

## Research Article

# Synthesis and Characterization of Nano-TiO<sub>2</sub>/SiO<sub>2</sub>-Acrylic Composite Resin

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Waterborne acrylic resin is widely used as a binder of waterborne printing ink because of its excellent comprehensive properties. However, its further developments and applications are hindered by its poor UV resistance and water resistance. Therefore, an approach to prepare acrylic resin with excellent UV resistance and water resistance is described in this present study. The nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles were first modified with a silane coupling agent (KH-570) and a titanate coupling agent (NDZ-101) and then embedded into acrylic resin via a blending method. Fourier transform infrared spectroscopy (FT-IR), scanning electron microscopy (SEM), and thermogravimetry analysis (TGA) were applied to investigate the structure and morphology of the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles. The effects of the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles on the UV and water resistance of the acrylic resin were investigated by UV spectroscopy and water resistance analysis. The weight loss of modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> was about 20% when heated to 600°C, which indicated that the nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles were modified by the coupling agents successfully. The UV-Vis spectra of acrylic resin showed that the UV resistance was improved upon the addition of nano-TiO<sub>2</sub>/SiO<sub>2</sub>. The water absorption of the nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic resin was less than 5%, indicating that the water resistance of the material was improved.

## 1. Introduction

Acrylic resin as a binder of waterborne printing ink has the advantages of printing adaptability and ink stability. It has been widely used in the printing industry due to its excellent properties such as good hardness, luster, acid and alkali resistance, weather and pollution resistance, and nontoxicity [1]. The relatively poor ultraviolet (UV) and water resistance of acrylic resin due to the introduction of hydrophilic carboxyl groups, however, restrain it from further developments and applications [2–5]. To achieve good UV and water resistance for acrylic resin, it is necessary and significant to prepare a modified waterborne acrylic resin [6].

There are four main popular methods that are widely applied to modify acrylic resin: monomer modification, compound modification, process modification, and nano-modification [7, 8], to be widely applied to modify acrylic

resin. Since titanium dioxide (TiO<sub>2</sub>) nanoparticles are widely used because of their good UV absorbance and photocatalytic activity, low cost, and nontoxicity as inorganic materials, the nanomodification was adopted as a more effective method to improve the UV and water resistance of the acrylic resin. The composite particles formed by coating silica (SiO<sub>2</sub>) nanoparticles on the surface of nano-TiO<sub>2</sub> particles may obtain excellent UV absorption properties. In addition, the photocatalytic activity of the nano-TiO<sub>2</sub> particles can be reduced, allowing the wide use of nanoparticles. The nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles, combined with low surface energy materials, may be incorporated into the acrylic resin to enhance UV resistance and hydrophobic properties, simultaneously. Thus, nano-TiO<sub>2</sub> particles have been widely introduced into polymers to improve the heat resistance, UV resistance, and photocatalytic performance of polymer materials in the past several years [9–11]. Duan

et al. [12] presented a novel approach to synthesize acrylic resin used as a binder of waterborne printing ink on plastic film with excellent adhesion and water resistance. Liu et al. [13] suggested a two-step esterification process to prepare epoxy-acrylic-graft-copolymer waterborne resins used in anticorrosion coatings on metal substrates. Zhang et al. [14] studied the properties of acrylic emulsion with 2-acrylamido-2-methylpropane sulfonic acid (AMPS) as a reactive comonomer and methyl methacrylate (MMA), *n*-butyl acrylate (BA), and 2-hydroxyethyl acrylate (HEA) as a copolymerization system. Viorney et al. [15] used phosphoric acid to modify the surface of nano-TiO<sub>2</sub>. Cheng et al. [16] synthesized acrylic resin with high gloss and strong water resistance by introducing nonionic groups.

In this study, a new, low cost, and easily industrialized technique was used to modify the UV and water resistance of acrylic resin. The nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles were first modified by  $\gamma$ -methacryloxypropyltrimethoxysilane (KH-570) and isopropyl dioleic acyloxy (dioctylphosphate) titanate (NDZ-101) [17, 18]. Fourier transform infrared (FT-IR), scanning electron microscopy (SEM), and thermogravimetric analysis (TGA) were applied to study the morphology of the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles. In fact, the method of using these two coupling agents to reduce the problem of easy agglomeration of nanomaterials in resins and improve their UV and water resistance has rarely been reported. A waterborne acrylic resin with excellent UV and water resistance was prepared by introducing modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles. We further investigated the effects of the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles on the UV and water resistance of the acrylic resin. The experimental data in this paper show that the UV and water resistance of the acrylic resin were all improved with this method. In this way, the ink coating can simultaneously obtain anti-ultraviolet and superhydrophobic properties and can be applied not only to areas such as umbrellas, sun protection clothes, waterproof packaging bags, food and medicine packaging materials, but also to aviation, the aerospace industry, medical treatment, and military fields. This work has the potential to expand the application fields of resin nanomaterials and has broad application prospects.

