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Influence of the PVC of Glass Fiber Powder on the Properties of a Thermochromic Waterborne Coating for Chinese Fir Boards

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Abstract: A thermochromic waterborne coating with thermal insulation efficacy was prepared by adding thermochromic microcapsules and glass fiber powder. The influence of the pigment volume concentration (PVC) of a glass fiber powder on the performance of the thermochromic coating for Chinese fir boards was investigated. It was found that a coating with a PVC of glass fiber powder of 0–22.0% had better discoloration properties. When the PVC of the glass fiber powder was more than 4.0%, with the increase of the PVC, the gloss of the coating decreased gradually, while, the adhesion, impact resistance, and liquid resistance were not affected. When the PVC of the glass fiber powder was 10.0%–30.0%, it showed thermal insulation efficacy and high hardness. The coating with a PVC of 16.0% glass fiber powder had better wear resistance. The discoloration property of the coating with thermal insulation efficacy was not affected by time. These results exhibit great potential for the application of a wood surface thermochromic and thermal insulation coating.

Keywords: pigment volume concentration; glass fiber powder; coating performance

1. Introduction

The chroma of a reversible thermochromic coating changes with the change of temperature, and the chroma can be restored after temperature recovery [1]. It is widely used in many fields such as commodity packaging, building materials, chemical anti-counterfeiting, as well as geothermal floor and decorative panels [2–4]. A reversible thermochromic waterborne coating can be prepared by adding thermochromic microcapsules to a waterborne coating [5]. This kind of coating is not only pollution-free [6,7], but also better than an oil-based coating in terms of continuous stability [8], and can change in chroma with the change of temperature [9]. However, it is difficult to control the temperature because the process of waterborne coating with a thermochromic microcapsule is easily affected by the environment [10].

The glass fiber powder can be prepared by cutting and grinding the specially drawn glass fiber precursor [11]. It generally contains various oxides such as SiO_2, Na_2O, MgO, etc. [12]. Due to its advantages of high-temperature resistance [13], corrosion resistance, wear resistance, and moisture absorption, fiber glass powder is often used as a filling material to enhance shear strength [14], hardness, and compressive strength along with tribological properties [15]. It is also widely used in the fields of construction, automobile, aviation, and daily necessities. It is most commonly used as external wall insulation material for automobile parts and buildings [16].

Wang et al. [17] prepared polyvinyl chloride/glass fiber composite by powder impregnation technology and molding technology and optimized the processing conditions and formulation of the composite. The results illustrated that the best mechanical properties were obtained at 160 °C molding temperature, 6 MPa molding pressure, and 10 min dwelling time after the optimization of the processing conditions. Besides, the addition of heat stabilizers also improved the thermostability of the samples as well as delaying the composite degradation temperature. Fang et al. [18] used glass fiber or glass fiber powder as a mineral admixture to prepare a new inorganic fire retardant, magnesium phosphate cement (MPC) coating. The fire retardancy test results illustrated that the new MPC coating had outstanding fire retardancy, and the glass fiber and glass fiber powder played a crucial part in avoiding cracks in the MPC coating. These studies proved that glass fiber can improve the mechanical properties and heat insulation performance of composite materials. Currently, there has been little research on glass fiber potential in the field of waterborne coating based wood substrate.

In a previous study [19], the optimum concentration and coating process were studied. It was determined that when the mass fraction of thermochromic microcapsule was 5.0% and the thermochromic waterborne coating with the process of “two-layer primer, two-layer topcoat and thermochromic microcapsule added to the topcoat” had a better performance. On this basis, in this paper, glass fiber powder with different pigment volume concentrations (PVC) was added into the thermochromic waterborne coating to obtain a reversible thermochromic waterborne coating with thermal insulation efficacy. The optical properties, mechanical properties, and liquid resistance properties of the coating were tested. The influence of the PVC of the glass fiber powder on the temperature change under natural cooling and the influence of the time on the discoloration property of the coating with thermal insulation efficacy were studied. Additionally, through the analysis of its microstructure and components, the optimum PVC of the glass fiber powder was determined when the total performance of the coating was better. The findings will be helpful to the application of multi-functional intelligent materials in wood materials.

2. Materials and Methods

2.1. Experimental Materials

The main components of the thermochromic microcapsule were methyl red (as leuco agent, M_W: 269.30 g/mol, CAS No. 493-52-7), bisphenol A (as chromogenic reagent, M_W: 228.29 g/mol, CAS No. 80-05-7), tetradecanol (as co-solvent, M_W: 214.39 g/mol, CAS No.112-72-1), and melamine (M_W: 126.12 g/mol, CAS No. 108-78-1) provided by Huancai Discoloration Technology Co., Ltd., Shenzhen, China. Formaldehyde solution (37.0%, M_W: 30.03 g/mol, CAS No. 50-00-0), triethanolamine (M_W: 149.19 g/mol, CAS No. 102-71-6), sodium dodecyl benzene sulfonate (SDBS, M_W: 348.48 g/mol, CAS No. 25155-30-0), citric acid monohydrate (CAM, M_W: 210.14 g/mol, CAS No. 5949-29-1) and anhydrous ethanol (M_W: 46.07 g/mol, CAS No. 64-17-5) were provided by Chemical Reagent Co., Ltd., Nanjing, China. Waterborne wood coatings were provided by Yihua Living Science and Technology Co., Ltd., Shantou, China. The main components of the waterborne wood coatings were aqueous acrylic copolymer dispersion, matting agent, additives, and water. The solid concentration of the waterborne coating was higher than 30.0%. Chinese fir boards (100.0 mm × 100.0 mm × 12.0 mm, uniform material chroma, after general mechanical grinding) were provided by Yihua Living Science and Technology Co., Ltd., Shantou, China. Chinese fir boards have a radial sawn grain and were placed at room temperature and 50.0% ± 5.0% relative humidity for 7 days to reach the state of equilibrium moisture concentration. Glass fiber powder (fineness: 800 mesh) was provided by Fuhua Nano New Materials Co., Ltd., Guangzhou, China. The main components of glass fiber powder are SiO_2, CaO, Al_2O_3, B_2O_2, and FeO, etc. All reagents used in the experiment were not further treated.

2.2. Preparation of Microcapsules

The preparation of thermochromic microcapsule was in-situ polymerization. The 20.0 g melamine and 40.0 g 37% formaldehyde solution were mixed and stirred to dissolve into a milky white solution, then 40.0 mL of deionized water was added. The pH was adjusted to 8.0–8.5 by triethanolamine.

The solution was stirred for 1 h in a 70 °C constant temperature water bath at 700 rpm and a transparent prepolymer (a) was obtained.

The 4.0 g SDBS was completely dissolved in 396.0 g deionized water to obtain 1.0% SDBS aqueous solution. Then 4.0 g methyl red, 4.0 g bisphenol A, and 40.0 g tetradecanol were added into 1.0% SDBS aqueous solution and placed in a 60 °C water bath. The system was stirred for 45 min at 1200 rpm to obtain a stable emulsion (b).

The prepolymer (a) was dropped to the emulsion (b) and mixed evenly. The CAM was added into the mixture to adjust the pH value to 4.5–5.0. The whole system was reacted at 60 °C for 3 h and naturally cooled to room temperature. Then 24.0 g thermochromic microcapsules were obtained by rinsing with deionized water and anhydrous ethanol many times and dried in a freeze-drying machine for 120 h.

2.3. Preparation of Coatings

The composition of waterborne coating with thermochromic microcapsule and glass fiber powder is illustrated in Table 1. Sample 1# was a blank sample without glass fiber powder. The preparation of sample 2# was as follows. The waterborne primer was coated on the Chinese fir board by SZQ tetrahedral fabricator (Senyuan Electric Co., Ltd., Zibo, China). After drying for 30 min, the sample was moved to a 35 °C drying box and heated to constant mass, then it was taken out and naturally cooled to room temperature. Following this, the coating was rubbed gently using 800-grit sandpaper and wiped by a dry cloth to remove surface dust. After the above process was repeated twice, the coating process of the primer was completed. Then, 1.0 g glass fiber powder and 5.0 g thermochromic microcapsule were added into 94.0 g of waterborne topcoat and mixed uniformly. The topcoat coating process was also repeated twice as was that of the primer. The detailed preparation process of the other samples is the same as that of sample 2# except that the PVC of the glass fiber powder is different. The thickness of the obtained dried film is approximately 60 μm. The weight percent gain (WPG) of the coated wood was about 2.2%, basically no increase.

