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Effect of Composite Addition of Antibacterial/Photochromic/Self-Repairing Microcapsules on the Performance of Coatings for Medium-Density Fiberboard

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Abstract: In order to expand the research on a combination of functional microcapsules and water-based coatings, antibacterial microcapsules using 3.0% sodium dodecyl benzene sulfonate as an emulsifier, self-repairing microcapsules, and photochromic microcapsules were added to water-based coatings separately or in combination and coated on medium-density fiberboard to analyze the various properties of the coating. From the perspective of the antibacterial effect, the photochromic microcapsules have little negative impact on antibacterial properties and can be used in combination with antibacterial microcapsules. When the photochromic microcapsules and antibacterial microcapsules were combined, their antibacterial rates against *Staphylococcus aureus* and *Escherichia coli* were 51.9% and 55.6%, respectively. The self-repairing microcapsules in combination with antibacterial microcapsules lead to a significant decrease in the antibacterial rate and are not suitable for use in combination with antibacterial microcapsules. From the perspective of the photochromic effect, the addition of self-repairing microcapsules can accelerate the photochromic speed of the coating, improving the photochromic effect. The addition of antibacterial microcapsules made the photochromic rate slower. Both the antibacterial microcapsules and photochromic microcapsules have weakened the self-repairing ability of self-repairing microcapsules. The width change rate in coating scratches has decreased from 21.9% to 14.7% and 17.6%, respectively. However, compared with the coating without microcapsules, the self-repairing ability still improved. The results have broad prospects in the application of antibacterial microcapsules, self-repairing microcapsules, and photochromic microcapsules for coatings on medium-density fiberboards.

Keywords: microcapsule; antibacterial; water-based coating; medium-density fiberboard; adhesion

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1. Introduction

A fiberboard is a type of artificial board that is made from a series of treatments, such as the gluing, heating, pressing, and sanding of raw materials. The main component is wood or plant fibers [1–7]. The fiberboard has three types: high-density, medium-density, and low-density types. Among them, the medium-density fiberboards (MDF) have excellent physical properties, easy processing, high quality, and low costs. Water-based coatings are green coatings that do not harm the environment or human health and have a certain protective effect on wooden materials [8,9]. Water-based coatings are commonly used for MDF due to their low adhesion during application. Applying transparent or translucent coatings gives the MDF a better gloss and a more esthetic effect [10]. The gloss level of a coating is usually influenced by a number of factors, such as the chemical composition, the amount applied, and the layer number [11]. The adhesive strength and durability of coatings on MDF are influenced by a number of factors, such as the composition of the coating, the type of MDF, and the wettability of the material surface [12,13].

It is hoped that water-based coatings will have more functions. When self-repairing microcapsules were added to the coating, a wall material broke, and a core material flowed out when the coating ruptured, which can fill and repair cracks [14–16], thus achieving a self-repairing function of the coating [17–19]. Photochromic coatings are also current research hotspots [20]. If the coating on MDF has the function of changing color, it can compensate for the monotonous color of MDF itself and meet the diverse and personalized needs of consumers. When exposed to ultraviolet (UV) light, the spirooxazine photochromic microcapsules are very sensitive [21]. This completely changes the color after being exposed to light for about 30 s, and this color change is reversible [22,23]. The coating with photochromic microcapsules not only has a photochromic function but is also reversible, so the photochromic coating has a broad application prospect. Research shows that pollution caused by microorganisms in the environment where people live is very severe [24]. Bacteria spread indirectly through surface coatings. If the coating has strong antibacterial properties, it can serve as an effective way to block indirect transmission. Bacteria attached to the coating surface can cause damage, leading to a decrease in its protective ability against wooden substrates [25,26]. Adding an active ingredient with an antibacterial effect into the coating can make the coating antibacterial [27] and protect the MDF [28]. The coatings with antibacterial microcapsules can protect the coating and optimize the living environment. The coatings with antibacterial properties can not only protect the substrate but also protect people's health [29].

Khorasani et al. [30] successfully prepared microcapsules with coconut oil-based alkyd resin as the core material, melamine resin as the wall material, and sodium dodecyl benzene sulfonate as the emulsifier. The effects of different technological conditions on the encapsulation efficiency and core content of microcapsules were studied, and the microcapsules with excellent performance were prepared under optimal technological conditions. Therefore, while optimizing the water-based coatings, it is necessary to enrich and explore other functions of water-based wood coatings. Zhang et al. [31] prepared polyaniline microcapsules with flaxseed oil as the core material and added them to waterborne epoxy resin coatings to prepare coatings with self-repairing and anti-corrosion functions. Aloe emodin, usually extracted from aloe, is a natural organic compound belonging to the anthraquinone group of compounds [32]. Aloe emodin has an antibacterial effect on *Staphylococcus*, *Streptococcus*, and other bacteria and has anti-inflammatory, anti-virus, and other effects [33–37]. With regard to research on the antibacterial properties, Hu et al. [38] proved that aloe emodin has an inhibitory effect on *Staphylococcus aureus*. Xiong et al. [39] used aloe emodin to modify the cationic waterborne polyurethane, and the thermodynamic properties of the modified materials were improved and the mechanical properties were maintained. In the previous results [14,18,20,23,28,40], the use of single-functional microcapsules can give the coating a specific function, such as photochromic, antibacterial, and self-repairing functions. When the antibacterial, photochromic, and self-repairing microcapsules are added at the same time, the coating may have antibacterial, photochromic, and self-repairing functions at the same time. Therefore, the research objective is to explore the composite addition of antibacterial/photochromic/self-repairing microcapsules on the performance of coatings for MDF.

In this paper, the antibacterial microcapsules, photochromic microcapsules, and self-repairing microcapsules were combined to enrich the functions of water-based coatings. The possibility of using functional microcapsules as composites was analyzed by testing and characterizing the surface morphology, antibacterial properties, photochromic properties, self-repairing properties, and mechanical properties of coatings for MDF. Through the discussion of the test results, the influence of the composite use of antibacterial microcapsules, photochromic microcapsules, and self-repairing microcapsules on the coating performance was summarized. By optimizing and combining three types of microcapsules, the water-based coating for MDF can simultaneously possess photochromic, self-repairing, and antibacterial functions, expanding the application range of water-based coatings.

2. Materials and Methods

2.1. Materials of Test

The size of the MDF used for the test was 50 mm × 50 mm × 5 mm (Superus SMART HOME Co., Ltd., Shanghai, China). The size of the polyethylene film was 40 mm × 40 mm × 0.08 mm. The diameter of the petri dish was 90 mm. The second generation standard strain ATCC25922 was used for *Escherichia coli* and ACTT6538 for *Staphylococcus aureus*. The UV power was 48 W, and the distance between plates was 20 cm. The specific test materials and parameters used are shown in Tables 1 and 2.

Table 1. List of experimental materials information.

Material	Molecular Formula	Molecular Weight	CAS No.	Content (%)	Manufacturer
Urea	CH_4N_2O	60.06	57-13-6	99.0	Xilong Scientific Co., Ltd., Shantou, China
Formaldehyde solution	-	-	-	37.0	Xilong Scientific Co., Ltd., Shantou, China
Triethanolamine	$C_6H_{15}NO_3$	149.19	102-71-6	99.9	Nanjing Chemical Reagent Co., Ltd., Nanjing, China
Polyvinyl alcohol	$[C_2H_4O]_n$	-	9002-89-5	99.0	Sinopharm Chemical Reagent Co., Ltd., Shanghai, China
Sodium dodecyl benzene sulfonate	$C_{18}H_{29}NaO_3S$	348.48	25155-30-0	99.0	Tianjin Beichen District Fangzheng Reagent Factory, Tianjin, China
Aloe emodin	$C_{15}H_{10}O_5$	270.2369	481-72-1	98.0	Xi'an Realin Biotechnology Co., Ltd., Xi'an, China
Citric acid monohydrate	$C_6H_{10}O_8$	210.14	5949-29-1	99.0	Xilong Scientific Co., Ltd., Shantou, China
Anhydrous ethanol	C_2H_6O	46.07	64-17-5	99.9	Tianjin Fuyu Fine Chemical Co., Ltd., Tianjin, China
Water-based acrylic primer and topcoat	-	-	-	-	Akzo Nobel Decorative Coatings Co., Ltd., Langfang, China
Escherichia coli	-	-	-	-	Beijing Microbiological Culture Collection Center, Beijing, China
Staphylococcus aureus	-	-	-	-	Beijing Microbiological Culture Collection Center, Beijing, China
Nutrient agar medium	-	-	-	-	Hangzhou Microbial Reagent Co., Ltd., Hangzhou, China
Nutrient broth	-	-	-	-	Hangzhou Microbial Reagent Co., Ltd., Hangzhou, China
NaCl	NaCl	58.4428	7647-14-5	99.5	Sinopharm Chemical Reagent Co., Ltd., Shanghai, China
SiO_2	SiO_2	60.084	14808-60-7	99.5	Sinopharm Chemical Reagent Co., Ltd., Shanghai, China
Polyethylene film	-	-	-	-	Shijiazhuang Xilong Packaging Co., Ltd., Shijiazhuang, China
Petri dish	-	-	-	-	Haimen Ruixing Biotechnology Co., Ltd., Nantong, China
Shellac solution	-	-	-	-	Anhui Shiyan Basic Building Materials Co., Ltd., Anqing, China
Rosin solution	-	-	-	-	Shantou Letong Musical Instrument Co., Ltd., Shantou, China
Melamine	$C_3H_6N_6$	125.12	108-78-1	99.9	Shandong Yousuo Chemical Technology Co., Ltd., Linyi, China
SPAN-20	$C_{18}H_{34}O_6$	346.46	1338-39-2	99.0	Wuxi Yatai United Chemical Co., Ltd., Wuxi, China
TWEEN-20	$C_{26}H_{50}O_{10}$	522.6692	9005-64-5	99.0	Wuxi Yatai United Chemical Co., Ltd., Wuxi, China
Photochromic microcapsules	-	-	-	-	Chongyu Technology Co., Ltd., Guangzhou, China

Table 2. Chemical composition of photochromic microcapsules.

