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Study on the Transformation of Corrosion Products on the Surface of Electric Steel Structure by Compound Rust Conversion

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Abstract:

The atmospheric corrosion of electric steel structure in strong electromagnetic field environment is serious. Sand blasting for rust removal is dangerous to operators due to its electric field environment. In this paper, phosphoric acid and phytic acid compound conversion solution is used to study the effect of different preparation technologies on the conversion of corrosion products on carbon steel surface. The experimental results revealed that phosphoric acid has a good dissolving capacity to the rust products, and the phytic acid was a superior complexing agent to the iron ion. The composited rust converter can well realize the purpose of rust conversion, and can form a layer on the surface of Q235 steel, which has certain protective effect to the steel.

Keywords: *Rust conversion coating, Carbon steel, Corrosion and Protection.*

I. INTRODUCTION

Steel structures, including transmission towers, steel frames, and the support of electrical devices, are major parts of the metal components of power facilities and are crucial to ensuring power security. Electric steel structures are perennially exposed in the atmospheric environment, and the corrosive medium and moisture contained therein cause severe erosion to the steel materials, rendering the structure fragile and causing material loss. More serious consequences are electricity accidents such as material fractures and structural collapse. Atmospheric corrosion is the form of corrosion that occurs the most frequently and does the greatest damage. The corrosion happens when air humidity reaches a threshold, with oxygen in the air acting as the depolarizing agent in the reaction. Sulfur dioxide, hydrogen sulfide, nitrogen oxides as well as salt and particulate matters are all capable of accelerating the corrosion. The strong electromagnetic field that exists in the operating environment of

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electrical steel structures renders the corrosion more severe due to its capability of ionizing the atmosphere. A survey was conducted on the atmospheric corrosion of steel structures and devices in 510 electrical substations with a voltage class of 110kV and higher in a region in North China. The outcome of the survey shows over 10% of the electrical substations endure severe atmospheric corrosion; substations with a higher voltage class corroded more severely [1].

The main anticorrosive design applied on electrical steel structures is the hot dipping galvanizing technique. From a practical aspect, the actual service life of the structure is much shorter than expectancy, especially in the marine atmosphere, heavily contaminated areas, and high voltage power transmission and transformation environments. In some cases, corrosion happens after usage of merely 3 to 5 years [2]. Corroded steel structures are unsightly and, more importantly, imperiling the electricity facility. Therefore, constant maintenance and anticorrosive paint are imperative to prevent further corrosion, thereby securing the power facilities. The atmospheric corrosion product formed on the surface of the structure is also detrimental as it segregates metal substrate and anticorrosive coating to be applied, reducing its adhesion and service life. Common approaches to remove corrosion products are removing them manually, by machine, and by sandblasting. Whatever the approach, removing the product in strong electromagnetic circumstances is extremely hazardous, rendering high cost in maintenance. New demands for the coating material arise consequently. Surface-tolerant and capable of being applied directly on rusty or moist surfaces are the properties to resolve the problem. In addition to ensuring adhesion and protecting the substrate, coating pretreatment is also required to function in a strong electromagnetic field.

II. TRANSFORMATION MECHANISM OF RUST ON METAL SURFACE

The main components of the atmospheric corrosion product of carbon steel are α-FeOOH, γ-FeOOH, and Fe3O4. In the industrial atmosphere, the composition of atmospheric corrosion products varies according to the type of particles and ions, such as sulfur dioxide and chloride ions in the atmosphere [3]. Corrosion product on the surface of the metal is stratified. The outer layer is an adhesive layer that is porous and may detach. The inner layer is composed of oxide with a compact structure and excellent adhesion. The conductivities of the oxide in the corrosion product vary: Fe3O4 is a conductor with compactness and stability; γ-FeOOH is a semiconductor with electrochemical activity. α-FeOOH is an insulator that displays nearly no activity in the layer. The corrosion product of carbon steel is porous, with cavities unevenly distributed in the structure. Altogether, the corrosion layers display a three-dimensional grid structure with cavities in different sizes intertwined inside.

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Rust coating first occurs in China in the 1970s and the technology develops rapidly in recent decades. The most significant advantage of the coating is the capability of being applied even with the presence of corrosion products on the surface of the metal, and its adhesion [4, 5]. Therefore, two special properties are required other than those of ordinary materials, namely permeability, so that the coating infiltrates the cavities and thereby sealing the layer, and high reactivity, with the purpose of deactivating the reactive ion compound in the rust layer and producing stable stuffing.

III. RESEARCH ON THE CONVERTING OF CORROSION PRODUCT ON THE SURFACE OF CARBON STEEL WITH COMPOSITE SOLUTION

Converting corrosion product on the surface of the carbon steel is feasible by using reactive substances that react with corrosion product and producing stable coordination complex or chelate that deposit on the surface of the substrate[6-8], thereby converting deleterious rust to stuffing of the coating and increasing its adhesion.

3.1 Research on rust transforming agent

Corrosion product on the surface of carbon steel is mostly the mixture of iron oxides with thermodynamic stability to a certain extent. According to the principle of rust transformation technology, reaching optimal converting effect requires oxides in corrosion product to be decomposed to ions since iron element in the corrosion product reacts with the complexing agent the most easily in ion form. In common rust removing techniques, dissolving rust with substances such as sulfuric acid, hydrochloric acid, nitric acid, and phosphoric acid are all feasible. However, in the rust converting technique, the reaction takes place on and only on the surface of steel material. Therefore, the long-term usage of strong acid becomes inappropriate since excessive acid corrodes the steel substrate. In addition, the residue of strong acid degrades and oxidizes the organic resin coating, accelerating the damage to the coating from the inside and reducing its service time. One kind of acid, phosphoric acid, is exceptional. Since phosphoric acid is a medium-strong acid, it is capable of dissolving rust effectively and, according to the mechanism of phosphating, cannot corrode deeper steel substrate layer since a compact phosphate membrane that prevents further reaction is formed when phosphoric acid contacts the steel substrate. The influence phosphoric acid has on the organic resin coating is minor. Furthermore, a special design enables phosphoric acid to react with organic functional groups and be carried in the resin network, reducing the effect free acid has on resin performance. Thus, phosphoric acid is selected as the transforming agent in the rust conversion solution.

