Application of Functional Nanomaterials in Process Design and Art Design

Meng Liu

Academy of Fine Arts, Hulunbeier University, Hulunbeier 021008, Inner Mongolia, China

Correspondence should be addressed to Meng Liu; liumeng@hlbec.edu.cn

Received 14 June 2022; Revised 11 July 2022; Accepted 21 July 2022; Published 5 September 2022

Academic Editor: Raghavan Dhanasekaran

Copyright © 2022 Meng Liu. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Coating is a kind of decorative material with decorative function, protection function, adjustment function, and various special functions. In recent years, with the continuous improvement of people’s material living standards, the relationship between environmental protection and health, environment and future development, and environment and nature has been increasingly deepened. The coating industry has developed rapidly in recent years. Nanomaterials have received much attention for their unique physical and chemical properties. Using nanomaterials to modify traditional coatings is a way to rapidly improve the development of the coating industry. In this paper, the properties and preparation technology of nano-TiO₂ and nano-ZnO are reviewed, the photocatalytic mechanism of TiO₂ and ZnO nanomaterials is discussed, and the two are applied in traditional coating systems to develop nanocomposite coatings. When nano-TiO₂ and nano-ZnO components were added to the pure acrylic and silicon acrylic coatings according to a certain proportion to explore the influence of different proportions of nanomaterials on the performance of the above coatings. The results showed a significant improvement in the main performance of the coating at the addition amount of 0.4%. Overall, the modification effect of the nanocomposite component was the most significant, and the nano-ZnO was better than the nano-TiO₂, and silicon propylene paint is better performance than pure propylene paint. The ratio of coating pairs prepared in the experiment was 0.98, the brush resistance number was 1990, the adhesion level was level 1, and the reflectance was decreased by 8.58%. The introduction of functional nanomaterials can significantly improve the contrast ratio, scrub resistance, and adhesion of coatings.

1. Introduction

A coating is a coating with good adhesion, which can cover the surface of an object so that it has good adhesion. The use of coating is very wide, and people’s daily life, national economy, and national defense construction are closely related to it. Handicraft coating is a kind of surface material with decorative function, protection function, adjustment function, and various special functions. Decoration function is used for the beautification effect of paint, and it improves the artistic effect of handicrafts; protection function is to prevent or reduce the external environment to crafts, such as oxidation and corrosion. Adjustment function refers to the use of different coatings and appropriate processing process, which can make the characteristics of the coating change. Special function refers to some coatings with mildew prevention, sterilization, thermal insulation, fire prevention, and other special special functions [1, 2].

Nanotechnology refers to a product that controls atoms and molecules within the spatial scale of 1 to 100 nm to process and produce materials. This paper studies a chemical so as to understand the atomic and molecular movement of the law and characteristicsof the new high-tech discipline. Its development has opened up a new stage of understanding of the world. The general application of nanomaterials refers to a metal material with at least one-dimensional nanoscale (usually 1~100 nm) in three dimensions. The application of nanomaterials has surface effects, small-scale effects, and macroscopic quantum tunneling effects, and it shows a series of special thermodynamic, electronic, optical, magnetic properties, and catalytic properties, so they are praised as the most
promising new material in the 21st century [3]. New functional nanomaterials have unique biomolecular characteristics, high light absorption capacity, chemical orientation characteristics, high biocompatibility, and molecular compatibility, which can increase the immobilization capacity of biomolecules (such as enzymes, DNA, etc.), label life molecules, catalyze biological reactions, accelerate electron transfer, and increase rated current signals, etc. It also can greatly enhance the optical efficiency, magnetic, electrical, and thermodynamic properties of coatings. Therefore, the research and development of functional nanocoatings will also become a key to coating research [4]. With the rapid development of nanoscience and technology, the development and application of nanoemulsion, nanopigment, and filler have created a new way for the development of high-performance coatings in the future.

According to the conventional water-based latex material, the coating is modified by using a small number of functional nanomaterials. It effectively reduced the production cost without affecting the original production process. At the same time, it enhanced the antiwashing brush, antipollution, and qualitative coating, so as to improve the effectiveness of the original latex coating, and make the coating has antibacterial, sterilization, photocatalytic degradation, and other characteristics. It improved the performance of traditional latex coatings and improved its cost performance. This paper aims to promote the use of functional nanomaterials, promote the sustainable development of decorative art, and provide a reference for the promotion and application of energy-saving, which provides a reference for the promotion and application of energy-saving, green, and environmentally friendly functional nanomaterials.

