Dean&Francis
ISSN 2959-6157

HOW DOES ADDING FILLERS AFFECT THE ENDURANCE OF COMPOSITE RESIN PAINT?

Yijun Ma

Abstract:
Epoxy resin is a kind of versatile polymer. It is widely used in various industries for stability under harsh chemical environment and flexibility. In this study, the effects of various inorganic fillers on the durability of water-soluble epoxy resin coatings were investigated. Different types of fillers including nano-alumina, talc, and calcium oxide, were incorporated into the coatings at concentrations ranging from 5% to 10%. The aim was to evaluate their impact on key properties such as hardness, elastic modulus, and barrier performance. The study also explored the role of ethanol as a solvent. Experimental results indicated that nano-alumina significantly enhanced the coating's hardness and elastic modulus, while calcium oxide had a detrimental effect on barrier properties due to micropore formation. The findings demonstrate that the choice of filler type and concentration is critical for optimizing coating performance. The research provides valuable insights into designing epoxy coatings tailored to specific mechanical and environmental requirements. Furthermore, it highlights the potential for future research into nanomaterial fillers and the importance of considering the interaction between fillers and the resin matrix.

Keywords: Composite Materials, Resin, Anti-corrosion, Inorganic Fillers, Eco-friendly Materials

1. INTRODUCTION

The origins of paint can be traced back to ancient China about 7,000 years ago, when the ancestors extracted natural resin from the lacquer tree, which was initially used to decorate pottery and wood, and gradually discovered its protective properties. With the advancement of industrial technology, modern coatings have developed into composite materials prepared by chemical synthesis, which have both protective and decorative functions.

In the construction and furniture sector, coatings do not act in main structures as steel or concrete, but they can extend the life of materials by insulating them from environmental erosion. For example, bare metal rusts slowly in a damp environment at a rate

ISSN 2959-6157

that is invisible to the naked eye, and high-quality paints can significantly slow down this process.
Taking the steel ladder in the college dormitory as an example, its protective coating often fails due to frequent use rather than natural aging. The pressure of the students going up and down the ladder causes the coating to bend repeatedly, gradually producing microcracks. The exposed metal at the crack reacts with oxygen and moisture to form rust, and the expanded rust layer lifts and peels off the surrounding coating. Peeling paint flakes and rust debris adhere to the user's palm, forming a hidden health hazard and repeated cleaning trouble.

2. LITERATURE REVIEW

2.1 PAINT MARKET

Due to the maturity of the petroleum industry, oil-based coatings are inexpensive and easy to mass-produce, and their curing forms a dense layer that effectively protects wood, concrete and metal surfaces. However, there are significant shortcomings in metal protection. The expansion coefficient of metal and oil-based coatings is quite different, and the expansion and contraction degree of the two is different when the temperature changes, which is easy to generate stress at the interface, which eventually leads to cracking or peeling of the coating. Oil-based paints are not compatible with moisture, and the water droplets mix in during construction form tiny holes after drying. These pores act as channels through which oxygen meets the metal, causing localized rust that gradually expands, eventually causing the coating to peel off in sheets. The problems of its performance promoted the seeking replacement.

2.2 EPOXY RESIN

Epoxy resin is the name of polymers containing more than two epoxy groups in the molecule. In reaction with compounds with active hydrogen, epoxy group cross-links after ring-opening [9] and forms insoluble, non-melting 3D structure. It has excellent insulation, physical performance, thermal and chemical stability, bringing it widely usage in anti-corrosion coatings, adhesives, semiconductor packaging materials and electrical insulators. It plays identical roles in car manufacturing, aerospace industry and construction industry [2]. Epoxy resin can adhere on most surfaces, especially metal. Hydroxyl groups, ether bonds and active epoxy groups attract metal surface through strong electromagnetic force. These properties make epoxy good material of anti-corrosion coatings.