Table 1. The composition of waterborne coating with thermochromic microcapsule and glass fiber powder.

Sample (#)	PVC of Glass Fiber Powder (%)	Weight of Glass Fiber Powder (g)	Weight of Thermochromic Microcapsule (g)	Weight of Waterborne Topcoat (g)	Weight of Waterborne Primer (g)	Total weight of Waterborne Coating (g)
1	0	0	5.0	95.0	100.0	200.0
2	4.0	1.0	5.0	94.0	100.0	200.0
3	10.0	3.0	5.0	92.0	100.0	200.0
4	16.0	5.0	5.0	90.0	100.0	200.0
5	22.0	7.0	5.0	88.0	100.0	200.0
6	30.0	10.0	5.0	85.0	100.0	200.0

2.4. Testing and Characterization

Chroma values of coating from 18 to 40 °C were gauged with the SEGT-J Portable Colorimeter (Chugong Industry Co., Ltd., Shanghai, China). The temperature of the coating was gauged by a hand-held infrared thermometer (Jining Chenxiang Mining Equipment Co., Ltd., Shandong, China). Samples of coating were heated by an HHP1 heating plate (Shanghai Hengyue Medical Devices Co., Ltd., Shanghai, China). In the meantime, the temperature of coating was gauged using the hand-held infrared thermometer. The chroma value of the coating was measured with a colorimeter to determine the temperature dependence of the coating. L stands for lightness, a positive value means the chroma on the surface of the sample being gauged is brighter, and a negative value means the chroma on the surface is darker. a indicates a change of chroma from red to green, a positive value indicates the chroma is red, and a negative value indicates the chroma is green. b refers to a change of chroma from yellow to blue, a positive value indicates that the surface chroma of the gauged sample is yellow, and a negative value indicates blue. c is the chroma saturation. H is the chroma phase. L_0, a_0, and b_0 represent the chroma value of the coating at 18 °C. Meanwhile, L_1, a_1, and b_1 represent the chroma value of the coating at other temperatures. ΔL (brightness difference) = $L_0 - L_1$, Δa (red-green difference) = $a_0 - a_1$, Δb (yellow-blue difference) = $b_0 - b_1$. The color difference (ΔE) was calculated in accordance with Formula (1):

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

The 60° gloss of coatings was gauged by an HG268 gloss meter (3NH Technology Co., Ltd., Shenzhen, China). The coating adhesion was gauged with a QFH-HG600 coating grader (Yuanxiao Marine Equipment Co., Ltd., Guangzhou, China). The handle was held, the multi-edge cutter was perpendicular to the board, and the coating was cut at a speed of 20–50 mm/s under equalizing pressure. The operation was then repeated by rotating 90° to form a grid pattern. The tape was placed over the entire mesh and removed at a minimum angle. The coating damage was observed using a magnifying glass. The level (level 0, 1, 2, 3, 4, and 5) of the coating was determined according to the damage degree. Level 0 of the coating adhesion level indicated the coating adhesion was the best. The impact resistance was gauged with a QCJ-50 impactor (Maike Instrument Equipment Co., Ltd., Dongguan, China). In the impact test, the sample was placed horizontally on the iron plate, with one side of the coating upward, and a heavy hammer was fixed at a certain height of the sliding cylinder through the control equipment. When the control button was pressed, the heavy hammer fell freely on the punch. As the heavy hammer was lifted and the test panel was taken out, the deformation degree of the coating surface was observed with a magnifying glass, and the height of the heavy hammer falling on the test panel recorded. The impact resistance of the coating was indicated by the maximum height at which the fixed weight fell on the test plate without causing damage to the coating. According to GB/T 6739-86, the hardness of the coating was determined by an HRS-150 digital Rockwell hardness tester (Suzhou Nanguang Electronic Technology Co., Ltd., Jiangsu, China). According to GB/T 4893.8-2013 [20], the wear resistance of the coating was gauged with a BGD-523 coating abrasion tester (Tongde Venture Technology Co., Ltd., Beijing, China). The liquid resistance of the coating was tested by 15.0% NaCl solution (Qingdao Haishi Hainuo Co., Ltd., Qingdao, China), 70.0% medical ethanol (Qingdao Haishi Hainuo Co., Ltd., Qingdao, China), detergent (containing 25.0% fatty alcohol ethylene oxide and 75.0% water, Hutchison Whitecat Co., Ltd., Shanghai, China), and red ink (Fine Stationery Co., Ltd., Shanghai, China). After soaking in the test solution, the filter paper was removed by tweezers and placed on the coating. Samples were covered with a glass cover. After 24 h, the glass cover and filter paper were removed. The residual liquid on the coating surface was absorbed, and the imprint and discoloration were checked. In the test of the heat preservation effect of the coating, the coatings were heated to 40 °C by a heating plate, and then naturally cooled to 18 °C. In the meantime, the temperature was gauged using the hand-held infrared thermometer every 30 s and stopped at 18 °C. The thermal conductivity of the coated assembly was tested with a DRE-2C thermal conductivity tester (Xiangtan Instrument Co., Ltd., Hunan, China). The morphology of glass fiber powder and coatings was analyzed by a Quanta 200 environment scanning electron microscope (SEM) (FEI company, Hillsboro, OR, USA). The composition of glass fiber powder and coatings was analyzed by a vertex 80 V infrared spectrum analyzer (Germany Bruker Co., Ltd., Karlsruhe, Germany). All the experiments were repeated four times with an error of less than 5.0%.

3. Results and Discussion

3.1. Influence of the PVC of Glass Fiber Powder on Optical Properties

Many properties of the coating (mechanical, permeability, optical properties, etc.) will change dramatically at the critical pigment volume concentration (CPVC). PVC refers to the volume ratio of pigments and fillers in the dry film to the total volume of all non-volatile components in the dry film, which is of great significance to the performance of the paint film. Therefore, the PVC should be less than the CPVC. According to Formula (2) of CPVC:

$$CPVC(\%) = \frac{1}{1 + \sum \left[OA\frac{\rho \cdot V}{93.5}\right]} \times 100\% \quad (2)$$

where OA is the oil absorption of pigment (g/100g), ρ is the density of pigment (g/cm^3), V is the volume fraction of pigment (%). The CPVC of the glass fiber powder in this experiment was calculated as 87.0%. On this basis, according to Formula (3), a series of parameters of PVC were designed: 0, 4.0%, 10.0%, 16.0%, 22.0%, and 30.0%, so as to optimize the ratio and obtain the best pigment volume concentration of fiber glass powder [21].

$$PVC(\%) = \frac{\text{volume of pigments and fillers in dry film}}{\text{volume of pigments and fillers in dry film} + \text{volume of base material in dry film}} \times 100\% \quad (3)$$

The results of the previous experiments [19] showed that the best concentration of the thermochromic microcapsule was 5.0% and the best coating technology of the thermochromic microcapsule in the waterborne coating was "two-layer primer, two-layer topcoat and thermochromic microcapsule added in the topcoat". The coating with glass fiber powder of different PVC was heated from 18 to 40 °C, and the chroma change is illustrated in Table 2. At 18 °C, the *L* value of coating without glass fiber powder was 51.1, the *a* value was 64.0, the *b* value was 41.7, the *c* value was 76.4, and the *H* value was 33.1. It was observed from Figure 1 that the color difference of the coating with the 0–30.0% PVC of glass fiber powder had no obvious change at 18–30 °C. With the increase of temperature, the chroma of the coating with the PVC of glass fiber powder of 0–22.0% changed obviously at 34 °C, while the coating with the PVC of glass fiber powder of 30.0% just began to change chroma at 36 °C.