Chemical Composition	Molecular Formula	Molecular Weight	CAS No.	Mass Fraction (%)
Melamine formaldehyde resin	$(C_3H_6N_6 \cdot CH_2O)_x$	-	9003-08-1	32.0–36.0
Styrene maleic anhydride copolymer	$C_{17}H_{16}O_7$	332.305	31959-78-1	6.5–8.0
1,2-dimethyl-4–(1-phenylethyl) benzene	$C_{16}H_{18}$	210.314	6196-95-8	50.0–60.0
photochromic dye (1,3,3-trimethylindolin-6′–(1-piperidinyl) spirophenoxazine)	$C_{27}H_{29}N_3O$	411.539	114747-45-4	2.6–4.0

2.2. Preparation Method of Microcapsules

2.2.1. Preparation Method of Antibacterial Microcapsules

When preparing the microcapsules of aloe emodin coated with urea–formaldehyde resin, 16.22 g of formaldehyde solution with a 37.0% concentration was mixed with 10 g of urea, and 227.95 g of deionized water was added. After the solution was stirred evenly, triethanolamine was added dropwise to make the pH of the solution reach 8, then 0.1 g of polyvinyl alcohol with a mass fraction of 1.0% was added. The container containing the solution was put into a magnetic stirrer (Changzhou Jintan Liangyou Instrument Co., Ltd., Changzhou, China) with a temperature of 80 °C and a rotation speed of 600 rpm for reaction for 1 h to make a urea–formaldehyde resin prepolymer of wall material.

The 7.05 g of 3.0% sodium dodecyl benzene sulfonate as an emulsifier was weighed and mixed with water. Then, 1.07 g aloe emodin was added, and the container containing the solution was placed in a magnetic stirrer. The stirring speed of magnetic stirrer was adjusted to 1000 rpm, the temperature was 60 °C, and the reaction time was 45 min so that the core material could be fully emulsified. The obtained solution was the core material emulsion.

The urea–formaldehyde resin prepolymer of wall material was aspirated and added dropwise to the core material emulsion. The citric acid monohydrate was used to adjust the pH to 2.5, then 1.28 g NaCl and 1.28 g SiO_2 powder were added. The microcapsule process occurs in an acidic environment. The addition of NaCl can enhance the ionic strength of the solution, destroy the electric double-layer structure formed by the adsorption of charged ions by the urea–formaldehyde resin prepolymer, increase the chance of collision between the prepolymers, and generate more and tougher urea–formaldehyde resin of wall material. Adding SiO_2 can improve the adhesion between particles during the formation of microcapsules. The urea–formaldehyde resin prepolymer of wall material gradually condensed and deposited onto the surface of the core material in an acidic environment using emulsifiers as a medium to form a solid wall material. After continuous microencapsulation for 2 h, the obtained solution was stored at room temperature for 24 h. The aged solution was filtered with ethanol and water through a suction filter several times, and the resulting product was placed in a 40 °C oven for 24 h, dried, and ground. After drying and grinding, the orange powder obtained was the antibacterial microcapsules of aloe emodin coated with urea–formaldehyde resin.

2.2.2. Preparation Method of Self-Repairing Microcapsules

The melamine and formaldehyde solutions were mixed well, an appropriate amount of deionized water was added, and triethanolamine was added dropwise to a pH of 8. The solution was put into a magnetic stirrer with a rotating speed of 600 rpm, the temperature was 70 °C, and the reaction lasted for 1 h to generate melamine formaldehyde resin prepolymer as a wall material solution.

The 0.15 g of SPAN-20 and 0.15 g of TWEEN-20 were weighed, and 78.9 g of anhydrous ethanol was added and stirred evenly to obtain an emulsifier solution. The 4.4 g of shellac solution and 4.4 g of rosin solution were mixed evenly, and the emulsifier solution was added dropwise using a dropper. The solution in a magnetic stirrer was at 60 °C and 600 rpm for 1 h to react, resulting in an emulsified core material solution.

The wall material solution was dropped into the emulsified core material solution at the speed of 600 rpm and then placed in the ultrasonic emulsion disperser (Nanjing Safer Biotech Co., Ltd., Nanjing, China) for 15 min. The pH of the solution was adjusted with citric acid monohydrate to approximately 3.5. The container with the solution was placed in a magnetic stirrer at 600 rpm and 60 °C and encapsulated for 3 h. After 48 h of aging, the obtained solution was filtered with deionized water and anhydrous ethanol, dried, and ground to obtain self-repairing microcapsules with the core material of shellac.

2.3. Preparation and Application Method of Coating

According to Huang et al. [40], when the content of microcapsules is 6.0%, the comprehensive performance of the coating is relatively good, so the amount of each microcapsule added is 6.0% of the total mass of the coating material. The MDF was coated with two layers of primer and two layers of topcoat by hand brushing; the amount of each layer was 78 g/m^2, and the total amount of coating for a single sample was 312 g/m^2. Due to the certain loss caused by actual brushing, the actual consumption of coating is 1.5–1.8 times the theoretical coating amount. The total amount of coating for one sample was 1.4 g. The room temperature in the laboratory was 26 °C, and the relative humidity was 60.0% ± 5.0%.

The detailed materials used for the coating are shown in Table 3. The sample 8# was used as an example. The 0.7 g of water-based primer was weighed and applied uniformly on MDF surface. The first primer was gradually dried at 40 °C for 20 min and sanded, followed by a second primer, which follows the same steps as the first. After both coats of primer had been applied, the 0.042 g antibacterial microcapsules, 0.042 g self-repairing microcapsules, and 0.042 g photochromic microcapsules were weighed and added to 0.574 g of water-based topcoat and stirred evenly. The drying process of the first topcoat was the same as for the primer. After the first topcoat was dried, the surface was lightly sanded with sandpaper and a second topcoat was applied. In addition, the coated MDF without microcapsules was used as a reference (sample 1#).

Table 3. List of materials for water-based coating.

Sample (#)	Water-Based Primer (g)	Antibacterial Microcapsules (g)	Photochromic Microcapsules (g)	Self-Repairing Microcapsules (g)	Water-Based Topcoat (g)
1	0.700	0	0	0	0.700
2	0.700	0.042	0	0	0.658
3	0.700	0	0.042	0	0.658
4	0.700	0	0	0.042	0.658
5	0.700	0.042	0.042	0	0.616
6	0.700	0.042	0	0.042	0.616
7	0.700	0	0.042	0.042	0.616
8	0.700	0.042	0.042	0.042	0.574

2.4. Testing and Characterization

2.4.1. Microstructure and Composition

An optical microscope (OM) (Shanghai Optical Instrument Co., Ltd., Shanghai, China) and Quanta-200 scanning electron microscope (SEM) (FEI Company, Hillsboro, OR, USA) were used to observe the microcapsules, and their microscopic morphology was recorded. When observing and recording the microscopic morphology of microcapsules with OM, an appropriate amount of prepared microcapsules was taken, and then a 20× microscope lens for observation was selected. When observing the samples of microcapsules and coatings by SEM, the prepared microcapsules and coatings were pasted on the sample table, the samples to be tested were sprayed with gold and placed in a specific position, and the microscopic morphology of the samples to be tested was observed and recorded.

The chemical composition of coatings was tested and characterized by a VERTEX 80V infrared spectrometer (FTIR) (BRUKER OPTICS, Karlsruhe, Germany).

2.4.2. Antibacterial Performance

The GB/T 21866-2008 [41] was used as a standard for antibacterial testing of coatings. Antibacterial resistance was tested using two bacteria, *Escherichia coli* and *Staphylococcus aureus*. First, a number of flat nutrient agar medium and nutrient broth cultures were made from nutrient agar medium powder and nutrient broth powder, respectively, and then set aside. The NaCl was dissolved in purified water to make a 0.85% NaCl solution, which was used as an eluent. The flat nutrient agar medium, nutrient broth medium, and eluent were autoclaved at 121 °C for 30 min. The polyethylene films were soaked in 70.0% ethanol solution for 30 min, then rinsed with eluent and dried.

The bacteria were transferred from the slant medium to the flat nutrient agar medium with a sterilized inoculation loop. After the bacteria were incubated for a period of time under constant temperature and humidity, the fresh bacteria were scraped with an inoculation loop, added to the broth culture and stirred thoroughly. These fresh bacteria were added to the broth culture and stirred well. Based on GB/T 4789.2-2022 [42], the samples were made into 1:1000 bacterial suspensions by using the method of making ten-fold incremental dilutions sequentially. The 0.5 mL of the bacterial suspension was added dropwise to the prepared coating, and the polyethylene film was picked up with tweezers and laid flat to cover the coating. The samples were placed in petri dishes and incubated at 37 °C and 98.0% humidity for 24 h.

Two sets of parallel tests were performed for each sample. After 24 h of incubation, 20 mL of eluent was added to rinse the coating and polyethylene film repeatedly. The 0.5 mL of the eluent was inoculated into the flat nutrient agar medium and incubated for 48 h in a constant temperature and constant humidity chamber at a temperature of 37 °C and a humidity of 98.0%. An XK97-A colony counter (Shanghai Precision Instrument Co., Ltd., Shanghai, China) was used to count all the colonies. The average of the two sets of parallel tests was the number of colonies. The results of the measured colony counts were multiplied by 1000 as the actual value of viable bacteria recovered after 48 h of incubation for each sample.

Formula (1) is the calculation method of antibacterial rate in the coating. In the formula, R denotes the antibacterial rate, B denotes the actual value of viable bacteria recovered after 48 h of incubation of the coating without microcapsules, and C denotes the actual value of viable bacteria recovered after 48 h of incubation of the coating with microcapsules, in CFU/piece.

$$R = (B - C)/B \times 100\% \quad (1)$$

2.4.3. Optical Properties

The color difference testing was conducted on the coating using an SC-10 color difference tester (Shenzhen 3NH Technology Co., Ltd., Shenzhen, China). Among them, "L" represents the brightness of the measured sample, "a" represents the red-green phase, and "b" represents the yellow-blue phase. When conducting color difference test, certain point on the coating without adding microcapsules was tested and recorded as "L_1", "a_1", and "b_1". The data obtained from testing a point on the coating by adding microcapsules were recorded as "L_2", "a_2", and "b_2". The color difference "ΔE" was calculated according to Formula (2). $\Delta L = L_2 - L_1$ (brightness difference), $\Delta a = a_2 - a_1$ (red/green difference), $\Delta b = b_2 - b_1$ (yellow/blue difference).

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

An X-rite ci60 glossmeter (Shenzhen Weifeng Instrument Co., Ltd., Shenzhen, China) was used to test the glossiness of the coating according to GB/T 4893.6-2013 [43]. The gloss loss rate in the coating at a 60° incidence angle was calculated according to Formula (3). "G_L" is the gloss loss rate, "G_0" is the gloss of the coating without the addition of microcapsules, and "G_1" is the gloss of the coating with the addition of microcapsules.

$$G_L = (G_0 - G_1)/G_0 \times 100\% \quad (3)$$

A U-3900 UV spectrophotometer (Techcomp Instrument Co., Ltd., Shanghai, China) was used to determine the transmittance of the coating.