2. Related Work

In recent years, the research results of the preparation and performance of functional nanomaterials by researchers from all over the world have been emerging, and rich achievements have been obtained in the fields of mechanical properties, physical properties, and microstructure of nanomaterials. Wang et al. used direct optical lithography to study a functional inorganic nanomaterial. The method of directly generating inorganic layers with the same exposure dose as organic photoresists opened up a new way for the preparation of thin-film devices. Experiments confirmed that the electrical conductivity, carrier mobility, dielectric, and luminescence properties of the optically patterned layer are comparable to those of the state-of-the-art solution-processed materials, which contributes to the realization of good electronic and optical properties of functional nanomaterials [5]. Wongkaew et al. discussed functional nanomaterials and nanostructures that enhance electrochemical biosensors and lab-on-a-chip performance. He answered many questions about the inherent properties of nanomaterials used in 2013–2018, their chemical properties of interest to analytical systems, and their role in analytical applications, and quantitatively assessed their positive impact on analysis [6]. It is helpful to gain insight into how functional nanomaterials can be effectively used in electrochemical biosensor-based lab-on-a-chip devices. Xiaojing developed a robust porous superhydrophobic composite (PSC) based on a multiwalled carbon nanotube network and a poly (ethylene-vinyl acetate) matrix for the reconstruction of recoverable structures and underwater vibration detection. Chi and Lee explored the important characteristics of functional nanomaterials, and they developed an ultra-small Mo2C nanoparticle dopamine and MoO42– dispersed on 3D carbon microflora by self-polymerization. This nanostructured material exhibits remarkable hydrogen evolution reactivity and stability in both acidic and alkaline solutions [8]. Zhong et al. reviewed the development of nanomaterial-based CL detection strategies and their applications in bioanalysis, highlighted recent advances in nanomaterials in CL detection and classified them into three groups according to their role in detection: as sensing platforms, as signaling probes, and applications in homogeneous systems [9]. Trulove PC utilized an ionic liquid-based approach to integrate functional nanomaterials into biopolymer composites. He synthesized metallic silver nanoparticles in flax meal using the initial wet dipping method. By controlling the amount of silver nitrate added during the synthesis, a flax meal with different concentrations of silver particles was prepared. The composites were experimentally characterized by XPS, SEM, EDS, ATR-IR, and Raman spectroscopy. The results showed that silver nanoparticles were uniformly distributed in all flax meals [10].

3. Functional Nanomaterials

Functional nanomaterials are generally agglomerated solids formed by pressing, sintering, and sputtering particles with a particle size of 1–100 nm [11]. According to their state of existence, they can be divided into tiny particles and nanoparticles, and their volume ratios are basically equal. One is several or dozens of nanoparticles, and the other is the interface between particles. The former is a crystal structure with a long program, and the latter is a disordered structure without a long program or a short program. Nanoparticles have three forms: crystalline, quasicrystalline, and amorphous. Since its size is smaller than that of atoms consisting of hundreds of atoms, its microstructural properties can change its macroscopic physical properties and expand its application range [12]. The effects involved in nanoparticles mainly include the following categories.

3.1. Surface Effect. The surface area of a spherical particle is proportional to the square of its diameter, so its surface (surface volume) is inversely proportional to its diameter. When the particle size becomes smaller, the specific surface area of its surface also increases. As the particle diameter decreases, the number of atoms on the particle surface increases rapidly, and the energy on its surface increases accordingly. The surface effect of nanomaterials means that with the decrease of particle size, the ratio of surface atoms to total atoms of nanoparticles increases, thereby changing
their properties [13]. Due to the small size of nanoparticles, the large ratio of atoms to atoms, the strong adhesion between atoms, and the lack of adjacent atoms between atoms, there are a large number of dangling bonds, which are unsaturated and have high chemical activity, so the surface reaction ability of nanoparticles is extremely strong, which is easy to react with other atoms and molecules [14]. This not only causes the migration of atoms on the surface of the nanoparticle and the change of the atomic structure, but also affects the change of the electron spin structure and energy spectrum on the surface of the nanoparticle. This makes it quite different from ordinary particles in absorption, magnetism, thermal resistance, chemical activity, catalytic activity, melting point, etc., so it has great development potential in catalytic kinetics and thermodynamics.

3.2. Small Size Effect. The small size effect of nanoparticles, also known as the volume effect, refers to the changes in physical properties such as electricity, magnetism, sound, heat, light, etc., caused by the reduction of particle size [15]. In terms of particle size and physical scales such as de Broglie wavelength, light wavelength, and superconducting state coherence length, particles will produce new physical properties in terms of sound, light, and magnetism. The small size effect of nanoparticles is mainly manifested in the following aspects: resistance and size changes of nanometal materials, changes in broadband absorption characteristics, improvement of exciton absorption properties, transition from magnetic ordered states to disordered magnetic ordered states, transformation of superconducting states, high coercivity of nanomaterials, etc.

