Research on Anti-Weathering Coating for Reinforced Concrete pole

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Abstract. The concrete pole of the early construction of the transmission line has weathered and cracked on its surface after long-term operation, and the surface concrete will break and fall off with further development, resulting in the decrease of the bearing capacity of the concrete pole. The anti-weathering coating for reinforced concrete of transmission lines was studied through thermal fatigue tests, achieving simultaneous treatment effects on pole cracking and surface anti-weathering. The anti-weathering coating is mainly composed of epoxy resin, epoxy resin curing agent, phthalate, alkyd resin, etc. Coatings prepared according to established proportions demonstrated good adhesion, compact structure, and durability through thermal fatigue tests. They are particularly suitable for sealing pole cracks and surface anti-weathering, providing a convenient and efficient solution to maintenance issues in transmission line reinforced concrete poles. It can be used for anti-weathering treatment of concrete surface of industrial building.

Keywords: concrete; electric pole; anti-weathering coating; thermal fatigue test, epoxy resin

1 Introduction

Reinforced concrete poles are crucial supporting components in overhead transmission lines. In the early construction phases, a large number of 35 kV, 110 kV, and similar transmission lines utilized reinforced concrete poles due to their simple structure, easy processing, and cost-effectiveness, widely adopting them in transmission line projects [1-3]. Subjected to comprehensive environmental factors like physical, chemical, and biological influences during service, under complex stress conditions, reinforced concrete poles inevitably develop cracks and fissures over prolonged operational periods. This leads to the infiltration of corrosive agents into the internal steel reinforcements, causing rusting and resulting in the fracturing or detachment of the outer concrete layer. Consequently, the safety performance and load-bearing capacity continuously deteriorate [4-8], posing a threat to the safe and stable operation of

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transmission lines. Through the random inspection of the concrete pole of the old transmission line of a power supply company, it is found that there are a number of fine cracks on a number of concrete poles, and the strength of the concrete without defects is usually not much reduced, but the maximum corrosion section of the exposed steel bar can reach 10%-30%, so when the concrete cracks, timely measures should be taken, otherwise it will cause the subsequent repair cost to increase.

Reinforced concrete poles for transmission lines are classified into prestressed and non-prestressed types [3]. Standards specify that when prestressed concrete poles develop cracks, or when non-prestressed concrete poles exhibit longitudinal or transverse cracks with a gap width exceeding 0.2 mm, they require treatment[9]. Currently, numerous reinforced concrete poles in transmission lines have entered an aging phase, displaying severe cracking. Xiaosan Yin et al.[10] proposed to strengthen the ring concrete pole by using the cladding steel method to improve the bending bearing capacity of its components; Miszczyk A et al.[11] improved the reinforcement method to solve the problem of cracks in the old and new parts of the reinforced concrete pole; Jinjun Xu et al.[12] proposed the carbon fiber reinforcement method to improve the bearing capacity of the concrete pole. Sudong Zhang et al.[13] put forward the reinforcement of concrete electric poles by adding cable-stayed cables, steel sleeve reinforcement and steel structure reinforcement. At present, the above studies have taken local repair and reinforcement measures for concrete electric poles, but none of them involve cracks in concrete electric poles, and the surface weathering and cracks of concrete electric poles have not been well solved. Due to various constraints, undertaking a complete replacement of damaged reinforced concrete poles in transmission lines is challenging and comes with considerable costs, causing substantial maintenance difficulties. Existing techniques involve using cement repair agents for patching or applying an overall slurry coating for "reinforcement" [14][15].However, these coatings exhibit poor specificity, short effective durations, and suboptimal outcomes. This study focuses on the sealing of cracks in reinforced concrete poles for transmission lines and the development of surface anti-weathering coatings. Its aim is to effectively protect the surface of concrete poles, prolong their service life, and address maintenance issues associated with transmission line reinforced concrete poles. It also provides reference for concrete surface maintenance of industrial buildings.