2.4.4. Mechanical Properties

When testing the surface roughness (R_a) of the coating, a JB-4C fine roughness tester (Shanghai Optical Instrument No.5 Factory Co., Ltd., Shanghai, China) was used. R_a is the average of the absolute value of the distance from each point on the contour to the centerline of the contour within the sampling length. When measuring the surface roughness of the coating, the coated MDF was placed on the test platform. The position of the contact pin was adjusted to contact the coating. The test was started, and the roughness was recorded.

Taking GB/T 6739-2006 [44] as the test standard, a portable coating hardness tester (Cangzhou Taiding Hengye Testing Instrument Co., Ltd., Cangzhou, China) was used for testing the hardness of the coating. When the pencil scratched the coating, the hardness of the pencil scratching the coating surface was the surface hardness of the coating.

When using the coating crosscutting instrument (Shanghai Jingge Instrument Equipment Co., Ltd., Shanghai, China) to test coating adhesion, GB/T 4893.4-2013 [45] was used as the standard. During the test, the template was placed on the operating platform, the handle of the scriber was held, the cutter was made perpendicularly to the plate surface, and then the plate surface was cut with uniform force and fixed speed. Then, the plate was rotated 90°, and the previous operation was repeated at the cutting point of the previous cutting to make the grid pattern appear on the surface of the template. All cuts in this operation shall penetrate the coating. The tape was first applied to the entire scribe and then removed. The adhesion of the paint film was judged by the peeling off of the coating on the sheet.

According to the GB/T 4893.9-2013 [46] standard for the Test of Surface Coatings of Furniture–Part 9: Determination of resistance to impact, a coating impact testing machine (Shanghai Rongjida Instrument Technology Co., Ltd., Shanghai, China) was used to test the impact resistance of the coating. The impact strength was the maximum height of the impact block without coating fracture after it fell.

2.4.5. Self-Repairing Performance

When conducting self-repairing testing, a testing method was used to scratch the MDF surface with a single blade to damage the coating. The OM was used to observe the crack width at the scratch site of the coating, denoted as "D_1". After standing for one week, the crack width at the same location was observed again, denoted as "D_2". The change rate in scratch width was calculated as "D_H" according to Formula (4). The higher the change rate, the better the self-repairing performance of the surface coating on the MDF.

$$D_H = (D_1 - D_2)/D_1 \times 100\% \quad (4)$$

3. Results and Discussion

3.1. Analysis of Microcapsule Morphology

Figure 1 shows the macro morphology of three kinds of microcapsules with different functions: antibacterial microcapsules, photochromic microcapsules, and self-repairing microcapsules. The antibacterial microcapsules are yellow, and the photochromic microcapsules and self-repairing microcapsules are white.

Figure 2 shows the color change of photochromic microcapsules before, during, and after UV irradiation. After UV irradiation, the microcapsules were changed from white to blue. When not irradiated by UV light, the indoline spirooxazine in the photochromic microcapsules had closed-loop structures and the color of the microcapsule was white. When the photochromic microcapsules were irradiated by UV light, an electron transfer occurred between the carbon atom and the oxygen atom. The closed-loop structure broke and became open-loop, forming a conjugated system, and the color of the microcapsule

changed to blue. When the microcapsules are not exposed to UV light, they return to a closed-loop structure [47–49], which is reversible.

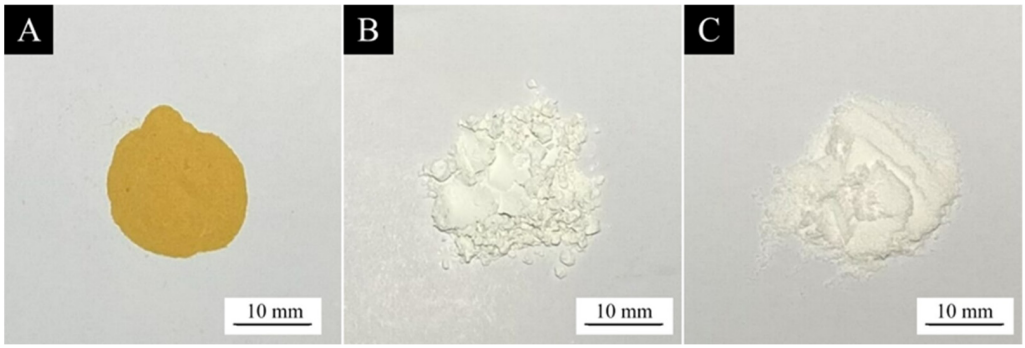


Figure 1. Macro morphology of (**A**) antibacterial, (**B**) photochromic, and (**C**) self-repairing microcapsules.

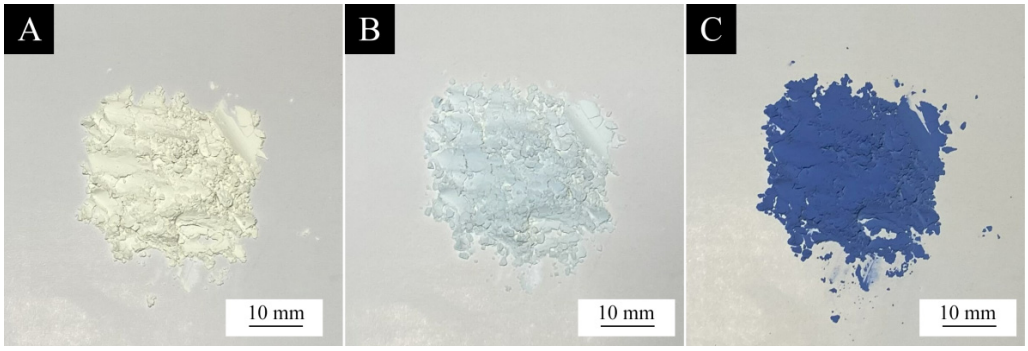


Figure 2. Color changes of photochromic microcapsules exposed to UV light: (**A**) Before irradiation, (**B**) Under irradiation, (**C**) After irradiation.

OM and SEM images of three kinds of microcapsules, namely, antibacterial microcapsules, photochromic microcapsules, and self-repairing microcapsules, are shown in Figures 3 and 4. Among them, the photochromic microcapsules have the best dispersibility, which is small in particle size and very homogeneously dispersed. The dispersion of self-repairing microcapsules was the worst, and an agglomeration was obvious.

The reason may be that the concentration of the emulsifier, stirring rate, and core-to-wall ratio of microcapsules affect the distribution and morphology of microcapsules [50].

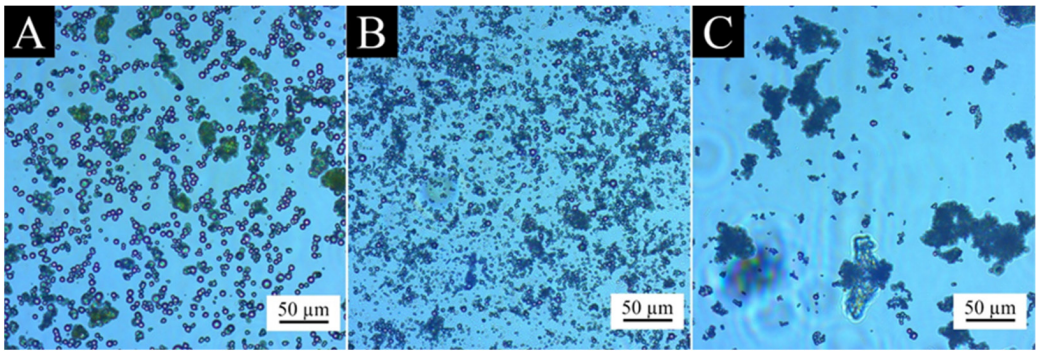


Figure 3. OM images of (**A**) antibacterial, (**B**) photochromic, and (**C**) self-repairing microcapsules.

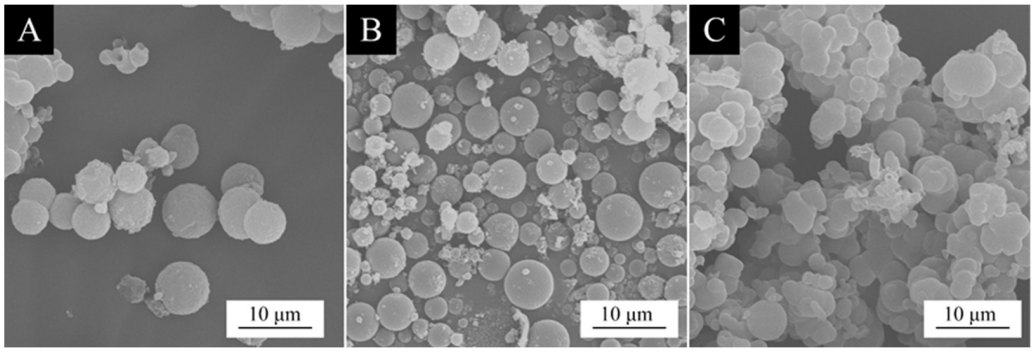


Figure 4. SEM images of (**A**) antibacterial, (**B**) photochromic, and (**C**) self-repairing microcapsules.

3.2. Analysis of Coating Morphology

The microscopic morphology of the eight sets of water-based coatings containing different microcapsules from sample 1# to sample 8# is shown in Figure 5. The surface of the coating without microcapsules (Figure 5A) was relatively smooth. The photochromic microcapsules with small and uniform particle size can be evenly dispersed in the coating (Figure 5C), which have little impact on the surface flatness. The coating added with self-repairing microcapsules (Figure 5D) had serious agglomeration, which is due to the fact that the microcapsules themselves adhere to each other, resulting in the inability to disperse evenly in the coating.