3.3. Macroscopic Quantum Tunneling Effect. The macroscopic quantum tunneling effect is a basic quantum mechanical phenomenon, which refers to a nanoparticle whose energy is below the potential barrier height, which can still exceed the energy barrier height of the macroscopic system [16]. In recent years, researchers have discovered that tunneling effects exist between the magnetization of small-scale particles, the magnetic flux in quantum coherent devices, and the charges carried by particles, which can be changed by the potential barriers of macroscopic systems. Therefore, it is called the macroscopic quantum tunneling effect. Macroscopic quantum tunneling can determine the possibility of minimizing microelectronics and how long tape signals are stored.

3.4. Quantum Effect. As the particle size of the nanoparticles decreases, the electron energy level close to the Fermi level transitions from the quasiquantum energy level to the dispersion level, with discontinuous maximum occupied molecular orbital energy level and minimum unoccupied molecular orbital energy level. The width of the energy level increases, and the absorption spectrum is red-shifted, which is the quantum effect [17]. The quantum-scale effects of nanoparticles mainly include the transformation of conductors into insulators, the phenomenon of absorption spectrum changes, the change of magnetic susceptibility, and the peculiar luminescence phenomenon.

Surface effect, small size effect, quantum effect, and macroscopic quantum tunneling effect are all inherent properties of nanomaterials, and these basic properties also make nanomaterials have unique physicochemical properties. Therefore, the addition of nanomaterials to the coating will also make the coating part obtain these special effects, thereby giving the coating different conventional mechanical, optical, electrical, and magnetic properties.

The dispersion stability mechanisms of coatings include DLVO theory, steric stabilization mechanism, and vacancy stabilization mechanism, which can be used to explain the dispersion of functional nanoparticles in coating systems [18].

3.4.1. DLVO Theory. The DLVO theory, also known as the electric double layer stability theory, refers to the formation of an electric double layer system between the particles and the liquid phase. When a nanoparticle is positively charged, a layer of negative charge attaches to its surface, forming an electric double layer similar to Figure 1. This theory points out that in a specific environment, the existence and aggregation of sols are determined by the competition between the mutual attraction and electrostatic repulsion between particles [19]. If the proportion of electrostatic repulsion is large, the sol will become very stable; if the proportion of mutual attraction is large, the sol will also be unstable. When the charged particles are close to the electric double layer, a large electrostatic repulsion force will be generated. The smaller the distance between particles, the greater the repulsive force. The electric double layer theory can well explain the stability of nanoparticles in an aqueous solution.

3.4.2. Space Stabilization Mechanism. The study of steric stability is mainly to explain the adsorption of polymer materials on the surface of functional nanoparticles [20]. When the polymer material is adsorbed on the surface of the nanoparticles, if the polymer has a long chain that can be dissolved by the solvent in the coating system, the two adsorbed nanoparticles will approach each other. This leads to an increase in the molecular concentration between the molecules, which creates a difference in osmotic force between the nanoparticles, resulting in the separation of the nanoparticles. When the nanoparticles are close to each other, the adsorbed polymer chains are also compressed, resulting in rebound and separation of the nanoparticles. Therefore, in order to maintain a certain dimensional stability, the thickness of the adsorption layer must be large enough. The steric stability mechanism is shown in Figure 2.

3.4.3. Vacancy Stabilization Mechanism. The vacancy stabilization theory is used to explain that the repulsive force can reduce the concentration of polymer on the surface of two nanoparticles that are close to each other [21]. That is,
3.5. Nanotitanium Dioxide. In recent decades, nanotitanium dioxide has attracted much attention due to its photoinduced electrical conversion phenomenon. Titanium dioxide exists in three crystal structures: anatase titanium dioxide \((a = h = 3.78 \times 10^{-10} \text{ m}; c = 9.50 \times 10^{-10} \text{ m})\), brookite titanium dioxide \((a = h = 4.58 \times 10^{-10} \text{ m}; c = 2.95 \times 10^{-10} \text{ m})\), and rutile titanium dioxide \((a = 5.43 \times 10^{-10} \text{ m}; h = 9.16 \times 10^{-10} \text{ m}; c = 5.13 \times 10^{-10} \text{ m})\) [22]. The most stable crystal phase of titanium dioxide is the rutile phase, and both anatase and brookite phases can be transformed into the rutile phase during high temperature treatment. The research showed that among the three crystal structures, the anatase type exhibits better photocatalytic activity and antibacterial properties. Anatase titanium dioxide is therefore widely used in antibacterial self-cleaning building materials. The photocatalytic effect of titanium dioxide in the coating comes from its electronic structure characteristics: TiO₂ is an N-type semiconductor material, and its electronic structure has an empty conduction band and a full valence band. Its photocatalytic mechanism is shown in Figure 3.

