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Fabrication of Nanocomposite Coatings and Application in Outdoor Architectural Design

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Abstract: The current outdoor architectural design requires simplicity and beauty. However, most of the traditional building materials are bulky and inconsistent with the requirements of modern building design, while nanocomposite coatings can solve this problem. Based on the characteristics of outdoor architectural design, this paper designed and produced nano-silica + nano-T_iO_2 composite pure acrylic/silicon acrylic paint in the form of latex paint, which can make the painted wall smoother and more applicable to the environment. In the experiment, in order to configure the coating with the best performance, different nanomaterial components and different volume fractions of pigments and fillers were tested in this paper. The test results showed the modification effect of the nano-silica was better than that of the nano- T_iO_2; the silicone acrylic paint was better than the pure propyl paint. The prepared coating had a contrast ratio of 0.98, a hardness of 2H, a scrub resistance of 60,124 times, and an acid resistance of 710 hours with excellent performance, which met the needs of applications in outdoor architectural design.

1. Introduction

Architectural paint has special functions of decoration, protection and adjustment of buildings, and it is an energy-saving building decoration material. The development of architectural coatings has also provided more space for the design of outdoor buildings. Nanomaterials possess a range of physical and chemical properties due to the extremely small geometric size and huge surface energy. Existing research results showed that nanomaterials can significantly improve the performance of traditional coatings. Therefore, the application of nanomaterials in exterior wall coatings has become a major research direction in today's coatings industry. In this paper, based on the dispersion of nano-materials, a new type of nano-scale modified latex paint for exterior walls was developed through a combination of chemical and physical methods. On the basis of not affecting the existing performance, a nano-level modified exterior wall latex paint with excellent performance was invented.

Nanocomposite materials have many excellent properties, so a large number of scholars have carried out research on nanocomposite materials. Ebrahimian-Hosseinabadi M modified the surface of Ti6Al4V titanium alloy by calcium phosphate/graphene composite coating. His experimental results demonstrated that the calcium phosphate/graphene composite coating can improve the bioactivity and biocompatibility of Ti6Al4V in biomedical applications [1]. Lee M fabricated ultra-thin nanocomposite coatings of zirconia, zinc oxide and titanium oxide on stainless steel by radio frequency sputtering and studied the effect of nanocomposite coatings on corrosion resistance [2]. Mahmoudi D successfully synthesized chromium-graphene oxide nanocomposite coating by electroplating method [3]. Belyakov A A designed and studied nanocomposite coatings based on cermets and carried out a comparative study of their mechanical properties [4]. It can be found that although many scholars have conducted research on nanocomposite coatings, most of their applications are in medicine, and there are few targeted coatings developed for outdoor architectural design.

Nanotechnology plays an important role in the application of new technologies such as information technology and biotechnology. At the same time, due to its unique physical, chemical and biological properties, it also brings new development opportunities for the application of coatings. Ren Y successfully electrodeposited Ni-ZrO_2 nanocomposite coatings for the first time by changing the concentration of ZrO_2 particles in the plating solution and successfully applied it to exterior wall stucco coatings [5]. Nazir M H analyzed and modeled the synergistic wear-corrosion properties of nickel-graphene (Ni/GPL) nanocomposite coatings and compared them to uncoated steels under reciprocating sliding contact [6]. Nonahal M introduced an efficient method to evaluate the delamination mechanism of epoxy coatings on steel substrates [7]. Lin J used deep oscillatory magnetron sputtering to generate large oscillatory high-power pulse-assisted deposition of thick TiSiCN nanocomposite coatings in order to improve the electromagnetic resistance of coatings [8]. However, most of the research is only aimed at the single performance of the coating, and few scholars have studied the overall performance of the coating. The design of outdoor buildings should not only pay attention to the thermal insulation performance of the building, but also meet the needs of indoor thermal environment through measures such as natural ventilation, night ventilation, evaporative cooling, radiation cooling and shading. These are questions to consider in building mechanics and engineering. The research of this paper focused on the performance research of exterior building exterior paint and combined the beauty of exterior architectural design color with the practicability of exterior walls, assisting outdoor architectural design to be carried out more quickly and perfectly.

2. Coating Requirements in Architectural Exterior Design

2.1. Architecture Exterior Design

The adaptability of the building to the weather is its inherent basic feature, and its most important role is to provide a good indoor thermal environment for the residents. In the spatial form of the building and the construction of the surrounding residents, the local climatic conditions must be taken into account. Under reasonable design schemes and equipment conditions, a better indoor environment is created through natural climatic factors such as solar radiation, temperature, humidity, wind, etc. [9]. Due to the difference of regional climate, architects must take various measures to deal with thermal environment problems such as heat insulation and ventilation in summer. Therefore, the architectural culture of each place has derived and developed many regional buildings suitable for the local climate characteristics, as shown in Figure 1.

Figure 1. Different architectural features

2.2. Nano Coatings

Nano-coating is based on nanoscale (1-100 nm) substrates, which has many wonderful properties. In the application of nanocoatings in architectural coatings, it has the function of firmness, antibacterial and air purification, beneficial to human body and environment [10]. In addition, compared with conventional paints, its color stability and UV resistance also have significant advantages.

In particular, the nano-coating has: 1) high weather resistance and high color retention; 2) high anti-pollution ability and waterproof performance; 3) good anti-scrubbing performance; 4) antibacterial properties. The special antibacterial properties of nano-coatings are unmatched by other paints. Using a coating made of nanomaterials and pure propylene, the 24-hour sterilization effect can reach 99.9%, and it can also be sterilized indoors for more than five years [11].

2.3. Application of Nanomaterials in Architectural Coatings

There are two main uses of nanocoatings: one is to disperse nanoparticles in conventional organic coatings and then disperse them on ordinary coatings; the other is to disperse all nanoparticles of nanocoatings. The former mainly modifies traditional coatings by adding nanoparticles, and its process is relatively simple and has good industrial application prospects; while the latter, due to technical and cost reasons, is difficult to achieve industrialization in a short period of time [12]. The application of various nanomaterials in architectural coatings is described below.

Application of Nano silica in architectural coatings

Nano silica is an amorphous white powder. Its surface has unsaturated residual bonds and different hydroxyl groups, and its molecular state is a ternary chain [13]. Normally, the hydrogen bonds formed on the surface of nanoparticles do not generate large forces and are easily separated by shear forces. However, when the external shear force is removed, these hydrogen bonds recover quickly and recombine quickly. This shear weakening reaction that relies on time and external force to restore it to its original state is called "thixotropy". Silica plays an important role in enhancing coating performance. The measurement results of the spectrophotometer showed that the nano-silica material exhibited good performance in terms of ultraviolet absorption and infrared reflection. After adding the coating, it can play the role of anti-ultraviolet and anti-heat aging to improve thermal insulation performance. Applying the nano-silica coating on the ship body can significantly improve the corrosion resistance of the coating with good self-cleaning and adhesion [14].