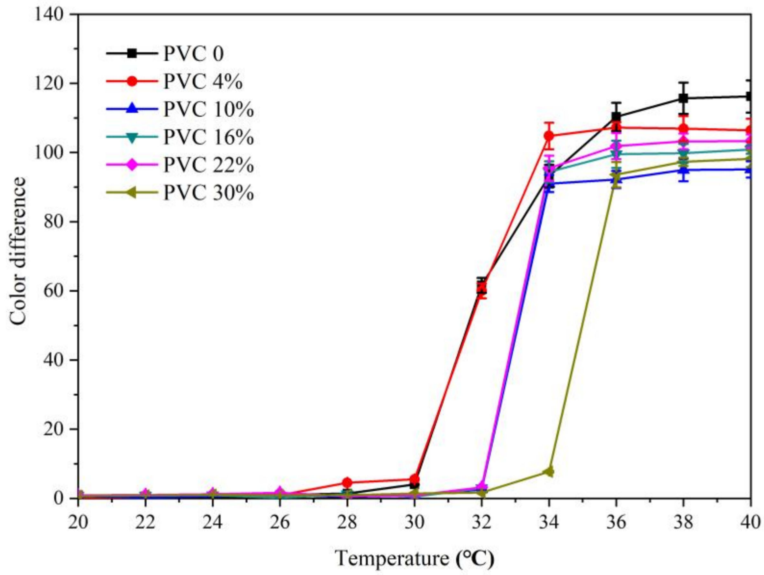

Figure 1. Influence of pigment volume concentration (PVC) of glass fiber powder on color difference of thermochromic waterborne coatings from 18 to 40 °C.

Table 2. Influence of pigment volume concentration (PVC) of glass fiber powder on the chroma change of the thermochromic waterborne coatings from 18 to 40 °C.

PVC of Glass Fiber (%)	Chroma Parameters	18 °C	20 °C	22 °C	24 °C	26 °C	28 °C	30 °C	32 °C	34 °C	36 °C	38 °C	40 °C
0	L	51.10 ± 1.69	51.30 ± 1.69	50.90 ± 1.69	51.00 ± 1.69	50.80 ± 1.69	50.90 ± 1.69	51.80 ± 1.69	77.40 ± 2.57	90.50 ± 3.29	95.90 ± 3.29	97.50 ± 3.29	98.10 ± 3.29
	a	64.00 ± 2.16	63.60 ± 2.16	63.50 ± 2.16	63.80 ± 2.16	63.10 ± 2.16	62.90 ± 2.16	60.30 ± 2.16	15.90 ± 0.29	−6.00 ± 0.08	−18.80 ± 0.29	−22.20 ± 0.50	−23.70 ± 0.50
	b	41.70 ± 1.31	42.50 ± 1.31	41.50 ± 1.31	41.70 ± 1.31	41.30 ± 1.31	42.50 ± 1.31	42.90 ± 1.31	69.70 ± 2.16	89.00 ± 2.16	99.10 ± 3.29	103.40 ± 3.15	101.70 ± 3.15
	c	76.40 ± 2.57	76.50 ± 2.57	75.80 ± 2.57	76.20 ± 2.57	75.50 ± 2.57	75.90 ± 2.57	74.10 ± 2.57	71.50 ± 2.57	89.20 ± 2.16	100.90 ± 3.15	105.70 ± 3.15	104.40 ± 3.15
	H	33.10 ± 0.83	33.70 ± 0.83	33.10 ± 0.83	33.10 ± 0.83	33.10 ± 0.83	34.00 ± 0.83	35.40 ± 0.83	77.10 ± 2.57	93.80 ± 3.29	100.70 ± 3.15	102.10 ± 3.15	103.10 ± 3.15
4.0	L	51.80 ± 1.69	51.80 ± 1.69	51.70 ± 1.69	51.90 ± 1.69	52.00 ± 1.69	53.80 ± 1.69	54.20 ± 1.69	78.60 ± 2.57	95.60 ± 3.29	96.40 ± 3.29	96.20 ± 3.29	95.90 ± 3.29
	a	60.20 ± 2.16	60.30 ± 2.16	60.00 ± 2.16	59.70 ± 1.69	59.70 ± 1.69	56.40 ± 1.69	55.40 ± 1.69	12.50 ± 0.29	−20.60 ± 0.50	−22.00 ± 0.50	−22.00 ± 0.50	−21.80 ± 0.50
	b	42.80 ± 1.31	42.90 ± 1.31	42.70 ± 1.31	42.20 ± 1.31	43.50 ± 1.31	44.20 ± 1.31	44.00 ± 1.31	67.50 ± 2.16	93.20 ± 3.29	95.30 ± 3.29	94.80 ± 3.29	94.40 ± 3.29
	c	73.90 ± 2.57	74.10 ± 2.57	73.70 ± 2.57	73.10 ± 2.57	73.90 ± 2.57	71.70 ± 2.57	70.80 ± 2.57	68.60 ± 2.16	95.50 ± 3.29	97.90 ± 3.29	97.30 ± 3.29	96.90 ± 3.29
	H	35.4 ± 0.83	35.4 ± 0.83	35.4 ± 0.83	35.2 ± 0.83	36.0 ± 0.83	38.0 ± 0.83	38.4 ± 0.83	79.40 ± 0.83	102.40 ± 3.15	102.90 ± 3.15	103.00 ± 3.15	103.00 ± 3.15
10.0	L	54.60 ± 1.69	54.40 ± 1.69	54.50 ± 1.69	54.50 ± 1.69	54.30 ± 1.69	54.30 ± 1.69	54.40 ± 1.69	55.60 ± 1.69	92.40 ± 3.29	93.20 ± 3.29	93.90 ± 3.29	94.30 ± 3.29
	a	56.30 ± 1.69	56.70 ± 1.69	56.10 ± 1.69	55.80 ± 1.69	56.50 ± 1.69	56.10 ± 1.69	55.60 ± 1.69	53.90 ± 1.69	−14.40 ± 0.45	−15.50 ± 0.45	−17.50 ± 0.45	−17.60 ± 0.45
	b	44.00 ± 1.31	43.40 ± 1.31	43.90 ± 1.31	43.70 ± 1.31	43.30 ± 1.31	44.40 ± 1.31	43.60 ± 1.31	43.90 ± 1.31	87.00 ± 2.16	87.00 ± 2.16	89.00 ± 2.16	88.80 ± 2.16
	c	71.40 ± 2.57	71.40 ± 2.57	71.30 ± 2.57	70.90 ± 2.57	71.30 ± 2.57	71.60 ± 2.57	70.70 ± 2.57	69.50 ± 2.16	88.20 ± 2.16	88.40 ± 2.16	90.70 ± 2.16	90.60 ± 2.16
	H	38.00 ± 0.83	37.40 ± 0.83	38.00 ± 0.83	38.10 ± 0.83	37.40 ± 0.83	38.30 ± 0.83	38.10 ± 0.83	39.10 ± 0.83	99.30 ± 3.29	100.00 ± 3.15	101.10 ± 3.15	101.20 ± 3.15
16.0	L	52.2 ± 1.69	51.9 ± 1.69	51.9 ± 1.69	52.0 ± 1.69	52.2 ± 1.69	52.2 ± 1.69	52.4 ± 1.69	53.8 ± 1.69	91.2 ± 3.29	93.2 ± 3.29	93.3 ± 3.29	93.6 ± 3.29
	a	56.00 ± 1.69	56.50 ± 1.69	56.30 ± 1.69	56.80 ± 1.69	56.20 ± 1.69	56.80 ± 1.69	55.90 ± 1.69	53.50 ± 1.69	−16.10 ± 0.45	−20.70 ± 0.45	−20.80 ± 0.45	−21.40 ± 0.45
	b	41.10 ± 1.31	40.50 ± 1.31	40.40 ± 1.31	40.70 ± 1.31	41.20 ± 1.31	40.20 ± 1.31	40.70 ± 1.31	41.50 ± 1.31	87.90 ± 2.16	89.50 ± 2.16	89.80 ± 2.16	90.80 ± 3.29
	c	69.50 ± 2.16	69.50 ± 2.16	69.30 ± 2.16	69.90 ± 2.16	69.70 ± 2.16	69.60 ± 2.16	69.20 ± 2.16	67.70 ± 2.16	89.30 ± 2.16	91.90 ± 3.29	92.20 ± 3.29	93.30 ± 3.29
	H	36.20 ± 0.83	35.60 ± 0.83	35.60 ± 0.83	35.60 ± 0.83	36.20 ± 0.83	35.30 ± 0.83	36.00 ± 0.83	37.70 ± 0.83	100.40 ± 3.15	103.00 ± 3.15	103.00 ± 3.15	103.20 ± 3.15
22.0	L	54.10 ± 1.69	53.80 ± 1.69	53.70 ± 1.69	53.20 ± 1.69	53.50 ± 1.69	53.80 ± 1.69	53.90 ± 1.69	55.10 ± 1.69	93.90 ± 3.29	96.30 ± 3.29	96.60 ± 3.29	96.80 ± 3.29
	a	57.90 ± 1.69	57.80 ± 1.69	57.60 ± 1.69	58.70 ± 1.69	58.10 ± 1.69	57.40 ± 1.69	57.20 ± 1.69	55.00 ± 1.69	16.50 ± 0.45	−21.30 ± 0.45	−22.40 ± 0.45	−22.50 ± 0.45
	b	43.60 ± 1.31	42.80 ± 1.31	42.70 ± 1.31	43.30 ± 1.31	42.10 ± 1.31	43.80 ± 1.31	43.30 ± 1.31	44.50 ± 1.31	88.30 ± 2.16	91.90 ± 3.29	92.60 ± 3.29	92.50 ± 3.29
	c	72.50 ± 2.57	72.00 ± 2.57	71.80 ± 2.57	73.00 ± 2.57	71.80 ± 2.57	72.30 ± 2.57	71.70 ± 2.57	70.80 ± 2.57	89.90 ± 2.16	94.30 ± 3.29	95.30 ± 3.29	95.20 ± 3.29
	H	37.00 ± 0.83	36.50 ± 0.83	36.50 ± 0.83	36.40 ± 0.83	35.90 ± 0.83	37.30 ± 0.83	37.10 ± 0.83	38.90 ± 0.83	100.50 ± 3.15	103.00 ± 3.15	103.60 ± 3.15	103.60 ± 3.15
30.0	L	53.70 ± 1.69	54.10 ± 1.69	53.90 ± 1.69	54.00 ± 1.66	53.80 ± 1.69	53.80 ± 1.69	53.60 ± 1.69	54.40 ± 1.69	57.20 ± 1.66	92.70 ± 3.29	93.90 ± 3.29	94.40 ± 3.29
	a	55.20 ± 1.69	54.60 ± 1.69	54.60 ± 1.69	54.20 ± 1.69	54.60 ± 1.69	54.40 ± 1.69	54.10 ± 1.69	53.60 ± 1.66	48.60 ± 1.31	−17.40 ± 0.45	−20.40 ± 0.45	−21.10 ± 0.45
	b	41.90 ± 1.31	42.00 ± 1.31	42.40 ± 1.31	41.80 ± 1.31	41.20 ± 1.31	42.30 ± 1.31	41.00 ± 1.31	41.90 ± 1.31	43.80 ± 1.31	86.30 ± 2.16	88.10 ± 2.16	88.40 ± 2.16
	c	69.30 ± 2.16	68.90 ± 2.16	69.10 ± 2.16	68.50 ± 2.16	68.50 ± 2.16	68.90 ± 2.16	67.90 ± 2.16	68.00 ± 2.16	65.50 ± 2.16	88.10 ± 2.16	90.50 ± 3.29	90.90 ± 3.29
	H	37.20 ± 0.83	37.50 ± 0.83	37.80 ± 0.83	37.60 ± 0.83	37.00 ± 0.83	37.80 ± 0.83	37.10 ± 0.83	38.00 ± 0.83	42.00 ± 1.31	101.40 ± 3.15	103.00 ± 3.15	103.40 ± 3.15