When TiO₂ captures photons of \(\lambda \leq 387.5 \text{ nm}\), electrons in the valence band acquire photons and transition to the empty conduction band, so holes \((h^+)\) are generated in the valence band. There is an electron \((e^-)\) in the conduction band. The excited electron is more active than ordinary electrons. O₂ in the air can react with it to generate highly active \(O_2^-\). At the same time, water vapor \((\text{H}_2\text{O})\) in the air will also be absorbed by holes \((h^+)\) to generate highly active hydroxyl radicals \((\cdot\text{OH})\). At this time, the organic matter adsorbed by the coating containing TiO₂ will react with hydroxyl radicals \((\cdot\text{OH})\) with a strong oxidizing ability to generate water and carbon dioxide. This one-step reaction is a key step for people to utilize the photocatalytic properties of TiO₂, and the rest of the reactions are side reactions, but these provide convenient conditions for the repeated utilization of TiO₂. The photocatalytic mechanism of nano-TiO₂ (anatase type) may proceed as follows:

\[
\begin{align*}
\text{TiO}_2 + \text{hv} & \rightarrow h^+ + e^-, \\
\text{O}_2 + e^- & \rightarrow \cdot\text{O}_2^-, \\
h^+ + \text{H}_2\text{O} & \rightarrow \text{HO}^- + \text{H}^+, \\
\text{C}_m\text{H}_n\text{O} + \cdot\text{OH} & \rightarrow \text{H}_2\text{O} + \text{CO}_2 + \text{C}_m\text{H}_n', \\
\cdot\text{O}_2^- + \text{H}^+ & \rightarrow \text{HO}_2', \\
2\text{HO}_2' & \rightarrow \text{H}_2\text{O}_2 + \text{O}_2, \\
\text{H}_2\text{O}_2 + \cdot\text{O}_2^- & \rightarrow \cdot\text{OH} + \text{OH}^- + \text{O}_2, \\
\text{OH}^- + \text{H}^+ & \rightarrow \text{H}_2\text{O}. 
\end{align*}
\]

In the formula, \(e^-\) and \(h^+\) represent electrons and holes on the crystal surface, respectively.

3.6. Nano Zinc Oxide. ZnO is a natural wide-bandgap n-type semiconductor with a bandgap of 3.37 eV, and its binding energy with excitons can reach 60 meV. Due to its high exciton energy, strong electron mobility, and not easy to generate exciton recombination reactions, ZnO has a very broad application prospect in optoelectronics. ZnO has three structures: rock salt structure, hexagonal sphalerite structure, and hexagonal wurtzite structure, among which the hexagonal wurtzite structure is the most common and is a stable phase at room temperature. ZnO is a typical hexagonal lattice type wurtzite. At room temperature, ZnO is a tetrahedron surrounded by tetrahedral oxygen ions, which is a tetrahedral structure composed of multiple layers of \(\text{O}_2^-\) and \(\text{Zn}^2+\), as shown in Figures 4 and 5. The tetrahedral coordination structure forms a polar axis on the hexagonal axis, so there is a difference between its polarity and the surface relaxation energy, which changes its physical and chemical properties.
properties. The structure of ZnO plays an important role in crystal growth, etching, and defect formation [23].

Nanozinc oxide particles size 1~100 nm and have the common effects of nanomaterials, including small size effects, surface effects, macroscopic quantum tunneling effects, etc. It has good application prospects in photocatalysis, deodorization, and antibacterial, formaldehyde removal, photoluminescence, conductive energy saving, absorption wavelength, and other aspects. Nanozinc oxide is mainly used for antibacterial, photocatalysis, infrared sensors, ultraviolet shielding, environmental protection materials, information storage, invisible materials, etc. The structure of nano-zinc oxide is diverse, with a small band gap, high catalytic activity, and high surface hydroxyl content. With nanozinc oxide as the electron trap, its adsorption oxygen amount is large, and its sterilization and photocatalytic properties are better. The research showed that the application of nanozinc oxide with light quality, good performance, good stability, good plasticity, and good comprehensive performance for its performance has become the hot spot of material research today. The surface activity of nanozinc oxide is rapidly enhanced with the decreasing particle size, and the free energy and surface area of its surface also increase. Similar to other nanomaterials, the molecule of nanozinc oxide has many suspended bonds on its surface and has a small number of surrounding atoms, so it is very unsaturated and easy to bind to other elements, and its chemical properties are very special. However, the unique feature of nanozinc oxide is that ZnO has excellent optoelectronic properties, achieves low resistance and high transmittance through element doping, and is often used to prepare solar cell electrode materials.