Application of Nano-TiO_2 in Architectural Coatings

Nano-TiO_2 is not harmful to the human body, so it can be added to the coating to significantly improve the anti-ultraviolet properties of the coating. The photocatalyst of TiO_2 has better performance and can effectively degrade organic matter. Its bactericidal effect is better than that of hypochlorous acid, and it can be used to produce disinfectant and antifouling paint. In addition, Nano-TiO_2 coating has the following advantages: 1) It cam significantly improve the anti-scour ability, anti-aging and anti-pollution ability; 2) it can purify pollutants in the atmosphere, reduce volatile organic compounds and other harmful gases caused by tobacco; 3) the coating has good cold resistance, which can effectively solve the problem that harmful gases cannot be discharged into the room in time due to the improvement of building sealing ability [15].

3. Preparation and Properties of Nanocomposite Coatings

3.1. Raw Materials

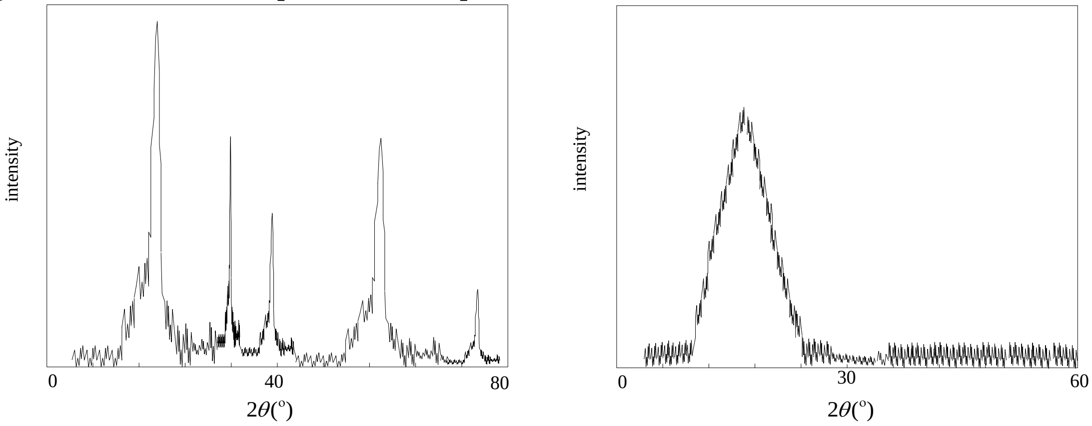
Nanomaterials

In recent years, with the continuous development of nanotechnology, a large number of nanomaterials have been industrially produced, and their application fields have gradually attracted people's attention. In order to ensure the stability and reliability of nanomaterials, some industrially produced nanomaterials are selected as raw materials and studied in this paper. Based on the properties of nano-powder materials in architectural coating system and the acidity of particle surface, nano-titanium dioxide and nano-silica powder are selected for modification experiments of coatings. Its main technical parameters are shown in Table 1.

Table 1. Main technical indicators of nano-titania and silica powder

	TiO_2	SiO_2
UV shielding rate (%)	⩾99	>85
Crystal phase	Rutile phase	Amorphous
Exterior	White loose powder	White loose powder
Particle shape	Acicular	Porous
Average particle size (nm)	Diameter 10, length 40	20±5
Specific surface area (m^2/g)	160±30	640±30
Bulk density (g/cm^3)	0.07-0.08	<0.12
Ignition reduction at high temperature (%)	⩽0.09	⩾99.5
Purity (%)	⩾99.9	>45

Figure 2 is an X-ray diffraction pattern showing two different types of nanopowders. As can be seen in Figure 2A, the spectrum matches the standard spectrum of rutile type TiO_2, indicating that it is rutile type. It can be seen from Figure 2B that there is a steamed bread peak at 2θ=23°, indicating that the silica is composed of amorphous.



A.X-diffraction pattern of nano-TiO_2 powder   B.X-diffraction pattern of nano-SiO_2 powder

Figure 2. X-diffraction pattern of nano-powder

Emulsion

Primers make up the majority of the coating's film-forming material, and the coating's film-forming quality is directly influenced by the primer's quality attributes. Therefore, it is important to choose high-quality polymer components for creating coatings. Pure acrylic, silicone acrylic, epoxy and other base materials are common architectural coatings for exterior walls. Other resins fall short of the superior qualities of fluorine-containing resin. However, because its application in the field of construction has just begun, there are technical problems in terms of cost and use, and it cannot be widely promoted at present. In this paper, a silicone acrylic emulsion with excellent performance was selected and used to make coatings, taking the pure acrylic emulsion as a reference. The main properties of the emulsion are shown in Table 2:

Table 2. The main properties of the emulsion

	Exterior	Total solids content	pH	Minimum film forming temperature
Indicator (Pure C)	Blue light, milky white liquid	501%	7.0~9.0	18 degrees Celsius
Indicator (silicon acrylic)	Milky white liquid	481%	7.5~9.0	25 degrees Celsius

Pigments and fillers

Pigments and fillers are the main components in paint, which can cover the paint and improve the strength of the paint. The filler, also known as the extender pigment, is insoluble in the coating and has no discoloration and coloring effect after being added to the matrix, which can not only reduce the production cost of the coating, but also improve the application effect, rheology, dispersion stability and protective effect of the coating.

The filler needs for latex paints are as follows [16]: provide the paint with the appropriate color so that the substrate can be covered and the color is more beautiful; reduce costs while minimizing the overall performance of the coating; improve the coating fluidity and plasticity.

Test equipment and instruments

The experimental equipment and instruments are shown in Table 3:

Table 3. Experimental equipment and instruments

Serial number	Model	Instrument
1	TG-704	Ordinary balance
2	MBE-100L	High-speed shearing emulsifier, the maximum speed is 10000r/min.
3	QL-425	Ultrasonic cleaner
4	NDJ-79	Rotational viscometer
5	WM2K-08	Temperature indicating controller
6	DW-40	Low temperature box
7	CS1012	Electric blast drying oven
8	L.XY-IV	Paint scrub tester
9	JSS-48AMS	Coating stain resistance flushing unit
10	QRS	Reflectance meter
11	QHQ-A	Coating pencil scratch hardness tester
12	QFD	Electric paint film adhesion tester

3.2 Experimental Methods and Test Indicators

Workability

The workability of paint refers to the difficulty of paint construction, which is used to check whether there is sagging, oil shrinkage, wire drawing, and painting difficulties in paint construction.

Drying time

The whole process from the liquid layer to the entire solid coating is called the drying period, which is the time it takes for the paint to change from a sticky to a solid coating.

Coverage capability

The ability of a coating to remove color on a substrate is called coverage, which is the ability to cover the substrate.

Washability

It is the ability to resist scrubbing. In the experiment, the number of times of washing with soap is used as the standard, and the number of times of washing that is kept as it is recorded.

Stain resistance

The stain resistance of paint refers to the difficulty of removing the dirt on the coating surface after being stained by pollutants such as dust and air suspension.

Freeze-thaw cycle resistance

The freeze-thaw cycle resistance of coatings, also known as coating temperature denaturation, refers to the ability to maintain the original characteristics of the coating under the condition of alternating temperature between cold and hot. After freeze-thaw cycles, changes in the surface state of the coating can be seen, manifesting as changes in powder, bubbles, cracking, spalling, etc.

Bond strength.

The strength of the combination of the coating and the surface of the object to be coated by physical and chemical forces is the bond strength.

Film hardness

Coating hardness is an important indicator reflecting the mechanical strength of the coating, and its physical meaning refers to the resistance of the coating to other objects with higher hardness. This resistance can apply the load to measure the coating's resistance within a small contact area to deformation from factors including bumps, dents, scratches, etc. The measurement is carried out in accordance with the *Pencil Measuring Method for Hardness of Coating Film*.

