Preparation and Performance Analysis of Marine Polymer Anti-corrosion and Wear-resistant Composite Coatings

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Abstract: ***Objective:*** ***Tailoring composite coatings based on the operational characteristics of ship hull structures is crucial to ensuring their high stability. Therefore, this study investigated the preparation and performance analysis of marine polymer anticorrosion and wear-resistant composite coatings.*** ***Methods:*** ***Using modified sepiolite as the core raw material, combined with water-based epoxy resin, epoxy curing agent, AB glue, and defoaming agent, composite coatings with contents of 0%, 1.0%, 2.0%, 3.0%, 4.0%, and 5.0% were prepared. Q235 steel plates were used as the substrate for salt spray testing and crosslinking density tests to evaluate coating performance.*** ***Results:*** ***When the modified sepiolite content was 3.0%, the composite coating exhibited the smallest corrosion area, with a mass change of only 1.46 g.*** ***Conclusion:*** ***At a modified sepiolite content of 3.0%, the marine polymer anticorrosion and wear-resistant composite coating demonstrated optimal performance in both corrosion resistance and wear resistance.***

Keywords: Polymer; Corrosion and wear resistance; Composite coating; Modified sepiolite; Salt spray test; Crosslinking density test; Rust area.

1. INTRODUCTION

For the hull structure, its materials are mainly composed of steel. Analyzing from the perspective of specific structural parts, the bottom of the ship is mainly corroded by highly saline and conductive seawater due to being immersed in seawater for a long time, and at the same time faces the attachment of marine organisms and the abrasion of seawater scouring. Therefore, high requirements are put forward for the water resistance and wear resistance of the coating. The waterline area is located between the ballast waterline and the full load waterline, and is frequently in the wet-dry alternating state, vulnerable to the combined erosion of seawater, marine atmosphere and sunlight, and faces a higher risk of mechanical impact. The part of the hull (above the full load waterline is exposed to the marine atmosphere for a long time, and the salty and humid air is easy to cause its corrosion, and it will also be eroded by sunlight, wind and rain. Combining the above analysis, it can be seen that for the hull structure, aiming at its specific application scenarios and the main risks faced, implementing effective coating protection is of great practical significance for realizing the effective life of the hull.

To address the corrosion and wear challenges faced by the hull structure in the complex marine environment, this article systematically carried out research on the preparation and performance analysis of marine polymer anti-corrosion and wear-resistant composite coatings. The research used modified sepiolite as the core functional filler, combined with a water-based epoxy resin system, and prepared a series of composite coatings by precisely controlling its content. Using methods such as salt spray test and crosslinking density test, the influence law of the content of modified sepiolite on the anti-corrosion performance and mechanical properties of the coating was mainly explored, aiming to determine its optimal addition amount and provide theoretical basis and experimental support for the development of high-performance protective coatings suitable for harsh marine environments. Sun (2024) explored microbial strain improvement by modifying and screening antibiotic-producing strains, highlighting the potential of directed evolution and high-throughput techniques to enhance yields of bioactive compounds [1]. In parallel, Narouei et al. (2025) investigated the unintended consequences of germicidal far-UVC light in indoor environments, reporting that such irradiation can significantly affect ozone and particulate matter levels in a conference room, thereby raising concerns about air quality management in occupied spaces [2]. From a different perspective, Xiao et al. (2022) developed an ultrasmall Fe_3O_4-decorated polydopamine hybrid nanozyme that enables continuous conversion of oxygen into toxic hydroxyl radicals via glutathione-depleted cascade redox reactions, achieving intensive wound disinfection with promising therapeutic efficacy [3]. Meanwhile, Wu et al. (2025) focused on catalytic chemistry by preparing a Pd/Ni bimetallic catalyst and examining its application in the selective hydrogenation of phenol, demonstrating improved activity and selectivity that could benefit industrial hydrogenation processes [4]. Collectively, these studies underscore the breadth of current research efforts, from biological production and indoor environmental safety to nanomedicine and heterogeneous catalysis, each contributing unique insights and practical solutions to their respective fields.

2. EXPERIMENTAL MATERIALS AND INSTRUMENTS

Considering the performance requirements of marine polymer composite coatings in anti-corrosion and anti-wear, the article took into account the properties of modified sepiolite and used it as the core raw material of marine polymer anti-corrosion and anti-wear composite coatings. Among them, the relevant performance parameters of the selected modified sepiolite are shown in Table 1.