Photocatalysis is the use of the action of catalysts to promote photochemical reactions so that the catalyst reacts with the matrix in its ground or excited state, thus producing photophotogenic products. Usually, the catalyst only participates in and accelerates the process of the reaction, and it does not change throughout the reaction cycle. Figure 6 shows the photocatalytic mechanism of zinc oxide. When zinc oxide is excited by photons, charge carriers are generated. Between light electrons and light holes, the carriers produce a form of light energy because the oxidation of valence band holes leads to oxidation, while conductive electrons produce a reduction, which leads to catalysis. In light irradiation, when the photon energy irradiated by light exceeds the bandwidth of ZnO, electrons are excited into the conduction band, and corresponding holes are formed in the process, thereby forming electron (e−)-holes in ZnO (h+) right. h+ has a strong oxidizing effect, which oxidizes the hydroxyl groups and water molecules of zinc oxide to form free oxygen. Free radical •OH is a strong oxidant, which can oxidize organic compounds or other pollutants into water, carbon dioxide, and other small molecular organics for photocatalytic degradation [24]. Compared with other commonly used TiO₂ photocatalytic materials, the production cost of ZnO is relatively low, the yield of hydroxide ions is high, and the recombination rate of photoinduced electron holes is also low. In addition, surface defects are also the main reason for efficient photochemical reactions. In
addition, surface area and surface defects are important factors for efficient photochemical reactions, and ZnO contains a large number of point defects generated by oxygen vacancies and thus is more photoactive.

The main reaction processes of the photocatalytic system under aerobic illumination are as follows:

Generation of carriers:

$$\text{ZnO} + h^+ \rightarrow e^- + h^+.$$  \hspace{1cm} \text{(2)}

Carrier trapping:

$$h^+ + \text{OH}^- \rightarrow \text{gOH},$$
$$h^+ + \text{H}_2\text{O} \rightarrow \text{gOH} + \text{H}^+,$$
$$\text{O}_2 \text{(ad)} + e^- \rightarrow \text{O}_2^- \text{(ad)},$$
$$2\text{O}_2 \text{(ad)} + \text{H}_2\text{O} \rightarrow \text{O}_4 + \text{HO}_2\text{g} + \text{OH}^-,$$
$$\text{H}_2\text{O}^- + h^+ \rightarrow \text{HO}_2\text{g},$$
$$2\text{HO}_2\text{g} \rightarrow \text{O}_4 + \text{H}_2\text{O}_2,$$
$$\text{HO}_2 + e^- + \text{H}^+ \rightarrow \text{H}_2\text{O}_2,$$
$$\text{H}_2\text{O}_2 + e^- \rightarrow \text{gOH} + \text{OH}^-,$$
$$\text{H}_2\text{O}_2 + \text{O}_2^- \rightarrow \text{gOH} + \text{OH}^- + \text{O}_2.$$  \hspace{1cm} \text{(3)}

Recombination of charge carriers:

$$e^- + h^+ \rightarrow \Delta.$$  \hspace{1cm} \text{(4)}

Migration of Carriers:

$$\text{C}_m\text{H}_n\text{O} + \text{gHO} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{C}_m\text{H}_n\text{O}^-,$$
$$M^{+n} + \text{ne}^- \rightarrow M^{0}.$$  \hspace{1cm} \text{(5)}

At present, the preparation methods of nanozinc oxide include physical methods and chemical methods, but it is difficult to prepare nanoparticles with quantum-level effects by physical methods. Chemical methods include solid phase method, gas phase method, and liquid phase method. The nanomaterial particles obtained by chemical synthesis technology are more uniform, and their crystal size and size can be controlled by adjusting the growth environment, which is the most widely used method for preparing zinc oxide nanomaterials. The solid-phase method mainly includes ball milling, electric discharge, thermal decomposition, etc.; the gas-phase reaction method, evaporation method, and sputtering method are the commonly used gas-phase reaction technologies; liquid phase methods include precipitation method, microemulsion method, hydrothermal method, sol-gel method, etc. Compared with gas phase method and solid phase method, the liquid-phase method has simple equipment and is easy to control the particle size and crystal phase.

4. Experimental Design of Functional Nanomaterials

Taking into account the stability and reliability of the source of nanomaterials, nanometer TiO$_2$ and nanometer ZnO were selected as raw materials in this experiment to prepare nanocomposite coatings. The main technical indicators are shown in Tables 1 and 2.