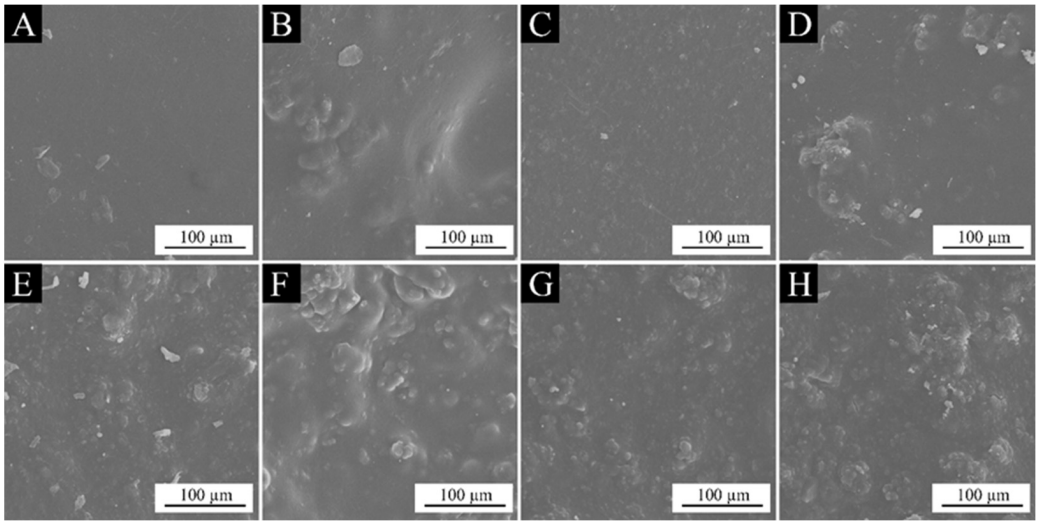


Figure 5. SEM images of the coatings: (**A**) 1#, (**B**) 2#, (**C**) 3#, (**D**) 4#, (**E**) 5#, (**F**) 6#, (**G**) 7#, (**H**) 8#.

The surface of the coating with the composite addition of antibacterial/photochromic/self-repairing microcapsules is heavily caked and non-uniform. The reason for this problem is that the total addition content of microcapsules is as high as 12.0%, which aggravates the agglomeration and uneven dispersion of microcapsules, resulting in an uneven coating surface.

3.3. Chemical Composition Analysis of Water-Based Coatings on MDF

Figure 6 is the infrared spectra of the water-based coatings on the surface of the MDF without microcapsules, as well as the infrared spectra of the coatings containing different microcapsules. Due to the existence of C-H and C-O in the water-based coating and the three microcapsules, the C-H bending vibration peak and C=O vibration peak were caused at 2950 cm^{-1} and 1144 cm^{-1}. The characteristic peak at 1730 cm^{-1} was the stretching vibration peak of C=O in water-based coatings. The stretching vibration peak of

(-CH_2)-CH_2 at 1450 cm^{-1} was unique to water-based coatings. The peak at 1247 cm^{-1} was caused by C-N telescopic vibrations and N-H deformation vibrations in three microcapsules, and the methyl group was caused by the stretching vibration peak at 1380 cm^{-1}.

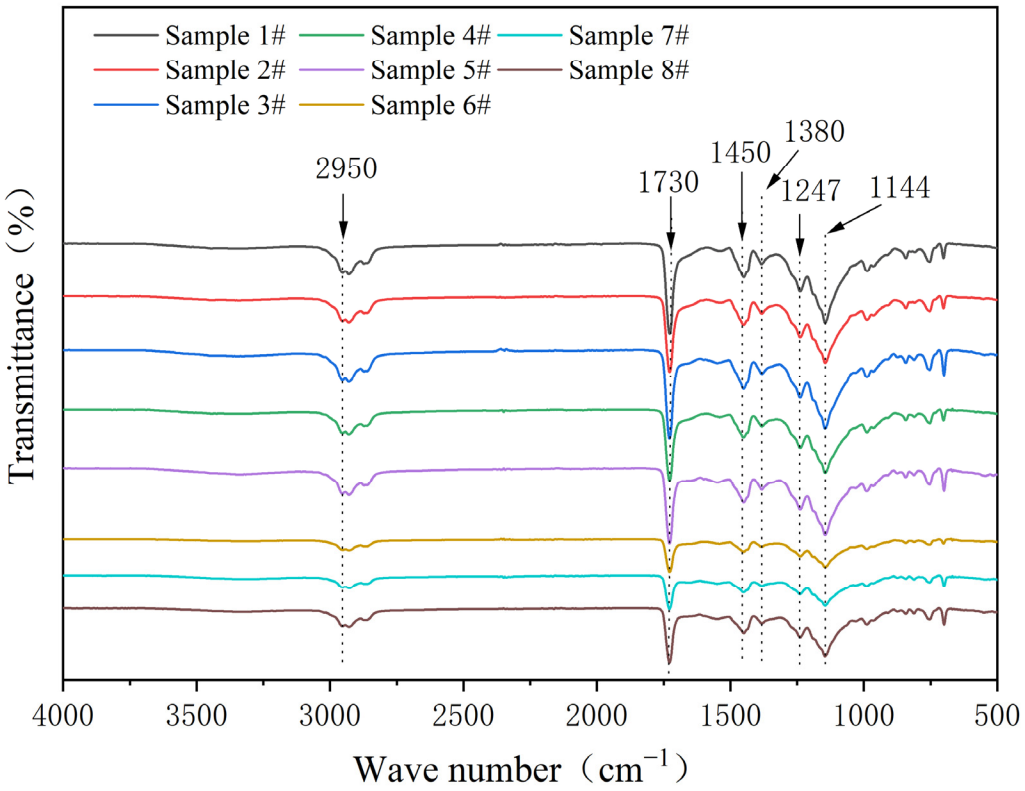


Figure 6. FTIR image of coatings with different types of microcapsules.

These peaks can be seen in the eight curves, indicating that the three microcapsules do not react with the water-based coating and that the chemical composition of the water-based coating is not damaged by the addition of the three different microcapsules. When the microcapsules are coated on the surface of MDF, the components of the water-based coatings and the three microcapsules remain intact.

3.4. Analysis of Antibacterial Properties of Water-Based Coatings on MDF

Table 4 and Figure 7 show the actual number of recovered viable bacteria and the antibacterial rate in water-based coatings with different types of microcapsules. The antibacterial rates of sample 2# with only antibacterial microcapsules against *Escherichia coli* and *Staphylococcus aureus* were 62.7% and 54.5%, respectively. The antibacterial rates of sample 5# with the composite addition of antibacterial microcapsules and photochromic microcapsules were also higher, reaching 55.6% and 51.9%, respectively. The addition of photochromic microcapsules had less influence on the antibacterial effect of antibacterial microcapsules. The antibacterial rate in the coatings did not change much when only photochromic microcapsules were added. The antibacterial rates of the surface coatings of sample 4#, with the addition of self-repairing microcapsules, and sample 7#, with a combination of photochromic microcapsules and self-repairing microcapsules, were both negative. The addition of self-repairing microcapsules reduced the antibacterial properties of the water-based coatings and had a negative effect on the antibacterial properties of the coatings.

Table 4. Antibacterial rate results from adding different types of microcapsules to the coating.

Sample (#)	Type of Microcapsules	Average Number of Recovered *Escherichia coli* (CFU·Piece^{-1})	Antibacterial Rate of Coating against *Escherichia coli* (%)	Average Number of Recovered *Staphylococcus aureus* (CFU·Piece^{-1})	Antibacterial Rate of Coating against *Staphylococcus aureus* (%)
1	-	126	-	156	-
2	Antibacterial microcapsules	47	62.7	71	54.5
3	Photochromic microcapsules	119	5.6	149	4.5
4	Self-repairing microcapsules	155	−23.0	186	−19.2
5	Antibacterial microcapsules + Photochromic microcapsules	56	55.6	75	51.9
6	Antibacterial microcapsules + Self-repairing microcapsules	81	35.7	132	15.4
7	Photochromic microcapsules + Self-repairing microcapsules	135	−7.1	171	−9.6
8	Antibacterial microcapsules + Photochromic microcapsules + Self-repairing microcapsules	107	15.1	126	19.2

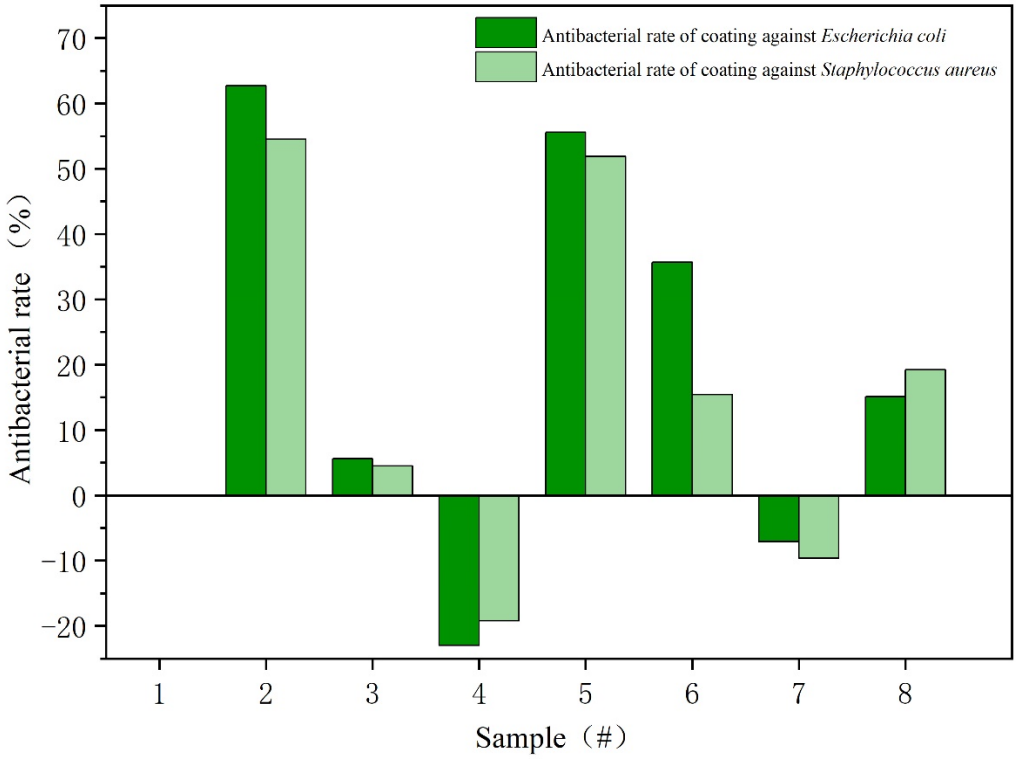


Figure 7. Effect of different types of microcapsules on antibacterial properties.