The auxiliary raw materials include waterborne epoxy resin, epoxy curing agent, AB glue, defoaming agent, sodium chloride, toluene and sodium hydroxide (all are of analytical grade).

Table 1: Performance Parameters of Modified Sepiolite

Performance parameters	Description
Chemical composition	Silicon dioxide (SiO) is approximately 52.62%, magnesium oxide (MgO) is approximately 19.52%
Crystal structure	Monoclinic system, fibrous structure, fiber length $0.2 \sim 5\mu$m, width $100 \sim 300$ nm, thickness $50 \sim 100$ nm, layer-chain structure
Physical form	White, light yellow, opaque
Specific surface area / (m^2/g)	900.0
Density $/(g/cm^3)$	2.06
Mohs hardness	2.66
Anti-corrosion performance /$(\Omega \cdot cm^2)$	Impedance value in the low-frequency region is 6.1×10^6

3. PREPARATION OF COMPOSITE COATINGS

3.1 Preparation of Composite Coating

At the preparation stage of marine polymer anti-corrosion and wear-resistant composite coatings, using the ratio of waterborne epoxy resin 100.0 g, epoxy curing agent 50.0 g, AB glue 10.0 g, defoamer 0.04 g [5], composite coatings with modified sepiolite contents of 0%, 1.0%, 2.0%, 3.0%, 4.0% and 5.0% were prepared respectively. The specific preparation process is as follows.

(1) Weigh 1.0 g, 2.0 g, 3.0 g, 4.0 g and 5.0 g of modified sepiolite filler in proportion, add them to a plastic container containing auxiliary materials, and then add 0.04 g defoamer to eliminate the bubbles generated during stirring. Stir for 5.0 min with a magnetic stirrer until the modified sepiolite filler is fully mixed and evenly dispersed with the waterborne epoxy resin raw materials.

(2) According to the mass ratio of waterborne epoxy resin to curing agent of 2:1, add 50.0 g curing agent to the mixed system, and continue to stir magnetically for 5.0 min to make the curing agent react fully with the composite system, obtaining a uniformly dispersed and stable composite coating.

3.2 Preparation of Composite Coating Samples

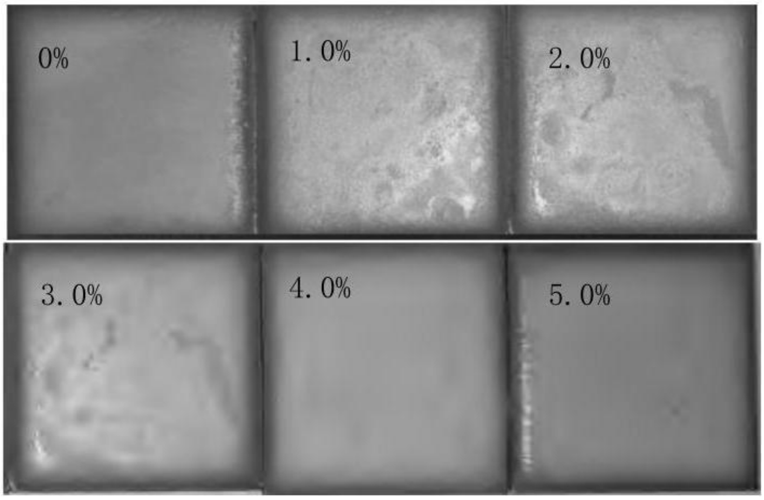

Figure 1: Marine Polymer Anti-corrosion and Wear-resistant Composite Coating Specimen

Combined with the specific properties of the hull material, Q235 steel plates were selected as the experimental substrates. At the same time, to eliminate the interference of the substrate surface state on the coating performance, before coating, the Q235 steel plates were pretreated. Q235 steel plates with dimensions of 30.0 mm×30.0 mm×2.0 mm were selected. The surface oxide layer and impurities were removed by sandpaper grinding to make the surface flat and smooth. Subsequently, the residual iron filings on the surface were wiped with anhydrous ethanol and left to dry naturally for later use, for testing the anti-corrosion and wear resistance of the coating. The prepared composite coating was evenly coated on the pretreated steel plates. Specifically, the brushing method was adopted, and two coats were evenly applied with an interval of 24 h between each coat. The total dry film thickness was controlled to be (80±10)μm, forming composite coating samples with different modified sepiolite contents. The samples were dried at room temperature for 3 days, and then placed in an oven at 25∘C for baking for 6.0 h. After the coating was completely cured, the performance tests were carried out on the composite coating samples with different modified sepiolite contents. The specific composite coating specimens are shown in Figure 1.