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In the experiment, phosphoric solution of three mass concentration-10%, 20%, and 30%-were prepared. Then brush the solution on the surface of Q235 steel that was treated in salt spray condition for 3 hours. After 24 hours at room temperature, record the different effects caused by the three types of solution. The outcome is displayed in Fig 1.

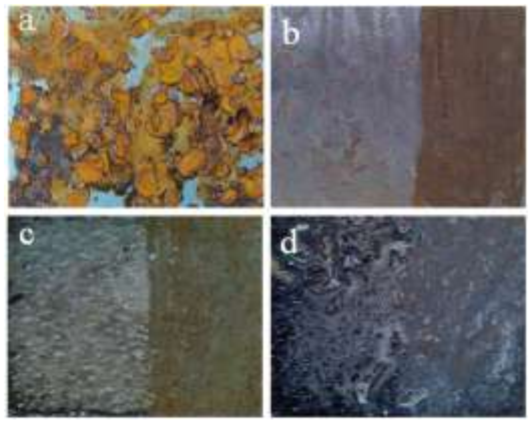

Fig 1: The effect of phosphoric acid on Q235 steel treated in salt spray condition for 3 hours(a: corrosion product after 3 hours, b: 10% phosphoric acid solution, c:10% phosphoric acid solution, d: 10% phosphoric acid solution)

Fig 1(b) shows that phosphoric acid solution with a mass concentration of 10% cannot display a sufficient converting effect. Removing the conversion layer on the surface shows that no reaction occurred on most corrosion products on the surface of the substrate.

Fig 1(c) shows that phosphoric acid solution with a mass concentration of 15% displays its good converting ability. Conversion product layer occurred but the rust at the bottom layer near the substrate could not fully convert.

Fig 1(d) shows that phosphoric acid with a mass concentration of 20% displays an optimal converting effect. It infiltrated to the surface of the substrate and formed an adhesive converting product there. However, the conversion product layer is inhomogeneous and partially black. The explanation is that the content of acid in acid solution with a mass concentration of 20% is slightly excessive. In the part with less corrosion product, the rust was reacted completely quickly. The excessive acid reacted with the Q235 steel substrate. Phosphoric acid reacts with iron rapidly, generating hydrogen and gas bubbles. The movement and breaking of bubbles render the product layer inhomogeneous. Furthermore, because of the thickness of the conversion layer, cracks and pulverization may occur, affecting the adhesion.

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3.2 Selecting the complexing agent

Molecules with multipolar functional groups are all able to have complex reactions with ferrous iron and ferric iron. The solutions of phosphoric acid, phytic acid, oxalic acid, tannic acid, and tartaric acid can all serve as the complexing agent. From the perspective of complex sedimentation, the product of phytic acid and ferric iron has a good settlement effect. The proportion of organic phase in its molecule is greater, providing it with better hydrophobicity and therefore better settlement effect, making it suitable for the main complexing agent.

3.3 Assistant agents

In order to improve the effect of rust transformation, it is necessary to enhance the ability of the conversion solution to infiltrate the rust and to make conversion liquid spread on the surface of the rust as much as possible, thereby improving the conversion rate. The addition of isopropanol renders the infiltration of metal and its oxide easier. Moreover, gas is generated when converting agent reacts with rust, forming bubbles that lead to inhomogeneous conversion product and affecting the outcome. Thus, deforming agents are needed to improve homogeneity and compactness.

3.4 Components of conversion solution

In summary, the composite converting solution of phosphoric acid and phytic acid has a good converting effect on corrosion products on the surface of carbon steel. The optimal component of the solution is displayed in TABLE I.

TABLE I. THE COMPONENTS OF CONVERSION SOLUTION

The Components Of Conversion Solution	**Components**				
	Phosphoric acid wt%	**Phytic acid wt%**	**Isoproanol wt%**	**Defoaming agent wt%**	**Water wt%**
Content	15~20	10~15	3	0.5	residual

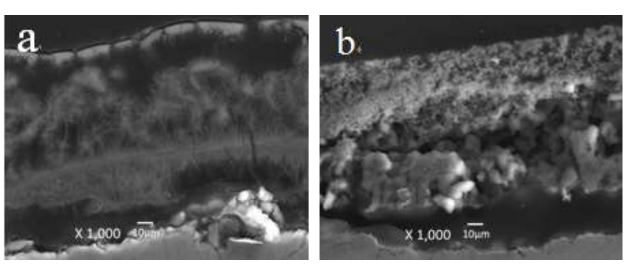

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Fig 2: SEM analysis of the section of composite solution effect (a)Section of rust, (b) Section of conversion

Fig 2. Shows that after the effect of composite solution, the rust on the surface of the carbon steel sample converts from iron oxide with the stratified distribution of multiple crystal forms to accumulation of granular complexes. Its arrangement status changes from porous to compact. The layer of conversion product has a thickness of approximately 20 to 30 μm.

IV. CONCLUSION

Phosphoric acid has a good converting effect on corrosion products, and phytic acid has a good complexation effect on the iron ions.

We designed an optimal composited solution with good effect on rust layer on the surface of carbon steel and forms homogeneous and compact conversion products.

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