Polymer emulsion is the main component of latex paint, and the polymer material is the film-forming component of latex paint, also known as matrix. Its function is to bond all kinds of fillers and additives in the coating together and combine with the surface of the coated base layer, which is easy to dry and solidify to form a uniform, lasting, and firm protective film. The film-forming material of the coating is mainly based on the matrix, and its quality characteristics directly affect the film-forming quality of the coating. Therefore, when preparing coatings, high-quality polymer compounds should be selected as the matrix for formulating coatings. Among common coatings, suitable substrates are Pure acrylic resin, silicone-acrylic resin, fluoride-containing resin, epoxy resin, etc. The excellent properties of fluoro-resin are unmatched by other resins. However, because its application in industrial production has just begun, there are technical problems in terms of cost and use, so it cannot be widely promoted at present. Therefore, in this experiment, silicone-containing silicone-acrylic resin emulsion with good performance in all aspects was used as the matrix to prepare the coating [25]. In addition, as a reference, pure acrylic emulsion was also selected. In this test matrix, pure acrylic and silicone-acrylic emulsions from Beijing Yakeli Chemical Technology Co., Ltd. were selected. The main properties are shown in Table 3.

The experimental equipment is shown in Table 4.

Nano-TiO$_2$ and nano-ZnO materials were added to pure acrylate and silion acrylate resins with a volume concentration of 40%, respectively, and the nanocomposite coating is prepared according to the addition amount of 0.2%, 0.4%, 0.6%, and 0.8% of the total mass of the coating. Its main properties were measured, and its effects on contrast ratio, scrub resistance, adhesion, and antipollution properties were compared. The research results are shown in the following figures.

The measurement results of the contrast ratio of the nanomaterial composite coatings are shown in Figure 7.

It can be seen from Figure 7 that the contrast ratio is the largest when the nano-TiO$_2$, nano-ZnO, and nano-TiO$_2$ and ZnO composite materials are added in an amount of 0.4%. In the pure acrylic coating, the contrast ratio of nano-TiO$_2$ and nanocomposite materials reaches 0.99, and the contrast ratio of nano-ZnO reaches 0.98. In the silicone-acrylic coating, the contrast ratio of nano-TiO$_2$ and nanocomposite materials reaches 0.98, and the contrast ratio of nano-ZnO reaches 0.97. After the addition of more than 0.4%, the contrast ratios of the three materials decreased with the increase of the nanomaterial content. The improvement effect of nano-TiO$_2$ on coatings is better than that of ZnO, and the effect of composite components of TiO$_2$ and ZnO on coatings can be achieved. The improvement effect of nano-TiO$_2$ and nano-ZnO materials on the contrast ratio of pure acrylic paint is better than that of silicon acrylic paint.

The measurement results of the scrub resistance of the nanomaterial composite coatings are shown in Figure 8.

It can be seen from Figure 8 that when the addition amount of nano-TiO$_2$ is 0.4%, the washing resistance times...
of pure acrylic and silicon acrylic coatings reach the maximum, which are 1340 times and 1491 times, respectively. When the addition of nano-ZnO and nano-TiO$_2$ and ZnO composites was 0.6%, the washing resistance of pure acrylic and silicon-acrylic coatings reached the maximum. Among them, the washing resistance times of nano-ZnO in pure acrylic and silicon-acrylic coatings are 1840 times and 1887 times, respectively. The washing resistance times of nano-TiO$_2$ and ZnO composites in pure acrylic and silicon acrylic coatings are 1946 times and 1990 times. After the addition amount exceeds 0.4% and 0.6%, the number of cleaning resistance decreases with the increase of nanomaterial addition amount. In general, the effect of nanocomposite components is better than that of adding nano-ZnO alone, and nano-TiO$_2$ is the least obvious. The improvement effect of nanomaterials on the scrubbing resistance of silicone-acrylic coatings is better than that of pure acrylic.

The measurement results of the adhesion of the nanomaterial composite coatings are shown in Figure 9.

The lower the adhesion rating, the better the adhesion of the paint. It can be seen from Figure 9 that when the additions of nano-TiO$_2$, nano-ZnO, and nano-TiO$_2$ and ZnO composite components are all 0.4% of the total coating, the adhesion results of pure acrylic and silicon-acrylic coatings are the same, which are all first-class. When the content of nano-TiO$_2$ and ZnO composite components is 0.2%, the adhesion grade of pure acrylic paint is 2, and the adhesion grade of silicon acrylic paint is 1. When its content reaches 0.6%, the coating adhesion grade is obviously increased, and the adhesion grade is 2. When the nano-TiO$_2$ content is 0.2%, the adhesion grade of pure acrylic paint is 2, and the adhesion grade of silicon acrylic paint is still level 2, and there is no obvious change. When the nano-ZnO content is 0.2%, the adhesion grade of pure acrylic paint is 2, and the adhesion grade of silicon acrylic paint is still level 2, and there is no obvious change. When the nano-ZnO content is 0.6%, the adhesion grade of pure acrylic paint is 2, and the adhesion grade of silicon acrylic paint is 1.

