Article

Effect of Water-Based Acrylic Acid Microcapsules on the Properties of Paint Film for Furniture Surface

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Abstract: In this paper, self-healing microcapsules with urea formaldehyde coated Nippon water-based acrylic acid were prepared, and the performance of water-based topcoat paint film added with self-healing microcapsules and the repair effect of microcapsules were investigated. The results show that when the content of microcapsules in water-based topcoat paint film on the surface of wood increased, the color difference and hardness rose gradually, the gloss and adhesion declined gradually, the impact resistance and tensile strength at break rose first and then declined. The 0.67:1 core-wall ratio microcapsules had a better micromorphology, and the water-based topcoat paint film with 0.67:1 microcapsules had a certain repair effect. The microcapsules were added to the water-based topcoat paint film to repair the coating to a certain extent, which provide technical reference for prolonging the service life of water-based topcoat paint film for the furniture surface.

Keywords: microcapsule; self-healing; water-based topcoat paint film

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1. Introduction

Microencapsulation is a kind of packaging technology that can store and protect the core material for a long time, and release the core material when needed. Self-repairing microcapsules release the core material to repair cracks when they appear [1–3]. Jeong et al. [4] prepared nifedipine-loaded poly(lactic acid) (PLA)/polyethylene glycol (PEG) microcapsules by solvent evaporation method, and the effects of PLA and PEG on the drug release behavior of microcapsules were studied. By analyzing and testing the microcapsules, PLA and PEG were found to react, and the safety of the drug carrier for clinical use was proved. Chen et al. [5] applied the microcapsule technology to waterborne fabric coating, and studied the coating with waterproof, ultraviolet resistance, heat preservation and other multi-functions. Novel multifunctional cellulose/silica hybrid microcapsules were prepared. It was found that the microcapsules can be well scattered into waterborne coatings. The coating had superhydrophobicity, ultraviolet resistance and thermal insulation. Nesterova et al. [6] studied the particle size of polyurea–formaldehyde microcapsules with linseed oil as the core material. The experiments showed that the stirring speed, the reaction temperature and stabilizer concentration were all factors affecting the diameter of microcapsules. The effect of microcapsules on the self-healing properties of epoxy resin coating was also studied. Njoku et al. [7] prepared a self-healing microcapsule which could inhibit the interfacial corrosion of the coating and was used for long-term protection of aluminum alloy. The experimental results showed that the modified intelligent epoxy coating had good resistance, active and self-repair properties, and had a certain corrosion inhibition ability. The prepared microcapsules could also improve the barrier and adhesion of the coating. In our study [8], prepared waterborne emulsion microcapsules and the various performance of microcapsules were tested. The results show that the microcapsules added to the water-based primer film had better liquid resistance, good stability and aging resistance.

The function of paint film is to protect the surface of furniture and prevent furniture from aging or damage due to environmental and human factors [9]. If the microcrack is not repaired in time, it will affect the use of furniture and the life of furniture. The microcapsule healing method can automatically repair microcracks in the process of no artificial repair and reduce the cost of manual repair.

Topcoat is a kind of coating on the surface of substrate. In the process of practical application, it is directly in contact with the environment and users, and will be affected by humidity, temperature, ultraviolet, human damage and other factors, so it is very easy to crack and reduce the service life of paint film on furniture surface [10–12]. Therefore, the topcoat paint film needs to have higher impact resistance, better gloss, smaller color difference and other properties. For the self-repairing coating, it also needs to have a certain crack self-healing effect [13–17]. The water-based acrylic acid coated with urea formaldehyde is a kind of self-healing microcapsule. The wood surface was coated by water-based topcoat paint with microcapsules that can repair the cracks [18–20].

The self-healing water-based microcapsules were prepared with urea formaldehyde resin as wall material and Nippon water-based acrylic acid as core material. As shown in Figure 1, the microcapsules ruptured and core material flowed to the crack, where the water-based acrylic acid was crosslinked into a solid to fill the crack so as to repair the crack. By exploring the self-healing properties of microcapsules and studying the effect of microcapsules on the properties of wood surface coating, this paper provides a reference for research on preventing cracks of wood furniture surface coating.

Figure 1. The repair process of crack.

2. Materials and Methods

2.1. Experimental Materials

Triethanolamine (M_w : 149.19 g/mol, CAS No.: 102-71-6), *n*-octanol (M_w : 130.23 g/mol, CAS No.: 111-87-5) and citric acid monohydrate (M_w : 210.14 g/mol, CAS No.: 5949-29-1) were provided by Tianjin Damao Chemical Reagent Factory Co., Ltd., Tianjin, China. Urea (M_w : 60.06 g/mol, CAS No.: 57-13-6) was provided by Shandong Ruijiang Chemical Co., Ltd., Jinan, China. Formaldehyde solution (37%, M_w : 30.03 g/mol, CAS No.: 50-00-0) and sodium dodecyl benzene sulfonate (M_w : 348.48 g/mol, CAS No.: 25155-30-0) were provided by Nantong Jiangtian Chemical Co., Ltd., Nantong, China. Waterborne acrylic acid which mainly composed of waterborne acrylic copolymer, and water-based topcoat were provided by Nippon Paint Co., Ltd., Nanjing, China. Basswood (80 mm × 75 mm × 6 mm) were provided by Hangzhou Yihong Wood Co., Ltd., Hangzhou, China.