2.2.1 WATER-SOLUBLE RESIN

Epoxy is high viscous. Raw resin on metal surface will contract. It is obviously not ideal for a coating. So, epoxy needs solvent to dilute before applied. Due to differences in solvent used, epoxy can be classified as water-soluble and oil based. Oil-based epoxy is an early-developed type. It uses organic solvents and emits pungent gases called volatile organic compounds (VOC). As considered serious pollutants damaging atmosphere and health, solvents with high VOCs have been banned in recent years. Consequently, water-soluble resin becomes preferred and quickly develops. As its name told, it is soluble in water at liquid state. Much lower VOCs emission not only fits the eco-demands but also eliminates fire risk [1].
Although water-soluble epoxy is invented later, it catches up with the oil-based in performance after few years of development. Owing to its good adhesion, high mechanical strength and chemical resistance, water-soluble epoxy is an ideal material for anti-rust paint.

2.3 ANTIRUST PAINT

Anti-rust paint is a coating that protects metal surfaces from chemical or electrochemical corrosion of the atmosphere, seawater, etc. It is categorized into physical and chemical anti-rust paint, each with distinct mechanisms of protection.

2.3.1 CLASS AND PRINCIPLE

Physical anti-rust paints rely on inert fillers (e.g., mica, iron oxide, glass flakes) to create a dense, continuous film that physically isolates the metal substrate from corrosive agents (H2O, O2, Cl^-). For instance, micaceous iron oxide (MIO) exhibits a lamellar structure, forming overlapping layers that extend the diffusion path of corrosive media by up to 10 times compared to spherical particles. This mechanism is particularly effective in mild environments (e.g., indoor storage), where mechanical abrasion resistance is less critical. However, its limitations include vulnerability to pinhole defects and poor self-healing capability [6].
Unlike physical barrier coatings suited for static conditions, electrochemical paints maintain effectiveness even under mechanical stress or salt spray exposure. Electrochemical antirust paint achieves protection by actively intervening in the electrochemical process of metal corrosion, which mainly includes two mechanisms: cathodic protection and passivation. For example, zinc-rich coatings release electrons through the preferential oxidation of zinc particles (activity higher than the base metal), which inhibits the anodic dissolution of steel and forms a "sacrificial anode" protective layer; Some chromate-containing coatings promote the formation of a dense oxide film on the metal surface, blocking the contact of corrosive media. This kind of coating has remarkable effect in harsh envi-

ronments such as ships and bridges.

2.3.2 DEFECTS AND PERFECTION

Except aging and the consuming of reductants in electrochemical coating, the duration of coating is harmed by mechanical motions. Abrasion makes cumulative thinning. In the affected areas, isolative layer becomes no longer barrier for oxidants or exposes metal surface. Adding specific fillers will improve the abrasion-resistance. Mainstream choice is nano oxide particles, including Alumina, quartz and silicon carbide. The shape of the filler has a certain influence on the condition of wear. When the shape of the filler is mostly sharp and flaked, under the action of sanding, it is easy to break, when the shape of the filler is rounded and spherical, it is more difficult to crush [8].

Stress on interface of metal and coating makes more violate destruction to the coating. Cause of differences in mechanical properties, the metal and resin have different deformation. Like most high polymers, epoxy has far lower hardness than metals and is easier to have plastic deformation. Meanwhile, metal recovers the elastic deformation quickly after force is removed. The carried behavior causes stress on interface. Stress beyond certain limitations drags the coating to peel off. Concentrated stress breaks the coating and produces tiny or terrible cracks, which disables the coating. Different resins have different surface tensions and chemical energy after curing with the hardener, which is the biggest factor affecting the adhesion of the substrate. In general, the viscosity of resin increases with the increase of molecular weight, and the use of low molecular weight resin can give the coating excellent adhesion after crosslinking. The greater the proportion of the binder in the formulation, the better the adhesion. Similarly, there is an increase in flexibility. Adhesion can also be improved by adding a catalyst to increase the crosslinking density. Besides the perfections to coating itself, cleaning and sandblasting improves the adhesion as the processed surface will have higher surface tension.