Acid resistance

Three test pieces made of GB 9125 were used to seal the periphery and back of the test piece with paraffin-rosin (weight ratio 1:1). Soak 2/3 of the area of the sample in the acid solution. At 23 ± 2 ℃, the surface of the sample was observed to be blistered, chalked, peeled off, and even the bottom was exposed [17].

3.3 Characterization of Dispersion Effect of Nano-powder Aqueous Suspension

The viscosity of the solution is expressed as follows:

$$(\eta-\eta_0)/\eta_0 = 2.5\phi\left[1+\frac{1}{\eta_0\gamma^2 k}\left(\frac{\varepsilon\varsigma}{\pi}\right)^2\right] \tag{1}$$

In the formula, γ is the particle radius in the solution; ς is the solution point; ε is the dielectric constant, and k is the conductivity of the solution; η is the overall dip of the sample solution, and η_0 is the dip of the medium in the solution. It can be seen from Formula 1 that the viscosity of suspended matter is related to the sedimentation amount, volume fraction, size and electric potential of suspended matter, but their action laws are different.

$$v_0 = \frac{(\rho_s-\rho_0)d^2}{18\mu}g \tag{2}$$

In the formula, g is the acceleration of gravity, and the final sedimentation speed v_0 is inversely proportional to the viscosity of the medium and is positively related to the apparent diameter d of the particles. The lower the precipitation rate, the greater the density of mucins μ; the greater the potential ρ_0, the greater the density ρ_s.

The DLVO theory believes that the interaction potential energy between particles is directly related to the surface potential energy of the particles, as shown in Formula (3) [18].

$$\phi = \frac{\kappa 64\prod_0 \kappa T\gamma_0^2}{\kappa}\exp(-\kappa d) \tag{3}$$

In the formula, ϕ_0 represents the potential, and γ_0 is the physical quantity related to the potential; κ represents the thickness of the electrical layer, and as γ_0 becomes larger, the surface repulsion energy increases. When ϕ_0 is high, γ_0 is approximately equal to 1, as shown in Formula (4).

$$\gamma_0 = \frac{\exp\left(\frac{ze\phi_0}{2kT}\right)-1}{\exp\left(\frac{ze\phi_0}{2kT}\right)+1} \tag{4}$$

There are a large number of hydroxyl groups on the surface of TiO_2 Nanomaterials, which may generate positively charged protons, or may lose protons and become negatively charged. At the isoelectric point, the rate of proton gain and loss of protons on the surface of TiO_2 reaches an equilibrium, resulting in the overall charged state of TiO_2. When the pH is higher than the isoelectric point, the proton concentration in the solution is lower and has a tendency to move outward, causing the hydroxyl group on the surface of TiO_2 to lose protons and become negatively charged [19].

Non-isothermal curing kinetics

The non-isothermal curing kinetic model is as follows [20]:

$$\ln\left(\frac{\beta}{T_p^2}\right)=\ln\left(\frac{AR}{E_a}\right)-\frac{E_a}{R}\cdot\frac{1}{T_p} \tag{5}$$

In the formula: R represents the gas constant; T_p represents the peak temperature of the curing reaction; E_a represents the apparent activation energy; β is the heating rate; A is the pre-exponential factor.

In general, the kinetic equation of the non-isothermal curing reaction of pure acrylic can be expressed as:

$$\frac{d\alpha}{dt}=\beta\frac{d\alpha}{dT}=K(T)f(\alpha) \tag{6}$$

In Formula (6), $f(\alpha)$ is the reaction mechanism function; α and β respectively represent the degree of reaction and the heating rate in the formula. Among them, K(T) follows the Arrhenius equation, representing the reaction constant:

$$K(T)=A\exp\left(\frac{-E_a}{RT}\right) \tag{7}$$

For the accuracy and convenience of calculation, two Målek function relations are introduced:

$$y(\alpha)=\left(\frac{d\alpha}{dt}\right)\exp(x) \tag{8}$$

$$z(\alpha)=\pi(x)\left(\frac{d\alpha}{dt}\right)\frac{T}{\beta} \tag{9}$$

T represents the absolute temperature (K), and $\pi(x)$ represents the integral of the temperature. The formula can be obtained:

$$x=\frac{E_a}{RT} \tag{10}$$

It can be expressed by the following relation:

$$\pi(x)=\frac{x^3+18x^2+88x+96}{x^4+20x^3+120x^2+240x+120} \tag{11}$$

Formula (6) is substituted into Formula (8), and the most suitable kinetic function can be judged by the values of $y(\alpha)$ and $z(\alpha)$ and the function graph.

$$f(\alpha)=\alpha^m(1-\alpha)^n \tag{12}$$

$$m=pn \tag{13}$$

m and n are the reaction order.

After Formula (7) and (12) are brought into Formula (6), the logarithms on both sides of the equation are removed simultaneously. The following equation can be obtained:

$$\ln\left[\left(\frac{d\alpha}{dt}\right)e^{x}\right]=\ln A+n\ln[\alpha^{p}(1-\alpha)] \tag{14}$$

$$p=\alpha_{M}/(1-\alpha_{M}) \tag{15}$$

$$\alpha_{M}\in(0,\alpha_{p}) \tag{16}$$

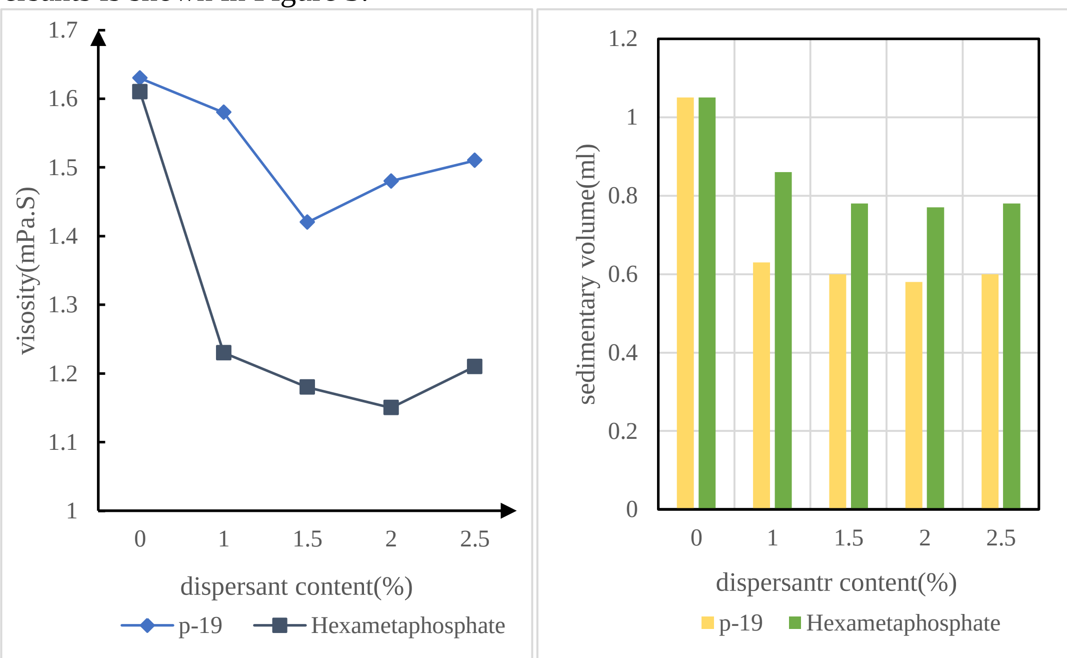
Namely:

$$Y=\ln\left[\left(\frac{d\alpha}{dt}\right)e^{x}\right] \tag{17}$$

$$X=\ln[\alpha^{p}(1-\alpha)] \tag{18}$$

If Formula (14) is used to plot, the ordinate is Y and the abscissa is X. According to the linear regression method, the slope is n and the intercept is ln A. The linear correlation coefficient R is 0.9952~0.9991, and the curing kinetic parameters of the system at different temperatures are obtained.