## 2. Experimental

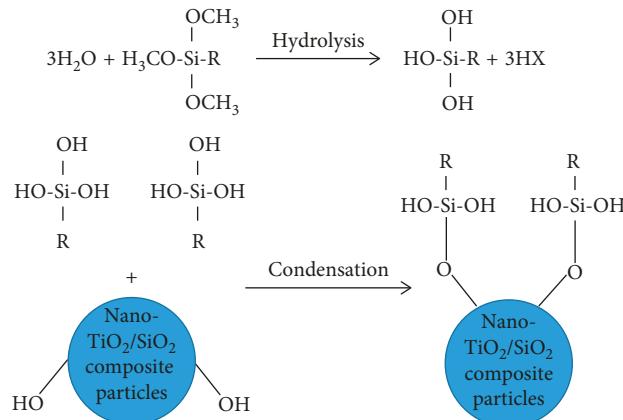
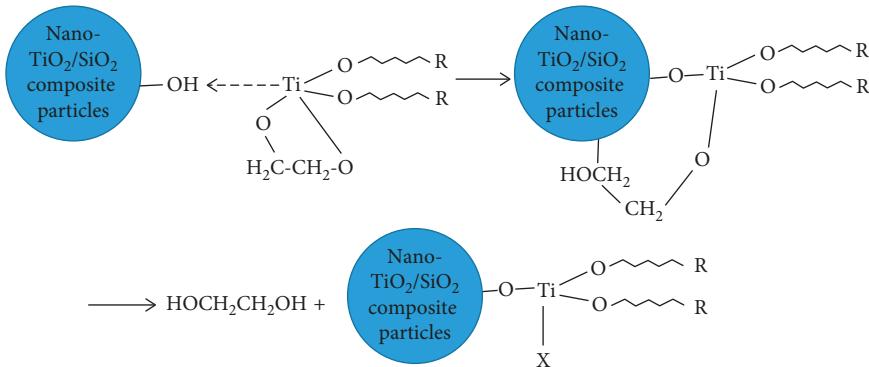
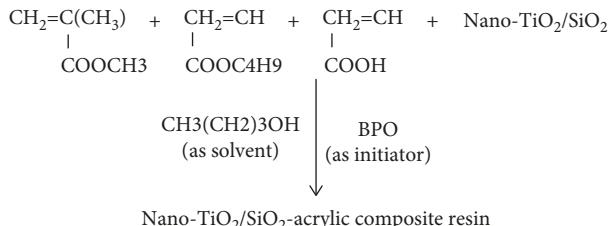
**2.1. Materials.** Nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles were fabricated by our laboratory. Butanol was purchased from Shanpu Chemical Co., Ltd., Shanghai, China. Benzoyl peroxide (BPO) and 95% ethanol were obtained from Kemiou Chemical Reagent Co., Ltd., Tianjin, China. Ammonia and absolute ethanol were bought from Tianli Chemical Reagent Co., Ltd., Tianjin, China. Methyl methacrylate (MMA), butyl acrylate (BA), acrylic acid (AA), KH-570, NDZ-101, and glacial acetic acid were all purchased from Ivkeyan Chemical Reagent Co., Ltd., Shanghai, China. All of the purchased reagents were used without further purification.

**2.2. Preparation of Modified Nano-TiO<sub>2</sub>/SiO<sub>2</sub> Composite Particles.** KH-570 (98%, 2wt.%) was added to 95% ethanol, with glacial acetic acid added dropwise into the solution under magnetic stirring to adjust the pH value to 3-4. The mixture was stirred for 30 min (Scheme 1). Briefly, NDZ-101 (reagent grade, 98%, 3 wt.%) was added to absolute ethanol and distilled water (Scheme 2) [19]. The nano-TiO<sub>2</sub>/SiO<sub>2</sub> powder was dissolved in 95% ethanol via an ultrasonic process for 20 min. The above KH-570 and NDZ-101 were added to this solution in a constant temperature water bath at 65°C. The reaction was carried out under ultrasonic dispersion for 1 h. After the reaction, the samples were washed by centrifugation, dried, and ground to obtain the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles.

**2.3. Synthesis of Acrylic Resin.** The acrylic resin was prepared by solution polymerization of MMA (99%), BA (99%), and AA (98%, 12.5 wt.%) as monomers and BPO (98%) as initiator. The ratios of the soft monomer to hard monomer and the solvent to monomers were all 1:1. A half of butanol (99.5%), a third of monomers, and a quarter of initiator were added to a dropping funnel (250 ml) equipped with a stirrer and a thermometer. The mixture was stirred at 100°C for 30 min. Then, the mixture of remaining monomers, initiator, and butanol was added dropwise into the dropping funnel within 2 h. The polymerization was carried out for another 3 h. Subsequently, the dropping funnel was naturally cooled down to 35°C, and ammonia (25%) was added under stirring to adjust the pH value to 8-9. After 0.5 h, the obtained product was waterborne acrylic resin.