The coating was irradiated at different incident angles (20°, 60°, and 85°), and the influence of different PVC of glass fiber powder on the coating gloss was observed. From Table 3, it is clear that the gloss increased with increasing incident angle. At the same incident angle, when the PVC was 4.0%, the gloss was the highest, and the gloss of the coating without glass fiber powder was lower. When the PVC was greater than 4.0%, the gloss decreased gradually with the increase of PVC. The glass fiber powder had a high gloss and could improve the gloss of the coating. However, after the coating reaching a certain PVC, the number of particles increased and the roughness of the coating was improved. The coating surface was more prone to cause reflection. Thus, the gloss of the coating was reduced at this time [22]. The results illustrated that when the PVC was 4.0%–16.0%, the gloss of the coating was good.

Table 3. Influence of PVC of glass fiber powder on gloss of thermochromic waterborne coating.

PVC of Glass Fiber Powder (%)	20° Gloss (%)	60° Gloss (%)	85° Gloss (%)
0	2.80 ± 0.09	14.20 ± 0.45	31.00 ± 0.83
4.0	3.20 ± 0.10	16.00 ± 0.45	36.00 ± 0.83
10.0	2.70 ± 0.09	13.40 ± 0.45	26.10 ± 0.45
16.0	2.20 ± 0.09	10.60 ± 0.45	22.30 ± 0.45
22.0	2.10 ± 0.09	9.70 ± 0.22	17.90 ± 0.45
30.0	1.90 ± 0.06	8.40 ± 0.22	12.70 ± 0.45

3.2. Influence of PVC of Glass fiber Powder on Mechanical Properties

When the PVC of the glass fiber powder was 0–30.0%, the adhesion level of coating was level 0, which meant that the adhesion was good. At the same time, the impact resistance was 7.0 kg·cm. Therefore, the PVC of the glass fiber powder has no influence on adhesion and impact resistance of the coating. The influence of the PVC of glass fiber powder on the hardness of the coating is illustrated in Table 4. When the PVC was 0–4.0%, the hardness was 116 $N \cdot mm^{-2}$. When the PVC increased to 10.0%–30.0%, the hardness of the coating increased to 118 $N \cdot mm^{-2}$ and remained unchanged. The influence of the PVC of the glass fiber powder on the wear resistance is illustrated in Table 5. The wear resistance grade [20] of the furniture surface coating is shown in Table 6. The results illustrated that the wear resistance increased with the increase of the PVC. When the PVC increased to 16.0%, the weightlessness rate of the coating decreased, and the wear resistance increased to level 2. However, with the continuous increase of PVC, the wear resistance of the coating began to decrease again. When the PVC of the glass fiber powder was 16.0%, the coating performance was better.

Table 4. Influence of the PVC of glass fiber powder on the hardness of the thermochromic waterborne coating.

PVC of Glass Fiber Powder (%)	Hardness ($N \cdot mm^{-2}$)
0	116.00 ± 3.27
4.0	116.00 ± 1.41
10.0	118.00 ± 1.63
16.0	118.00 ± 1.63
22.0	118.00 ± 3.56
30.0	118.00 ± 1.63

Table 5. Influence of the PVC of glass fiber powder on wear resistance of the thermochromic waterborne coating.

PVC of Glass Fiber Powder (%)	Weightlessness Rate (%)	Level of Wear Resistance (Level)
0	0.344 ± 0.012	4 ± 0
4.0	0.345 ± 0.012	4 ± 0
10.0	0.328 ± 0.012	3 ± 0
16.0	0.145 ± 0.005	2 ± 0
22.0	0.217 ± 0.007	3 ± 0
30.0	0.250 ± 0.007	3 ± 0

Table 6. Wear resistance grade of furniture surface coating.