3. METHODOLOGY

3.1 MATERIAL SELECTION

When discussing the influence of fillers on the durability of composite resin coatings, the selection of experimental design and methods is particularly important. This chapter will detail the basis for the selection of raw materials used in the experiment and their basic properties to ensure the reliability and accuracy of the experimental results. First, the selection of matrix resin is a key part of experimental design. Water-based bisphenol an epoxy is chosen as the matrix, which is widely used in various fields cause of stable chemical properties, good adhesion and strength. It makes an excellent basis for experiments and helps to gain more precise data to accurately evaluate the effect of fillers on the durability of coatings. In terms of fillers, a range of materials including alumina powder, talc, and calcia powder were selected. Nano alumina has good mechanical strength and chemical stability, talc can enhance the hardness and wear resistance of coatings, and calcium carbonate helps to improve the toughness and impact resistance of coatings. In order to ensure the reliability of the experimental results, strict quality control on all raw materials should be carried out. Ordinary alumina powder and nano alumina powder are selected as a comparison with each other. In the course of the experiment, detailed paint preparation process to mix the matrix resin with different proportions of fillers and stirred to ensure that the fillers were evenly dispersed in the resin. Subsequently, the prepared paint sample is applied to the cleaned steel sheet and dried in shade. A series of test outlines are designed to evaluate the durability of coating. Including corrosion resistance test, abrasion resistance test and impact resistance test. These tests provide a comprehensive evaluation of the coating's performance in a variety of harsh environments, providing accurate data on the impact of fillers on the durability of the coating.

3.2 SAMPLE PREPARATION PROCESS

Sample preparation is a key part of experimental research, which is crucial to exploring the effect of fillers on the durability of composite resin coatings. In this study, the sample preparation process is carefully designed to ensure the accuracy and reliability of the experimental results. First, determine the mixing ratio. In order to explore the effect of different filler content on the performance of composite resin coatings, it is necessary to set up several experimental groups, and the ratio of filler to resin in each group should be different. This allows for a comprehensive assessment of the effect of changes in filler content on the durability of coatings and provides rich experimental data for subsequent data analysis. In terms of mixing conditions, a adjustable-speed mixer is for mixing. To ensure that the mixture is homogeneous, a specific mixing speed and mixing time is set. Too high a stirring speed may result in the separation of the filler from the resin, while too low a stirring speed may not guarantee homogeneity of mixing. Therefore, when choosing the stirring conditions, several pre-experiments are performed to determine the optimal stirring parameters. During the mixing process, special attention is paid to the temperature control. Due to the heat that may be generated during the mixing process, it can lead to a local temperature increase, which can af-

ISSN 2959-6157

fect the performance of the coating. To avoid this, a water bath is applied during the mixing process to ensure that the temperature of the mixture remains within a relatively stable range. Samples with obvious defects will not be used to ensure that the test is not subject to too many random errors. Overall, the attention to detail and precision in the sample preparation process is designed to ensure the reliability and validity of experimental results. Success is gained in preparing multiple sets of composite resin coating samples with different filler contents.

3.3 TESTING METHOD

When evaluating the durability of composite resin coatings, there are a variety of testing methods to ensure a comprehensive and accurate measure of the coating's performance. Among them, mechanical strength test and isolation test are the two aspects being focused on. Mechanical strength testing mainly evaluates the performance of coatings under stress. This test includes a number of aspects such as tensile strength, compressive strength and impact strength. The tensile strength test is to determine the tensile performance of the coating by gradually stretching the sample to measure the maximum tensile force it can withstand before breaking. The compressive strength test evaluates the stability of the coating under pressure and analyzes its compressive performance by measuring the deformation of the coating during compression and the maximum pressure it is subjected to. The impact strength test is used to simulate the sudden impact that the coating may encounter in actual use and evaluates the impact resistance of the coating by measuring the degree of damage after the impact of the coating. The isolation test is to test whether the coating can better isolate the oxidant and protect the metal. It is an artificial acceleration method to accelerate the redox reaction by forming galvanic cells. In this test, the quality change of the sample is measured and recorded and the degree of corrosion to assess the isolation of the paint is observed. When performing these tests, it was adhered to standard experimental specifications and used the precise measurement equipment to ensure the accuracy and reliability of the test data. A comparative test of different formulations of composite resin coatings is conducted to investigate the effect of filler addition on the durability of the coating. Through these systematic test methods, it is able to provide strong data support for the next comprehensive evaluation of the performance of composite resin coatings.