**2.4. Preparation of Nano-TiO<sub>2</sub>/SiO<sub>2</sub>-Acrylic Composite Resin.** The basic preparation procedure is shown in Scheme 3. The nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic composite resin was prepared via a blending method. The modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles at mass ratios of 1%, 5%, and 10% were added into the acrylic resin solution. The reaction was carried out under ultrasonic dispersion for 30 min. Finally, the product was placed on a glass dish and dried at room temperature for several hours.

**2.5. Characterization.** The surface morphologies of the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles were observed by SEM (SU-8010, Hitachi, Japan). FT-IR was used to characterize various functional groups of the composite particles using KBr tablets for samples. TGA (Q600SDT, TA Instruments, USA) was performed on the nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles before and after modification under nitrogen gas with a heating rate of 10°C/min to determine their thermal stability. In the TGA experiment, the scanned temperature ranged from ambient temperature to 600°C. The acrylic resins with nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles before and after modification at mass ratios of 1%, 5%, and 10% were cut into 2 cm × 2 cm × 2 mm dimensions after being allowed to

SCHEME 1: Modification of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles with KH-570.SCHEME 2: Modification of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles with NDZ-101.SCHEME 3: Preparation of nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic composite resin.

stand for 7 days. Absorbance was obtained by a UV spectrophotometer at 200–800 nm. The absorbance of acrylic resin both with and without nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles at 200–800 nm was measured and compared. The cut films were washed by distilled water and placed on a glass dish. After being dried in an oven under 50°C for 1 h, the films were cooled down to room temperature and weighed ( $M_{W1}$ ). Then, the coating films were soaked in distilled water for 24 h. The weights of both applied films and adsorbed water ( $M_{W2}$ ) were used to calculate the water absorption by the following formula:

$$\text{water absorption (\%)} = \frac{M_{W2} - M_{W1}}{M_{W1}} \times 100\%, \quad (1)$$

where  $M_{W1}$  is the weight of the applied films cooled to room temperature and  $M_{W2}$  is the weight of the coating films soaked in distilled water for 24 h.

### 3. Results and Discussion

**3.1. Morphological Analysis.** As seen in Figures 1(b), 1(d), and 1(f), the nano-TiO<sub>2</sub>/SiO<sub>2</sub> composites without modification were completely precipitated in acetone [20, 21].

In comparison, the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles were preferably dispersed in acetone as shown in Figures 1(a), 1(c), and 1(e), which exhibit good lipophilicity. As can be seen from the figures of modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles, the dispersion effect of Sample 3 was inferior to that of Samples 1 and 2.

**3.2. SEM Analysis.** The surface morphologies of the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles were observed by SEM. As a reference, the SEM images of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles without the modification of coupling agents are marked as “none” in Figures 2(a) and 2(e). It can be seen that the agglomeration of nano-TiO<sub>2</sub> particles is of considerable amounts. There were many free nano-SiO<sub>2</sub> particles that could not be formed and coated well on the surface of the nano-TiO<sub>2</sub> particles.



FIGURE 1: Dispersion of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles before and after modification in acetone for 24 h. (a) Sample 1. (b) Sample 1 before modification. (c) Sample 2. (d) Sample 2 before modification. (e) Sample 3. (f) Sample 3 before modification.

