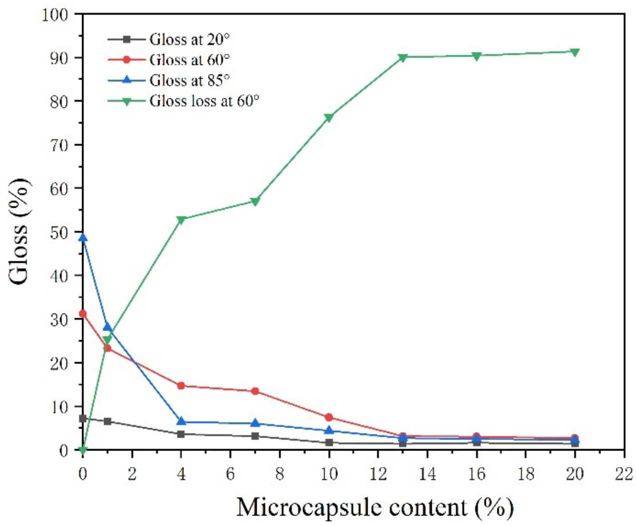

Figure 7. Effect of the microcapsule content on gloss of the coatings.

3.4. Effect of Microcapsule Content on Mechanical Properties of the Coatings

The effect of microcapsules with different content on the hardness of the coatings on wood is shown in Figure 8. With the increase of microcapsule content, the hardness of the coatings slowly increases. The hardness of the coating without microcapsules is H. When the content of the microcapsules is 1.0%–7.0%, the hardness of the coating increases to 2H. When the content of the microcapsules is 10.0%–16.0%, the hardness of the coating increases to 3H. When the content of the microcapsules is 20.0%, the hardness reaches 4H. This may be because the coating hardness is mainly determined by the material properties of the coating itself. The microcapsules act as fillers in the coating. The increase of filler content has a positive effect on the coating hardness, so the coating hardness increases slightly.

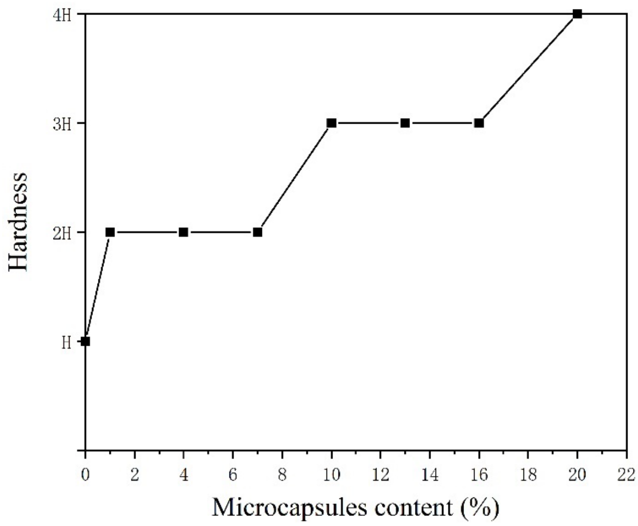

Figure 8. Hardness of the coatings.

The coating adhesion test results are shown in Figure 9. When the content of the microcapsules is 0%–13.0%, the adhesion of the coatings is basically unchanged. When the content increases to 16.0%–20.0%, the adhesion of the coatings decreases significantly and the adhesion grade increases. This is because when there are many microencapsulated particles in the coating, the binder content in the coating decreases, and the adhesion to wood decreases, resulting in the reduction of adhesion.

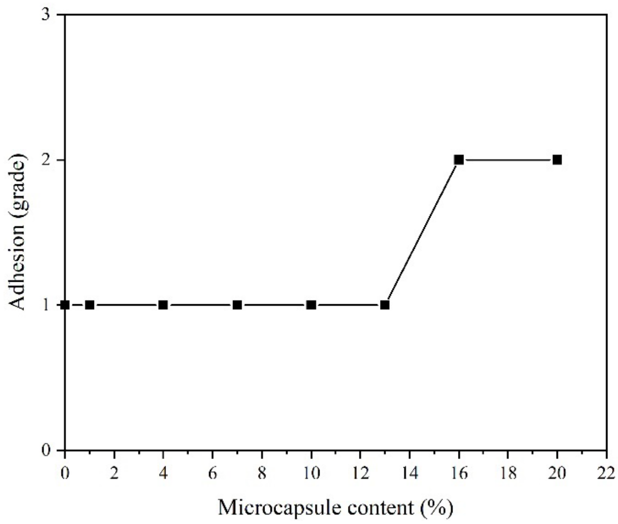

Figure 9. Adhesion grade of coatings.

