Study on Compatibility of Waterborne Surface Treatment Coatings

Wenbo Li 1, Yingfei Yang 2, Dongdong Song 2, Jiran Zhu 1, Yi Xie 1

(1. State Grid Hunan Electric Power Company Limited Research Institute, 388 ShaoShan N Rd, Changsha 410000, China; liwb@alum.imr.ac.cn;
(2. Institute of Advanced Wear & Corrosion Resistant and Functional Material, Jinan University, 601 Huangpu W Ave, Tianhe District, Guangzhou 510632, China)

Abstract: the severe corrosion of power grid equipment has always been an important factor affecting the service life of equipment. Rust transfer technology is used to treat the corroded equipment to improve the corrosion resistance of transmission grid cabinet equipment in high temperature and high humidity environment. Taking acid modified acrylic acid as the main component, the composite conversion solution was obtained by adding phosphoric acid and phytic acid. Through the surface morphology, electrochemical test and adhesion test after rust conversion, the universality and corrosion resistance of the rust conversion solution were analyzed; Combined with zinc phosphate primer and zinc rich primer, the effects of rust conversion solution on the adhesion and salt spray corrosion resistance of the two commercial primers were studied. The compound conversion solution has good rust conversion effect on atmospheric corrosion rust layer, salt spray corrosion rust layer and damp heat corrosion rust layer; The corrosion resistance and adhesion of atmospheric corrosion rust layer are obviously improved after being treated with rust conversion solution. The adhesion of zinc phosphate primer and zinc rich primer on rust conversion solution is 2.1 times and 0.8 times higher than that of atmospheric corrosion rust layer without rust conversion, respectively. The compound rust conversion solution has strong universality and can convert atmospheric corrosion, salt spray corrosion and damp heat corrosion rust layers. At the same time, it has good corrosion resistance, which can significantly improve the corrosion potential of the corroded surface and reduce the corrosion current density. In addition, the composite rust conversion solution can significantly improve the adhesion and corrosion resistance of the primer coating.

1 Introduction
Infrastructure networks, such as transmission grid and communication network, are the blood of industrial production and people's life. Ensuring the safe and reliable operation of infrastructure networks such as power grid is a necessary prerequisite to ensure economic activities. When the power grid operates in high humid and hot natural environment and industrial pollution environment, important control components such as metal cabinet equipment are also faced with corrosion and accelerated damage caused by long-term condensation in humid atmosphere. Aiming at the problem of metal corrosion protection, organic anti-corrosion coatings are the most effective and feasible means at present because of their shielding effect [1], chemical protection effect [2], electrochemical protection [3]. However, research shows that it is necessary to ensure good coating / metal interface bonding in order to realize the function of anti-corrosion coating [4].

Common substrate pretreatment includes mechanical method and chemical derusting method [5],
which can ensure good bonding of coating / metal interface. However, due to the limitations of equipment, site and environmental protection in the field, effective substrate treatment cannot be carried out. Therefore, low surface treatment coatings have become a research hotspot. Rust coating, also known as low surface tolerance coating, can directly stabilize, passivate or transform the rust layer, so that the active rust layer becomes a stable substance, so as to achieve the dual purpose of rust removal and protection of metal surface. At present, there are three types of rust coatings widely studied: permeable [6,7], stable [8,9] and conversion [10,11]. Some products developed for solvent based epoxy resin in China have excellent performance [12,13], but they are not conducive to popularization and use due to environmental protection restrictions.

Waterborne coatings are an important direction for the development of coatings industry in the future. Phosphoric acid [14], phytic acid [15] and phosphate functional components [16] are the most commonly used functional components in low surface treatment coatings, but most of these substances are acidic, resulting in hidden dangers in the stability of aqueous film-forming system, which limits the development of high-performance waterborne low surface treatment coatings. Based on this, this paper uses the new modified acrylic resin as the film-forming system, combined with the functional components of phosphoric acid, phytic acid and phosphate, to trial produce the waterborne low surface treatment coating. By studying the synergistic effect of each functional component and its compatibility with the resin system, and analyzing the matching with the subsequent coating, it provides a basis for the development of the new waterborne low surface treatment coating.

2 Experimental procedure

2.1 coating preparation
Chemical composition of Q235 steel used (calculated by mass fraction): C \( \leq \) 0.22\%, Mn \( \leq \) 1.4\%, Si \( \leq \) 0.35\%, S \( \leq \) 0.05\%, P \( \leq \) 0.05\%, Fe balance. The pretreatment process is: soak in degreasing solution for 40 min → clean with water → grind with sandpaper to No. 150 → wash with alcohol → dry in air for standby. The substrate is treated in three ways to form rust layer as coating substrate: 1 indoor damp and heat, 2 indoor salt spray, 3 natural exposure.

Film forming resin system: acid modified acrylic resin. The drugs used in this paper are phosphoric acid, phytic acid, zinc phosphate, propionic acid, hexamethylenetetramine and glycerol.