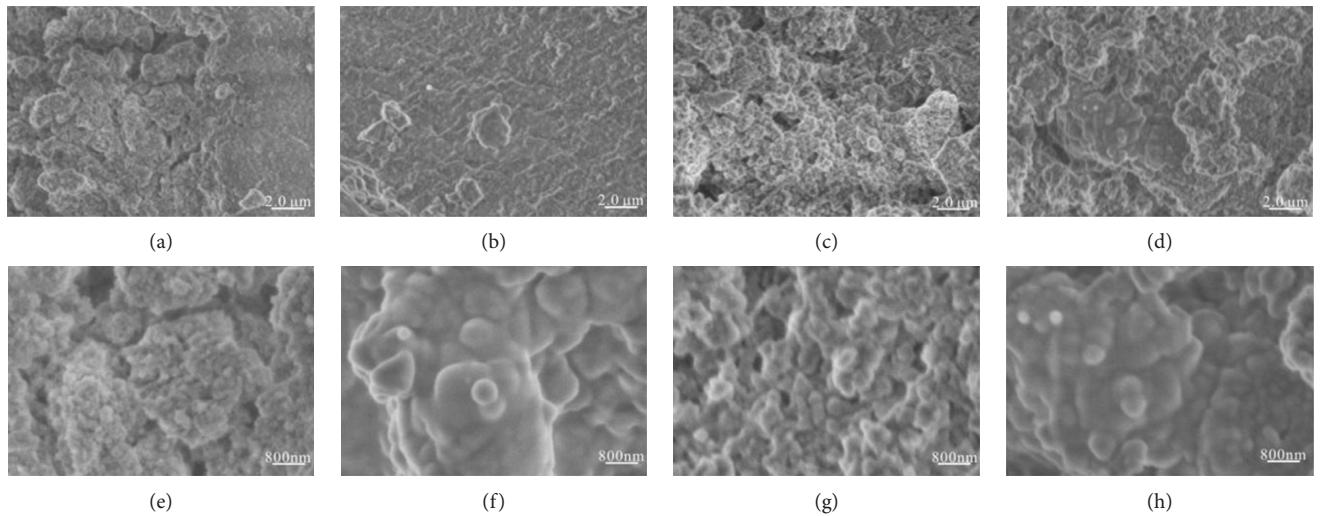


FIGURE 2: SEM images of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles without the modification (Sample 0) and modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles (Samples 1, 2, and 3): (a) Sample 0 in 45,000 magnification, (b) Sample 1 in 45,000 magnification, (c) Sample 2 in 45,000 magnification, (d) Sample 3 in 45,000 magnification, (e) Sample 0 in 130,000 magnification, (f) Sample 1 in 130,000 magnification, (g) Sample 2 in 130,000 magnification, and (h) Sample 3 in 130,000 magnification.

As shown in Figures 2(b)–2(d), the surface of the nano-TiO<sub>2</sub>/SiO<sub>2</sub> particles is covered with a rounded organic layer. It can be seen clearly in Figures 2(f)–2(h) that the organic coating is dense, while the coating effect is quiet clear under a magnification of 130,000. There is still a little agglomeration in the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles, which may be due to the insufficient grinding of the composite particles or the poor dispersion effect of the powder in the preliminary experiment [22, 23]. The SEM images of modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> particles combined with the figures of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles before and after modification in acetone indicate that the coating effect of Sample 1 and Sample 2 is better than that of Sample 3.

**3.3. FT-IR Analysis.** The FT-IR spectra of the nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles before and after modification are shown in Figure 3. The peak at 3500 cm<sup>-1</sup> in Figures 3(a)–3(c) is the bending vibration peak of -OH in the absorbed water of nano-TiO<sub>2</sub> particles, while a broad absorption band at 3460 cm<sup>-1</sup> in Figures 3(d)–3(f) may be

attributed to an -OH group of absorbed water in the nano-TiO<sub>2</sub>/SiO<sub>2</sub> particles. The stretching vibration of C=O in KH-570 is also observed at 1650 cm<sup>-1</sup>, while the absorption peak at 1880 cm<sup>-1</sup> can be attributed to C=O groups in NDZ-101 [24, 25]. The asymmetric stretching vibration of Si—O—Si near 1080 cm<sup>-1</sup> can be attributed to a change in the chemical state, which is ascribed to the chemical reaction of KH-570 with nano-SiO<sub>2</sub> particles. At the same time, the spectrum clearly illustrates the absorption peak of Si—O—Ti at 975 cm<sup>-1</sup> due to the chemical reaction of NDZ-101 with nano-SiO<sub>2</sub> particles on the nano-TiO<sub>2</sub> [22]. These results indicate the presence of KH-570 and NDZ-201 on the surface of the nanoparticles, and the coupling agents are grafted onto the surface of the nanoparticles through chemical changes rather than a simple physical coating.

**3.4. TG Analysis.** Figure 4 shows the TGA curves of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles both before and after modification with the coupling agents (KH-570 and NDZ-101). All the samples were dried in a vacuum oven for 24 h before

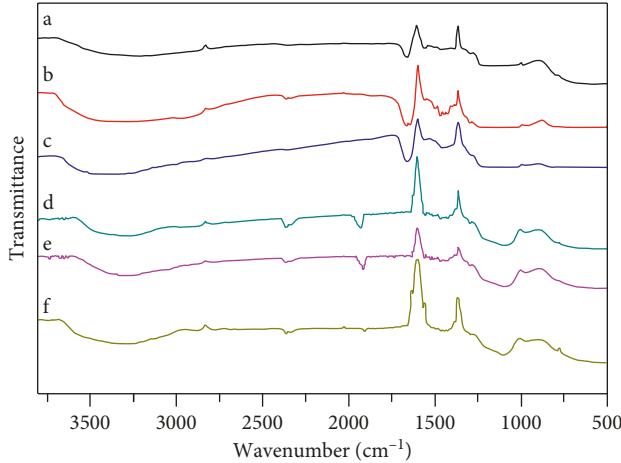


FIGURE 3: Infrared spectrum of modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles: (a) Sample 1 before modification, (b) Sample 2 before modification, (c) Sample 3 before modification, (d) Sample 1, (e) Sample 2, and (f) Sample 3.