2.2. Experimental Method

Firstly, the quality of wall material of microcapsules was fixed, the 20.0 g urea and 27.0 g of 37% formaldehyde solution were reacted completely by molar ratio of 1:1 to

generate 30 g urea–formaldehyde. The reaction equation of urea and formaldehyde is as follows:

Microcapsules with different core-wall ratios were prepared by changing the quality of core material. The 20.0 g urea and 27.0 g of 37% formaldehyde solution were mixed, stirred and heated, and a few drops of triethanolamine were used to adjust the pH of the solution to 8.5. The wall material solution was obtained by continuous reaction for 1 h at 60 °C. The core material waterborne acrylic acid was added into the sodium dodecylbenzene sulfonate emulsifier solution and emulsified at 50 °C for 30 min. Then, the core and wall materials were mixed, the pH value was adjusted to 3–4 with citric acid, and the temperature was adjusted to 60 °C for 2 h. Finally, the product was filtered and dried to obtain powder microcapsules.

Seven kinds of microcapsules were added into the waterborne topcoat paint with five different contents. The quality of the self-healing water-based topcoat prepared was 4.0 g, and all the self-healing water-based topcoat was coated on the Basswood. The optical properties, mechanical properties, liquid resistance and self-repair properties of the film were tested, and the microstructure and composition of the water-based topcoat paint film were analyzed.

The paint film on the surface of the wood was scratched with a blade, and the width of the crack was observed and measured with the microscope. Then, the sample was placed for five days, and the size of the crack in the same place was observed again. The size of the crack in the same place over different days was measured, which can compare whether the crack healed or not.

2.3. Testing and Characterization

The MA-5QC chromatic meter (X-Rite Pantone Co., Ltd., Shanghai, China) was used to test the color difference of water-based topcoat paint film. The L_1 , a_1 and b_1 of one point on the surface of the paint film were measured by the chromatic meter, and then L_2 , a_2 and b_2 of another point on the surface of the paint film were measured, too. The color difference is calculated according to the formula: $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$.

The AIBEVS 1502K trigonometric glossometer (Guangzhou Shenghua Industrial Co., Ltd., Guangzhou, China) was used to test the gloss of water-based topcoat paint film. The glossiness meter was placed on the surface of the paint film, and the glossiness of the paint film can be measured.

The pencil hardness tester (Shenzhen Jiangcheng Instrument Co., Ltd., Shenzhen, China) was used to test the hardness of water-based topcoat paint film. The pencil was placed on the mechanical trolley and fixed with a clip to keep the instrument level with the paint film. The tip of the pencil should contact the surface of the paint film, and then the trolley was pulled at a uniform speed to move the tip of the pencil across the paint film. If there is a scratch of more than 3 mm, the hardness of the paint film is the corresponding pencil hardness. If there is no scratch, a higher hardness of the pencil was used to measure, until the scratch is more than 3 mm.

The film scribe (Shenzhen Xinhengsen Instrument Equipment Co., Ltd., Shenzhen, China) was used to test the adhesion of water-based topcoat paint film. First, the tool was perpendicular to the sample surface and the sample surface was cut at a uniform speed, then rotated 90° and cut in the same way once, so that the sample surface was cut into a grid pattern. The tape was adhered to the grid pattern and torn off at an angle of 60° within 0.5–1.0 s, and the peeling of the paint film on the tape was observed.

The impact testing machine (Jinan Ruima Testing Machine Manufacturing Co., Ltd., Jinan, China) was used to test the impact resistance of water-based topcoat paint film. The test board was placed on the impact testing machine base, the small iron ball was fixed to a height, and the control button was pressed so the small iron ball would freely fall to the test plate. The test board was taken out and it was observed whether there were cracks and spalling on the test board after being hit by the small iron ball.

The mechanical testing machine (Dongguan Bolaide Instrument Equipment Co., Ltd., Dongguan, China) was used to test the tensile strength at break of water-based topcoat paint film. The paint film was placed in the fixture and clamped to ensure that the paint film will not slide, and then, under a certain longitudinal load at the tensile speed of 0.12 mm/min, it deforms and breaks. The tensile strength at break = (elongation of paint film/original length of paint film between clips) * 100%.

The 15% NaCl, 70% medical ethanol (Shandong Duofeng Chemical Co. Ltd., Linyi, China), detergent (LibY Group Co., Ltd., Hangzhou, China) and red ink (Weifang Meicai Inkjet Technology Co., Ltd., Weifang, China) were used to test the liquid resistance of water-based topcoat paint film. First, the filter paper was placed in the solution for 30 s, and then the filter paper was placed on the surface of the paint film and covered with a glass cover. After one day, the filter paper was removed and the residual water on the surface of the paint film was blotted with absorbent paper, and it was checked whether there were traces of discoloration and other damage in the tested area.

The Quanta-200 scanning electron microscope (FEI Co., Ltd., Hillsboro, OR, USA), Optical Microscope (Guangzhou Liss Optical Instrument Co., Ltd., Guangzhou, China) and vertex 80 V infrared spectrum analyzer (Germany Bruker Co., Ltd., Karlsruhe, Germany) were used to observe the microstructure and chemical composition of water-based topcoat paint film. All experiments were repeated 4 times with standard error less than 5%.