Table 1 test for level of corruption

<u>APPARATUS:</u>
250ml beaker*3
stir rod*1
tweezer*1
conduct wire*1
coated steel sheets (cathode)*~
copper sheet (anode)*~
distilled water*~
copper sulfate*~
glue remover*~
timer*1
time switch*1
pencil*1
<u>A" BEFORE THE EXPERIMENT</u>
1.Origional mass of steel sheets and amount of filler are recorded. Write down the code and figure of each sample used clearly.
2.Operator should wear gloves and goggles to prevent being harmed by spilt liquid and possible sharp edge of metal sheet.
3.No flame aside, potential explosion caused by hydrogen gas produced in reaction.
6.No food and drinks
<u>B" PREPARATION OF CATHODE</u>
1. Add 200ml of distilled water into one beaker and 150 ml glue remover into another beaker.
2. Draw a line with pencil at 1cm on the coated steel sheet.

3. Hold the sheet by tweezer, put the closer side from line into the glue remover to expose steel inside.
4. Clean the sheet in water and dry it.
5. Repeat B (2,3,4) for all samples.

C" OPERATION: speed up corrosion in primary cell.

1. Connect anode and cathode with a piece of conduct wire each. Draw a line 1cm with pencil.
2. Add 100ml of distilled water into the beaker.
3. Slowly add excessive $CuSO_4$ into water and stir until it stops to dissolve and some solid is left in solution.
4. Put two electrodes into solution. Electrode should not contact with solid $CuSO_4$ at bottom. Start up the timer.
5. Take cathode out of solution after 10min.
6. Clean cathode in water.
7. Remove all paint with glue remover.
8. Clean steel sheet in water again and dry it.
9. Repeat C (1,4,5,6,7,8) for each sample. Add $CuSO_4$ into solution when one loop is finished.

D" PROCCESS OF DATA: mass loss of steel sheet

1. Weigh steel sheet.
2. Divide original mass by present mass
3. Repeat D (1,2)
4. Plot a diagram.

X-axis: percentage of fillers in paint
Y-axis: scale of changed mass

AFTER EXPERIMENT

Clean all apparatus. Place in order.

Table 2 sample preparation

MATERIALS

steel sheets
bisphenol-A epoxy resins
alumina powder (48 μm)
alumina powder (20 nm)
talc powder
calcia powder
Cellulose
95% ethanol
distilled water

APPARATUS

square wooden stand
thermostatic box
500ml beaker*2
paper cup*8
brush
wooden sticks
precautions

ISSN 2959-6157

wear gloves to prevent glue on hand
wear goggles to prevent possible splashes
wear mask to decrease harm of toxic gases
keep away from flame

OPERATION
mix resin and ethanol (95%) in ratio 9:1 in mass. This mixture will be the basis of following formulation
Formulations
empty group
resin 90% ethanol 10% (in mass)
set 1: ethanol addition
A
resin 80% ethanol 20%
B
resin 75% ethanol 25%
set 2: filler addition

Table 3 recipe of coating with different filler addition

Resin base	alumina	talc	calcia
Resin and ethanol (9:1)	5.00%	-	-
Resin and ethanol (9:1)	10.00%	-	-
Resin and ethanol (9:1)	-	5.00%	-
Resin and ethanol (9:1)	-	10.00%	-
Resin and ethanol (9:1)	-	-	5.00%
Resin and ethanol (9:1)	-	-	10.00%

20 samples for each group
apply paint always from one direction
stir the paint again before applying
apply paint always from one direction
Stick samples on the wooden stand, use pencil to label the group on wood.
Put wooden stands in thermostatic box vertically. Avoid shaking or tilting.
Put box a cool and ventilated place.
OTHER
check the samples every 12 hours, more frequent observation if possible
when the surface of sample is cured and fingerprints do not leave, record the time and weigh samples on regular time. If readings of time get stable, record the time taken as the whole coating cured.

Table 4 other tests

test of adhesion	*GB/T9286—2021*
test of elastic modulus	GB1040-79
Test of shore hardness	sclerometer
(the sample used in test should not be reused in another test)	

4. RESULT

In this chapter, the effects of different types of fillers on the durability of composite resin coatings will be discussed in detail. Added paring and analyzing the performance indicators of different fillers added to the coating, insight into the impact of the filler type on the key properties of the coating is gained, such as hardness and barrier properties.