2 Experimental Materials and Methods

2.1 Composition of Coating

To prevent the continuous deterioration of the performance of aged transmission line reinforced concrete poles and to provide effective protection to the structural surfaces, thereby extending the lifespan of the poles, a method involving synchronous treatment of crack sealing and surface anti-weathering for cement poles was proposed. Epoxy resin was selected as the base material for the coating due to its strong cohesive force, excellent bonding ability[16], and the capability to be formulated into water-soluble environmentally friendly coatings without generating significant low-molecular-weight volatiles during curing. For the epoxy resin curing agent, a

polyamide epoxy resin curing agent was chosen for its superior properties as a curing agent and toughening agent for epoxy resin. It exhibits minimal toxicity and volatility and offers a wide range of proportions compatible with epoxy resin. Additionally, it is easy to handle and can cure at room temperature, surpassing other combinations in both bonding performance and toughness. The phthalatewaschosen from dibutyl phthalate, selected for its good compatibility, suitable flexibility, excellent adhesion, and outstanding weather resistance, along with its lower viscosity, making it suitable for operational and spraying processes.

The anti-weathering coating for reinforced concrete poles in transmission lines was formulated using epoxy resin as the base, incorporating toughening agents and mixed paint. Through multiple trials and practical experimentation, suitable component contents were determined: epoxy resin 20%-30%, epoxy resin curing agent 20%-30%, phthalate 5%-10%, and alkyd resin 30%-55%. To thoroughly investigate the performance and engineering application effects of the anti-weathering coating, samples with different proportional formulations were prepared. Table 1 illustrates the coating formulations for the samples, following which thermal fatigue tests were conducted.

Table 1. Formulation Ratio Table of Sample Coatings (Volume %)

Sample No.	Epoxy Resin	Curing Agent	Dibutyl Phthalate	Alkyd Resin Coating
#1	20	20	5	55
#2	25	25	10	40
#3	30	30	10	30

The epoxy resin curing system typically consists of two components, A and B. Component A serves as the base material, composed of epoxy resin, active diluent, toughening agent, and other additives, while component B functions as the curing agent, consisting of curing agent, diluent, and accelerator. Considering the compatibility of the epoxy resin curing system with the alkyd resin coating and phthalate, the epoxy resin curing system (only including epoxy resin and curing agent) was optimized to ensure effective bonding, curing time, and compliance with field application requirements for coatings.

2.2 Preparation Steps

The steps for preparing the anti-weathering coating for reinforced concrete poles in transmission lines are as follows:

(1) Mix epoxy resin and epoxy resin curing agent thoroughly until uniform. The weight ratio of epoxy resin to epoxy resin curing agent is 1:1.

(2) Add dibutyl phthalate and stir evenly.

(3) Continuously add alkyd resin coating on the basis of Step (2) to adjust the viscosity and color intensity of the coating.

(4) Thoroughly mix the above materials to create the coating solution.

After the preparation of the anti-weathering coating for reinforced concrete poles, the coating is applied using spraying or brushing methods, ensuring uniform thickness ranging from 120 μm to 150 μm. The coating exhibits good adhesion, compacted structure, and provides convenient and swift application.

2.3 Thermal Fatigue Test

Thermal fatigue test evaluates the performance and life of materials under high temperature and harsh environment by simulating the strain, temperature cycle and other states of materials in actual use. In order to study the fatigue resistance of concrete pole anti-weathering coatings, cement blocks of dimensions 50 mm × 50 mm × 100 mm are prepared following the formulation ratios in Table 1 to create coatings. Subsequently, the thermal fatigue test is conducted with heating and cooling cycles according to the scheme shown in Table 2, continuing until cracks appear. The procedure is as follows:

(1)Maintain at 150 °C for 15 minutes, followed by cyclic heating and cooling for 100 repetitions.

(2)Maintain at 200 °C for 15 minutes, followed by cyclic heating and cooling for 50 repetitions.