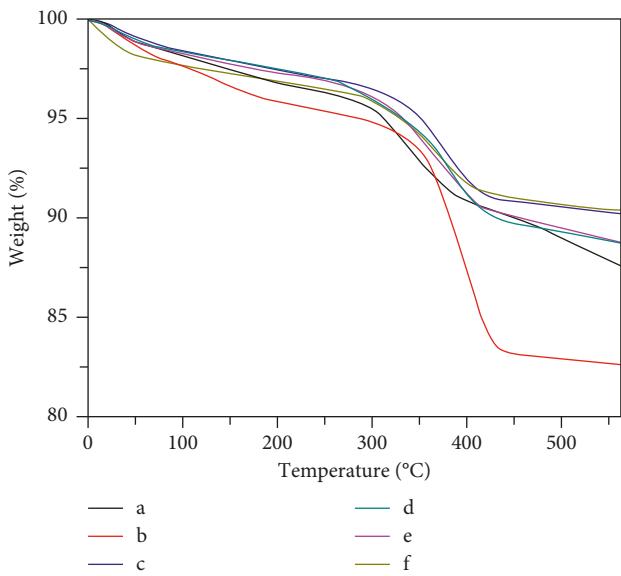


FIGURE 4: TGA curves of composite particles: (a) Sample 1 before modification, (b) Sample 2 before modification, (c) Sample 3 before modification, (d) Sample 1, (e) Sample 2, and (f) Sample 3.

being tested. The small mass loss observed for nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles between 0°C and 200°C is probably due to the evaporation of water vapor adsorbed on the surface of the samples at high temperatures. The temperature at which 20% mass loss occurs is about 600°C for modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles. The appearance of the Tg indicates that nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles have been modified by coupling agents successfully. A sharp transition occurs at about 450°C corresponding to the thermal decomposition of the coupling agents, while the weight loss in the temperature range of 500°C–600°C is due to the thermal decomposition of grafted coupling agents at high temperatures [26].

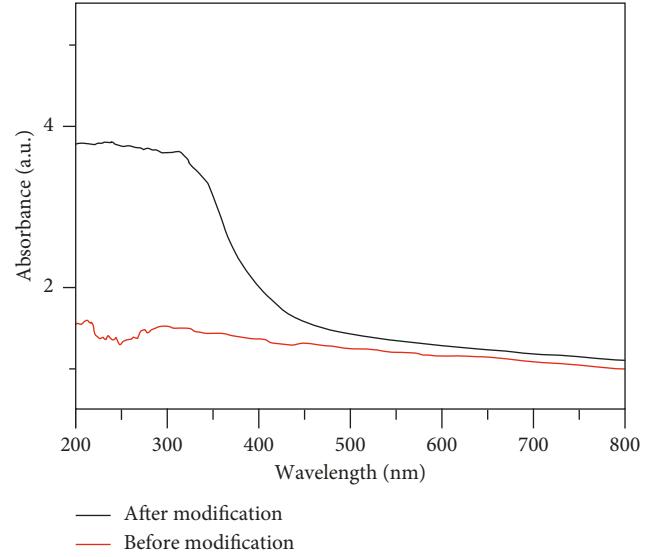


FIGURE 5: UV-Vis absorption spectrum of acrylic resin before and after adding nano-TiO<sub>2</sub>/SiO<sub>2</sub>.

**3.5. UV Resistance Properties Analysis.** The UV resistance characteristic of nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic composite resin was investigated by UV-Vis absorption spectra shown in Figure 5. The UV resistance characteristic is only discussed in the UVA band (320–400 nm) and the UVB band (280–320 nm) [27]. Figure 5 shows the UV-Vis spectra of acrylic resin before and after adding modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles. The absorbance of acrylic resin without nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles is always lower than 2 in the wavelength range of 200–800 nm, while the absorbance of nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic composite resin reaches about 4 in the wavelength range of 200–320 nm. There is a high absorption at 280–320 nm, that is, a low transmittance. The same phenomenon occurs at 320–400 nm. The enhancement of UV resistance can be ascribed to the production of electron-hole pairs caused by the nano-TiO<sub>2</sub> particles being irradiated by the light whose energy greater than the forbidden bandwidth [28, 29].

The effects of the content of modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles on the UV resistance of modified acrylic resin are shown Figure 6. It can be seen that the UV absorbance improves as the content of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles increases. As the content of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles increases from 1% to 10%, the UV wavelengths were completely shielded by the composite acrylic coating when the range was from 310 nm to 350 nm, while the transparency was still maintained above 90%. The UV transmittance of the composite particles is below 30% when the mass ratio of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles is 10%. The result indicates that the UV resistance and transparency of modified acrylic resin are all improved and the effect of nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic composite resin with 10% nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles is better than the others.