3. Results and Discussion

3.1. Variation of Optical Performances of Water-Based Topcoat Paint Film

The color difference change in water-based topcoat paint film is shown in Table 1. The color difference of the water-based topcoat paint film increased with the content of microcapsules increased, from 0.6 to around 5.0. This is because the microcapsule is a kind of white powder and may affect the original color of wood. Because of the uneven distribution of white powder, the color of the water-based topcoat paint film surface is also uneven, resulting in a larger color difference [21]. When the content of microcapsules with different core-wall ratios was less than 10.0%, the color difference was smaller.

Table 1. Variation of color difference of water-based topcoat paint film.

Content of Microcapsules (%)	Color Difference						
	0.42:1	0.50:1	0.58:1	0.67:1	0.75:1	0.83:1	0.92:1
0	0.6	0.6	0.6	0.6	0.6	0.6	0.6
5.0	1.8	1.5	1.5	1.6	1.3	1.2	1.6
10.0	2.8	2.2	2.3	2.0	1.5	2.1	2.9
15.0	3.6	3.2	2.8	2.4	2.4	2.7	4.1 ± 0.1
20.0	4.4	3.3	3.2	3.5	4.4	3.4	4.4 ± 0.1
25.0	5.1	5.5	5.0 ± 0.2	4.8 ± 0.1	4.7 ± 0.1	3.9 ± 0.1	5.3 ± 0.2

The gloss measured is shown in Table 2. The gloss of water-based topcoat paint film declined gradually with the rise in the content of microcapsules. When the content of microcapsules was 0–5%, the gloss of water-based topcoat paint film declined more obviously. When the content of microcapsules increased, the gloss of water-based topcoat paint film decreased slowly. This is because the surface of the water-based topcoat paint film without microcapsules is smooth, and the microcapsules particles added lead to uneven surface, which enhanced diffuse reflection and reduced gloss [22]. The gloss of the water-based topcoat paint film with the microcapsules core-wall ratio of 0.67:1 and the content of 0–10% is higher than others.

Table 2. Variation of gloss of water-based topcoat paint film.

Content of Microcapsules (%)	Gloss (%)						
	0.42:1	0.50:1	0.58:1	0.67:1	0.75:1	0.83:1	0.92:1
0	29.4 ± 0.8	29.4 ± 0.8	29.4 ± 0.8	29.4 ± 0.8	29.4 ± 0.8	29.4 ± 0.8	29.4 ± 0.8
5.0	15.3 ± 0.8	8.9 ± 0.2	10.2 ± 0.2	17.9 ± 0.7	13.6 ± 0.6	11.2 ± 0.9	11.8 ± 0.3
10.0	9.4 ± 0.1	7.1 ± 0.1	9.1 ± 0.1	11.9 ± 0.2	10.4 ± 0.2	8.6 ± 0.2	10.6 ± 0.1
15.0	4.0 ± 0.1	4.6 ± 0.1	7.3 ± 0.2	6.7 ± 0.1	5.2 ± 0.1	3.4 ± 0.1	5.0 ± 0.1
20.0	2.6	3.6 ± 0.1	2.9 ± 0.1	5.5	3.2	2.8 ± 0.1	3.3 ± 0.1
25.0	2.4 ± 0.1	3.3	2.3	3.2	2.1 ± 0.1	2.1 ± 0.1	3.2

3.2. Variation of Mechanical Performances of Water-Based Topcoat Paint Film

Table 3 shows the change in the hardness of the water-based topcoat paint film. Under the same core-wall ratio, with the content of microcapsules rose, the hardness of the water-based topcoat paint film rose. This is because the microcapsules are a kind of solid powder, and the addition of microcapsules into the water-based topcoat paint film can increase the hardness of the film surface [23,24]. The hardness of the water-based topcoat paint film with 0.67:1 microcapsules was higher than others. When the content of microcapsules was 0–5.0%, the hardness of the water-based topcoat paint film rose from HB to 2H. When the content increased to 5.0–10.0%, the hardness increased to 3H. When the content continued to increase, the hardness of the water-based topcoat paint film remained unchanged for 3H. In conclusion, when the content of microcapsules was 10.0–15.0%, the hardness of the water-based topcoat paint film was better, and the core-wall ratio of microcapsules was 0.67:1, the hardness of the water-based topcoat paint film was increased more obvious.

Table 3. Variation of hardness of water-based topcoat paint film.

Content of Microcapsules (%)	Hardness						
	0.42:1	0.50:1	0.58:1	0.67:1	0.75:1	0.83:1	0.92:1
0	HB	HB	HB	HB	HB	HB	HB
5.0	H	2H	2H	2H	2H	2H	2H
10.0	2H	2H	2H	3H	2H	2H	2H
15.0	2H	2H	2H	3H	2H	2H	3H
20.0	2H	2H	3H	3H	2H	3H	3H
25.0	2H	2H	3H	3H	2H	3H	3H

The test results of the adhesion of water-based topcoat paint film are in Table 4. At the same core-wall ratio, the adhesion of the water-based topcoat paint film declined with the rise in microcapsules content, because the increase in microcapsules leads to the poor interfacial adhesion between the coating and wood [25,26]. When the core-wall ratio was 0.67:1, the adhesion of the water-based topcoat paint film was the best. When the content of microcapsules was 0–10.0%, the water-based topcoat paint film adhesion was grade 0. When the content increased to 15.0–20.0%, the water-based topcoat paint film adhesion decreased to grade 1. When the content reached 25.0%, the worst adhesion was grade 2. When 0.67:1 and the content of microcapsules was 0–10.0%, the adhesion of the water-based topcoat paint film was the best.