Level of Wear Resistance (level)	Instruction
1	The paint film is not white
2	The paint film is slightly white
3	The paint film is obviously white
4	The paint film is very white

3.3. Influence of PVC of Glass Fiber Powder on Liquid Resistance

The liquid resistance experiments of NaCl solution, detergent, ethanol, and red ink were carried out for the coating with the PVC of glass fiber powder of 0–30.0%. The temperature was controlled at 18 °C, and the values of *L*, *a*, *b*, *c* and *H* were gauged before and 24 h after the test, respectively. Table 7 illustrates that after the test of the four kinds of liquid resistance solutions, the chroma value of red ink liquid resistance changed most obviously. The calculated data of color difference is illustrated in Table 8. The lower the liquid resistance level of the coating, the better the performance of the coating. Table 9 illustrates the relationship between the liquid resistance level and the PVC of glass fiber powder for thermochromic waterborne coatings. From Tables 8 and 9, it can be seen that the coating with the PVC of glass fiber powder of 0–30.0% had a liquid resistance level 1 to NaCl solution, detergent, ethanol, and there was no mark on the surface of the coating. When the PVC of glass fiber powder was 0–30.0%, the liquid resistance of the coating to red ink was level 3, and the coating surface was obviously marked. Therefore, the PVC of glass fiber powder had no influence on the liquid resistance of the coating.

3.4. Influence of the PVC of Glass Fiber Powder on Temperature Change under Natural Cooling

The cooling time of the coating with the PVC of glass fiber powder of 10.0%–30.0% was longer than that without glass fiber powder (Figure 2). The temperature change of the coating with PVC of glass fiber powder of 4.0% was close to that of the film without glass fiber powder. When the PVC of glass fiber powder was 10.0%–30.0%, the coating had a heat preservation effect. When 4.0% PVC of glass fiber powder was added, the heat preservation effect was not obvious. This phenomenon is due to the fact that the PVC of glass fiber powder in this experiment was relatively low, which avoided the thermal bridge effect caused by the contact between fibers, so it had a certain thermal insulation efficacy [23]. The glass fiber powder reduced the thermal conductivity of the coating assembly (Figure 3), the thermal conductivity became poor, so the thermal insulation effect became better. When the waterborne coating with the thermochromic microcapsule was added with the glass fiber powder, it could be used as a thermochromic energy-saving coating in related fields, with the purpose of achieving environmental protection [24,25].

Table 7. Influence of the PVC of glass fiber powder on liquid resistance of the thermochromic waterborne coatings.

PVC of Glass Fiber Powder (%)	Chroma Parameters	Before the Test	After the Test (NaCl Solution)	After the Test (Detergent)	After the Test (Ethanol)	After the Test (Red Ink)
0	L	51.10 ± 1.69	50.90 ± 1.69	50.40 ± 1.69	50.00 ± 1.69	53.50 ± 1.69
	a	64.00 ± 2.16	62.20 ± 2.16	62.70 ± 2.16	63.30 ± 2.16	66.40 ± 2.16
	b	41.70 ± 1.31	41.50 ± 1.31	41.20 ± 1.31	41.40 ± 1.31	40.90 ± 1.31
	c	76.40 ± 2.57	74.10 ± 2.57	74.60 ± 2.57	75.70 ± 2.57	77.20 ± 2.57
	H	33.10 ± 0.83	34.40 ± 0.83	33.50 ± 0.83	33.10 ± 0.83	32.00 ± 0.83
4.0	L	51.80 ± 1.69	52.00 ± 1.69	52.10 ± 1.69	52.10 ± 1.66	44.10 ± 1.31
	a	60.20 ± 2.16	60.50 ± 2.16	59.60 ± 1.69	60.90 ± 2.16	68.00 ± 2.16
	b	42.80 ± 1.31	41.30 ± 1.31	42.00 ± 1.31	41.40 ± 1.31	34.00 ± 0.83
	c	73.90 ± 2.57	73.30 ± 2.57	73.10 ± 2.57	73.70 ± 2.57	76.10 ± 2.57
	H	35.40 ± 0.83	34.30 ± 0.83	34.60 ± 0.83	34.20 ± 0.83	26.50 ± 0.41
10.0	L	54.60 ± 1.69	54.00 ± 1.69	54.30 ± 1.66	53.70 ± 1.69	45.90 ± 1.31
	a	56.30 ± 1.69	56.50 ± 1.69	56.40 ± 1.69	56.60 ± 1.69	63.60 ± 2.16
	b	44.00 ± 1.31	42.80 ± 1.31	43.20 ± 1.31	43.80 ± 1.31	32.90 ± 0.83
	c	71.40 ± 2.57	70.70 ± 2.57	71.10 ± 2.57	70.30 ± 2.57	71.60 ± 2.57
	H	38.00 ± 0.83	36.90 ± 0.83	37.50 ± 0.83	36.80 ± 0.83	27.30 ± 0.41
16.0	L	52.20 ± 1.69	52.50 ± 1.69	53.10 ± 1.69	52.90 ± 1.69	44.80 ± 1.31
	a	56.00 ± 1.69	55.40 ± 1.66	56.50 ± 1.69	56.90 ± 1.69	65.80 ± 2.16
	b	41.10 ± 1.31	41.60 ± 1.31	40.90 ± 1.31	40.40 ± 1.31	31.30 ± 0.83
	c	69.50 ± 2.16	69.30 ± 2.16	69.80 ± 2.16	69.80 ± 2.16	72.90 ± 2.57
	H	36.20 ± 0.83	36.80 ± 0.83	35.90 ± 0.83	35.30 ± 0.83	25.40 ± 0.41
22.0	L	54.10 ± 1.69	54.80 ± 1.69	54.10 ± 1.69	53.40 ± 1.69	46.30 ± 1.31
	a	57.90 ± 1.69	57.20 ± 1.69	58.30 ± 1.66	57.40 ± 1.69	67.60 ± 2.16
	b	43.60 ± 1.31	43.10 ± 1.31	42.600 ± 1.31	42.70 ± 1.31	34.60 ± 0.83
	c	72.50 ± 2.57	70.70 ± 2.57	72.2 ± 2.57	71.80 ± 2.57	76.00 ± 2.57
	H	37.00 ± 0.83	37.80 ± 0.83	36.10 ± 0.83	36.80 ± 0.83	27.00 ± 0.83
30.0	L	53.70 ± 1.69	53.10 ± 1.69	54.60 ± 1.69	53.70 ± 1.69	46.20 ± 1.31
	a	55.20 ± 1.69	55.90 ± 1.66	55.20 ± 1.66	55.10 ± 1.69	66.00 ± 2.16
	b	41.90 ± 1.31	41.30 ± 1.31	42.20 ± 1.31	40.10 ± 1.31	33.30 ± 0.83
	c	69.30 ± 2.16	69.80 ± 2.16	69.50 ± 2.16	68.60 ± 2.16	74.00 ± 2.57
	H	37.20 ± 0.83	36.30 ± 0.83	37.40 ± 0.83	36.30 ± 0.83	26.70 ± 0.41

Table 8. Influence of the PVC of glass fiber powder on color difference of thermochromic waterborne coating before and after liquid resistance.

PVC of Glass Fiber Powder (%)	After the Test (NaCl Solution)	After the Test (Detergent)	After the Test (Ethanol)	After the Test (Red Ink)
0	1.80 ± 0.02	1.60 ± 0.04	1.30 ± 0.03	3.50 ± 0.08
4.0	1.50 ± 0.05	1.00 ± 0.01	1.60 ± 0.04	14.10 ± 0.50
10.0	1.40 ± 0.05	0.90 ± 0.03	1.00 ± 0.01	15.90 ± 0.22
16.0	0.80 ± 0.02	1.00 ± 0.01	1.30 ± 0.03	15.70 ± 0.57
22.0	1.10 ± 0.01	1.10 ± 0.01	1.20 ± 0.04	15.40 ± 0.43
30.0	1.10 ± 0.05	0.90 ± 0.02	1.80 ± 0.06	15.70 ± 0.45

Table 9. Influence of the PVC of glass fiber powder on liquid resistance level of thermochromic waterborne coating.