(3)Maintain at 250 °C for 15 minutes, followed by cyclic heating and cooling for 50 repetitions, with cooling achieved via water cooling.

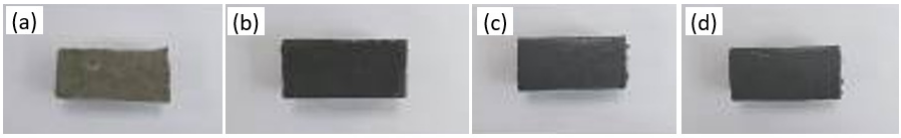
Table 2. Thermal Fatigue Test Scheme

Test Name	Heating Temperature/°C	Holding Time/min	Cooling Method	Cooling Time/min	Heating-Cooling Cycles
A	150	15	Water Cooling	15	100
B	200	15	Water Cooling	15	50
C	250	15	Water Cooling	15	50

3 Thermal Fatigue Test Results and Analysis

3.1 Thermal Fatigue Test Results

The coating was uniformly applied to the surface of cement blocks following the formulation ratios in Table 1, with a coating thickness not exceeding 500 μm. After drying, the blocks were set aside for testing, as depicted in Figure 1.



(a) Cement block; (b) Sample 1; (c) Sample 2; (d) Sample 3

Fig. 1. Photographs of Cement Blocks After Coating Application

Following the heating and cooling scheme detailed in Table 2, thermal fatigue tests were conducted until cracks appeared on the sample surfaces. The test results are outlined in Table 3. After 183 cycles of thermal cycling, cracks appeared on the surfaces of the samples. Notably, Sample 1 exhibited 6 cracks, Sample 2 exhibited 3 cracks, and Sample 3 exhibited 1 crack. This indicates that Sample 1 had poorer fatigue resistance while Sample 3 demonstrated better fatigue resistance.

Table 3. Thermal Fatigue Test Results

Sample No.	Test Scheme (A+B+C)			Cumulative Thermal Fatigue Cycles	Test Result
	A/cycle	B/cycle	C/cycle		
1	100	50	33	183	6 cracks
2	100	50	33	183	3 cracks
3	100	50	33	183	1 crack

3.2 Surface Morphology of Thermal Fatigue Test Samples

The surface morphology of the samples after the thermal fatigue test is illustrated in Figure 2. Clear cracks are observed on the surface of the samples, accompanied by a small amount of blistering. Notably, Sample 1 has the highest number of cracks and a relatively large number of blistering points. In contrast, Sample 3 exhibits only one crack, and the number of blistering points is the lowest.

(a) Sample 1; (b) Sample 2; (c) Sample 3

Fig. 2. Photographs of Surface Morphology After Cracking of Test Samples

3.3 Results Analysis

Concrete surface coating protection mainly includes three types: pore sealing coatings, surface modeling coatings, and organic silicon penetrating coatings[17][18] as shown in Figure 3. Coatings utilize the permeability of concrete to penetrate to a certain depth on the surface of the concrete, completely blocking the pores or forming a coating to seal the pores on the surface, or forming a hydrophobic layer on the surface of the concrete pores that does not seal the pores.

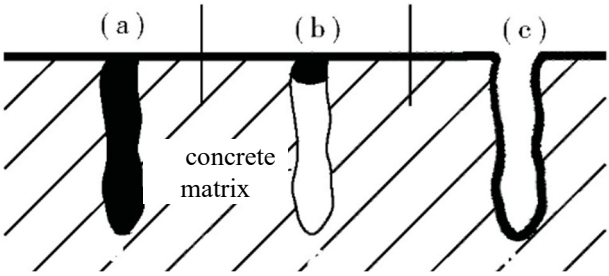


Fig. 3. Protection methods of concrete surface (a) pore sealing; (b) Surface molding; (c) Silane based hydrophobic agents

In operation, cracks in reinforced concrete poles primarily manifest in forms such as densely distributed fine surface-visible cracks, one or multiple long vertical fissures, localized area fractures, crazing, and exposed reinforcement. Due to natural aging and prolonged subjection to imbalanced forces, initial manifestations include the generation of fine cracks on the pole's surface. At this stage, air, rainwater, and humid air gradually penetrate inward. When the reinforcement comes into contact with air or humid air, corrosion begins, exerting expansive forces that gradually increase the width and length of the cracks, ultimately resulting in the detachment of concrete from the exterior of the reinforcement.