Table 4. Variation of adhesion of water-based topcoat paint film.

Content of Microcapsules (%)	Adhesion (Grade)						
	0.42:1	0.50:1	0.58:1	0.67:1	0.75:1	0.83:1	0.92:1
0	0	0	0	0	0	0	0
5.0	0	1	0	0	0	0	0
10.0	1	1	1	0	1	1	1
15.0	1	2	1	1	1	2	2
20.0	2	2	1	1	2	2	2
25.0	2	2	2	2	2	3	3

As shown in Table 5, when the core-wall ratios of microcapsules were 0.42:1, 0.50:1 and 0.67:1, the impact resistance of the water-based topcoat paint film increased gradually with the increase in microcapsules content, and remained stable after reaching the maximum value. When the core-wall ratios were 0.58:1, 0.75:1, 0.83:1 and 0.92:1, the impact resistance rose first and then declined. Because the content of microcapsules increases too much, the water-based topcoat paint film performance declines, as it is difficult to resist the damage of external forces, and the impact resistance declines slightly [27]. From the overall results, when the content of microcapsules was 10.0–15.0%, the impact resistance was stronger.

Table 5. Variation of impact resistance of water-based topcoat paint film.

Content of Microcapsules (%)	Impact Resistance (kg·cm)						
	0.42:1	0.50:1	0.58:1	0.67:1	0.75:1	0.83:1	0.92:1
0	6	6	6	6	6	6	6
5.0	8	8	8	10	10	9	9
10.0	9	12	9	13	13	12	12
15.0	13	12	13	13	13	12	13
20.0	15	12	11	13	11	10	10
25.0	15	13	11	13	11	10	10

According to the above performance test results, the tensile strength at break of water-based topcoat paint film with core-wall ratios of 0.42:1, 0.50:1, 0.58:1 and 0.67:1 microcapsules was tested. It can be seen from Figure 2 that with the rise in microcapsule content, the tensile strength at break of the coating rose first and then declined at the same core-wall ratio. Among them, the tensile strength at break of paint film with a core-wall ratio of 0.67:1 microcapsules was better.

Figure 2. Variation of elongation at break of water-based topcoat paint film.

3.3. Variation of Self-Healing Microcapsules on Liquid Resistance of Water-Based Topcoat Paint Film

The changes in optical properties of water-based topcoat paint film after liquid resistance tests are shown in Table 6. The color difference of the water-based topcoat paint film after the red ink resistance test was larger than that of other liquid resistance tests, and the color difference before and after the other resistance tests barely changes because the color of the red ink itself affects the color difference of the water-based topcoat paint film. The gloss of water-based topcoat paint film with core-wall ratios of 0.67:1 and 0.75:1 microcapsules was better than others.

Table 6. The change in optical properties of water-based topcoat paint film after liquid resistance.