In order to ensure the dispersibility of nano-powders under weak alkaline conditions, this paper selected a method for measuring the dispersibility of nano-powders in aqueous media, namely sodium hexametaphosphate, sodium polyacrylate (P-19) [21]. The comparison of the effects of the two dispersants is shown in Figure 3.



A. Relationship between viscosity and dispersant

B. Relationship between settling volume and dispersant

Figure 3. Effect of anionic dispersants on the stability of nanopowders

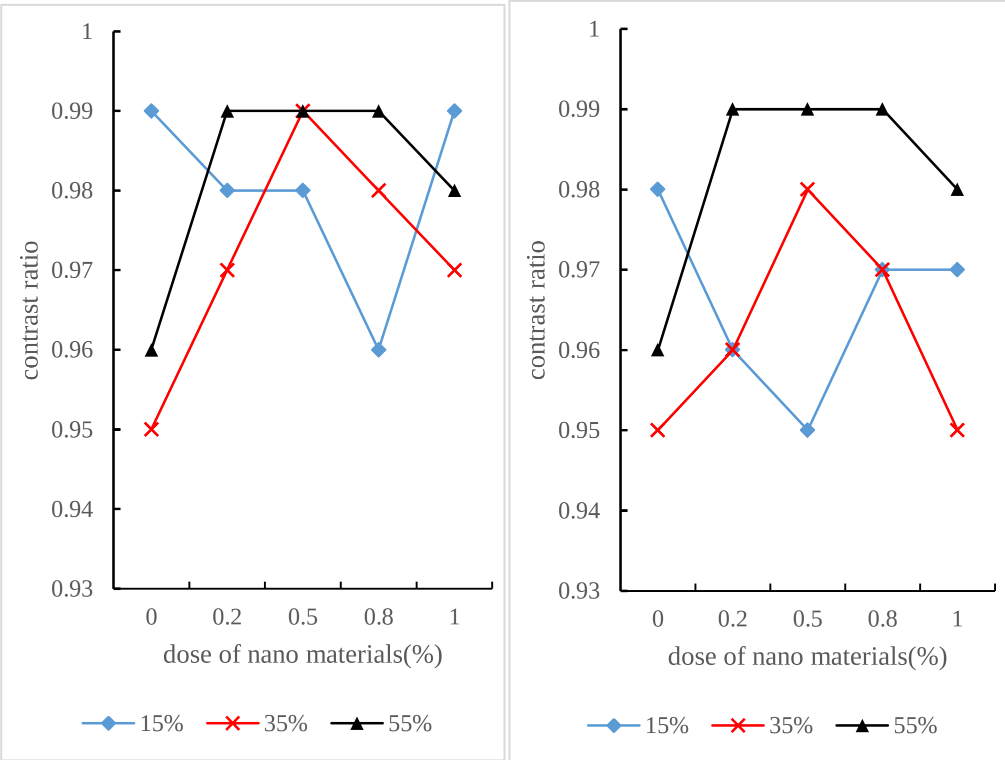
As shown in Figures 3A and 3B, the addition amount of sodium hexametaphosphate is 2%. In general, when the addition amount of P-19 is 1.5%, the viscosity is the lowest; the precipitation amount is the lowest, and the dispersion effect is the best.

3.4. Fabrication and Performance testing of Nanocomposite Exterior Wall Coatings

PVC in this context refers to the bulk density of coatings and fillers in dry film. In the coating system, the ratio of pigment and matrix has a great influence on the composition and properties of the coating. On this basis, the effects of different pigment mass fractions on the properties of nanocomposite coatings were studied. 15%, 35%, and 55% of the pigment volume density were selected, and then different dosages were added to the prepared aqueous suspension of nano-TiO_2 and silica composite components to make a new type of nano-composite exterior wall coating. The main performance was tested.

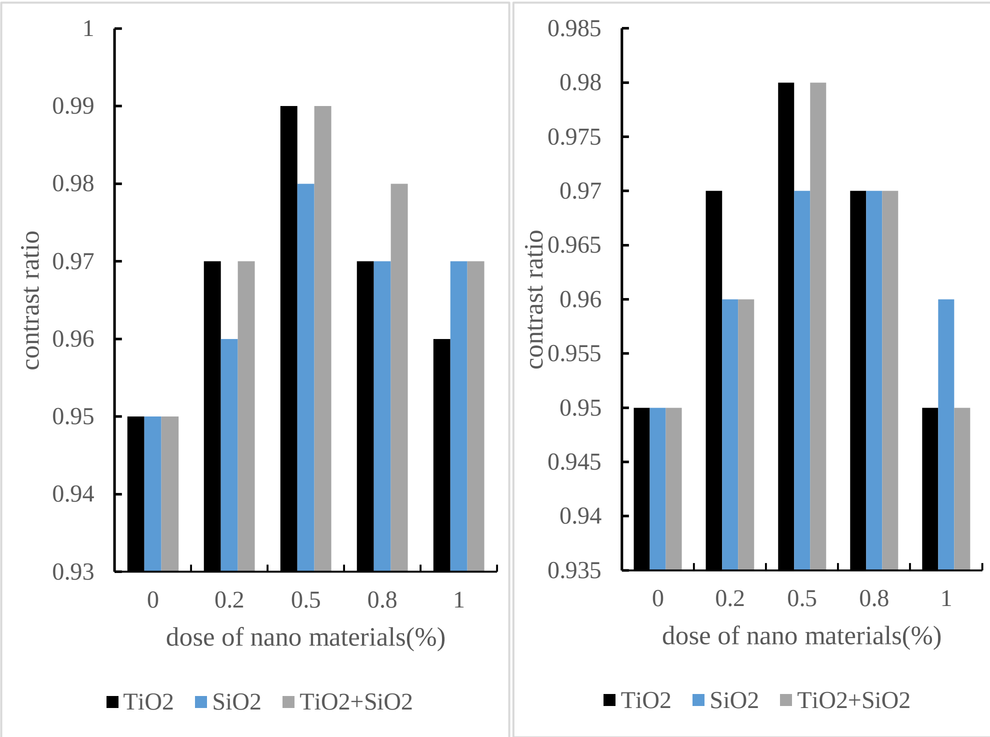
Nanocomposite exterior paint contrast ratio

Figures 4 and 5 showed the effects of PVC and different nanomaterial components on the contrast ratio of pure acrylic and silicone-acrylic system exterior paints.