Epoxy resin possesses strong cohesive forces and a compact molecular structure, and its epoxy groups exhibit high to concrete. It resists bursting under sunlight and boasts excellent bonding capabilities, effectively sealing cracks on the pole. However, it is relatively costly and tends to be brittle after the curing process. The epoxy resin curing system primarily bonds and seals various cracks on the pole[19], exhibiting highly effective bonding and sealing properties against pole cracks[20]. The molecular formula of epoxy resin is shown in Figure 4. Phthalates, as plasticizers, can adjust the flexibility of epoxy resin coatings. They exhibit good compatibility with epoxy resin. The enhancement of color, adhesion, and extensibility of epoxy resin and alkyd resin coatings under conditions of thermal and light aging is attributed to the use of phthalate plasticizers.

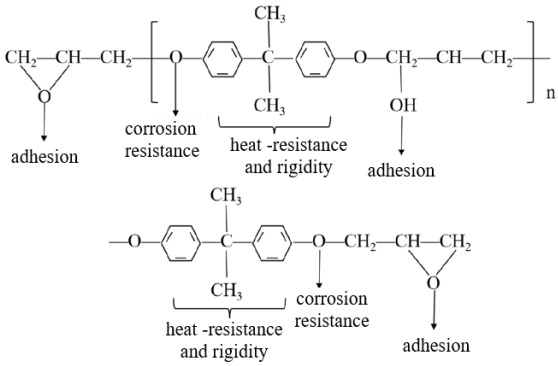


Fig. 4. Molecular formula of epoxy resin

Based on the aforementioned analysis, leveraging the advantages of epoxy resin, incorporating plasticizers and film-forming synthetic resin within epoxy resin as the base creates coatings with strong adhesion and toughness. These coatings exhibit good fatigue resistance below 150 °C and maintain a favorable surface state even at 200 °C. At 250 °C, the performance of epoxy resin under high-temperature conditions deteriorates, resulting in the occurrence of melting. Typically, the working temperature range for epoxy resin is -50 °C to 180 °C. Introducing a higher proportion of alkyd resin into epoxy resin compromises its high-temperature resistance. Sample 1, with a lower plasticizer content in its coating, exhibited the most severe surface coating damage. From the research findings, considering the comprehensive performance of coatings, Sample 1's formulation should be prioritized in practical engineering. If cost and appearance are both factors, Sample 2' s formulation could be utilized in engineering applications.

4 Conclusions

(1) We propose a wind-resistant coating for synchronous treatment of cracks and surface anti-weathering in transmission line reinforced concrete poles. The coating primarily consists of a combination of epoxy resin, epoxy resin curing agent, phthalates, and alkyd resin. The anti-weathering coating can not only ensure the elasticity and elongation of the coating, but also not excessively reduce the tensile strength of the coating.

(2) The molecular structure of epoxy resin is dense, and its epoxy group has high adhesion to concrete, which can effectively seal the cracks on the pole. The epoxy resin curing system is extremely effective in the adhesion and sealing of the cracks on the pole, and can bond and seal various cracks on the pole. The coating of epoxy resin and alkyd resin after plasticizing phthalates can improve the color, adhesion and extensibility under heat and light aging conditions.

(3) Through thermal fatigue testing, a suitable anti-weathering coating for cement poles has been developed. The coating demonstrates good adhesion, compact structure, and durability. It is particularly suitable for sealing cracks and surface anti-weathering in cement poles, facilitating convenient and swift maintenance of transmission line reinforced concrete poles.

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