**3.6. Effects of Modified Nanocomposite Particles Ratio on Water Resistance.** The water resistance of acrylic resin is its

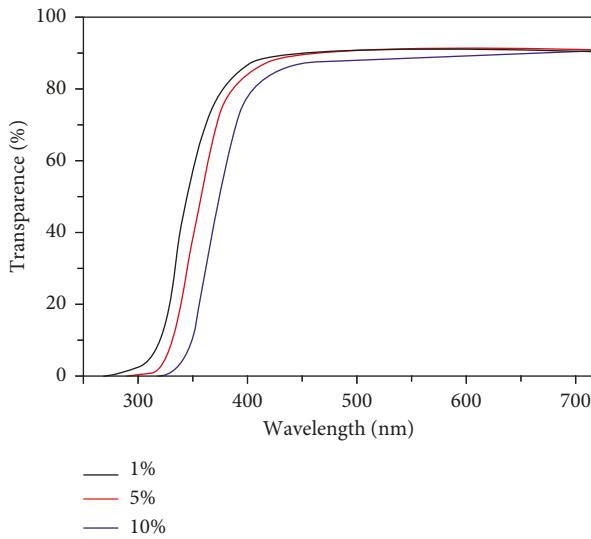


FIGURE 6: UV-Vis absorption spectrum of composite resin with different nano-TiO<sub>2</sub>/SiO<sub>2</sub> contents.

capacity to absorb water. It is a property that mainly depends on the ratio of hydrophilic/hydrophobic functional groups and on the nature of these groups as well [30]. As waterborne acrylic resin contains a lot of hydrophilic carboxyl groups, they generally have an ability to absorb considerable amounts of water. Thus, water-resistant modifications must be applied to the surface of the nanoparticles. The effects of altering the modified nanocomposite particles ratio (1%, 5%, and 10%) on water resistance of acrylic resin were investigated. As a reference, a pure acrylic resin was prepared. The test values of water absorption are listed in Table 1. It was determined that the water absorption decreases when the mass ratio changes from 1% to 5%. The result may be due to the formation of micro- and nanoconvex structures on the surface of the acrylic resin coating caused by the addition of nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles and the hydrophobic treatment by coupling agents. However, the water absorption increases when the ratio changes from 5% to 10%. The reason is the agglomeration of excess SiO<sub>2</sub> molecules due to interactions between hydroxyl hydrogen bonds, which results in a reduction in the length of the movable segment unit and a weakening of the bonding force between the material and the substrate so that the water resistance is reduced. As shown in Table 1, the water absorption of the acrylic resin with modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> particles is less than 5% for all three contents, indicating that the water resistance of composite acrylic resins is improved compared with pure acrylic resin [31].

#### 4. Conclusions

A novel preparation method was developed to prepare nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic composite resin with excellent UV and water resistance. The main purpose of this study is to investigate the methodology of improving the properties of acrylic resin as a binder of waterborne printing ink. Through TGA curves, it can be shown that the nano-TiO<sub>2</sub>/SiO<sub>2</sub>

TABLE 1: Effects of different ratios of nanocomposite particles on water resistance.

Mass ratio of nano-TiO <sub>2</sub> /SiO <sub>2</sub> (%)	Weight before immersion, M <sub>w1</sub> (g)	Weight after immersion, M <sub>w1</sub> (g)	Water absorption (%)
0	0.50	0.54	8.00
1	0.48	0.50	4.16
5	0.49	0.50	2.04
10	0.51	0.53	3.92

composite particles were modified by the coupling agents successfully. FT-IR confirms that KH-570 and NDZ-101 were grafted on the surface of nanocomposite particles in a bonding form. According to UV-Vis absorption spectra, it was observed that, after introducing modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles into acrylic resin, the UV resistance and transparency of modified acrylic resin were all improved. The water absorption of the nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic resin, which was less than 5%, indicates that the water resistance of these materials is enhanced by the modified nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles. In summary, the results show that the UV and water resistance of acrylic resin modified with nano-TiO<sub>2</sub>/SiO<sub>2</sub> composite particles by a blending method are improved. The experiment data indicate that the nano-TiO<sub>2</sub>/SiO<sub>2</sub>-acrylic composite resin synthesized in this study can be hopeful candidates for environmentally waterborne printing ink to be used in printing and related industries.

#### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

#### Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

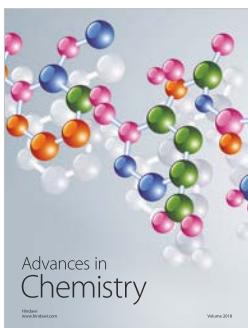
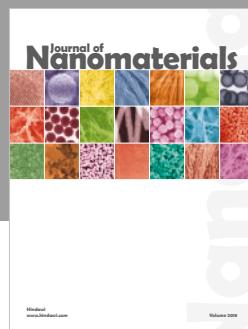
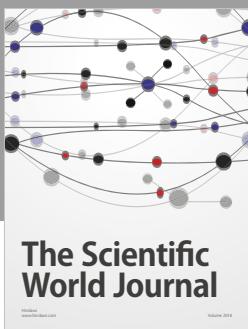
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#### References

- [1] M. L. Nobel, E. Mendes, and S. J. Picken, "Enhanced properties of innovative laponite-filled waterborne acrylic resin dispersions," *Journal of Applied Polymer Science*, vol. 103, no. 2, pp. 687–697, 2007.
- [2] J. V. Barbosa, E. Veludo, J. Moniz, A. Mendesa, F. D. Magalhães, and M. Bastosa, "Low VOC self-crosslinking waterborne acrylic coatings incorporating fatty acid derivatives," *Progress in Organic Coatings*, vol. 76, no. 11, pp. 1691–1696, 2013.