A. Contrast ratio of compound pure acrylic *B. Contrast ratio of composite silicon acrylic*

Figure 4. The relationship between PVC and paint contrast ratio



A. Contrast ratio of pure acrylic exterior wall paint
B. Contrast ratio of silicone acrylic external wall paint

Figure 5. The relationship between nanocomponents and paint contrast ratio

As shown in Figures 4A and 4B, when the PVC is 15%, with the increase of nano-components, the contrast ratio increases from low to high. After adding nano-components, the ratio of pure acrylic and silicon acrylic does not increased but decreased. When the PVC content is 35% and 55%, the contrast ratio increases with the improvement of the content. When the addition amount is 0.5%, the contrast ratios all reach the maximum value. When the PVC content is 55%, the contrast ratio is greatly improved.

It can be seen from Figure 5A and Figure 5B that the effect of different nanomaterial components on the contrast ratio is consistent. With the increase of the dose, it shows a trend of first increasing and then decreasing. When the additive dose is 0.5%, $TiO_2 + SiO_2$ compound group has the best effect. The contrast ratios of pure acrylic paint and silicone acrylic paint are increased from 0.95 to 0.99 and 0.98, respectively.

Nanocomposite exterior paint pencil hardness

The analysis results of the effect of PVC and nano-components on the pencil hardness of pure acrylic and silicone-acrylic exterior wall coatings are shown in Table 4 and Table 5.

Table 4. Pencil hardness of nanocomposite exterior wall coatings of different PVC

Amount of nanomaterials (%) / PVC	0	0.2	0.5	0.8	1
15% (Pure acrylic/silicone acrylic)	2B/B	2B/B	2B/B	3B/3B	3B/3B
35% (Pure acrylic/silicone acrylic)	2B/B	HB/H	H/2H	H/2H	H/2H
55% (Pure acrylic/silicone acrylic)	B/B	B/2B	B/B	B/B	B/B

Table 5. Pencil hardness of nanocomposite exterior wall coatings with different nanocomponents

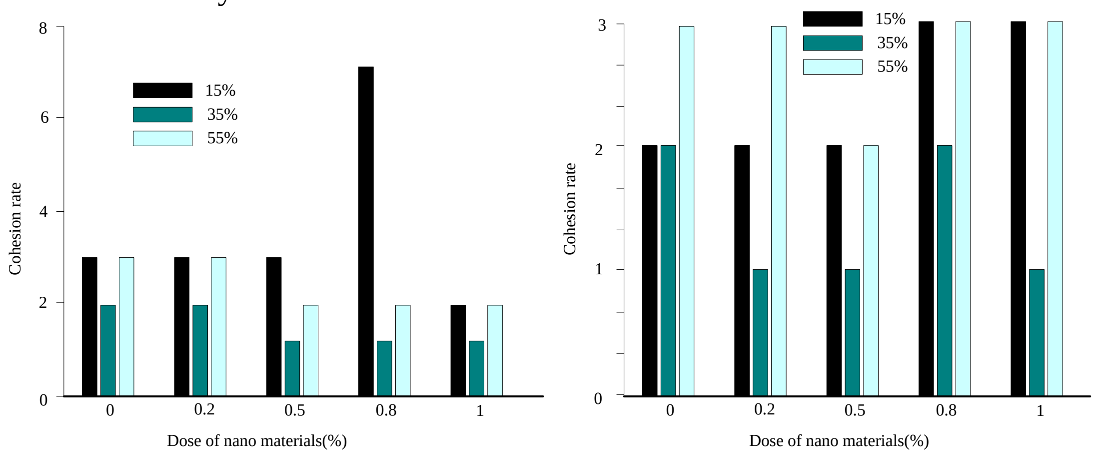
Nano components \ Amount of nanomaterials (%)	0	0.2	0.5	0.8	1
Nano TiO_2 (Pure Acrylic/Silicone Acrylic)	2B/B	2B/HB	HB/HB	HB/HB	B/HB
Nano SiO_2 (Pure acrylic/silicon acrylic)	2B/B	B/H	H/H	HB/H	HB/H
Nano $TiO_2 + SiO_2$ (Pure acrylic/silicon acrylic)	2B/B	HB/H	H/2H	H/2H	H/2H

It can be seen from Table 4 that when the PVC is 15% and 55%, the pencil hardness of the coating has no significant effect, and even has a downward trend. When the PVC is 35%, nanomaterials can significantly improve the pencil hardness of exterior wall coatings.

It can be seen from Table 5 that the nanomaterial components have a significant effect on the hardness of the coating. The three different nanomaterial components can effectively improve the hardness of the coating. On the whole, nano $TiO_2 + SiO_2$ has a great influence on hardness. When the additive amount is 0.5%, the hardness of pure acrylic coating and silicon acrylic coating is increased by three grades.

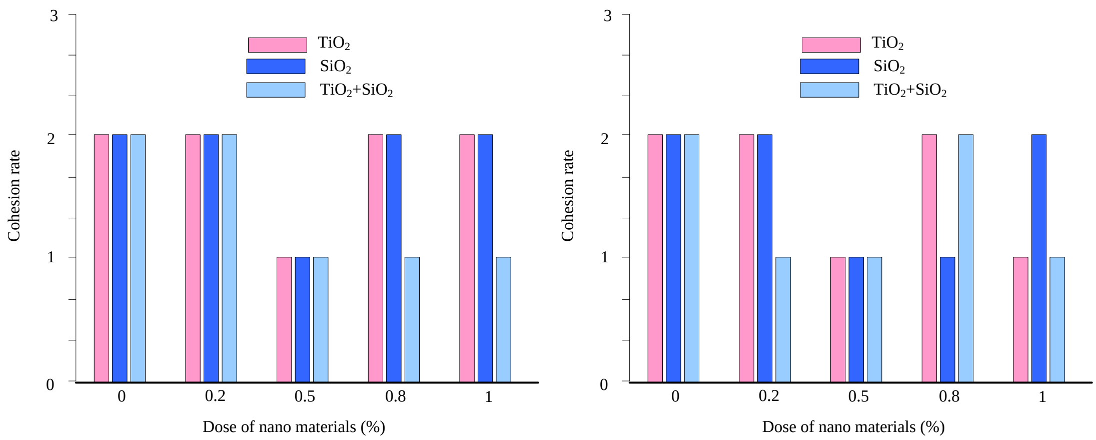
Nanocomposite exterior paint adhesion

Figures 6 and 7 showed the results of the analysis of the effects of PVC and nanomaterial components on the two systems on the exterior wall.