First, comparing the hardness of paints without fillers and paints with different types of fillers. The experimental results show that the hardness of the coating is significantly increased after the addition of inorganic oxide filler, because the inorganic oxide filler has high hardness and stiffness, which can effectively improve the strength of the coating. The selected talc, calcium oxide and alumina have a good improvement in physical strength. Compared with ordinary alumina, the hardness of the coating with nano-alumina is significantly increased as shown in table 5, which may be related to the special effects of the nano-filler, such as the size effect and surface effect of the nanoparticles. Normal alumina, talc and calcia have similar physical enhancement, though their prince is far different.

The next is the effects of different types of filler on the elastic modulus of the coating. The modulus of elasticity is an important indicator of a material's ability to resist elastic deformation. Experimental data in table 5 showed that the coatings with added nano alumina outperformed the other groups in terms of elastic modulus. The modulus of elasticity of 10%allumina-containing coatings is almost twice that of paints without fillers. The increase of addition amount of calcia brings the largest upgrade, from 2.5GPa to 3.2GPa. The results show that the filler can effectively improve the elastic deformation resistance and enhance the structural stability of the coating.

Table 5 effects of filler on physical properties of coating

filler	Amount/%(mass)	Mean Shore hardness	Young's modulus(GPa)
——	——	70	1.9
nano allumina	5	82	3.4
	10	85	4.0*
normal allumina	5	78	3
	10	80	3.1*
talc	5	77	3
	10	80	3.3*
calcia	5	78	2.5
	10	79	3.2*

In addition to hardness and modulus of elasticity, there is study on the effect of fillers on the barrier properties of coatings. Tests have shown that packing materials may have more than a positive effect on isolation performance. Mass loss per unit volume reflexes protection performance in table 6. As a blank group, the uncoated steel sheet was anodically corroded for one hour with a mass loss of 25.8mg/cm^3. Coatings containing nano-alumina showed excellent performance in the test. When the addition amount is 10%, the mass loss of the steel sheet is very small, only 2.1mg/cm^3, and the protective performance (1-mass loss of group/mass loss of empt) is 91.0%. This may have something to do with the fine barrier it forms. Talc powder is slightly inferior. On the other hand, calcium oxide powder unexpectedly causes negative effects. The protective performance of 5% calcia added is 14.7% lower than when resin is applied alone. When the addition amount is 10%, it is only 39.5% as be seen in table 6. After follow-up research, it may be because the absorption of water in the coating by calcium oxide leads to the formation of micropores, which accelerates the contact of corrosion factors with the metal surface.

Table 6 protectivity of different groups

Sample(steel sheets)	Amount/%	Mass loss(mg/cm^3)	Protectivity relative to blank group/%
Uncoated	——	25.8 ± 2.1	——
Only resin	——	8.3 ± 0.9	67.8
nano allumina	5	3.2 ± 0.5	87.6
	10	2.1 ± 0.3	91.9
talc	5	5.6 ± 0.7	78.3
	10	4.0 ± 0.5	84.5
calcia	5	12.1 ± 1.3	53.1
	10	15.6 ± 1.8	39.5

In addition, the effect of adding ethanol on the paint substrate is compared. Simple resin has high viscosity and is difficult to spread evenly. After adding a certain amount of ethanol or other solvents, the viscosity is moderate,

ISSN 2959-6157

which is conducive to the construction and leveling of the coating. The effects of different amounts of ethanol were mixed in the experiment (pure resin was difficult to use, so no control group was set up without additives). According to table 7, when adding 10% of the mass number, the surface is dried after 1~2 hours, and completely dry after 48 hours. There is no peeling in the scratch test, and the shore hardness is 65~74. The addition of 20% allows the paint to dry faster, and the surface drying and complete drying time are about 60% of the previous level. However, a small amount of peeling appeared in the scratch test, and the hardness was also reduced to 60~68.