The measurement results of the pollution resistance of the nanomaterial composite coatings are shown in Figure 10.

The greater the rate of decrease in the reflection coefficient, the better the pollution resistance of the coating. It can be seen from Figure 10 that when nanomaterials are added, the rate of decrease in the reflection coefficient of the coating can be reduced. That is, the pollution resistance can be improved. When the addition amount of nanomaterials is 0.4%, in pure acrylic coating, the decrease rate of the reflection coefficient of nano-TiO$_2$ is 10.95%, that of ZnO is 10.24%, and that of nano-TiO$_2$+ZnO is 8.58%; in the silicone-acrylic coating, the decrease rate of the reflection coefficient of nano-TiO$_2$ is 10.82%, that of ZnO is 9.74%, and that of nano-TiO$_2$+ZnO is 8.86%. At this time, the pollution resistance of the composite coating is the best, followed by the nano-ZnO material. In addition, nanomaterials improve the stain resistance of silicone-acrylic coatings better than pure acrylic coatings.
Figure 7: The effect of nanomaterials on coating contrast ratio. (a) shows the effect of nanomaterials on the contrast ratio of pure acrylic coatings. (b) shows the effect of nanomaterials on the contrast ratio of silicone-acrylic coatings.

Figure 8: The effect of nanomaterials on the scrub resistance of coatings. (a) shows the effect of nanomaterials on the scrub resistance of pure acrylic coatings. (b) shows the effect of nanomaterials on the scrub resistance of silicone-acrylic coatings.

Figure 9: Influence of nanomaterials on cohesion of composite coatings. (a) shows the effect of nanomaterials on the adhesion of pure acrylic coatings. (b) shows the effect of nanomaterials on the adhesion of silicone-acrylic coatings.
5. Conclusion

With the rapid development of science and technology, new nanomaterials have a great development and application space in the field of coatings. The application of nanomaterials in coatings, on the one hand, improved the performance of traditional coatings; on the other hand, it can prepare new functional nanocoatings, improve the mechanical properties of coatings. It also improves the ratio of materials, brush resistance, adhesion, and pollution resistance. In this experiment, the prepared nano-TiO₂ and nano-ZnO were added to the traditional coating system to prepare excellent nanocomposite exterior wall coatings. It studied the modification effect of nanomaterials on coatings under different addition quantities. However, the research in this paper is not comprehensive enough, and later in-depth research is still needed, for example, the development of new nanomaterials, the modification mechanism of coatings, and the interaction principle between the components of nanomaterials and coatings. The study of functional nanomaterials is an ongoing process that still needs to be further refined and deepened.

Data Availability

The data that support the findings of this study are available from the author upon reasonable request.