A. Pure acrylic paint adhesion B.Silicone acrylic paint adhesion

Figure 6. Effect of PVC on the adhesion of nanocomposite coatings



B.Adhesion of pure acrylic exterior paint B.Silicon acrylic exterior paint adhesion

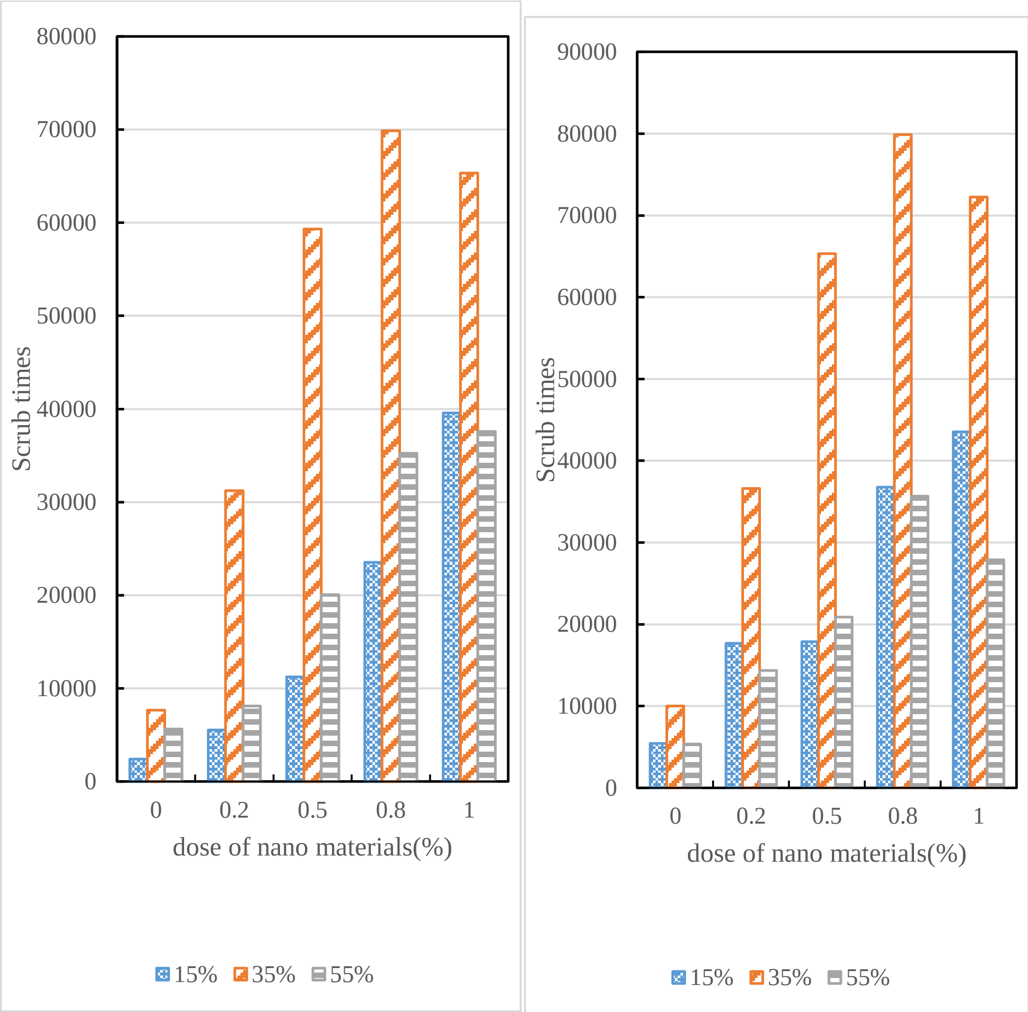
Figure 7. Influence of nanomaterial components on the adhesion of exterior paint

As shown in Figures 6A and 6B, when the PVC is 15%, the adhesion of the paint coating can not be improved after adding nanomaterials. When the PVC content is 35% and 55%, the adhesion of the coating can be improved after adding 0.5% nanoparticles.

From Figure 7A and Figure 7B, it can be seen that the addition of nanomaterials has a certain effect on the adhesion of the exterior wall paint, and the coating adhesion grade is the best when 0.5% of the nanomaterials are added.

Washability of nanocomposite exterior wall coatings

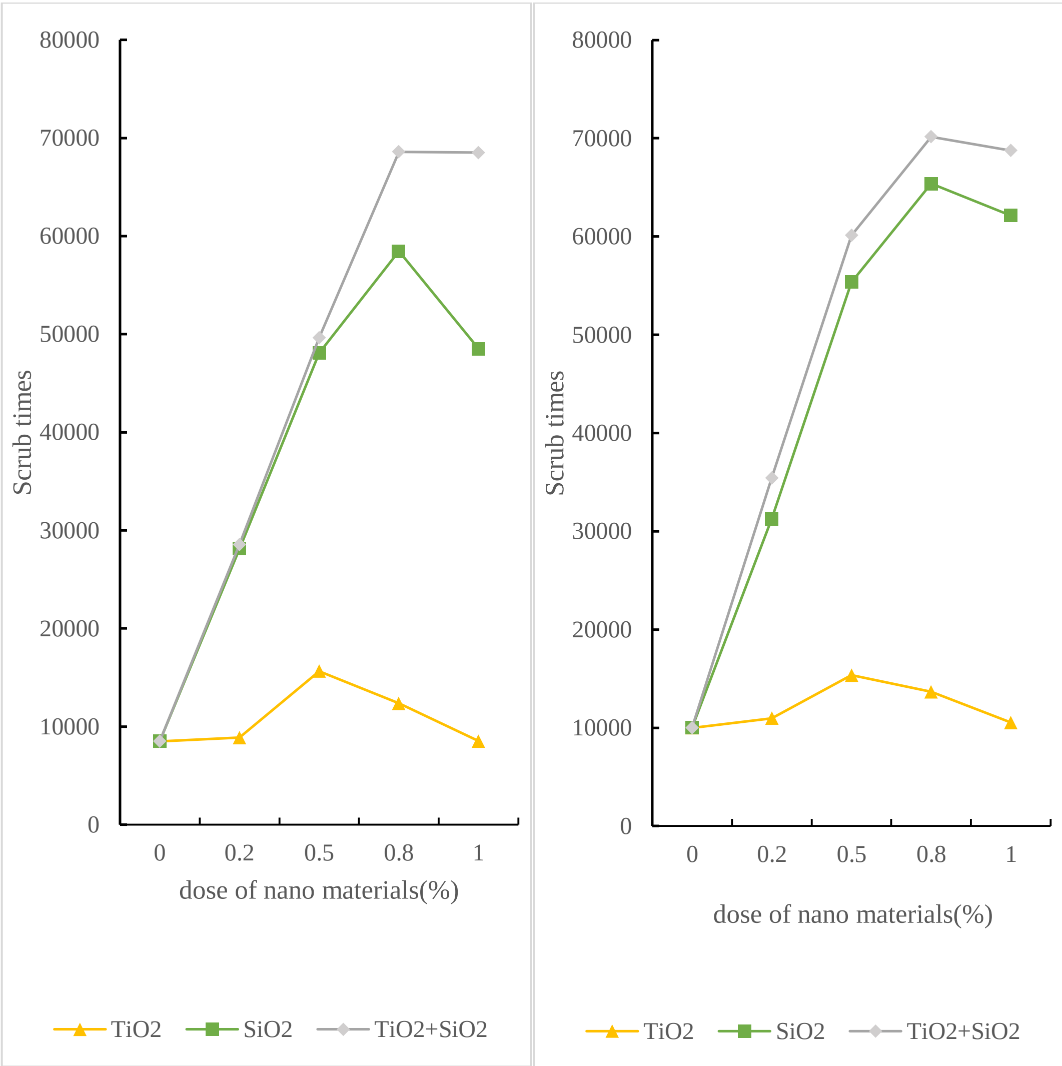
Figure 8 and Figure 9 showed the results of the analysis of the effects of PVC and nanomaterial components on the scrub resistance of pure acrylic and silicone-acrylic exterior paints.