Compared to metal surfaces, which are smooth and flat, wood surfaces are more prone to bacterial growth because of the large number of pores on the surface and inside. Compared with sample 1#, the surface of sample 4# and sample 7# were rougher. The large number of agglomerated microcapsules causes an uneven coating so that the bacterial suspension cannot be evenly covered on the surface of the water-based coatings. The bacterial suspensions accumulate in the surface grooves, which not only allows bacteria to gather and multiply but also makes the MDF absorb water and expand. The MDF, after hygroscopic expansion, provides a better place for bacteria to grow, so bacteria propagate more than the blank control sample without microcapsules; the antibacterial rate is negative.

This led to a significant reduction in the antibacterial rate in sample 6# and sample 8#, which included antibacterial microcapsules and self-repairing microcapsules.

From the perspective of antibacterial properties, the combination of antibacterial microcapsules and photochromic microcapsules can better retain the original antibacterial property. However, the self-repairing microcapsules are not suitable for combined use with antibacterial microcapsules, and the combined use of self-repairing microcapsules and antibacterial microcapsules will lead to significantly worse antibacterial effects in the coating.

The test results were analyzed for significance based on the type of microcapsules added to the coating and the type of strain, respectively (Table 5). The significance analysis was performed using ANOVA unrepeated two-way analysis of variance. The SS in the table represents the sum of squares of the mean square, d_f is the degree of freedom within the group, and MS is the mean square obtained by dividing the sum of squares by the degree of freedom. The F is used to test the overall significance level of the econometric model. The p_{value} represents the probability value under the corresponding F-value, used to determine whether the experimental results have statistical significance. The F_{crit} represents the F-critical value at the corresponding significance level. Usually, if $F < F_{crit}$, $p > 0.05$ indicates that the difference is not significant. If $F > F_{crit}$, $0.01 < p < 0.05$ indicates a significant difference, and $p < 0.01$ indicates an extremely significant difference. As shown in Table 5, the effect of microcapsule type on the antibacterial properties was highly significant.

Table 5. Significant difference analysis of antibacterial properties.

Item	SS	d_f	MS	F	p_{value}	F_{crit}
Types of microcapsules	11,353.41	7	1621.916	52.26822	0.00	3.787044
Types of bacteria	48.65062	1	48.65062	1.567826	0.2507367	5.591448
error	217.2144	7	31.03063	-	-	-
total	11,619.27	15	-	-	-	-

3.5. Optical Performance Analysis of Water-Based Coatings on MDF

The color difference between sample 7# and sample 4# was the largest, reaching 21.36 and 20.05, respectively (Table 6 and Figure 8). The addition of self-repairing microcapsules had a significant effect on the color difference of coatings.

Table 6. Color difference values of water-based coatings with different types of microcapsules.

Sample (#)	Type of Microcapsules	*L*	*a*	*b*	Δ*E*
1	-	48.4 ± 1.3	8.9 ± 0.2	25.2 ± 0.1	-
2	Antibacterial microcapsules	49.0 ± 0.7	15.3 ± 1.4	34.8 ± 0.8	11.55
3	Photochromic microcapsules	58.8 ± 1.4	3.2 ± 0.1	18.6 ± 1.0	13.57
4	Self-repairing microcapsules	64.0 ± 1.7	5.9 ± 0.2	13.0 ± 0.9	20.05
5	Antibacterial microcapsules + Photochromic microcapsules	57.1 ± 0.7	6.4 ± 0.1	34.1 ± 1.2	12.69
6	Antibacterial microcapsules + Self-repairing microcapsules	62.4 ± 1.8	6.8 ± 0.3	34.5 ± 1.3	16.96
7	Photochromic microcapsules + Self-repairing microcapsules	65.6 ± 0.5	4.6 ± 0.2	13.3 ± 0.3	21.36
8	Antibacterial microcapsules + Photochromic microcapsules + Self-repairing microcapsules	64.5 ± 1.4	4.9 ± 0.2	34.1 ± 0.7	18.86

Because the self-repairing microcapsules are white and more agglomerated, while the MDF is brownish-yellow, the color changes greatly and the color difference is large after adding the self-repairing microcapsules. The parameter *b* of these eight groups of samples also confirms this point. The value of parameter *b* reflects the degree of yellow. The larger

the parameter "*b*", the darker the yellow color. The "*b*" value of sample 7# and sample 4# was significantly lower than that the "*b*" value of sample 1# without microcapsules, which indicated that the white self-repairing microcapsules covered the color of the MDF surface to a certain extent, resulting in the decrease in "*b*" value. The "*L*" values of the eight samples did not differ much. The addition of different kinds of microcapsules in the coatings had little influence on the brightness of the coating for MDF.

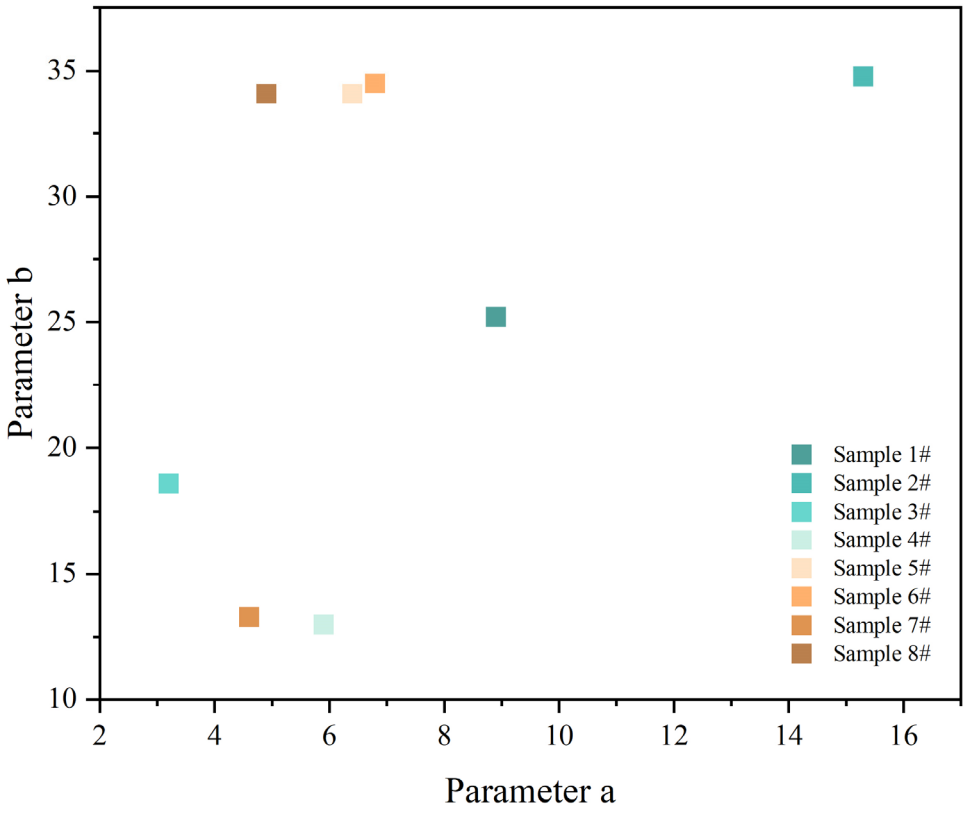


Figure 8. CIELAB color space map for composite use of different microcapsules.

Figures 9–12 are the photochromic process of the surface coating of MDF with photochromic microcapsules under UV irradiation. With the increase in irradiation time, the surface color of MDF gradually turned blue, and the color was stable after 30 s. When the coating is not exposed to UV light, it gradually recovers to its original color and returns to its original color after 30 s. The whole photochromic process is reversible.

It can be seen that the photochromic microcapsules still retain reversible photochromic properties when mixed with water-based coatings and are sensitive to UV light. In Figure 9, sample 3#, with only photochromic microcapsules, showed an obvious blue color when the coating was exposed to UV light for 10 s, and the blue color obviously faded after the coating was not exposed to UV light for 15 s.

Figure 10 shows the photochromic process of sample 5# coating with the composite addition of photochromic microcapsules and antibacterial microcapsules. When sample 5# was exposed to UV light for 15 s, the coating began to change color significantly, and the color change was slightly reduced. Due to the addition of yellow antibacterial microcapsules, the coating of this sample showed a yellowish hue compared to other samples without antibacterial microcapsules, which prevented the blue color of the photochromic microcapsules after irradiation. The yellow antibacterial microcapsules had a slight negative effect on the photochromic effect of the coating.

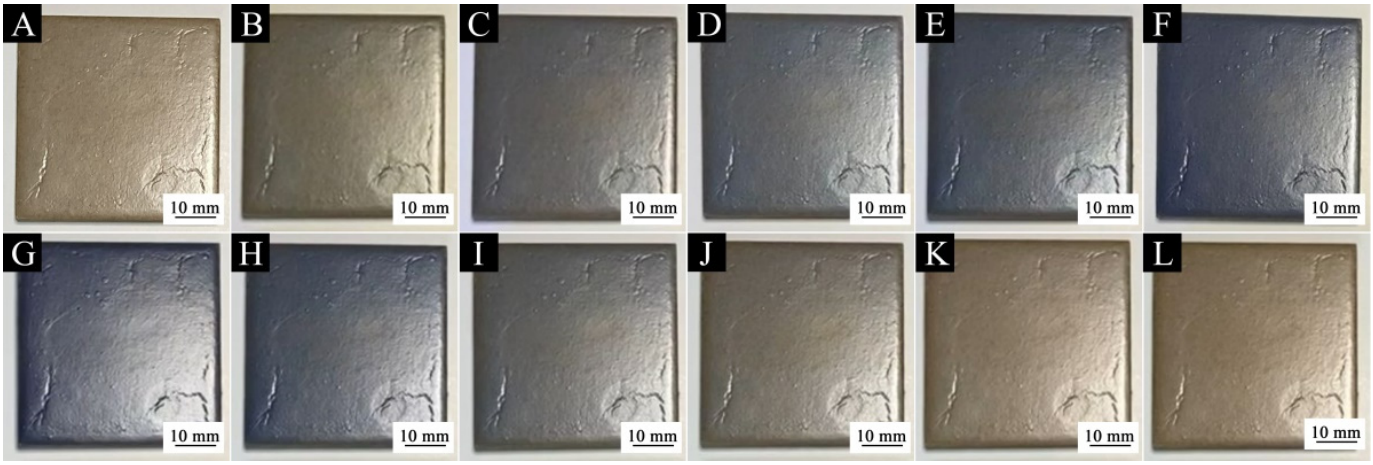


Figure 9. The photochromic process of 3# water-based coatings under UV light process: (**A**) 0 s, (**B**) 5 s, (**C**) 10 s, (**D**) 15 s, (**E**) 20 s, (**F**) 30 s. Recovery process: (**G**) 0 s, (**H**) 5 s, (**I**) 10 s, (**J**) 15 s, (**K**) 20 s, (**L**) 30 s.