Conflicts of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

[1] Y. Zhang, Y. Li, and C. Bai, “Microstructure and oxidation behavior of Si-Mosi₂ functionally graded coating on Mo substrate,” Ceramics International, vol. 43, no. 8, pp. 6250–6256, 2017.
[2] P. Wang, S. Wang, X. Zhang et al., “Rational construction of CoO/CoF₂ coating on burnt-pot inspired 2D CNs as the battery-like electrode for supercapacitors,” Journal of Alloys and Compounds, vol. 819, Article ID 153374, 2019.
[3] X. Xu, D. Shahsavari, and B. Karami, “On the forced mechanics of doubly-curved nanoshell,” International Journal of Engineering Science, vol. 168, Article ID 103538, 2021.
[4] X. Xu, B. Karami, and D. Shahsavari, “Time-dependent behavior of porous curved nanobeams,” International Journal of Engineering Science, vol. 160, Article ID 103455, 2021.
[5] Y. Wang, I. Fedin, H. Zhang, and D. V. Talapin, “Direct optical lithography of functional inorganic nanomaterials,” Science, vol. 357, no. 6349, pp. 385–388, 2017.
[6] N. Wongkaew, M. Simsek, C. Griesche, and A. J. Baemumer, “Functional nanomaterials and nanostructures enhancing electrochemical biosensors and lab-on-a-chip performances: recent progress, applications, and future perspective,” Chemical Reviews, vol. 119, no. 1, pp. 120–194, 2019.
[7] S. U. Xiaoqing, "Hongqiang. Functional nanomaterials: 3D porous superhydrophobic CNT/EVA composites for recoverable shape reconfiguration and underwater vibration detection," Advanced Functional Materials, vol. 29, no. 24, Article ID 1970166, 2019.
[8] L. Chi and S. T. Lee, "Research on functional nanomaterials, interfaces, and applications at Soochow university," ACS Nano, vol. 13, no. 3, pp. 2667–2671, 2019.
[9] Y. Zhong, J. Li, A. Lambert, Z. Yang, and Q. Cheng, "Expanding the scope of chemiluminescence in bioanalysis with functional nanomaterials," Journal of Materials Chemistry B, vol. 7, no. 46, pp. 7257–7266, 2019.
[10] P. C. Trulove, D. P. Durkin, P. J. Fahy et al., “Integration of functional nanomaterials in biopolymer composites using ionic liquid based methods,” ECS Transactions, vol. 86, no. 14, pp. 287–296, 2018.
[11] S. Wang and J. Liu, “Advanced food safety inspection techniques based on functional nanomaterials,” Journal of Chinese Institute of Food Science and Technology, vol. 18, no. 6, pp. 1–8, 2018.
[12] S. I. Sanchez, L. F. Allard, M. T. Schaal et al., “From atoms to functional nanomaterials: structural modifications as observed using aberration-corrected STEM,” Microscopy today, vol. 26, no. 3, pp. 24–31, 2018.
[13] Y. Zhang, C. Z. Wang, and Q. Wang, “A special issue on functional nanomaterials for energy and environmental applications,” Science of Advanced Materials, vol. 11, no. 8, pp. 1059–1063, 2019.
[14] D. Alloyeau, A. Khelfa, K. Aliyah et al., “Revealing the dynamics of functional nanomaterials in their formation and application media with liquid and gas-phase TEM,” Microscopy and Microanalysis, vol. 26, no. S2, pp. 196–198, 2020.

[15] Y. Zhang, S. Wei, Y. Hu, and S. Sun, “Membrane technology in wastewater treatment enhanced by functional nanomaterials,” Journal of Cleaner Production, vol. 197, no. 1, pp. 339–348, 2018.

[16] S. Seki, T. Sakurai, and A. Horio, “From ‘rays’ to ‘ray’-development of functional nanomaterials using ion beams,” Radioisotopes, vol. 66, no. 11, pp. 579–585, 2017.

[17] R. Ciardiello, L. T. Drzal, and G. Belingardi, “Effects of carbon black and graphene nano-platelet fillers on the mechanical properties of syntactic foam,” Composite Structures, vol. 178, pp. 9–19, 2017.

[18] P. Zhang, D. J. Arceneaux, Z. Liu, P. Nikaeen, A. Khattab, and G. Li, “A crack healable syntactic foam reinforced by 3D printed healing-agent based honeycomb,” Composites Part B: Engineering, vol. 151, pp. 25–34, 2018.

[19] M. D. Goel, V. Parameswaran, and D. P. Mondal, “High strain rate response of cenosphere-filled aluminum alloy syntactic foam,” Journal of Materials Engineering and Performance, vol. 28, no. 8, pp. 4731–4739, 2019.

[20] K. Cunefare, D. N. Ramsey, and N. Pedigo, “In-line syntactic-foam device for control of water hammer and fluid-borne noise,” Journal of the Acoustical Society of America, vol. 146, no. 4, p. 2767, 2019.

[21] D. Carolan, A. Mayall, J. P. Dear, and A. Fergusson, “Micromechanical modelling of syntactic foam,” Composites Part B: Engineering, vol. 183, no. 15, Article ID 107701, 2020.

[22] R. Freund, U. Lachelt, T. Gruber, B. Ruhle, and S. Wuttke, “Multifunctional efficiency: extending the concept of atom economy to functional nanomaterials,” ACS Nano, vol. 12, no. 3, pp. 2094–2105, 2018.

[23] T. Sen and M. Mahmoudi, “Special focus issue Part I: functional nanomaterials in cancer therapy,” Nanomedicine, vol. 16, no. 11, pp. 879–882, 2021.

[24] W. Yan, M. Ramos, and B. E. Koel, “As(III) sequestration by iron nanoparticles: study of solid-phase redox transformations with X-ray photoelectron spectroscopy,” Journal of Physical Chemistry C, vol. 116, no. 9, pp. 5303–5311, 2017.

[25] T. X. Tran, X. P. Nguyen, D. N. Nguyen, O. I. Khalaf, and A. T. Hoang, “Effect of poly-alkylene-glycol quenchant on the distortion, hardness, and microstructure of 65Mn steel”, Computers,” Materials and Continua, vol. 67, no. 3, pp. 3249–3264, 2021.