A. Washability of composite pure acrylic

B. Washability of composite silicone acrylic

Figure 8. The relationship between PVC and material washing resistance



A. Scrub resistance of pure acrylic exterior wall paint

B. Scrub resistance of silicone acrylic exterior wall paint

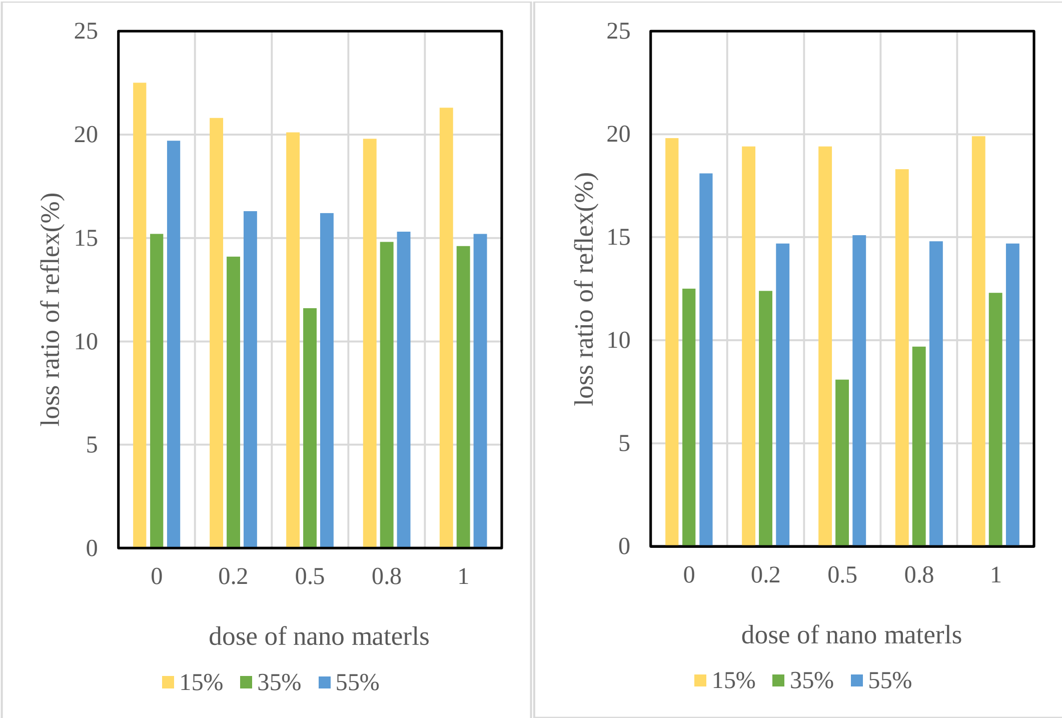
Figure 9. The relationship between nanocomponents and paint washability

As shown in Figures 8A and 8B, under different conditions of PVC, with the increase of nanometer addition, the anti-scouring properties of the coatings are improved. Compared with the composite coating of 15% and 55% PVC, 35% PVC has better scrub resistance.

As shown in Figures 9A and 9B, the difference in nanocomponents has a significant effect on scrub resistance. Nano-titanium dioxide has little effect on the abrasion resistance of coatings. However, nano-$TiO_2 + SiO_2$ composite group and nano-silica can significantly improve the abrasion resistance of coatings. The scrub resistance of nano-silica + silica composite group pure acrylic and silicon-acrylic coatings has been improved the most, reaching 49653 and 60124 respectively when the nanomaterial addition amount is 0.5%.

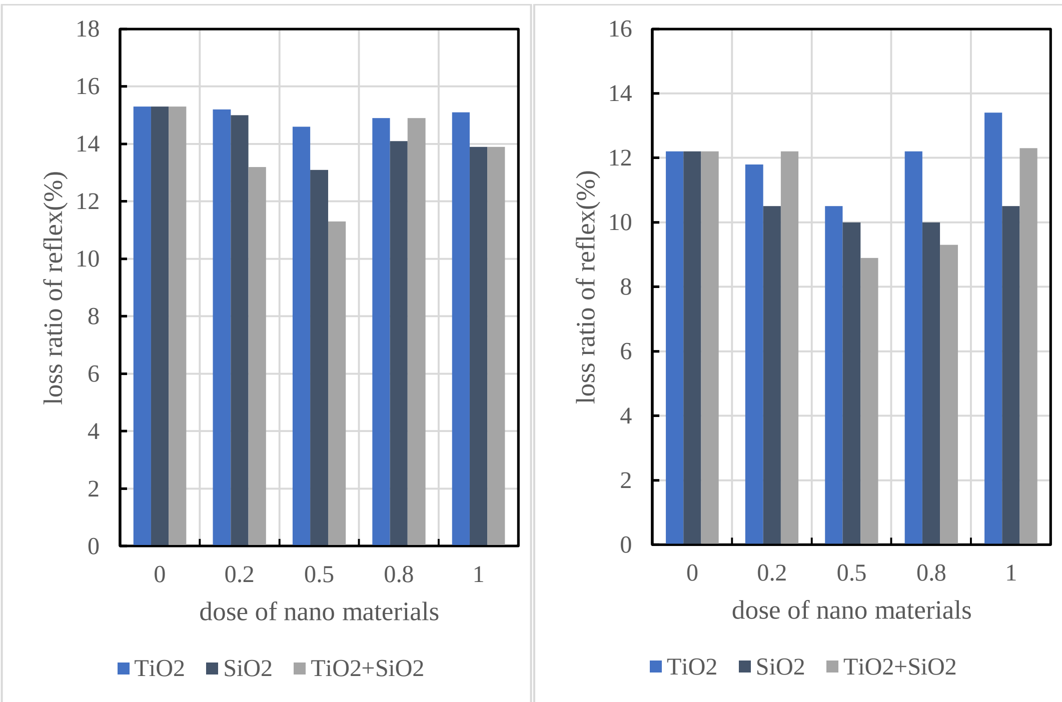
Effect of nanocomposite exterior wall coatings on stain resistance

Figure 10 and Figure 11 showed the analysis results of the effect of PVC and nano-components on the stain resistance of pure acrylic and silicone-acrylic exterior wall coatings.