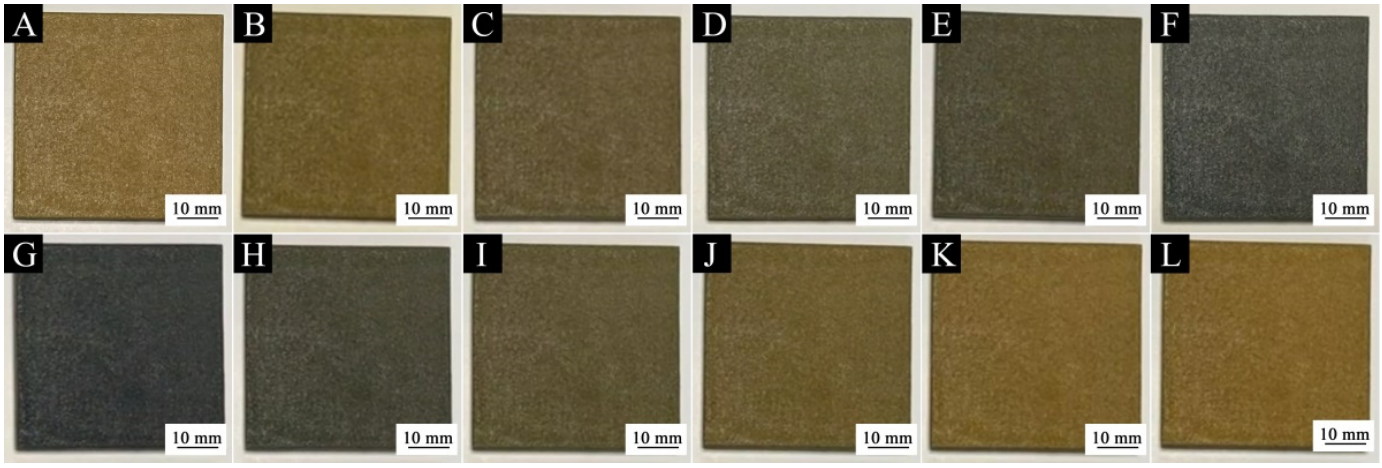


Figure 10. The photochromic process of 5# water-based coatings under UV light process: (**A**) 0 s, (**B**) 5 s, (**C**) 10 s, (**D**) 15 s, (**E**) 20 s, (**F**) 30 s. Recovery process: (**G**) 0 s, (**H**) 5 s, (**I**) 10 s, (**J**) 15 s, (**K**) 20 s, (**L**) 30 s.

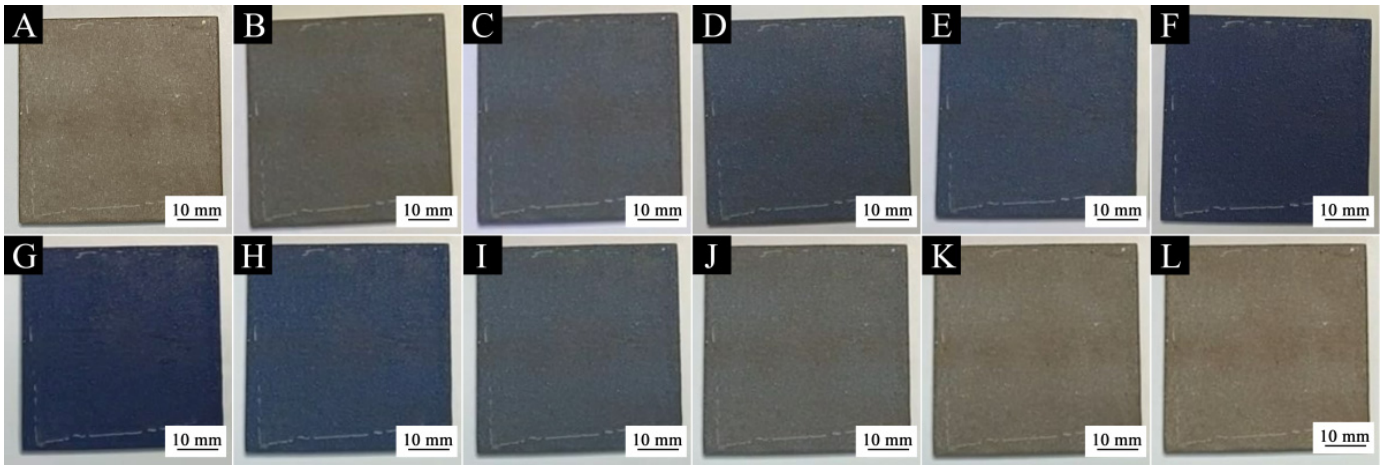


Figure 11. The photochromic process of 7# water-based coatings under UV light process: (**A**) 0 s, (**B**) 5 s, (**C**) 10 s, (**D**) 15 s, (**E**) 20 s, (**F**) 30 s. Recovery process: (**G**) 0 s, (**H**) 5 s, (**I**) 10 s, (**J**) 15 s, (**K**) 20 s, (**L**) 30 s.

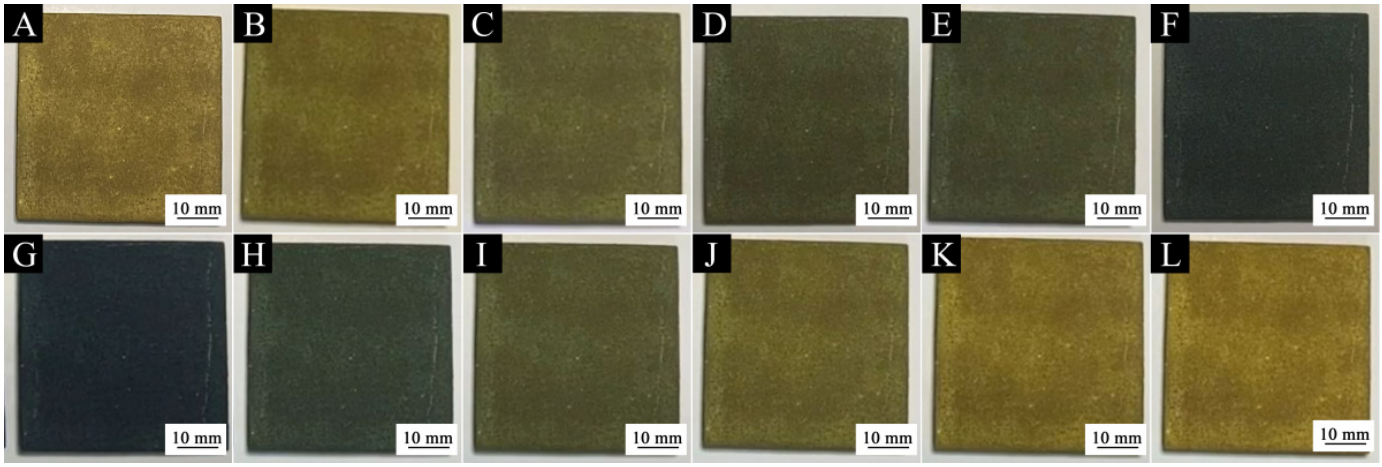


Figure 12. The photochromic process of 8# MDF surface under UV light process: (**A**) 0 s, (**B**) 5 s, (**C**) 10 s, (**D**) 15 s, (**E**) 20 s, (**F**) 30 s. Recovery process: (**G**) 0 s, (**H**) 5 s, (**I**) 10 s, (**J**) 15 s, (**K**) 20 s, (**L**) 30 s.

Figure 11 shows the photochromic process of sample 7# with the composite addition of photochromic microcapsules and self-repairing microcapsules. The color change of the coating was very fast, and it turned to an obvious blue when exposed to UV light for 5–10 s, and the degree of blue was very high. The reason is that the white self-repairing microcapsules cover the color of a part of the MDF itself, making the color of the substrate lighter, and the photochromic microcapsules are also white before the color change. Therefore, after mixing with the self-repairing microcapsules, the color of the coating is white, and the photochromic effect is more significant.

Figure 12 shows the coating of sample 8# with three kinds of microcapsules. When the coating was exposed to UV light for 15 s, the photochromic effect of the coating was obvious. Although the photochromic speed of the coating of sample 8# was reduced, the overall photochromic effect was better than that of the coating of sample 5# due to the addition of self-repairing microcapsules, which proved that the composite addition of self-repairing microcapsules and photochromic microcapsules could accelerate the photochromic effect of the coating.

Table 7 and Figure 13 show the chromaticity value and color difference value of coatings with different types of microcapsules when the color changes completely after 30 s of UV light. It can be seen in Table 7 that the color difference values of sample 1#, sample 2#, sample 4#, and sample 6# without photochromic microcapsules were almost unchanged and had no photochromic ability. The color difference of sample 3#, sample 5#, sample 7#, and sample 8#, with photochromic microcapsules, was very large, and the color change before and after photochromism was very obvious. Among them, the color difference value of sample 3#, which was only added with photochromic microcapsules, was the most pronounced, and the color difference before and after color change was the largest. Chromaticity analysis was performed by the CIELAB color space method, where the parameter L, a, and b denotes luminance (L = 100 for white, 0 for black) [51]. The "b" value of sample 7# with compound addition of photochromic microcapsules and self-repairing microcapsules was the lowest, indicating that this sample had the highest degree of blue color and the best photochromic effect.

The test results were analyzed for significance based on the type of microcapsules added to the coatings and exposure to UV light, respectively. As shown in Table 8, the effect of exposure to UV light on the photochromic effect was significant.

The gloss levels and gloss loss rates of the eight samples are shown in Table 9 and Figure 14. The coatings without microcapsules had a higher gloss, the gloss of the coating with microcapsules was significantly reduced, and the gloss loss rate at a 60° incidence angle was significantly improved. The gloss of a coating is strongly influenced by the particle size

of the pigments and fillers in the coating. The three types of microcapsules in the coating had a large effect on the gloss when they were added individually or incombination.

Table 7. Color difference and chromaticity values of coatings under UV light irradiation.