PVC of Glass Fiber Powder (%)	NaCl Solution	Detergent	Ethanol	Red Ink
0	1 ± 0	1 ± 0	1 ± 0	3 ± 0
4.0	1 ± 0	1 ± 0	1 ± 0	3 ± 0
10.0	1 ± 0	1 ± 0	1 ± 0	3 ± 0
16.0	1 ± 0	1 ± 0	1 ± 0	3 ± 0
22.0	1 ± 0	1 ± 0	1 ± 0	3 ± 0
30.0	1 ± 0	1 ± 0	1 ± 0	3 ± 0

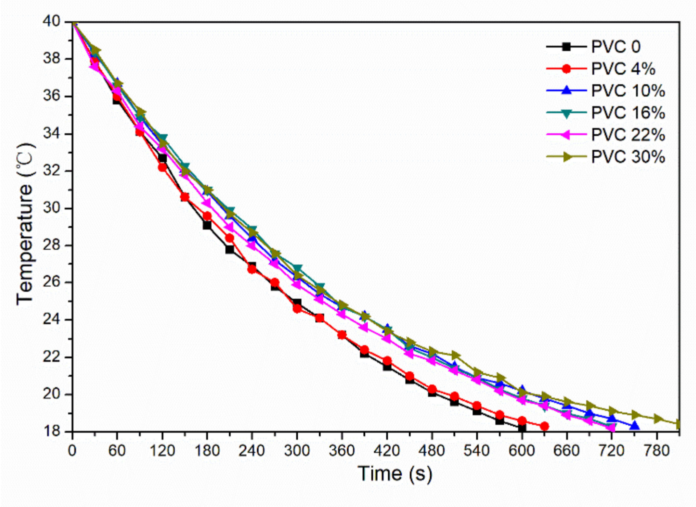

Figure 2. Influence of the PVC of glass fiber powder on temperature change of the thermochromic waterborne coating under natural cooling.

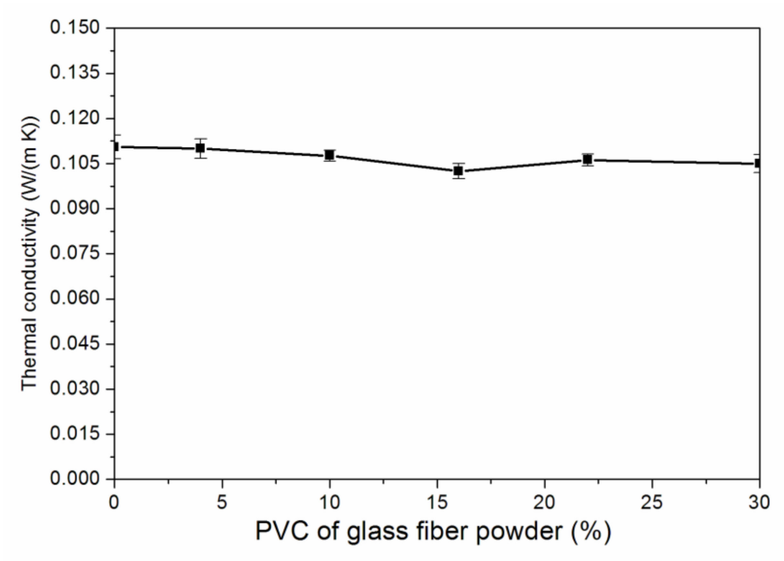

Figure 3. Thermal conductivity of the coated assembly with different PVC of glass fiber powder.

3.5. Influence of Time on Discoloration of the Waterborne Coating with Thermal Insulation Efficacy

The color values of the coating after three months at room temperature and three days of baking in a 30 °C oven were measured. As shown in Table 10, the chroma value of the coating containing 10.0%–30.0% PVC of glass fiber powder after three months is basically unchanged. It is clear from Table 11 that after three months, the color difference of the coating with 10.0%–30.0% PVC of glass fiber powder at 18 °C and the color difference range at 30 °C for three consecutive days is 0.9–1.8, without obvious discoloration, which illustrates that the time has no influence on the discoloration property of the coating with thermal insulation efficacy after glass fiber powder was added.

Table 10. Influence of time on chroma change of the waterborne coatings with thermal insulation efficacy.

PVC of Glass Fiber Powder (%)	Chromaticity Parameters	18 °C	18 °C after 3 Months	30 °C	The First Day at 30 °C after 3 Months	The Second Day at 30 °C after 3 Months	The Third Day at 30 °C after 3 Months
10.0	L	54.60 ± 1.69	54.20 ± 1.69	54.40 ± 1.69	53.60 ± 1.69	55.20 ± 1.66	53.50 ± 1.69
	a	56.30 ± 1.69	56.60 ± 1.69	55.60 ± 1.66	55.70 ± 1.69	54.70 ± 1.69	54.60 ± 1.69
	b	44.00 ± 1.31	43.20 ± 1.31	43.60 ± 1.31	42.40 ± 1.31	42.60 ± 1.31	43.10 ± 1.31
	c	71.40 ± 2.57	70.60 ± 2.57	70.70 ± 2.57	69.60 ± 2.16	69.90 ± 2.16	70.20 ± 2.57
	H	38.00 ± 0.83	36.60 ± 0.83	38.10 ± 0.83	36.80 ± 0.83	39.10 ± 0.83	39.70 ± 0.83
16.0	L	52.20 ± 1.69	52.20 ± 1.69	52.40 ± 1.69	53.00 ± 1.69	52.30 ± 1.69	53.40 ± 1.69
	a	56.00 ± 1.69	55.40 ± 1.69	55.90 ± 1.69	54.80 ± 1.69	55.20 ± 1.69	55.30 ± 1.69
	b	41.10 ± 1.31	39.80 ± 0.83	40.70 ± 1.31	40.80 ± 1.31	39.90 ± 0.83	41.50 ± 1.31
	c	69.50 ± 2.16	67.90 ± 2.16	69.20 ± 2.16	68.30 ± 2.16	68.70 ± 2.16	68.20 ± 2.16
	H	36.20 ± 0.83	35.70 ± 0.83	36.00 ± 0.83	36.80 ± 0.83	35.80 ± 0.83	36.50 ± 0.83
22.0	L	54.10 ± 1.69	54.90 ± 1.69	53.90 ± 1.69	52.70 ± 1.69	54.70 ± 1.69	54.20 ± 1.69
	a	57.90 ± 1.69	56.70 ± 1.69	57.20 ± 1.69	56.50 ± 1.69	56.80 ± 1.69	56.10 ± 1.69
	b	43.60 ± 1.31	42.90 ± 1.31	43.30 ± 1.31	42.70 ± 1.31	42.40 ± 1.31	42.70 ± 1.31
	c	72.50 ± 2.57	72.00 ± 2.57	71.70 ± 2.57	71.10 ± 2.57	70.30 ± 2.57	70.50 ± 2.57
	H	37.00 ± 0.83	36.60 ± 0.83	37.10 ± 0.83	38.40 ± 0.83	38.30 ± 0.83	37.70 ± 0.83
30.0	L	53.70 ± 1.69	55.20 ± 1.69	53.60 ± 1.69	54.60 ± 1.69	54.30 ± 1.69	54.10 ± 1.69
	a	55.20 ± 1.69	55.50 ± 1.69	54.10 ± 1.69	54.00 ± 1.69	53.30 ± 1.69	53.00 ± 1.69
	b	41.90 ± 1.31	40.90 ± 1.31	41.00 ± 1.31	41.40 ± 1.31	40.10 ± 1.31	41.20 ± 1.31
	c	69.30 ± 2.16	69.00 ± 2.16	67.90 ± 2.16	66.70 ± 2.16	67.30 ± 2.16	67.20 ± 2.16
	H	37.20 ± 0.83	36.30 ± 0.83	37.10 ± 0.83	38.00 ± 0.83	38.20 ± 0.83	38.20 ± 0.83

Table 11. Influence of time on color difference of the waterborne coatings with thermal insulation efficacy.