Core-Wall Ratio	Content (%)	Color Difference				Gloss (%)			
		NaCl	Ethanol	Detergent	Red Ink	NaCl	Ethanol	Detergent	Red Ink
0.42:1	0	0.4	1.2	0.4	2.3	29.1 ± 1.2	29.0 ± 1.0	29.4 ± 1.3	29.6 ± 1.5
	5.0	0.6	0.4	0.4	0.3	15.1 ± 0.6	15.4 ± 0.5	15.0 ± 0.5	15.1 ± 0.9
	10.0	0.3	0.6	0.8	0.9	9.1 ± 0.3	9.2 ± 0.3	9.2 ± 0.3	9.0 ± 0.6
	15.0	0.4	0.8	0.5	1.5	4.0 ± 0.1	3.9 ± 0.1	3.8 ± 0.1	3.3 ± 0.2
	20.0	1.0	1.2	1.0	2.9	2.4	2.4	2.6 ± 0.1	2.0
	25.0	0.8	3.3	0.8	2.0	2.2	2.2	2.3	2.0
0.50:1	0	0.4	1.2	0.4	2.3	29.1 ± 1.2	29.0 ± 1.0	29.4 ± 1.3	29.6 ± 1.5
	5.0	1.1	1.0	1.1	1.8	8.4 ± 0.3	8.3 ± 0.2	8.5 ± 0.3	8.3 ± 0.7
	10.0	1.1	0.7	1.0	0.9	7.0 ± 0.2	7.1 ± 0.1	6.9 ± 0.2	6.6 ± 0.5
	15.0	1.0	1.0	1.0	2.4	4.3 ± 0.1	4.3	4.4 ± 0.2	4.0 ± 0.2
	20.0	0.9	1.9	0.9	6.2 ± 0.1	3.4 ± 0.1	3.7 ± 0.3	3.6 ± 0.1	3.2 ± 0.2
	25.0	0.9	1.8	1.1	3.0	3.3 ± 0.1	3.4 ± 0.1	3.2 ± 0.1	2.8 ± 0.1
0.58:1	0	0.4	1.2	0.4	2.3	29.1 ± 1.0	29 ± 1.0	29.4 ± 1.3	29.6 ± 1.5
	5.0	1.0	1.1	1.1	0.8	9.7 ± 0.3	9.8 ± 0.2	10.0 ± 0.4	9.1 ± 0.3
	10.0	0.7	1.0	0.6	1.3	8.8 ± 0.2	8.9 ± 0.1	8.6 ± 0.5	8.3 ± 0.2
	15.0	0.7	1.3	0.3	0.7	7.2 ± 0.1	7.3 ± 0.2	7.2 ± 0.3	6.9 ± 0.2
	20.0	1.0	1.8	1.1	2.4	2.7	2.8	2.7	2.6 ± 0.1
	25.0	0.5	1.3	0.7	4.2 ± 0.1	2.5 ± 0.1	2.3	2.1	2.0
0.67:1	0	0.4	1.2	0.4	2.3	29.1 ± 1.2	29.0 ± 1.0	29.4 ± 1.3	29.6 ± 1.5
	5.0	0.9	1.1	0.7	0.8	13.5 ± 0.6	13.5 ± 0.8	13.6 ± 0.6	13.1 ± 0.9
	10.0	0.7	1.1	0.8	0.8	11.9 ± 0.5	11.4 ± 0.7	11.7 ± 0.7	11.2 ± 0.6
	15.0	1.1	0.6	1.1	0.9	6.4 ± 0.1	6.4 ± 0.6	6.6 ± 0.4	6.2 ± 0.4
	20.0	1.0	0.9	1.0	2.7	5.4 ± 0.1	5.3 ± 0.2	5.4 ± 0.2	5.0 ± 0.3
	25.0	1.1	1.1	1.1	3.2	3.2	3.2 ± 0.1	3.0 ± 0.1	2.8 ± 0.1
0.75:1	0	0.4	1.2	0.4	2.3	29.1 ± 1.2	29 ± 1.0	29.4 ± 1.3	29.6 ± 1.5
	5.0	1.2	1.0	0.7	1.2	17.5 ± 0.4	17.5 ± 0.4	17.3 ± 0.8	16.8 ± 0.9
	10.0	0.7	1.0	0.3	0.7	10.3 ± 0.2	10.2 ± 0.3	10.0 ± 0.4	9.9 ± 0.8
	15.0	0.6	0.9	0.7	1.8	5.1 ± 0.1	5.2 ± 0.2	5.3 ± 0.1	5.0 ± 0.3
	20.0	1.0	0.8	1.9	1.2	3.1	3.2 ± 0.1	3.2 ± 0.1	2.8
	25.0	0.3	1.0	1.9	3.5	2.0	2.1	2.1	1.9
0.83:1	0	0.4	1.2	0.4	2.3	29.1 ± 1.2	29.0 ± 1.0	29.4 ± 1.3	29.6 ± 1.5
	5.0	1.5	0.7	0.9	1.6	11.1 ± 0.4	11.2 ± 0.3	11.2 ± 0.4	11.0 ± 0.5
	10.0	0.5	1.0	0.7	1.8	8.4 ± 0.3	8.3 ± 0.3	8.5 ± 0.3	8.0 ± 0.4
	15.0	0.9	2.5	1.1	2.3	3.2	3.4 ± 0.1	3.4 ± 0.1	2.9 ± 0.1
	20.0	1.3	3.0 ± 0.1	1.9	2.6	2.5	2.4 ± 0.1	2.7 ± 0.1	2.5
	25.0	1.5	3.3 ± 0.1	1.5	2.1	2.1	2.0	2.1 ± 0.1	2.0
0.92:1	0	0.4	1.2	0.4	2.3	29.1 ± 1.2	29.0 ± 1.0	29.4 ± 1.3	29.6 ± 1.5
	5.0	0.6	1.1	0.9	1.8	11.3 ± 0.3	11.8 ± 0.5	11.6 ± 0.4	10.8 ± 0.5
	10.0	0.7	1.3	0.4	0.9	10.3 ± 0.2	10.4 ± 0.3	10.4 ± 0.6	10.2 ± 0.7
	15.0	1.1	1.5	0.7	2.2	4.9 ± 0.1	4.9 ± 0.2	4.8 ± 0.2	4.5 ± 0.2
	20.0	0.7	2.1	1.0	2.6 ± 0.1	3.2 ± 0.1	3.3 ± 0.2	3.3 ± 0.1	3.2 ± 0.1
	25.0	0.8	1.7	1.3	8.8 ± 0.3	3.0	3.1 ± 0.1	3.2 ± 0.1	2.9 ± 0.1

The performance of the water-based topcoat paint film after liquid resistance was graded, and the results are shown in Table 7. After the resistance to NaCl and detergent test, the surface of the water-based topcoat paint film was smooth without any mark, and the liquid resistance grade was level 1. After the resistance to ethanol test, the surface of the water-based topcoat paint film was basically free of marks, and the grade was basically level 1. However, when the core-wall ratios of microcapsules were 0.42:1, 0.83:1 and 0.92:1, and the content was higher, the liquid resistance grade of the water-based topcoat paint film was poor. The water-based topcoat paint film without microcapsules had obvious marks on the surface after the liquid resistance test of red ink, and the grade was level 2. When the content of microcapsules was between 5.0–10.0%, there was no obvious mark on the surface of the water-based topcoat paint film after the liquid resistance test of red ink, and it was level 1. When the content of microcapsules rose, the liquid resistance of the

water-based topcoat paint film began to decline. When the core-wall ratio was 0.42:1, 0.58:1, 0.67:1 and 0.75:1, and the content of microcapsules was 5.0–15.0%, the liquid resistance of the water-based topcoat paint film was better.