Sample (#)	Type of Microcapsules	*L*	*a*	*b*	Δ*E*
1	-	48.5 ± 1.6	8.8 ± 0.4	25.3	0.17
2	Antibacterial microcapsules	49.0 ± 0.9	15.6 ± 0.6	35.1 ± 0.6	0.39
3	Photochromic microcapsules	33.4 ± 1.2	−4.5 ± 0.2	−10.7 ± 0.1	39.70
4	Self-repairing microcapsules	64.8 ± 0.4	5.6 ± 0.3	13.1 ± 0.2	0.87
5	Antibacterial microcapsules + Photochromic microcapsules	38.2 ± 1.3	−0.72	7.7 ± 0.4	33.28
6	Antibacterial microcapsules + Self-repairing microcapsules	62.0 ± 1.6	6.8 ± 0.3	34.4 ± 0.8	0.42
7	Photochromic microcapsules + Self-repairing microcapsules	43.2 ± 1.3	−4.7 ± 0.2	−11.9 ± 0.8	35.04
8	Antibacterial microcapsules + Photochromic microcapsules + Self-repairing microcapsules	45.2 ± 0.9	−7.8 ± 0.4	6.4 ± 0.5	36.11

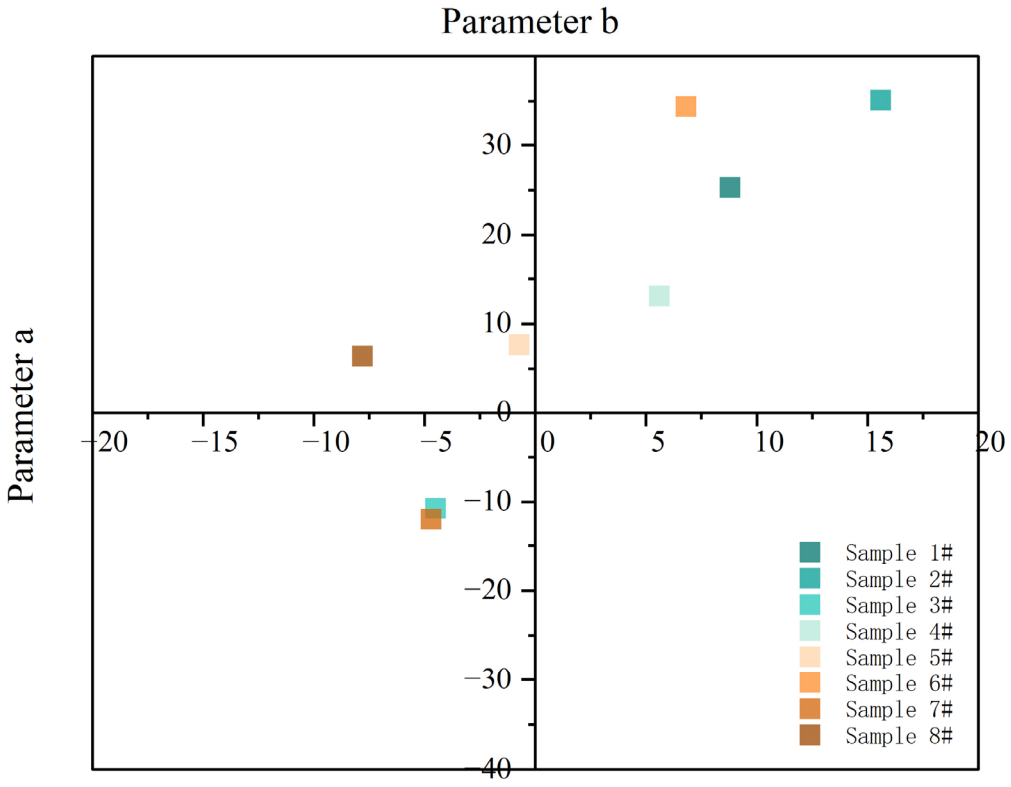


Figure 13. CIELAB color space map of the coatings after exposure to UV light.

Table 8. Significant difference analysis of photochromic effect.

Item	SS	d_f	MS	F	p_{value}	F_{crit}
Types of microcapsules	2267.708	7	323.9582	3.034748	0.083114	3.787044
Before and after exposure to UV light	731.7025	1	731.7025	6.854379	0.034505	5.591448
error	747.2475	7	106.7496	-	-	-
total	3746.658	15	-	-	-	-

Table 9. Gloss and gloss loss rate in water-based coatings for MDF with different microcapsules.

Sample (#)	Type of Microcapsules	Gloss at 20° (GU)	Gloss at 60° (GU)	Gloss at 85° (GU)	Gloss Loss Rate (%)
1	-	48.5 ± 1.9	77.7 ± 1.9	84.5 ± 0.6	-
2	Antibacterial microcapsules	1.4 ± 0.1	5.6 ± 0.5	2.7 ± 0.3	92.7
3	Photochromic microcapsules	5.4 ± 0.6	21.2 ± 0.2	37.2 ± 0.5	72.6
4	Self-repairing microcapsules	0.9 ± 0.2	2.8 ± 0.1	0.9 ± 0.1	96.3
5	Antibacterial microcapsules + Photochromic microcapsules	0.8 ± 0.1	3.4 ± 0.1	1.2 ± 0.2	95.5
6	Antibacterial microcapsules + Self-repairing microcapsules	0.7 ± 0.1	1.5 ± 0.1	0.4 ± 0.1	98.0
7	Photochromic microcapsules + Self-repairing microcapsules	1.0 ± 0.2	3.7	0.7 ± 0.1	95.1
8	Antibacterial microcapsules + Photochromic microcapsules + Self-repairing microcapsules	0.8 ± 0.1	1.8 ± 0.1	0.5 ± 0.1	97.7

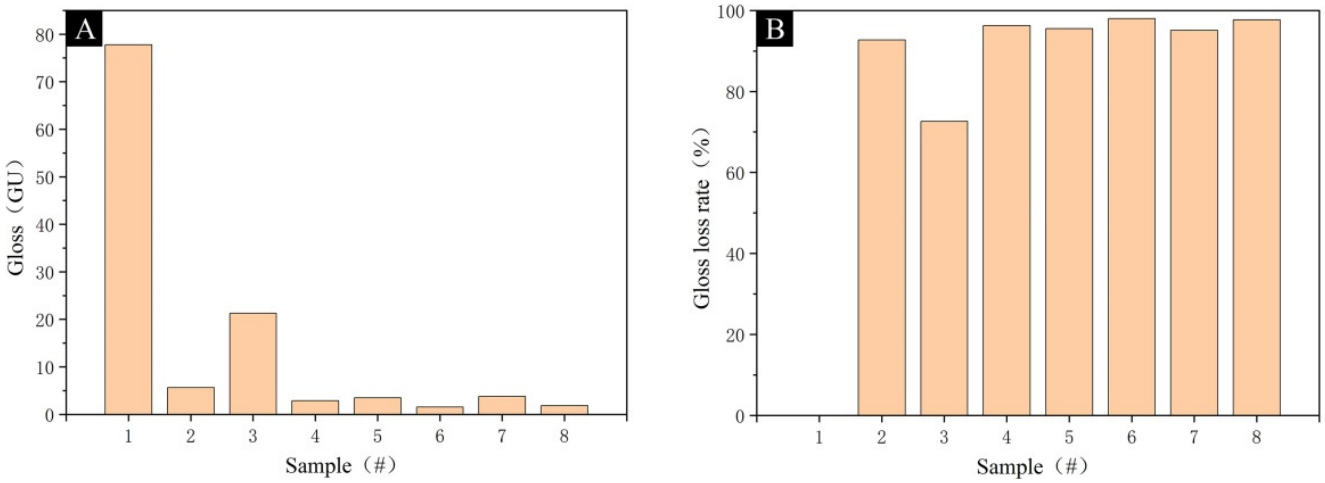


Figure 14. Effect of composite addition of different microcapsules on (**A**) gloss and (**B**) gloss loss rate at 60° of water-based coatings on MDF.

The addition of granular microcapsules makes the coating on the MDF uneven, thus exacerbating the diffuse reflection phenomenon on the surface and reducing the smoothness of the coating. Among them, the gloss of sample 3# with only photochromic microcapsules is relatively high because the photochromic microcapsules have small and average particle sizes and can be more evenly dispersed in the coating; the light loss rate is slightly lower than that of other groups. The particle size of antibacterial microcapsules and self-repairing microcapsules is relatively large, and the self-repairing microcapsules are seriously agglomerated, so the gloss of coatings added with these two types of microcapsules is very low.

Figure 15 shows the reflectance of water-based coatings with different microcapsule types on MDF in the visible light band. In the 400–500 nm band, the reflectivity of eight groups of samples is uneven, which is caused by the inconsistent content and color of microcapsules in the coating.

In general, the reflectivity of the coating with microcapsules was higher than that of sample 1# without microcapsules, which indicated that the addition of microcapsules improves the reflectivity of the water-based coatings to visible light. When the surface is exposed to light and generates heat, it can weaken the conduction of heat into the interior of the MDF, playing a protective role in the substrate.

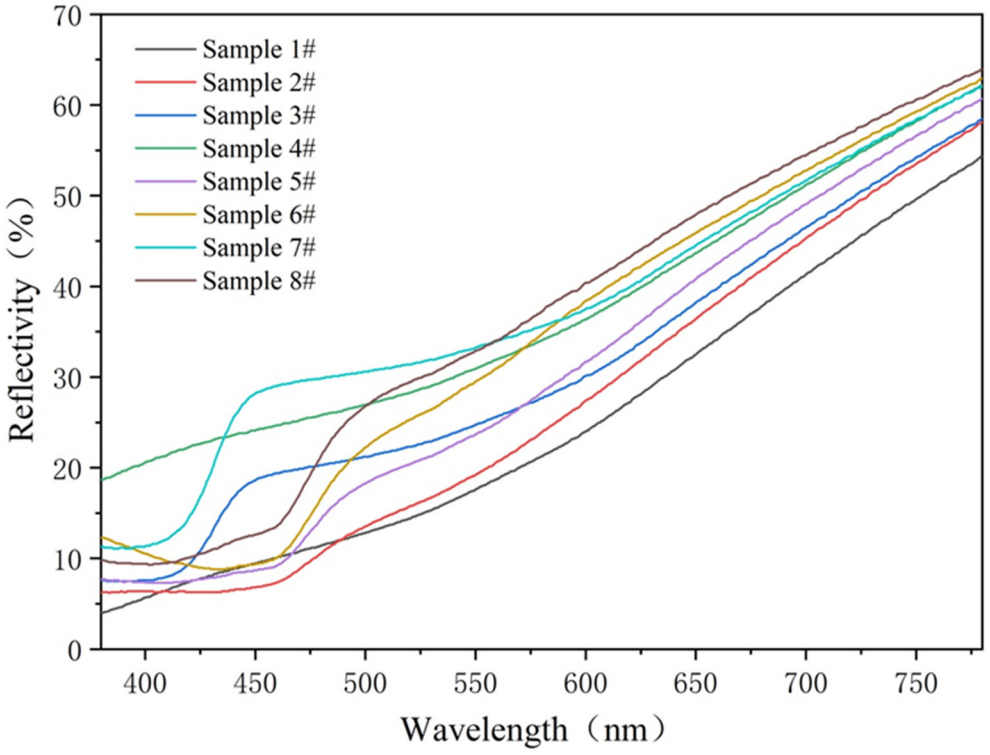


Figure 15. Effect of composite addition of different microcapsules on reflectivity.