- [3] T. Mi, Q. Chen, Y. Hu, Y. Yang, and G. Chen, "Synthesis and characterization of acrylic resin applied for UV-curing conductive ink," *Applied Sciences in Graphic Communication and Packaging*, vol. 477, pp. 649–655, 2018.
- [4] A. D. Gianni, R. Bongiovanni, S. Turri, F. Deflorian, G. Malucelli, and G. Rizza, "UV-cured coatings based on waterborne resins and  $\text{SiO}_2$  nanoparticles," *Journal of Coatings Technology and Research*, vol. 6, no. 2, pp. 177–185, 2008.
- [5] H. J. Naghash, S. Mallakpour, and N. Kayhan, "Synthesis and characterization of silicone modified acrylic resin and its uses in the emulsion paints," *Iranian Polymer Journal*, vol. 14, no. 3, pp. 211–222, 2005.
- [6] C. Chen, Y. Wang, G. Pan, and Q. Wang, "Gel-sol synthesis of surface-treated  $\text{TiO}_2$  nanoparticles and incorporation with waterborne acrylic resin systems for clear UV protective coatings," *Journal of Coatings Technology and Research*, vol. 11, no. 5, pp. 785–791, 2014.
- [7] T. Meguro, K. Kobashi, T. Ishii et al., "Highly-charged ion induced surface nano-modification," *Surface and Coatings Technology*, vol. 201, no. 19–20, pp. 8452–8455, 2007.
- [8] H. J. Kim, I. G. Kang, D. H. Kim, and BH. Choi, "Dispersion characteristics of  $\text{TiO}_2$  particles coated with the  $\text{SiO}_2$  nano-film by atomic layer deposition," *Journal of Nanoscience and Nanotechnology*, vol. 11, no. 12, pp. 10344–10348, 2011.
- [9] M. A. Habib, M. T. Shahadat, N. M. Bahadur, IM. Ismail, and AJ. Mahmood, "Synthesis and characterization of  $\text{ZnO}-\text{TiO}_2$  nanocomposites and their application as photocatalysts," *International Nano Letters*, vol. 3, no. 1, p. 5, 2013.
- [10] N. T. Hue and D. T. T. Hang, "Photocatalytic decomposition of benzene by UV illumination with the presence of nano- $\text{TiO}_2$ ," *International Journal of Nanotechnology*, vol. 10, no. 3–4, pp. 214–221, 2013.
- [11] X. Liu, J. H. Gao, and W. Xu, "Analysis and application of nano  $\text{TiO}_2$  photocatalytic properties," *Advanced Materials Research*, vol. 529, pp. 574–578, 2012.
- [12] Y. Duan, Y. Huo, and L. Duan, "Preparation of acrylic resins modified with epoxy resins and their behaviors as binders of waterborne printing ink on plastic film," *Colloids and Surfaces A Physicochemical and Engineering Aspects*, vol. 535, pp. 225–231, 2017.
- [13] M. Liu, X. Mao, H. Zhu et al., "Water and corrosion resistance of epoxy-acrylic-amine waterborne coatings: effects of resin molecular weight, polar group and hydrophobic segment," *Corrosion Science*, vol. 75, no. 7, pp. 106–113, 2013.
- [14] Y. Zhang, B. Wang, M. Dai, S. Pan, F. Zhang, and P. He, "Studies on the preparation of stable and high solid content emulsifier-free poly(MMA/BA/HEA) latex with the addition of AMPS and characterization of the obtained copolymers," *Journal of Macromolecular Science: Part A - Chemistry*, vol. 48, no. 5, pp. 409–415, 2011.
- [15] V. Carine, C. Yann, L. Didier et al., "Surface modification of titanium with phosphonic acid to improve bone bonding: characterization by XPS and ToF-SIMS," *Langmuir*, vol. 18, no. 7, pp. 2582–2589, 2002.
- [16] X. Cheng, Z. Chen, T. Shi, and H. Wang, "Synthesis and characterisation of core-shell LIPN-Fluorine-Containing polyacrylate Latex," *Colloids & Surfaces A Physicochemical and Engineering Aspects*, vol. 292, no. 2, pp. 119–124, 2007.
- [17] Y. Min, Y. Fang, X. Huang et al., "Surface modification of basalt with silane coupling agent on asphalt mixture moisture damage," *Applied Surface Science*, vol. 346, pp. 497–502, 2015.
- [18] Y. Li, J. Xie, Z. Chu, X. Wang, and X. Yao, "Dielectric and energy storage properties of ceramic/PVDF composites with titanate coupling agents," *Ferroelectrics*, vol. 452, no. 1, pp. 101–106, 2013.
- [19] H. Y. Jeong, H. L. Min, and B. K. Kim, "Surface modification of waterborne polyurethane," *Colloids and Surfaces A Physicochemical and Engineering Aspects*, vol. 290, no. 1, pp. 178–185, 2006.
- [20] A. M. Natu and M. R. VD. Mark, "Synthesis and characterization of an acid catalyst for acrylic-melamine resin systems based on colloidal unimolecular polymer (CUP) particles of MMA-AMPS," *Progress in Organic Coatings*, vol. 81, pp. 35–46, 2015.
- [21] H. Wei, Z. Cleary, P. San, K. Senevirathne, and H. Eilers, "Fluorescence lifetime modification in  $\text{Eu}:\text{Lu}_2\text{O}_3$  nanoparticles in the presence of silver nanoparticles," *Journal of Alloys and Compounds*, vol. 500, no. 1, pp. 96–101, 2010.
- [22] R. Wang, X. Wang, X. Xi et al., "Preparation and photocatalytic activity of magnetic  $\text{Fe}_3\text{O}_4/\text{SiO}_2/\text{TiO}_2$  composites," *Advances in Materials Science & Engineering*, vol. 2012, Article ID 409379, 8 pages, 2015.
- [23] R. Nandanwar, P. Ingh, F. F. Syed, and F. Z. Haque, "Preparation of  $\text{TiO}_2/\text{SiO}_2$  nanocomposite with non-ionic surfactants via sol-gel process and their photocatalytic study," *Nanoscale Research Letters*, vol. 8, no. 1, pp. 1–9, 2014.
- [24] M. C. Suzana, S. R. Ivan, M. C. Milena et al., "Glycolyzed poly(ethylene terephthalate) waste and castor oil-based polyols for waterborne polyurethane adhesives containing hexamethoxymethyl melamine," *Progress in Organic Coatings*, vol. 78, pp. 357–368, 2015.
- [25] M. R. Mafra, L. Igarashimafra, D. R. Zuim et al., "Adsorption of remazol brilliant blue on an orange peel adsorbent," *Brazilian Journal of Chemical Engineering*, vol. 30, no. 3, pp. 657–665, 2013.
- [26] C. J. Shih, S. J. Shih, H. Lin, H. H. Yeh, and Y. C. Hung, "Thermal-decomposition and crystallization behaviour of coupling agents for silver paste application," *Nanotechnology*, vol. 14, no. 9, p. 1014, 2003.
- [27] Y. Wang, S. J. Marling, S. M. McKnight, A. L. Danielson, K. S. Severson, and H. F. Deluca, "Suppression of experimental autoimmune encephalomyelitis by 300–315 nm ultraviolet light," *Archives of Biochemistry and Biophysics*, vol. 536, no. 1, pp. 81–86, 2013.
- [28] F. Liu and G. Liu, "Enhancement of UV-aging resistance of UV-curable polyurethane acrylate coatings via incorporation of hindered amine light stabilizers-functionalized  $\text{TiO}_2-\text{SiO}_2$  nanoparticles," *Journal of Polymer Research*, vol. 25, no. 2, p. 59, 2018.
- [29] M. R. Hoffmann, S. T. Martin, W. Choi, and D. W. Bahnemann, "Environmental applications of semiconductor photocatalysis," *Chemical Reviews*, vol. 95, no. 1, pp. 69–96, 1995.
- [30] S. Zuppolini, A. Borriello, M. Pellegrino, V. Venditto, L. Ambrosio, and L. Nicolais, "Potential contact and intraocular lenses based on hydrophilic/hydrophobic sulfonated syndiotactic polystyrene membranes," *Journal of King Saud University-Science*, vol. 29, no. 4, pp. 487–493, 2017.
- [31] P. Pi, W. Wang, X. Wen, S. Xu, and J. Cheng, "Synthesis and characterization of low-temperature self-crosslinkable acrylic emulsion for PE film ink," *Progress in Organic Coatings*, vol. 81, pp. 66–71, 2015.



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