4. PERFORMANCE ANALYSIS OF COMPOSITE COATINGS

4.1 Salt Spray Test

In the salt spray test stage, a NaCl solution with a mass fraction of 5.0% was prepared and its pH value was adjusted to 6.5~7.2 with sodium hydroxide. The temperature of the test chamber was controlled within the range of (35.0±2.0)°C, the corresponding spraying mode was selected as continuous spraying, and the salt spray deposition rate was set to 2.0 mL/(80 cm^2·h); a deep water layer of 25.4 mm was maintained at the bottom of the chamber to maintain a high-humidity environment, so as to simulate the actual operation scenario of the hull in seawater.

In the specific test stage, the specimens were fixed in the test chamber at an inclination angle of 30∘, while avoiding mutual occlusion between the specimens, and the salt spray chamber was started for continuous testing for 240 h. At the same time, the rust area on the surface of the coating was recorded and observed every 24 h. The salt spray test results of the composite coatings with the modified sepiolite contents of 0%, 1.0%, 2.0%, 3.0%, 4.0% and 5.0% were statistically analyzed, and the results are shown in Figure 2.

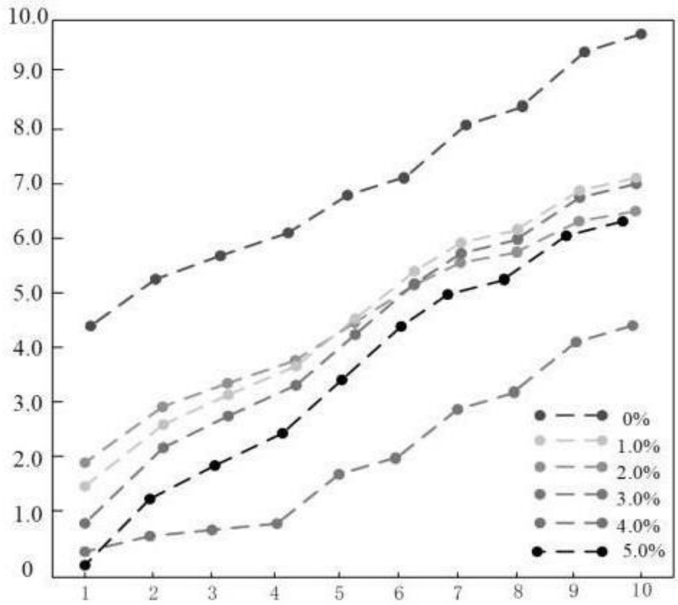

Figure 2: Salt Spray Test Results

Combined with the information in Figure 2, it can be seen that the composite coating with 3.0% modified sepiolite content shows the best corrosion resistance in the salt spray test (that is, the increase in the rust area is the smallest, only increasing from $0.2mm^2$ to $4.3mm^2$, and the overall rust area is the smallest within 240.0 h). From the perspective of the physical barrier effect of modified sepiolite, this may be because sepiolite is a fibrous silicate mineral, which transforms into a flaky structure after modification and forms a "brick wall" - like layered stack in the coating. When the addition amount of modified sepiolite is 3.0%, the flaky particles reach the best dispersion state in the coating, forming a continuous and dense physical barrier layer, effectively blocking the penetration paths of water, oxygen and chloride ions Cl^-. Compared with the low content 0%~2.0%, the lack of fillers results in a discontinuous barrier layer, and the corrosive medium is easy to diffuse through the defects; compared with the high content (4.0% - 5.0%), the excessive fillers cause agglomeration, forming local pores, which instead reduces the barrier effect. From the perspective of chemical corrosion inhibition, modified sepiolite retains some silanol and magnesium hydroxide groups, which can undergo ion exchange or adsorption with Cl^-. When the addition amount is 3.0%, the number of active sites on the coating surface matches the concentration of the corrosive medium, and it can effectively adsorb Cl^- and fix it inside the coating, thereby reducing its migration to the Q235 steel plate interface. Compared with the low content (0% - 2.0%), the number of active sites is insufficient and the adsorption amount of C1~is limited; compared with the high content (4.0% - 5.0%), the excessive fillers cause the adsorption sites to be saturated, and the remaining $C1^-$ can still penetrate to the substrate.