3.6. Self-Repairing Performance Analysis of Water-Based Coatings on MDF

The change rate in the scratch width after self-repairing is shown in Table 10 and Figure 16 for coatings with and without self-repairing microcapsules. The water-based coatings that do not contain microcapsules have certain self-repairing properties that are determined by the nature of the water-based coatings. The coating with only self-repairing microcapsules had the largest change rate in the scratch width and the best self-repairing performance. When the scratch occurs, the wall material of self-repairing microcapsules at the edge of the scratch ruptures. Within one week, the core material shellac slowly flows out, playing the role of leveling and filling and making the scratch width smaller. The change rate in the the scratch width of the coating combined with antibacterial microcapsules and photochromic microcapsules decreased slightly. Because the presence of other microcapsule particles hinders the outflow and filling of shellac core material, the self-repairing performance decreases slightly.

Table 10. Change rate in the scratch width of water-based coatings on MDF with and without self-repairing microcapsules.

Sample (#)	Type of Microcapsules	Width of Scratch before Repair (μm)	Width of Scratches after One Week of Repair (μm)	Change Rate of Scratch Width (%)
1	-	97.3	90.6	6.9
4	Self-repairing microcapsules	54.2	42.3	21.9
6	Antibacterial microcapsules + Self-repairing microcapsules	33.2	28.3	14.7
7	Photochromic microcapsules + Self-repairing microcapsules	23.3	19.2	17.6
8	Antibacterial microcapsules + Photochromic microcapsules + Self-repairing microcapsules	59.1	52.4	11.3

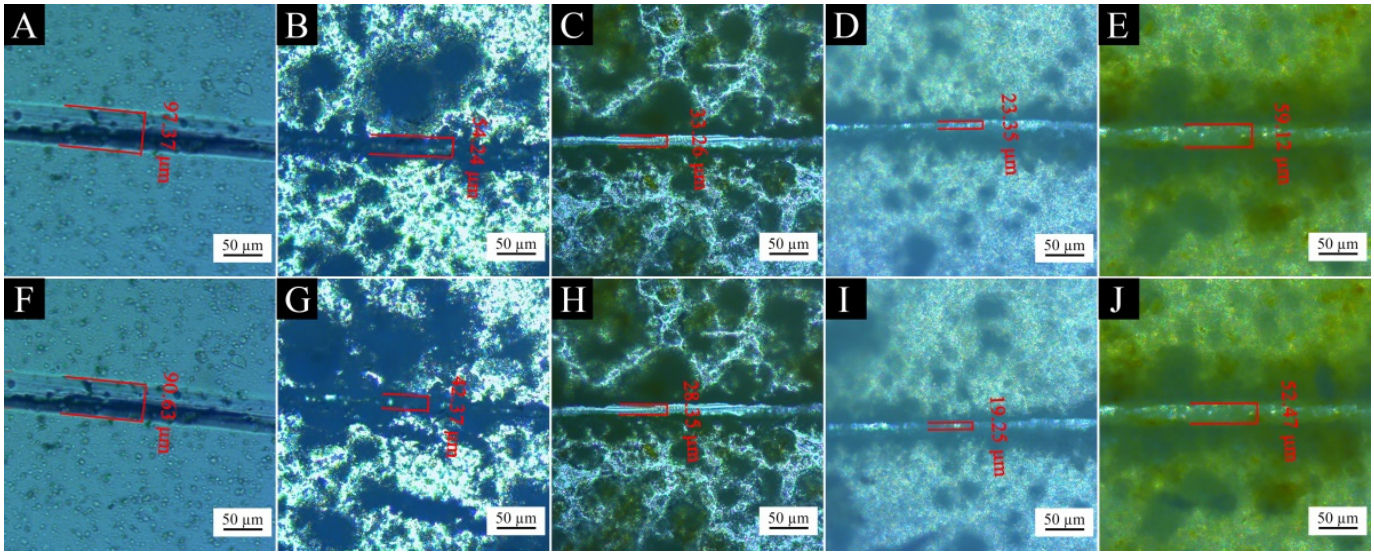


Figure 16. Coatings at the beginning of scratch formation: (**A**) 1#, (**B**) 4#, (**C**) 6#, (**D**) 7#, (**E**) 8#, and coatings after one week of self-repairing: (**F**) 1#, (**G**) 4#, (**H**) 6#, (**I**) 7#, (**J**) 8#.

When three types of microcapsules were added to the coating, the self-repairing performance of the coating was further affected, so the change rate in the scratch width was very low. However, compared with the coating without microcapsules, the self-repairing ability was still improved. Due to the uneven distribution of self-repairing microcapsules, the self-repairing properties on different substrate surfaces may be different, which can also lead to inconsistent results.

3.7. Analysis of Mechanical Properties of Water-Based Coatings on MDF

As shown in Table 11, the hardness of MDF without microcapsules and with photochromic microcapsules alone was lower, which was HB, while the hardness of other water-based coatings for MDF with microcapsules was increased, which was 3H. This may be because the particles of photochromic microcapsules are very small and uniform, while the particles of antibacterial microcapsules and self-repairing microcapsules are large, which has a good effect on improving the surface hardness of water-based coatings for MDF. In terms of adhesion, in the coating with one type of microcapsules, the adhesion with only self-repairing microcapsules was lower than that of the other two. This is because of the largest particles of the self-repairing microcapsules and their significant aggregation, which affects the adhesion of the coating on MDF. The adhesion of water-based coatings for MDF is reduced, resulting in lower adhesion. The coating with three kinds of microcapsules added at the same time had the lowest adhesion. Because the content of microcapsules is as high as 18.0%, resulting in a low proportion of coatings and adhesives, the adhesion decreases. In terms of impact resistance, it can be clearly seen that the impact resistance of sample 6# and sample 8# were significantly improved. When impacted by external forces, sample 6# and sample 8# can disperse some of the applied force, thereby improving the impact resistance of the coating. The particle size of antibacterial and self-repairing microcapsules is large, so the impact resistance effect is better, but this also leads to the coarser surface of the coating with antibacterial microcapsules and self-repairing microcapsules.

Sample 1# without microcapsules had lower mechanical properties compared to the other samples. The addition of photochromic microcapsules alone had almost no effect on the properties of the coating, which may be due to the small particle size and uniform distribution of the photochromic microcapsules so that when the photochromic microcapsules are added, they have less effect on the properties of the coating. In other practices, there may be variations in the mechanical properties of the coatings due to differences in the amount and number of coats required.

Table 11. Mechanical properties of water-based coatings for MDF with different microcapsules.

Sample (#)	Type of Microcapsules	Hardness	Adhesion (Grade)	Impact Resistance (kg·cm)	Roughness (μm)
1	-	HB	1	4	0.4 ± 0.1
2	Antibacterial microcapsules	3H	1	5	3.1 ± 0.2
3	Photochromic microcapsules	HB	1	4	0.5 ± 0.2
4	Self-repairing microcapsules	3H	2	5	7.7 ± 0.3
5	Antibacterial microcapsules + Photochromic microcapsules	3H	2	5	3.6 ± 0.1
6	Antibacterial microcapsules + Self-repairing microcapsules	3H	2	11	7.1 ± 0.2
7	Photochromic microcapsules + Self-repairing microcapsules	3H	3	5	4.6 ± 0.1
8	Antibacterial microcapsules + Photochromic microcapsules + Self-repairing microcapsules	3H	4	14	7.6 ± 0.1

At present, the water-based coatings with the composite addition of antibacterial, photochromic, and self-repairing microcapsules have the potential for application on the surface of most wood products. But, the research results in this study still have a certain gap for practical applications. When the antibacterial, photochromic, and self-repairing microcapsules were added at the same time, the antibacterial rates of water-based coatings were less than 20%, the color difference after photochromic was 36.11, and the width change rate in scratches after self-repairing was 11.3%. In practical applications, the antibacterial, photochromic, and self-repairing effects of water-based coatings need to be more significant, and the overall performance still needs to be improved. This is expected to increase the self-repairing rate to 80% and the antibacterial rate to 90% within the next 3–10 years.

4. Conclusions

When adding antibacterial microcapsules alone, the antibacterial rate in the coating against *Escherichia coli* was 62.7%, and the antibacterial rate against *Staphylococcus aureus* was 54.5%. The photochromic microcapsules had little effect on the antibacterial properties of the coating and could be combined with antibacterial microcapsules. Antibacterial rates were 55.6% and 51.9%, respectively. After adding self-repairing microcapsules, the antibacterial rates were reduced to 35.7% and 15.4%, respectively, which indicated that the addition of self-repairing microcapsules had a significant effect on the antibacterial properties of the coatings and was not suitable for use together with antibacterial microcapsules. The photochromic microcapsules added alone or in combination have a good, reversible photochromic effect. The coating with photochromic microcapsules began to change color significantly after 10 s of UV irradiation. When self-repairing microcapsules and photochromic microcapsules were combined, the photochromic speed was shortened to 5–10 s and the photochromic effect was more excellent. When antibacterial microcapsules and photochromic microcapsules were combined, the photochromic time was extended to 15 s and the photochromic effect was slightly weakened. On the basis of self-repairing microcapsules, the change rate in the scratch width of coatings with antibacterial or photochromic microcapsules decreased from 21.9% to 14.7% and 17.6%, respectively. The change rate in the scratch width of coatings with three kinds of microcapsules was 11.3%. Although the addition of antibacterial microcapsules and photochromic microcapsules weakened the self-repairing ability of self-repairing microcapsules, the self-repairing effect still existed. It was feasible to add photochromic, antibacterial, and self-repairing microcapsules to obtain coatings with antibacterial, photochromic, and self-repairing properties at the same time. The coatings with multiple functions have a broad application prospect in furniture. The results obtained from the study provide ideas for the study of furniture coatings that have multiple functions at the same time.

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