A. Stain resistance of composite pure acrylic B. Stain resistance of composite silicon acrylic

Figure 10. The relationship between PVC and material stain resistance



A. Stain resistance of pure acrylic exterior paint

B. Stain resistance of silicone acrylic exterior paint

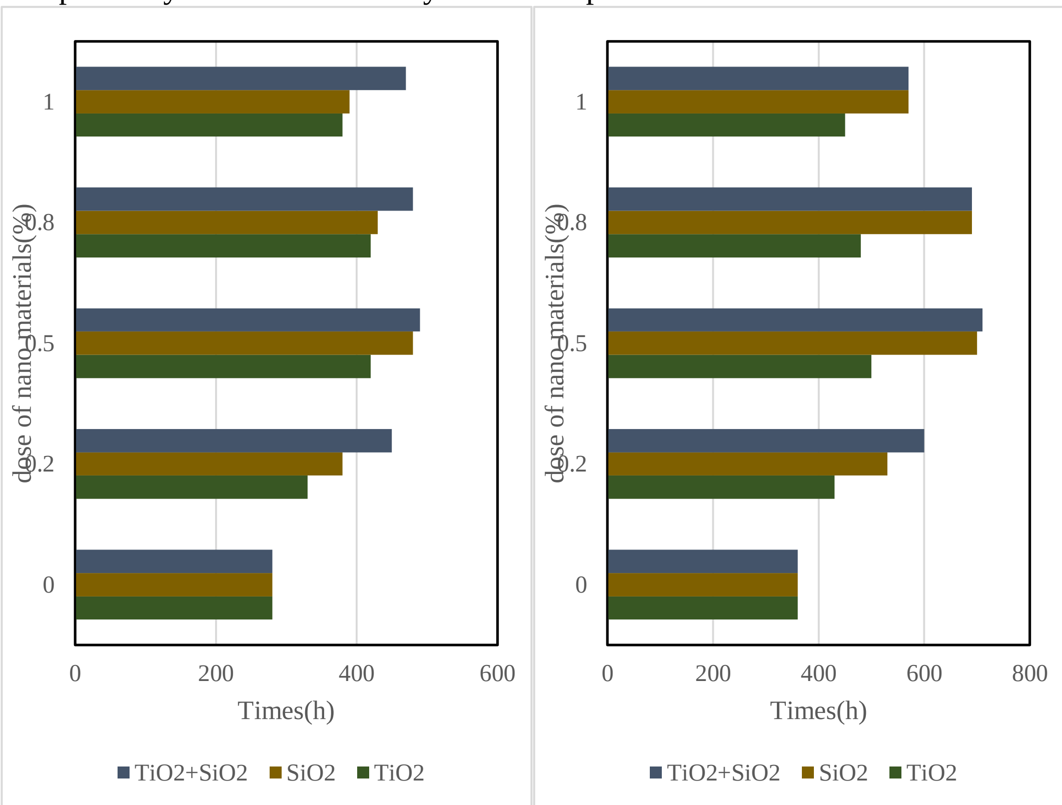
Figure 11. The relationship between nano-components and stain resistance of coatings

As shown in Figure 10A, in the pure acrylic system, the anti-fouling performance of the paint coating is not significantly improved after adding 15% PVC and does not meet the national high-quality standard (reflection coefficient reduction rate ⩽ 15); when the PVC is 55%, the anti-fouling performance of the pure acrylic film is improved after adding nanomaterials, but it does not meet the high-quality product standards stipulated by the state; when the PVC is 35%, the anti-fouling performance of the pure acrylic coating is significantly improved, and it is an excellent product. As shown in Figure 10B, the 35% PVC silicone acrylic coating has better anti-staining performance, while the 15% PVC has the worst anti-staining performance. PVC is one of the main performance indicators of exterior wall coatings. When there are less high molecular weights in the coating, the modification of the polymer has no effect on the antifouling properties of the coating.

It can be seen from Figure 11A and Figure 11B that after adding the nanomaterials, almost all the coating layers reach the national standard high-quality products. Overall, the Nano $TiO_2 + SiO_2$ composite group is better than the single group. When the additive amount is 0.5%, the anti-fouling index of pure acrylic and silicone acrylic coatings decreases by 4 percentage points and 3.3 percentage points.

Effect of Nanomaterial Components on Acid Resistance of Building Exterior Wall Coatings

Figure 12 showed the analysis results of the effect of nanomaterial components on the acid resistance of pure acrylic and silicone-acrylic exterior paints.



A. Acid resistance of pure acrylic exterior paint

B. Acid resistance of silicone acrylic exterior paint

Figure 12. The relationship between nano-components and acid resistance of coatings

As shown in Figures 12A and 12B, when the addition amount of nano-TiO_2, nano-silica, and nano-$TiO_2 + SiO_2$ composition is 0.5%, the acid resistance is the best; the acid resistance of pure acrylic exterior paint reaches 490 hours; the acid resistance of silicone-acrylic exterior wall paint reaches 710 hours. The improvement effect of nano-silica on exterior wall paint is greater than that of nano-TiO_2. In addition, silicone acrylic can improve acid resistance better than pure acrylic exterior wall paint.

3.5. Mechanism of Nanomaterials to Improve the Performance of Exterior Wall Coatings

The coating is mainly composed of pigments, fillers and matrix polymers, and its volume concentration has an important influence on the structure and properties of the film. Due to the distribution of nanoparticles in the coating system, the interaction of coating components has a certain influence on the modification effect of the coating.

The experimental results showed that when the PVC is 35%, the properties of the coating have a good comprehensive improvement effect after adding 0.5% titanium dioxide and nano-silica. It is mainly manifested in: the contrast ratio of pure acrylic paint and silicone acrylic paint is increased from 0.95 to 0.99 and 0.98; the hardness is increased by 3 grades; the wear resistance is 49653 and 60124 respectively; the pollution tolerance index dropped by 4 percent and 3.3 percent, respectively. When the PVC is too high (55%) or too low (15%), the improvement effect of nanomaterials is not as good as 35%. Only under suitable PVC can nanomaterials fully develop their special properties. When the PVC is too low, the content of the binder in the coating is too high, resulting in an increased chance of the nanomaterial reacting with the resin, but the interaction with the pigment can be weakened, resulting in that its properties cannot be fully exerted, and some properties of the coating can be affected. There is no significant effect on some properties of the coating.

Nano-silica and TiO_2 have a smaller particle size and a larger number of surface atoms with larger coordination loss, which are easy to link with oxygen, thereby increasing the bonding force between molecules and the bonding strength between the coating and the substrate; moreover, during the coating process, nano-silica can form a network structure to greatly improve the strength and density of the coating; in addition, silica is a three-dimensional chain structure, and its surface has hydroxyl groups in different bonding states, which can react with hydroxyl groups in latex to form macromolecules and greatly improve the erosion resistance of the coating.

TiO_2-nano particles have a good particle size distribution, which can well fill the pores formed by the micron-sized filler particles, so that a dense nano-TiO_2 film can be formed on the surface of the coating, thereby improving the anti-fouling property of the coating. The anti-fouling effect of nano-silica is remarkable, because the particles of nano-silica are very small, so after coating on the substrate, the originally rough surface can be covered by nanoparticles. The results showed that the surface of the nano-modified coating is obviously smooth; in addition, its network structure can form a relatively complete film to make it difficult for pollutants to adhere, thus improving its anti-fouling performance.

4. Conclusion

When the coating is formed into a film, due to the volume reduction of the coating itself, there is a certain expansion between the coating and the substrate, resulting in shrinkage and thermal stress between the coating and the substrate. Although these stresses cause molecular movement between the interfaces, which is also known as the relaxation process, residual internal stresses can disrupt the bond. In addition, TiO_2 nanometer material has many surface atoms, high surface energy, and serious coordination of surface atoms with high surface activity and strong adsorption capacity.

After being added to the coating, it can easily bond with oxygen, thus enhancing the bond strength of the coating to the substrate. Studies have found that properties of the coating can be improved after adding certain ingredients to the coating. The nanoscale of TiO_2 mainly improves the contrast ratio of the coating, and the role of nano-silica is to improve the surface properties of the coating, such as anti-scour properties. Therefore, adding these components at the same time can maximize the synergistic effect and complementarity, so that the overall performance of the coating can be significantly improved.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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