PVC of Glass Fiber Powder (%)	18 °C after 3 Months	The First Day at 30 °C after 3 Months	The Second Day at 30 °C after 3 Months	The Third Day at 30 °C after 3 Months
10.0	0.90 ± 0.03	1.40 ± 0.04	1.60 ± 0.06	1.40 ± 0.04
16.0	1.40 ± 0.04	1.30 ± 0.03	1.10 ± 0.01	1.40 ± 0.03
22.0	1.60 ± 0.06	1.50 ± 0.05	1.30 ± 0.03	1.30 ± 0.03
30.0	1.80 ± 0.02	1.10 ± 0.01	1.40 ± 0.03	1.20 ± 0.05

3.6. Microstructure and Infrared Spectrum Analysis

It can be observed from Figure 4 that the glass fiber powder has a columnar structure. The coating with different PVC of glass fiber powder contains particles, and the particles are distributed uniformly without agglomerate phenomenon. The coating with the PVC of 4.0% of glass fiber powder has less particles, and the columnar fibers are not protruding. When the PVC of the glass fiber powder was 16.0%, the particles are obvious, and columnar fibers can be seen. The coating with the PVC of 30.0% of glass fiber powder has more particles, and from which part of the columnar fiber there appeared protrusions. Therefore, with the PVC increasing, the number of particles increased, which also was the primary cause for the decrease of gloss [22]. When the PVC of the glass fiber powder is 16.0%, the microstructure of the coating is the best. The cross-sectional SEM micrographs of the pure coating and the coatings with different PVCs of glass fiber powder are shown in Figure 5. The cross-sectional SEM showed that 16.0% PVC of fiber glass powder was evenly distributed in the coating and not impregnated in the wood structure.

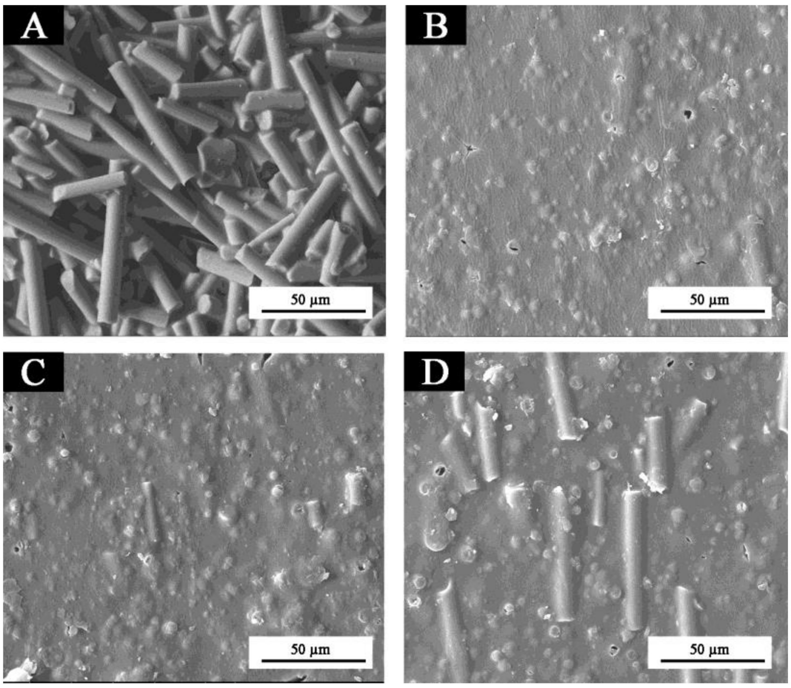

Figure 4. SEM of the waterborne coatings with thermochromic microcapsule and different PVC of glass fiber powder. (**A**) glass fiber powder, (**B**–**D**) thermochromic waterborne coating with the PVC of glass fiber powder of 4.0%, 16.0%, and 30.0%.

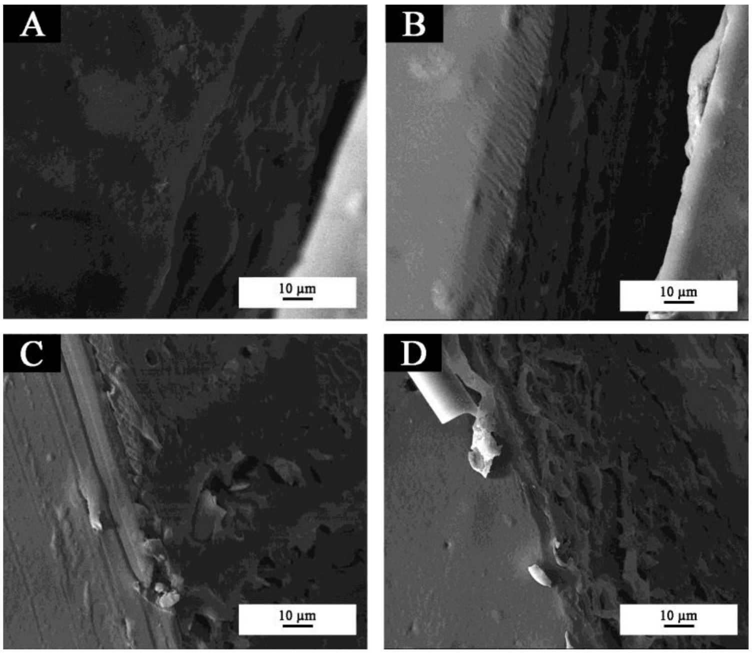

Figure 5. Cross-sectional SEM micrographs. (**A**–**D**) thermochromic waterborne coating with the PVC of glass fiber powder of 0, 4.0%, 16.0%, and 30.0%.

From Figure 6, 3430 cm^{-1} was the –OH absorption peak of pure glass fiber powder. When the glass fiber powder was added into the waterborne coating, the –OH peak gradually weakened with the increase of the PVC of the glass fiber powder, indicating that a dehydration reaction took place between the waterborne coating and the glass fiber powder, which may have been caused by the reaction between a large number of oxygenates in the glass fiber powder and water [26]. The absorption peaks of $–CH_2$ were 2919 cm^{-1}, 2850 $cm^{-1,}$ and 1446 cm^{-1}. At 1730 cm^{-1} there was a strong and sharp characteristic peak of C=O, which belonged to the absorption of waterborne acrylic resin, the main component of the waterborne coating. Under the infrared spectrum test, with the change of the PVC of the glass fiber powder, no peak disappeared or appeared. When the color of the coating changes, the infrared spectrum does not change (Figure 6), which indicated that there was no difference in the composition of the coating before and after color changing.

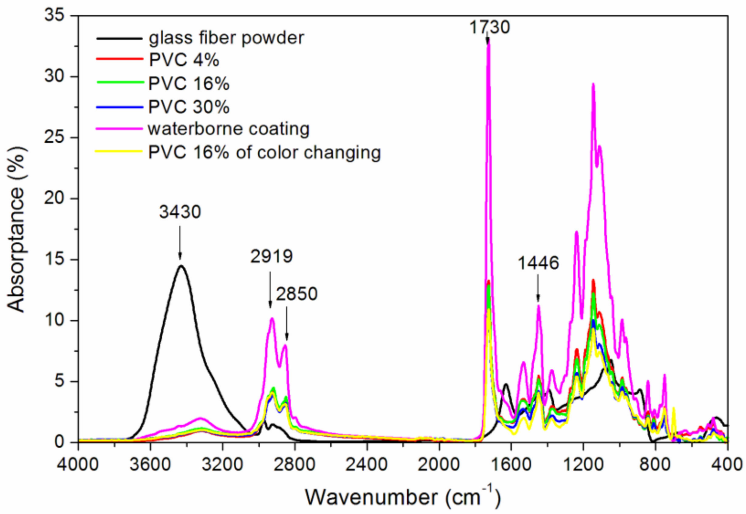

Figure 6. FT-IR of the thermochromic waterborne coating with different PVC of glass fiber powder.