4.2 Crosslink Density Test

Immerse the specimen into a glass bottle containing 50.0 mL toluene solvent. After sealing, place it in an incubator at 25 °C. Take out the specimen every 24.0 h, dry the surface solvent with filter paper, and weigh it until the mass no longer changes. Record the obtained equilibrium mass. Among them, when the mass no longer changes, the apparent appearance of the substrate specimens of the coatings with different modified sepiolite contents is shown in Figure 3.

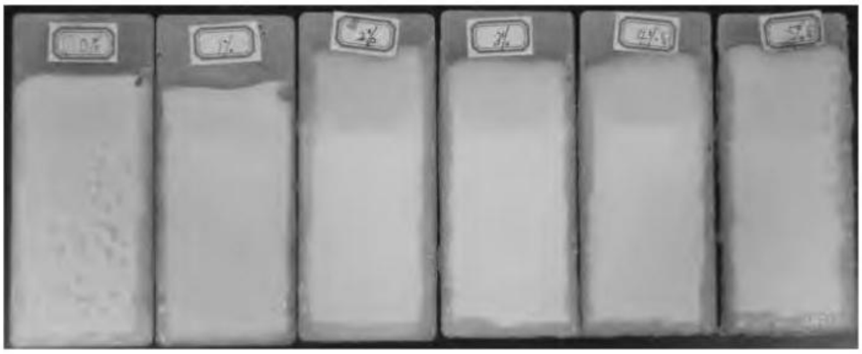

Figure 3: Apparent Appearance of Substrate Specimens

The specific mass change situation is shown in Table 2.

Table 2: Statistical Table of Mass Change Situation

Content of modified sepiolite in composite coating /%	Initial mass / g	Final mass / g	Mass change / g
0.0	10.0	6.33	3.67
1.0	10.0	7.12	2.88
2.0	10.0	7.44	2.56
3.0	10.0	8.54	1.46
4.0	10.0	7.69	2.31
5.0	10.0	7.50	2.50

Combined with the crosslink density test data in Table 2, it can be clearly seen that when the content of modified sepiolite is 3.0%, the composite coating performs the best, with its mass change in toluene solvent being only 1.46 g, significantly lower than other groups (such as 3.67 g in the 0% content group). This quantitative result directly proves that the denseness of the three-dimensional crosslink network of the coating reaches its peak at this ratio, forming a more complete and stable polymer topological structure. This highly crosslinked feature is not only verified by the toluene swelling experiment but is also directly related to the excellent corrosion resistance and optimized anti-wear mechanical properties demonstrated by the coating in the salt spray test. Analyzed from the perspective of the microstructural effect relationship, the realization of this optimal performance is the result of the synergistic effect of multiple mechanisms at a specific content: the flaky modified sepiolite forms a continuous and highly oriented "brick wall type" physical barrier structure in the matrix, significantly extending the penetration paths of water, oxygen, and chloride ions; its surface rich in active sites such as silanol groups and magnesium hydroxide groups effectively adsorbs and fixes the erosive Cl^{-}, playing the chemical passivation function of an "ion trap"; at the same time, sepiolite, as a nano-level crosslinking point, participates in the epoxy resin curing reaction through surface functional groups, significantly enhancing the overall crosslinking degree of the coating. When the content is too low, there are insufficient crosslinking points, and when it is too high, interfacial defects are generated due to filler agglomeration, which instead hinders the construction of a complete network; in addition, the uniformly dispersed rigid sepiolite units also help to release and disperse the internal stress during curing, reducing the initiation of microcracks, thereby improving the long-term durability of the coating in the corrosion-wear coupling environment. In summary, the 3.0% content of modified sepiolite is the critical threshold for the synergistic amplification of the four functions of physical shielding, chemical stability, crosslink strengthening, and stress regulation, constructing a composite coating system with both high crosslink density and excellent comprehensive protection performance.

5. CONCLUSION

In view of the operating environment characteristics of the hull structure, this paper carried out the research on the preparation and performance analysis of marine polymer anti-corrosion and wear-resistant composite coatings from the perspective of maintaining the stability of hull materials. Using modified sepiolite as the core raw material, combined with waterborne epoxy resin, and with the assistance of epoxy curing agent, AB glue and defoamer, composite coatings with different contents of modified sepiolite were prepared. The results of salt spray test and crosslinking density test based on Q235 steel plate show that when the content of modified sepiolite is 3.0%, the anti-corrosion and wear-resistant performance of the corresponding composite coating is the best, which can maximize the protection of the stability of hull steel in the seawater environment.

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