Table 7 effects of solvent amount on physical properties of coating

Ethanol/%(mass)	curing(surface)/h	curing(complete)/h	adhesion(peeling off)	Shore hardness
10	1~2	48	none	65~74
20	0.6~1	30	slightly	60~68
25	delaminated	delaminated	——	——

As shown in picture 1, coating with nano-alumina or raw resin is carved. Along the scar of raw resin, air enters and creates unprotected areas. Coating it with nano alumina just breaks at the path of knife. The fragments of them are also different. From raw resin, fragments appear to be like plastic. Coating with alumina, which has good adhesion and hardness, is likely to perform as wax.

Picture 1 scars made by knife on coating

In summary, by comparing and analyzing the effects of different types of fillers on the performance indexes of coatings, it can be found that fillers play an important role in improving the hardness, elastic modulus and isolation of coatings. Different types of fillers have their own characteristics in terms of affecting the performance of coatings, so the choice of fillers needs to be considered comprehensively according to the specific application scenarios and needs. The amount of solvent added also needs to be carefully considered. Future research can further explore the interaction mechanism between fillers and coating substrates and optimize the selection and ratio of fillers to improve the comprehensive performance of composite resin coatings.

5.DISCUSSION

5.1 THE EFFECT OF FILLER CONTENT

These composite coatings combine the flexibility of the resin with the special enhancement of the filler to get a multiplied improvement. The effect of changes in filler on the durability of composite resin coatings is discussion worthy.

First of all, it is necessary to clarify the role of fillers in composite resin coatings. Fillers improve the physical properties and durability of coatings. By adding the right amount of filler, a range of properties of the coating can be improved. However, more fillers do not mean better, and too much filler may disperse unevenly, resulting in stress concentrations inside the coating, which in turn reduces the durability of the coating (like the data of calcia in table 5). Potential side effects of some coatings may also become apparent with increasing dosage, such as micropores caused by calcium oxide water absorption.

Filler type and particle size also have a significant impact on durability of coating (two kinds of alumina in table 5). Different types of fillers have different physical and chemical properties. Their compatibility with resins also varies. Fillers with a specific particle size can provide better reinforcement, while particles that are too large or too small can lead to reduced performance. Therefore, when selecting fillers, it is necessary to comprehensively consider factors such as type of compound, particle size and amount of addition.

The special appearance of scar and fragments shows that coating with bad adhesion will be less durable. When scratch is made to it, larger area is going to be unprotected. Especially for the coating frequently rubbed, the speed of losing efficacy can be incredibly high.

5.2 ANALYSIS OF INFLUENCING MECHANISMS

The influence mechanism of fillers on the durability of composite resin coatings is a complex and multidimensional problem. It can be seen at the microstructural level. The addition of fillers can significantly change the internal structure and properties of the coating, which in turn affects the macroscopic physical properties of the coating.
When fillers play a reinforcing role in coatings, they are usually dispersed in the resin matrix in the form of particles, which can effectively hinder crack propagation and improve the crack resistance of coatings. When the coating is subjected to external forces, the filler particles can act as nodes to share the stress, reduce the damage to the matrix resin, and thus enhance the durability of the coating. Based on experimental data of the two sizes of alumina powder, the filler with a smaller particle size may be more effective because it is more closely attached to the resin molecules.
Secondly, the addition of fillers can also improve the thermal stability of the coating. Since fillers typically have high thermal conductivity, they can effectively conduct the heat generated inside the paint and prevent local overheating from degrading the performance of the paint. In addition, some fillers have excellent heat resistance and remain stable in high-temperature environments, and their use in specific operating environments can improve the service life of the coating.
In addition to enhancing and improving thermal stability, fillers also affect the corrosion resistance of the coating. Some fillers are inherently chemically stable and resistant to acids, alkalis, salts, and other chemicals. When these fillers are evenly dispersed in the paint, they form a protective barrier that stops or slows down the erosion of the coating substrate by chemicals, thereby increasing the durability of the coating.
From the literature read, it is found that there is a certain commonality in the effect of fillers on coatings. For example, some hard fillers such as glass fiber, carbon fiber, etc. can enhance the strength and stiffness of coatings, while some soft fillers such as rubber particles, plastic particles, etc. can improve the toughness and impact resistance of coatings. This allows for the exploitation of similar substances.
It is important to note the interface compatibility between the fillers. The resin matrix is also a key factor in the durability of coatings. If the compatibility between the filler and the resin is poor, voids and cracks will appear at the interface, which will reduce the performance of the coating. Compatibility with the resin matrix must be considered when selecting the filler to ensure the uniformity and stability of the internal coating.