The impact resistance test result of the coatings is shown in Figure 10. The impact resistance of the coating is directly proportional to the content of the microcapsules, which indicates that the impact resistance of the coating surface can be increased by adding microcapsules into the waterborne coating. The impact resistance of the coating without microcapsules is 4.0 kg·cm. When the microcapsules were added to 7.0%, the impact resistance was significantly enhanced, which is 12.0 kg·cm. When the microcapsule content is 20.0%, the impact resistance of the coating is the best, which is 18.0 kg·cm. This is because the composition of the microcapsules is that the wall material covers the core material, and the wall material can play a certain protective function on the core material. When the coating surface is subjected to external force, the microcapsules can form a force layer to disperse the force on the buffer coating, so as to improve the impact resistance of the coating.

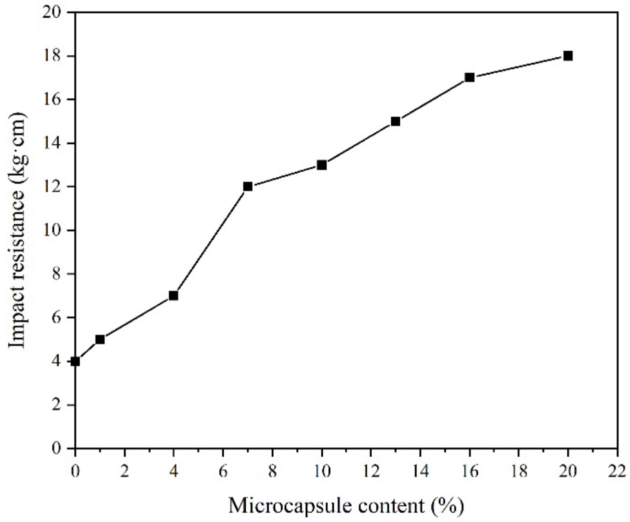

Figure 10. Impact resistance of coatings.

3.5. Effect of Microcapsule Content on Aging Resistance of the Coatings

In the actual use of wood furniture, the coating will be affected by the external environment for a long time, which will produce cracks, bubbles and other phenomena. This will cause the wall material of microcapsules in the coating to crack, and the core material epoxy resin can fill the cracks, playing a certain repair function [44,45]. Therefore, in this paper, the situation of coating damage in the external environment was simulated. The coating without microcapsules and the coatings with microcapsules were destroyed through the aging test, and the influence of microcapsules on the self-healing function of the coating was explored by comparing the aging test of the coatings. The coated wood boards were put into an oven at 120 °C for aging test. After 12 h, the condition of the coating surface was observed, and the color difference and gloss of the coatings were recorded. The surface damage of the coating without microcapsules and the coating with different content of microcapsules was compared under high temperature aging environment.

The color difference and test results of the coating are shown in Table 6. The color difference comparison before and after aging of the coating is shown in Figure 11. By observing the results of the aging resistance test of the coating, it can be found that under the same environment and after the same aging time, when the content of microcapsules is 1.0%–16.0%, the color difference of the coatings with microcapsules is less than that of the coating without microcapsules. This may be because the coating is affected by the high temperature environment of the oven, which will produce microcracks or bubbles. The microcapsules can play a protective role in the coating, and the epoxy resin can play a repair function, filling some cracks, so the color difference is small. When the microcapsule content is 16.0%–20.0%, the color difference of the coatings with microcapsules is larger than that of the coating without microcapsules. This may be because when the content is too high, the microcapsules cannot be evenly distributed in the coating, resulting in the reduction of the adhesion between the coatings and between the coatings and wood. Therefore, the toughness of the coatings is reduced, and the protective effect of the coatings on wood is also reduced, so the cracks and bubbles are more likely to occur at high temperatures, resulting in larger color differences.

By comparing the color difference before and after aging, it can be found that when the content of the microcapsules is less than 7.0%, the color difference of the coating without microcapsules and the coatings with microcapsules increases after aging. This is because the color of wood and coatings will change greatly under high temperature environment, and the content of the microcapsules is too low to effectively play the role of protective coating and aging resistance, so the color difference of the coating is large. When the content of the microcapsules is more than 7.0%, the color difference after aging is less than that before aging. This shows that microcapsules need to reach a certain content in order to have an obvious anti-aging effect. The above results show that the microcapsules can repair the coatings and improve the aging resistance of the coatings. When the content is 7.0%–16.0%, the aging resistance is the best.

Table 6. Chromaticity value and color difference of the coatings before and after aging.

Microcapsules Content (%)	State	*L**	*a**	*b**	Δ*L**	Δ*a**	Δ*b**	Δ*E**
0	before aging	62.25	15.56	41.63	5.57	4.68	0.77	7.31
	after aging	56.68	10.88	40.86				
1.0	before aging	54.26	13.50	39.53	5.87	3.32	1.36	6.88
	after aging	48.39	10.18	38.17				
4.0	before aging	56.61	10.98	33.40	5.32	2.38	2.16	6.22
	after aging	51.29	8.60	35.56				
7.0	before aging	35.49	16.98	35.03	4.89	2.67	1.17	5.69
	after aging	40.38	14.31	33.86				
10.0	before aging	39.96	9.66	37.17	5.63	2.40	0.98	6.20
	after aging	34.33	7.26	36.19				
13.0	before aging	34.8	7.98	22.30	6.21	3.78	1.91	7.52
	after aging	28.59	4.20	24.21				
16.0	before aging	35.05	14.64	21.16	7.14	2.80	2.51	8.07
	after aging	27.91	11.84	18.65				
20.0	before aging	17.19	10.22	14.46	8.23	2.66	3.13	9.20
	after aging	8.96	12.88	11.33				