4. Conclusions

In this paper, the influence of glass fiber powder with different PVC on the properties of thermochromic waterborne coating was studied. A suitable discoloration property appeared in the coatings with a PVC of glass fiber powder of 0–22.0%. When the PVC of the glass fiber powder was more than 4.0%, the coating gloss decreased gradually with the increase of the PVC. When the PVC was 10.0%–30.0%, the hardness of coating was 118 N·mm^{-2}. The wear resistance of the coating with 16.0% PVC of glass fiber powder was level 2. The coating with 10.0%–30.0% PVC of glass fiber powder had thermal insulation efficacy. The discoloration property of the coating with thermal insulation efficacy was not affected by time. Taking the total analyses into account, when the PVC of the glass fiber powder was 16.0%, the comprehensive performance of the coating was perfect. This study may help in the development of intelligent thermochromic and thermal insulation coatings for practical applications on wood and in many other important fields.

Author Contributions: Conceptualization, Methodology, Validation, Resources, Data Curation, Writing— Original Draft Preparation, Supervision, X.Y.; Data Analysis, L.W. and X.Q.; Investigation, Writing— Review and Editing, L.W. All authors have read and agreed to the published version of the manuscript.

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

References

1. Ma, X.G.; Wang, L.; Li, L.; Bian, L.R.; Yang, W.F.; Meng, Q.T. The novel thermochromic and energy-storage microcapsules with significant extension of color change range to different tones. *J. Macromol. Sci. Part A.* **2019**, *56*, 588–596. [CrossRef]
2. Xiong, X.Q.; Yuan, Y.Y.; Niu, Y.T.; Zhang, L.T. Research on the effects of roughness on the tactile properties of rice straw particleboard surface. *Sci. Adv. Mater.* **2020**, *12*, 795–801. [CrossRef]
3. Wu, Y.; Zhou, J.C.; Huang, Q.T.; Yang, F.; Wang, Y.J.; Liang, X.M.; Li, J.Z. Study on the colorimetry properties of transparent wood prepared from six wood species. *ACS Omega* **2020**, *5*, 1782–1788. [CrossRef] [PubMed]
4. Xiong, X.Q.; Ma, Q.R.; Ren, J. The performance optimization of oriented strand board veneer technology. *Coatings* **2020**, *10*, 511. [CrossRef]
5. Oberhofnerova, E.; Hysek, S.; Panek, M.; Bohm, M. Effect of artificial weathering and temperature cycling on the performance of coating systems used for wooden windows. *J. Coat. Technol. Res.* **2018**, *15*, 851–865. [CrossRef]
6. Zhao, Z.Y.; Huang, C.X.; Wu, D.; Chen, Z.; Zhu, N.; Gui, C.S.; Zhang, M.; Umemura, K.; Yong, Q. Utilization of enzymatic hydrolysate from corn stover as a precursor to synthesize an eco-friendly plywood adhesive. *Ind. Crop. Prod.* **2020**, *152*, 112501. [CrossRef]
7. Zhu, X.D.; Liu, Y.; Li, Z.; Wang, W.C. Thermochromic microcapsules with highly transparent shells obtained through in-situ polymerization of urea formaldehyde around thermochromic cores for smart wood coatings. *Sci. Rep.* **2018**, *8*, 4015. [CrossRef]
8. 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]
9. Hu, L.; Lyu, S.Y.; Fu, F.; Huang, J.D.; Wang, S.Q. Preparation and properties of multifunctional thermochromic energy-storage wood materials. *J. Mater. Sci.* **2016**, *51*, 2716–2726. [CrossRef]
10. Pedaballi, S.; Li, C.C.; Song, Y.J. Dispersion of microcapsules for the improved thermochromic performance of smart coatings. *RSC Adv.* **2019**, *9*, 24175–24183. [CrossRef]

11. Baumard, T.; Menary, G.; De Almeida, O.; Martin, P.; Schmidt, F.; Bikard, J. Experimental characterization and modeling of the temperature and rate-dependent shear behaviour of powder-impregnated glass fiber/PA66 woven semipregs. *Compos. Sci. Technol.* **2019**, *180*, 23–32. [CrossRef]
12. Yang, S.; Heyl, H.; Homa, D.; Pickrell, G.; Wang, A.B. Powder-in-tube reactive molten-core fabrication of glass-clad BaO-TiO_2-SiO_2 glass—Ceramic fibers. *Materials* **2020**, *13*, 395. [CrossRef] [PubMed]
13. Zhai, H.; Zhou, X.D.; Fang, L.; Lu, A. Study on mechanical properties of powder impregnated glass fiber reinforced poly(phenylene sulphide) by injection molding at various temperatures. *J. Appl. Polym. Sci.* **2010**, *115*, 2019–2027. [CrossRef]
14. Algburi, A.H.M.; Sheikh, M.N.; Hadi, M.N.S. Mechanical properties of steel, glass, and hybrid fiber reinforced reactive powder concrete. *Front. Struct. Civ. Eng.* **2019**, *13*, 998–1006. [CrossRef]
15. Panin, S.V.; Kornienko, L.A.; Huang, Q.; Buslovich, D.-G.; Bochkareva, S.-A.; Alexenko, V.-O.; Panov, I.-L.; Berto, F. Effect of adhesion on mechanical and tribological properties of glass fiber composites, based on ultra-high molecular weight polyethylene powders with various initial particle sizes. *Materials* **2020**, *13*, 1602. [CrossRef] [PubMed]
16. Kou, S.C.; Xing, F. The effect of recycled glass powder and reject fly ash on the mechanical properties of fibre-reinforced ultrahigh performance concrete. *Adv. Mater. Sci. Eng.* **2012**, *2012*, 263243. [CrossRef]
17. Wang, S.W.; Liu, Y.Q.; Chen, K.; Xue, P.; Lin, X.D.; Jia, M.Y. Thermal and mechanical properties of the continuous glass fibers reinforced PVC composites prepared by the wet powder impregnation technology. *J. Polym. Res.* **2020**, *27*, 82. [CrossRef]
18. Fang, Y.; Cui, P.; Ding, Z.; Zhu, J.X. Properties of a magnesium phosphate cement-based fire-retardant coating containing glass fiber or glass fiber powder. *Constr. Build. Mater.* **2018**, *162*, 553–560. [CrossRef]
19. Yan, X.X.; Chang, Y.J. Investigation of waterborne thermochromic topcoat film with color-changing microcapsules on Chinese fir surface. *Prog. Org. Coat.* **2019**, *136*, 105262. [CrossRef]
20. *GB/T 4893.8-2013 Test of Surface Coatings of Furniture—Part 8: Determination of Wearability*; Standardization Administration of the People's Republic of China: Beijing, China, 2013; pp. 1–8. (In Chinese)
21. Kasyanenko, I.M.; Kramarenko, V.Y. The effect of pigment volume concentration on film formation and the mechanical properties of coatings based on water-dispersion paint and varnish materials. *Mech. Compos. Mater.* **2018**, *53*, 767–780. [CrossRef]
22. Relosi, N.; Neuwald, O.A.; Zattera, A.J.; Piazza, D.; Kunst, S.R.; Birriel, E.J. Effect of addition of clay minerals on the properties of epoxy/polyester powder coatings. *Polimeros* **2018**, *28*, 355–367. [CrossRef]
23. Li, X.L.; Li, G.Z. Effect of latex powder and glass fibers on the performance of glazed hollow bead thermal insulation materials. *Sci. Eng. Compos. Mater.* **2015**, *22*, 279–286. [CrossRef]
24. Zheng, X.L.; Zhu, Z.H.; Li, X.M. The absorbing properties of Fe73.5Cu1Nb3Si13.5B9 amorphous powder/S-glass fiber-reinforced epoxy composite panels. *Rare Met.* **2013**, *32*, 294–298. [CrossRef]
25. Granqvist, C.G.; Lansaker, P.C.; Mlyuka, N.R.; Niklasson, G.A.; Avendano, E. Progress in chromogenics: New results for electrochromic and thermochromic materials and devices. *Sol. Energy Mater. Sol. Cells* **2009**, *93*, 2032–2039. [CrossRef]
26. Melinte, G.; Baia, L.; Simon, V.; Simon, S. Hydrogen peroxide versus water synthesis of bioglass-nanocrystalline hydroxyapatite composites. *J. Mater. Sci.* **2011**, *46*, 7393–7400. [CrossRef]