Table 7. Liquid resistance rating of water-based topcoat paint film.

Core-Wall Ratio	Content of Microcapsules (%)	Liquid Resistance (Level)			
		NaCl	Ethanol	Detergent	Red Ink
0.42:1	0	1	1	1	2
	5.0	1	1	1	1
	10.0	1	1	1	1
	15.0	1	1	1	1
	20.0	1	1	1	3
	25.0	1	3	1	2
0.50:1	0	1	1	1	2
	5.0	1	1	1	1
	10.0	1	1	1	1
	15.0	1	1	1	2
	20.0	1	1	1	3
	25.0	1	1	1	3
0.58:1	0	1	1	1	2
	5.0	1	1	1	1
	10.0	1	1	1	1
	15.0	1	1	1	1
	20.0	1	1	1	2
	25.0	1	1	1	3
0.67:1	0	1	1	1	2
	5.0	1	1	1	1
	10.0	1	1	1	1
	15.0	1	1	1	1
	20.0	1	1	1	2
	25.0	1	1	1	3
0.75:1	0	1	1	1	2
	5.0	1	1	1	1
	10.0	1	1	1	1
	15.0	1	1	1	1
	20.0	1	1	1	1
	25.0	1	1	1	3
0.83:1	0	1	1	1	2
	5.0	1	1	1	1
	10.0	1	1	1	1
	15.0	1	2	1	3
	20.0	1	3	1	3
	25.0	1	3	1	3
0.92:1	0	1	1	1	2
	5.0	1	1	1	1
	10.0	1	1	1	1
	15.0	1	1	1	2
	20.0	1	2	1	2
	25.0	1	1	1	3

3.4. Structure Analysis

Through the performance test of the water-based topcoat paint film, it can be seen that when the core-wall ratio of microcapsules was 0.67:1, the comprehensive performance of the water-based topcoat paint film was better. The microstructure of the microcapsule with a core-wall ratio of 0.67:1 is shown in Figure 3. The microcapsules seen in the microscopic image were not so obvious, but a small number of round microcapsules can be seen. This is due to the thick powder observed, which causes the microcapsules to be clumped together [28,29]. It was obvious from the scanning electron microscope images that the

number of microcapsules was large, and most of them were spherical. The morphology of microcapsules was good, and the size difference was small.

Figure 3. Microstructure of 0.67:1 microcapsules: (A,B) SEM of microcapsules, (C,D) OM of microcapsules.

The SEM picture of the water-based topcoat paint film with 0.67:1 microcapsules is shown in Figure 4. The surface of the water-based topcoat paint film without microcapsules was smooth and has no grain feeling. The surface of the water-based topcoat paint film with 5.0% and 10.0% microcapsules was uneven due to minor agglomeration in microcapsules. The surface particles of the water-based topcoat paint film with 25.0% microcapsules increased, and the agglomeration was serious. When the content of microcapsules was 0–10.0%, the microstructure of the water-based topcoat paint film was clearly characterized. The self-healing performance of the water-based topcoat paint film with the 0.67:1 microcapsules is shown in Figure 5. First, the surface of the water-based topcoat paint film was scratched and the size of the scratch on the first day was observed. Then, the water-based topcoat paint film was placed for five days, and the size of the same place was observed again. The size of water-based topcoat paint film scratches reduced from 33.23 μm to 22.85 μm , and the repair rate was 31.23%. Compared with literature [30], the coating repair rate in this paper was higher than the 21.53% reported in literature. It can be seen that microcapsules have a certain repair effect, but because the scratches were larger, it was impossible to completely repair the cracks.

3.5. Composition Analysis

The infrared spectrum of 0.67:1 microcapsules and water-based topcoat paint films is shown in Figure 6. In the infrared spectrum of microcapsules, 3360 cm^{-1} was the N-H absorption peak; 2929 cm^{-1} and 2865 cm^{-1} were C-H stretching vibration peaks; 1639 cm^{-1} was attributed to the C=O stretching vibration of urea formaldehyde resin in wall material; and 1730 cm^{-1} was the C=O characteristic peak, which proved the existence of water-based acrylic resin in microcapsules. In the infrared spectrum of the water-based topcoat paint film without microcapsules, 2929 cm^{-1} , 2865 cm^{-1} and 1447 cm^{-1} were the stretching vibration peaks of $-\text{CH}_2$, 1730 cm^{-1} was the vibration absorption peaks of C=O. The main component of the coating is waterborne acrylic acid copolymer dispersion. Because the main components of microcapsules and coatings with microcapsules were very similar, there was not much difference between the functional groups in the spectrum [31,32].

Figure 4. SEM images of waterborne topcoat paint film with different contents of 0.67:1 microcapsules: (A) 0; (B) 5.0%; (C) 10.0%; (D) 25.0%.

Figure 5. Self-healing test of water-based topcoat paint film (0.67:1 microcapsules): (A) for one day, (B) for five days.