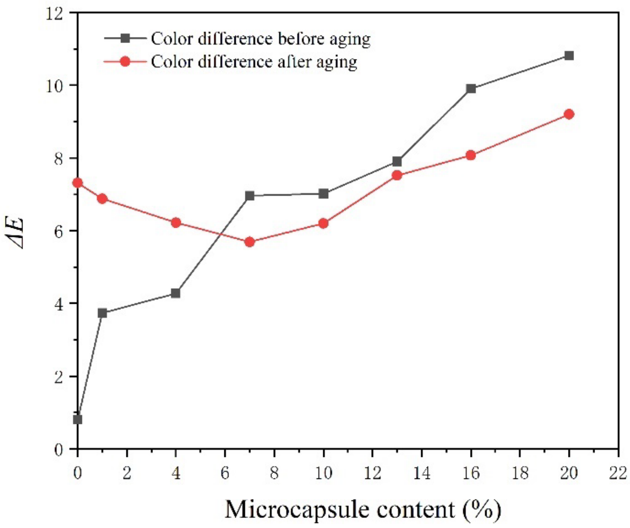

Figure 11. Effect of the microcapsule content on color difference of the coatings before and after aging.

The coating gloss test result is shown in Table 7. The comparison of the gloss loss of the coating before and after color aging is shown in Figure 12. It is obvious that with the increase of microcapsule content, the gloss shows a downward trend. However, under

60° incident light, the light loss rate of the coating with microcapsules after aging test is significantly lower than that before aging. This is because the core material in the microcapsule fills the cracks and bubbles of the coating during aging to a certain extent, so the light loss rate is reduced.

Table 7. Gloss loss of the coatings before and after aging.

Microcapsules Content (%)	20°	60°	85°	Light Loss Rate after Aging (%)
0	5.3	26.8	43.0	-
1.0	7.4	28.5	45.2	−6.34
4.0	3.3	14.4	14.0	46.27
7.0	3.2	14.4	13.9	47.76
10.0	2.2	10.9	13.6	59.33
13.0	2.7	10.6	12.2	60.45
16.0	2.1	10.0	5.0	62.69
20.0	2.0	8.1	3.5	69.78

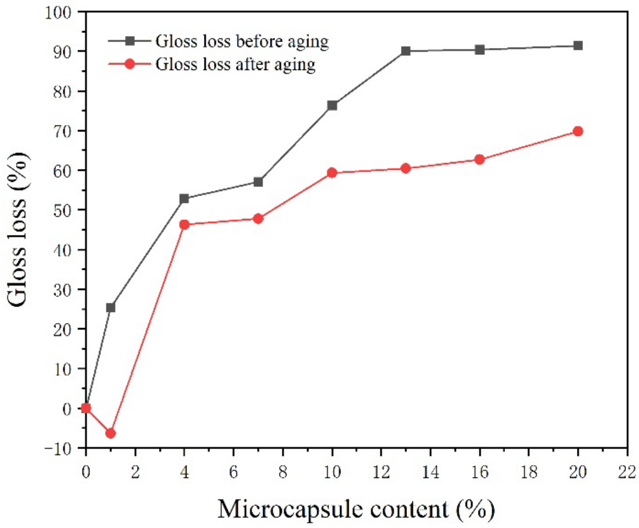

Figure 12. Effect of the microcapsule content on gloss loss of the coatings before and after aging.

4. Conclusions

In this paper, the microcapsules were successfully prepared with melamine-formaldehyde resin/rice husk powder as wall material and epoxy resin as core material. The *Tilia europaea* boards were selected as the base material, and the waterborne acrylic coating was used as the paint base. The microcapsules were added to the topcoat according to different contents. The optical properties, mechanical properties and aging resistance of the coatings were tested and analyzed. The results showed that with the increase of microcapsule content, the color difference of the coating increased, the gloss decreased, the hardness increased, the adhesion decreased, and the impact resistance increased. The mechanical properties of the coatings have been enhanced. The results of aging test showed that the microcapsules can effectively improve the aging resistance of the coatings. When the microcapsule content is 7.0%, the comprehensive performance of the coating is the best. At this time, the color difference of the coating is 6.96, the gloss at 60° is 13.4%, the hardness is 2H, the adhesion grade is 1, the impact resistance is 12.0 kg·cm, the color difference after aging test is 5.69, and the gloss at 60° is 11.6%. This study provides a certain reference for the expansion of the optical properties, mechanical properties and self-healing function of waterborne coatings.

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