6. EVALUATION

The project focuses on the filler addition and relevant effects on performance of coating. Durability is evaluated by corrosion acceleration tests, mechanical strength tests and use controlled trials to ensure preciseness.
Due to several limitations, the tests are compromised into fast and simple methods. Scribing test, for example, discovers the difference in adhesion of formulations effectively, but the result cannot be quantified. If the class interval is small, the result will be too general. One more complex investigation that can get exact quantity should be applied as complementary. Moreover, anodic corrosion is used to simulate attacks from gaseous or ionic acidic chemicals. It accelerates the supper long-term process to one hour bath. In mixed natural environment rather than simply sulfate radical, some other substance may work as catalysts which will overturn the data gained in beaker. Longer time period is also possible to lead out effects beyond expectation.
In operation, liquid paint is a factor that is hard to control with unprofessional approaches. Formulation brings varied performance while the fluidity is changed. Each group has different thickness of stable coating. It is not a controlled variable; some hidden impact may exist. While stirring the paint the speed is a compromised value. Resin foams or filler deposits, whether it is too fast or not enough. This is able to be eliminated by vacuumizing. Because of no access to equipment, the improvement measure is abandoned.
Research needs effort in other directions. According to the great performance of nano alumina, it is worth doing further work on the nano material fillers. Due to their unique dimensional and surface effects, introducing different types of nanofillers, synergistic efficiency of multiple functions can be achieved. Graphene and carbon nano tubes are promising objects of study. As epoxy is developed to be more eco-friendly, the bio-based fillers are also highlighted. Fiber materials like lignin, cellulose and chitin are degradable in natural environment. They are also cheap because they are extracted from wood and shrimp shells. Compared to inorganic fillers, these reproducible materials are undoubted to be preferred in approaching future. It is also interesting to discover potential of combination of organic and inorganic materials. Probably, this will bring coating with multiplied benefits.
If there is access to professional equipment, testing methods can also be improved. Salt spray test is a national standard testing. The anodic corrosion test is a substitution for it. The standard test will provide more powerful evidence.

ISSN 2959-6157

7. CONCLUSION

This study investigates how inorganic fillers influence the durability of water-soluble epoxy resin coatings, focusing on hardness, elastic modulus, and barrier properties. Experiments compared nano-alumina, talc, and calcium oxide fillers at varying concentrations (5–10%), with solvent effects (ethanol) also analyzed.

Filler selection and concentration critically determine coating performance. Nano-alumina emerges as the optimal choice for enhancing durability, while solvent ratios require careful optimization. This work provides actionable guidelines for tailoring epoxy coatings to specific mechanical and environmental demands.

Fillers affect the durability of composite resin coatings in several ways. All the main defects of the resin are reduced or even eliminated with specific fillers. In the design of coating formulations, the type of filler, the amount of filler used, and compatibility with resins must be considered to optimize the quality of the coating.

To further optimize the performance of composite resin coatings, the filler content can be adjusted to the specific needs of the application. For example, in the case of high hardness and wear resistance, the amount of filler can be appropriately increased; In cases where better flexibility and durability are required, the amount of filler used is reduced. At the same time, select the appropriate filler type and particle size for each application.

In the experiment, time required for solidification impacts the efficiency of controlled trials. Costs on raw material and testing equipment limit width of exploration. The research is scientific in terms of method design and data acquisition, but it is necessary to strengthen statistical verification, expand environmental simulation and microscopic analysis to improve the universality and depth of conclusions.

If the research can be deeply integrated with advanced manufacturing technology and computational materials science, it is expected to promote the transformation of the coating industry from “experience trial and error” to “digital twin” mode to release its great application potential. In the future 3-dimension printing will make surface far different to present materials. The application and theory of coating is probably to be overturned. The requirement of factors of filler can be totally changed.

REFERENCE

[1] Liu, S., Zhao, X., Sun, H.Y. et al. (2014) ‘Anti-corrosion properties of epoxy coatings modified with nano-TiO_2’, Materials Protection, 47(1), pp. 11–13.