Figure 6. Infrared spectrogram of 0.67:1 microcapsule and water-based topcoat paint film.

4. Conclusions

Through the test of water-based topcoat paint film properties, it can be concluded that the lower the content of microcapsules, the less the influence on the color difference. The gloss of the water-based topcoat paint film with the microcapsule content of 0–10% and the 0.67:1 microcapsule ratio was better than others. When the core-wall ratio was 0.67:1, the hardness rose more obviously. When the core-wall ratio was 0.67:1 and the content of microcapsules was 0–10.0%, the adhesion was the best. When the content of microcapsules was 10.0–15.0%, the impact resistance was stronger. The tensile strength at break was better when the core-wall ratio was 0.67:1. When the content of microcapsule was 5.0–15.0%, the water-based topcoat paint film had better liquid resistance. Comprehensive analysis shows that when the core-wall ratio of self-repairing water-based acrylic resin microcapsules was 0.67:1 and the content was 10.0%, the comprehensive performance of the water-based topcoat paint film was better. The water-based topcoat paint film had a certain repairing effect. On the basis of not destroying the performance of the original film, it can also enhance other properties of the film, which provides references for future research on protecting the surface water-based topcoat paint film of wooden furniture.

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References

1. Yan, X.X.; Wang, L. Preparation of shellac resin microcapsules coated with urea formaldehyde resin and properties of waterborne paint films for *Tilia amurensis* rupestris. *Membranes* **2020**, *10*, 278. [\[CrossRef\]](#)
2. Jiang, W.J.; Zhou, G.; Duan, J.J.; Liu, D.; Zhang, Q.T.; Tian, F.C. Synthesis and characterization of a multifunctional sustained-release organic-inorganic hybrid microcapsule with self-healing and flame-retardancy properties. *ACS Appl. Mater. Interfaces* **2021**, *13*, 15668–15679. [\[CrossRef\]](#) [\[PubMed\]](#)
3. Parsaee, S.; Mirabedini, S.M.; Farnood, R.; Alizadegan, F. Development of self-healing coatings based on urea-formaldehyde/polyurethane microcapsules containing epoxy resin. *J. Appl. Polym. Sci.* **2020**, *137*, e49663. [\[CrossRef\]](#)
4. Jeong, H.; Lim, H.; Lee, D.Y.; Song, Y.S.; Kim, B.Y. Preparation and drug release behavior of nifedipine-loaded poly (lactic acid) /polyethylene glycol microcapsules. *J. Nanosci. Nanotechnol.* **2021**, *21*, 3735–3741. [\[CrossRef\]](#) [\[PubMed\]](#)
5. Chen, K.L.; Zhou, J.L.; Che, X.G.; Zhao, R.Y.; Gao, Q. One-step synthesis of core shell cellulose-silica/n-octadecane microcapsules and their application in waterborne self-healing multiple protective fabric coatings. *J. Colloid Interface Sci.* **2020**, *566*, 401–410. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Nesterova, T.; Dam-Johansen, K.; Pedersen, L.T.; Kiil, S. Microcapsule-based self-healing anticorrosive coatings: Capsule size, coating formulation, and exposure testing. *Prog. Org. Coat.* **2012**, *75*, 309–318. [\[CrossRef\]](#)
7. Njoku, C.N.; Bai, W.C.; Arukalam, I.O.; Yang, L.H.; Hou, B.R.; Njoku, D.I.; Li, Y. Epoxy-based smart coating with self-repairing polyurea-formaldehyde microcapsules for anticorrosion protection of aluminum alloy AA2024. *J. Coat. Technol. Res.* **2020**, *17*, 797–813. [\[CrossRef\]](#)
8. Yan, X.X.; Zhao, W.T.; Qian, X.Y. Effect of urea-formaldehyde (UF) with waterborne emulsion microcapsules on properties of waterborne acrylic coatings based on coating process for American lime. *Appl. Sci.* **2020**, *10*, 6341. [\[CrossRef\]](#)
9. Liu, M.; Xu, G.L.; Wang, J.A.; Tu, X.W.; Liu, X.Y.; Wu, Z.H.; Lv, J.F.; Xu, W. Effects of shellac treatment on wood hygroscopicity, dimensional stability and thermostability. *Coatings* **2020**, *10*, 881. [\[CrossRef\]](#)
10. Peng, X.R.; Zhang, Z.K. Improvement of paint adhesion of environmentally friendly paint film on wood surface by plasma treatment. *Prog. Org. Coat.* **2019**, *134*, 255–263. [\[CrossRef\]](#)
11. Li, R.R.; Chen, J.J.; Wang, X.D. Prediction of the color variation of moso bamboo during CO₂ laser thermal modification. *BioResources* **2020**, *15*, 5049–5057. [\[CrossRef\]](#)