[2] Han, S.Z. (2009) Modification of epoxy resin with nano-silica and its application in solvent-free low-surface-treatment coatings. PhD thesis. Beijing: China Academy of Machinery Science and Technology.

[3] Li, C.Y., Qiu, D.J., Xie, G.X. et al. (2008) ‘Study on toughening modification of epoxy resin using nano-SiO_2’, Materials Protection, 41(4), pp. 21–23.

[4] Yu, F., Wang, X. & Zhang, Z. (2023) ‘Research progress on the application of nano-fillers in epoxy anti-corrosion coatings’, Journal of Chinese Society for Corrosion and Protection, 43(2), pp. 220–230.

[5] Yan, Y.S. & Yin, H.Z. (2017) ‘Preparation and performance of nano-solvent-free epoxy antirust paint’, Materials Protection, 50(3), pp. 54–56.

[6] *He, X.Y., Chen, L., Yan, Z.C. et al. (2014) ‘Development of nano-TiO_2 solvent-free epoxy anti-corrosion coatings’, Electroplating & Finishing, 33(2), pp. 41–45.*

[7] *Xu, K., Wang, X.J., Fang, J.J. et al. (2022) ‘Preparation and properties of high-performance phenolic epoxy glass flake coatings’, Paint & Coatings Industry, 52(3), pp. 38–43.*

[8] *Gao, L. & Wang, J. (2016) ‘Development of environmentally friendly solvent-free epoxy heavy-duty anti-corrosion coatings’, China Coatings, 31(5), pp. 34–37.*

[9] *Zhang, H.H. (2019) ‘Development of graphene-modified underwater-curing solvent-free epoxy anti-corrosion coatings’, Paint & Coatings Industry, 49(6), pp. 11–14.*

[10] *Sun, Q., Wang, Z.P., Gao, S. et al. (2013) ‘Preparation of high-impact solvent-free epoxy anti-corrosion coatings’, Corrosion Research, 27(8), pp. 46–48.*

[11] *Kang, S.B., Gao, X.H., Ding, R. et al. (2015) ‘Development of low-temperature-curing solvent-free epoxy heavy-duty anti-corrosion coatings for ballast tanks’, Paint & Coatings Industry, 45(7), pp. 1–7.*

[12] *Song, Y.Q. (2017) Modification of flake inorganic fillers and their effects on coating performance. PhD thesis. Jiangsu: Nanjing University of Aeronautics and Astronautics.*

[13] *Liu, X.Q., Ni, X.H., Liu, J.Z. et al. (2007) ‘The size effect in Young’s modulus of nano composite ceramics’, Rare Metal Materials and Engineering, 36(2), pp. 131–133.*

[14] *Zhou, Y.X., White, E., Hosur, M. et al. (2010) ‘Effect of particle size and weight fraction on the flexural strength and failure mode of TiO_2 particles reinforced epoxy’, Materials Letters, 64(7), pp. 806–809.*

[15] *Srivastava, I. & Koratkar, N. (2010) ‘Fatigue and fracture toughness of epoxy nanocomposites’, JOM: Journal of the Minerals, Metals and Materials Society, 62(2), pp. 50–57.*

[16] *Manjunatha, C.M., Taylor, A.C., Kinloch, A.J. et al. (2010) ‘The tensile fatigue behavior of a GFRP composite with rubber particle modified epoxy matrix’, Journal of Reinforced Plastics and Composites, 29(14), pp. 2170–2183.*

[17] *Kim, B.C., Park, S.W. & Lee, D.G. (2008) ‘Fracture toughness of the nano-particle reinforced epoxy composite’, Composite Structures, 86(1–3), pp. 69–77.*

[18] *Adachi, T., Osaki, M. & Araki, W. (2008) ‘Fracture toughness of nano- and micro-spherical silica-particle-filled epoxy composites’, Acta Materialia, 56(9), pp. 2101–2109.*

[19] *Lu, C., Tieu, K. & Wexler, D. (Year missing) ‘Significant enhancement of bond strength in the accumulative roll bonding process’. [Journal/Conference details incomplete].*