12. 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. [\[CrossRef\]](#)
13. Yu, F.; Feng, H.Y.; Xiao, L.H.; Liu, Y. Fabrication of graphene oxide microcapsules based on Pickering emulsions for self-healing water-borne epoxy resin coatings. *Prog. Org. Coat.* **2021**, *155*, 106221. [\[CrossRef\]](#)
14. Xiong, X.Q.; Yuan, Y.Y.; Niu, Y.T.; Zhang, L.T. Development of a cornstarch adhesive for laminated veneer lumber bonding for use in engineered wood flooring. *Int. J. Adhes. Adhes.* **2020**, *98*, 102534.
15. Zhang, T.X.; Ting, G.; Wu, Z.H.; Sun, T. Reinforced strength evaluation of binding material for the restoration of Chinese ancient lacquer furniture. *BioResources* **2019**, *14*, 7182–7192.
16. Abbaspoor, S.; Ashrafi, A.; Salehi, M. Cathodic disbonding of self-healing composite coatings: Effect of ethyl cellulose micro/nanocapsules. *Corros. Eng. Sci. Technol.* **2021**. [\[CrossRef\]](#)
17. Han, T.L.; Wang, X.F.; Li, D.W.; Li, D.F.; Xing, F.; Han, N.X. Influence of strain rate on mechanical characteristic and pore structure of self-healing cementitious composites with epoxy/urea-formaldehyde microcapsules. *Constr. Build. Mater.* **2021**, *268*, 121138. [\[CrossRef\]](#)
18. 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. [\[CrossRef\]](#)
19. Liu, Q.Q.; Gao, D.; Xu, W. Influence of the bottom color modification and material color modification process on the performance of modified Poplar. *Coatings* **2021**, *11*, 660. [\[CrossRef\]](#)
20. Wu, S.S.; Tao, X.; Xu, W. Thermal conductivity of Poplar wood veneer impregnated with graphene/polyvinyl alcohol. *Forests* **2021**, *12*, 777. [\[CrossRef\]](#)
21. Zhang, B.D.; Huang, C.X.; Zhang, L.Y.; Wang, J.; Huang, X.Q.; Zhao, Y.; Liu, Y.; Li, C.C. Application of chlorine dioxide microcapsule sustained-release antibacterial films for preservation of mangos. *J. Food Sci. Technol. Mys.* **2019**, *56*, 1095–1103. [\[CrossRef\]](#)
22. Ebrahimnezhad-Khaljiri, H.; Eslami-Farsani, R. The tensile properties and interlaminar shear strength of microcapsules-glass fibers/epoxy self-healable composites. *Eng. Fract. Mech.* **2020**, *230*, 106937. [\[CrossRef\]](#)
23. Ji, X.P.; Li, J.; Hua, W.L.; Hu, Y.L.; Si, B.T.; Chen, B. Preparation and performance of microcapsules for asphalt pavements using interfacial polymerization. *Constr. Build. Mater.* **2021**, *289*, 123179. [\[CrossRef\]](#)
24. Li, K.K.; Liu, Z.J.; Wang, C.J.; Fan, W.H.; Liu, F.T.; Li, H.Y.; Zhu, Y.J.; Wang, H.Y. Preparation of smart coatings with self-healing and anti-wear properties by embedding PU-fly ash absorbing linseed oil microcapsules. *Prog. Org. Coat.* **2020**, *145*, 105668. [\[CrossRef\]](#)
25. Pan, S.H.; Cao, H.C.; Li, B.X.; Zhang, D.X.; Mu, W.; Liu, F. Improving the efficacy against crop foliage disease by regulating fungicide adhesion on leaves with soft microcapsules. *Pest Manag. Sci.* **2021**. [\[CrossRef\]](#)
26. Shi, S.S.; Netravali, A.N. Bacterial cellulose integrated irregularly shaped microcapsules enhance self-healing efficiency and mechanical properties of green soy protein resins. *J. Mater. Sci.* **2021**, *56*, 12030–12047. [\[CrossRef\]](#)
27. Santana, J.J.; Mena, V.F.; Betancor-Abreu, A.; Rodriguez-Raposo, R.; Izquierdo, J.; Souto, R.M. Use of alumina sludge arising from an electrocoagulation process as functional mesoporous microcapsules for active corrosion protection of aluminum. *Prog. Org. Coat.* **2021**, *151*, 106044. [\[CrossRef\]](#)
28. Zhang, S.N.; Ye, T.T. Preparation of natural composite microcapsules containing orchid black currant fragrance and its sustained-release properties on hair bundle. *J. Polym. Environ.* **2021**. [\[CrossRef\]](#)
29. Adibzadeh, E.; Mirabedini, S.M.; Behzadnasab, M.; Farnood, R.R. A novel two-component self-healing coating comprising vinyl ester resin-filled microcapsules with prolonged anticorrosion performance. *Prog. Org. Coat.* **2021**, *154*, 106220. [\[CrossRef\]](#)
30. Yan, X.X.; Peng, W.W. Effect of microcapsules of a waterborne core material on the properties of a waterborne primer coating on a wooden surface. *Coatings* **2021**, *11*, 657. [\[CrossRef\]](#)
31. Rao, Y.S.; Kumari, P.V.K.; Chowdary, K.P.R. Ethylene vinyl acetate microcapsules of nifedipine: Characterization, release kinetics and pharmacokinetic evaluation. *Indian J. Pharm. Sci.* **2020**, *82*, 6. [\[CrossRef\]](#)
32. Lee, J.; Jo, B. Surfactant-free synthesis protocol of robust and sustainable molten salt microcapsules for solar thermal energy storage. *Sol. Energy Mater. Sol. Cells* **2021**, *222*, 110954. [\[CrossRef\]](#)