The sample preparation steps are as follows: 1) dissolve a certain amount of phosphoric acid, phytic acid and propionic acid mixture, a certain amount of zinc phosphate and hexamethylenetetramine mixture and a certain amount of glycerol in an appropriate amount of deionized water, stir at 1000 rpm for 1 h to obtain component A; 2) adding a certain amount of silicone modified defoamer in a certain amount of acid modified acrylic resin emulsion to obtain 0.5h B at low speed. 3) Mix components a and B, stir evenly at low speed and stand still for 20min; 4) Apply to the surface of rusted substrate.

2.2 performance test and organization observation
1) The coating was observed by phenom prox scanning electron microscope, digital camera and Leica dmi3000m optical microscope, and the elements and components were analyzed by EDS attached to the scanning electron microscope.

2) Use Ultima IV; RIGAKU corporationxrd was used to analyze the composition before and after rust transformation.

3) Chenhua e604 was used for electrochemical test, the solution was tested with 3.5\% NaCl, and the corrosion properties before and after rust transformation were analyzed.

4) The coating adhesion was tested with defelko at-m adhesion tester.

5) Salt spray test shall be conducted for the coating according to the national standard GB t 1771-2007 determination of resistance to neutral salt spray of paints and varnishes.
3 Results and discussion

3.1 surface morphology of different rust layers after rust transformation

Atmospheric corrosion (outdoor exposure for one month), salt spray corrosion (neutral salt spray corrosion for 72 h) and damp heat corrosion respectively (humidity 85%, temperature 80 °C 200 h) the surface is coated with compound conversion solution. The micro morphology after rust conversion is shown in Figure 1. It can be seen from the figure that the rust layer of conversion solution has good film-forming effect under three conditions, and there are a small amount of cracks and bulges on the surface. The existence of microcracks can increase the permeability of the coating, and bulges can increase the surface roughness and improve the adhesion of the coating. The composite conversion solution has good conversion function for the surface of a variety of corrosion products.

![Fig. 1 surface morphology of different rust layers after rust Transformation: (a, d) atmospheric corrosion rust layer, (B, e) salt spray corrosion rust layer and (C, f) damp heat corrosion rust layer](image)

3.2 binding performance of rust conversion solution after treatment

In order to analyze the adhesion between the rust conversion layer and the substrate, the adhesion of the rust conversion layer was tested. First, a pull-out test was carried out. However, after the rust conversion layer completely reacts and is stable, the surface energy of the film layer is low and the adhesion with the adhesive is poor. The pull-out test is due to the fracture between the adhesive and the film surface, and the real bonding condition of the film layer cannot be measured, as shown in Fig. 2 (a) and Fig. 2 (b), indicating that the conversion layer has a good bonding with the substrate.

![Fig. 2 drawing test results of atmospheric corrosion rust layer after rust Transformation: (a) sample surface, (b) test column surface](image)

3.3 electrochemical performance after rust conversion solution treatment

After atmospheric corrosion The polarization curve and impedance spectrum of the (actual exposure) rust layer before and after rust transformation are shown in Fig. 3. After the treatment of the composite conversion solution, the corrosion potential of the sample increases significantly and the corrosion current decreases slightly. The specific electrochemical results are shown in Table 1. The results of the planned curve show that the corrosion resistance of the sample is significantly improved after the
treatment of the composite conversion solution. The composite corrosion conversion solution is used for conversion. The corrosion potential increased obviously and the corrosion current decreased obviously, indicating that the corrosion conversion layer has a good protective effect. The results of electrochemical impedance spectroscopy showed that the composite corrosion conversion solution improved the corrosion resistance of the corroded substrate.

![Fig. 3 polarization curve of atmospheric corrosion rust layer after rust transformation](image)

Table 1 electrochemical parameters of actual exposed samples and rust transformation

| number                  | corrosion potential (mV) | Corrosion current (10^-5 A/cm²) |
|------------------------|--------------------------|---------------------------------|
| Actual exposure sample | -806                     | 3.54                            |
| After rust transformation | -698                   | 0.89                            |

3.4 effect of rust conversion solution on coating adhesion

In order to verify the practical application performance of the rust conversion solution, commercial zinc phosphate and zinc rich primer were selected as reference materials and coated on the surface of the test piece after rust conversion. It is compared with coating two kinds of commercial anti-corrosion paint on the rusted surface after three days of salt spray. As shown in Fig. 4, it can be seen that when zinc phosphate antirust coating is directly applied on the rusted surface, the rusted part of the substrate penetrates into the coating surface, forming unevenly distributed yellow corrosion points on the coating surface; After rust conversion, the surface is coated with zinc phosphate antirust coating with uniform and complete color distribution. When zinc rich primer is directly applied on the corroded surface, the color distribution of the sample surface is uniform after the paint film is cured, but the surface roughness is uneven. In contrast, the surface after rust conversion is uniform and complete after zinc rich primer is applied.

![Fig. 4 surface morphology of atmospheric corrosion rust layer coated with primer and rust conversion solution plus primer, surface morphology with zinc phosphate antirust primer (a), with zinc rich primer (b), with rust conversion solution and zinc phosphate antirust primer (c), with rust conversion solution and zinc rich primer (d).](image)
The results of pull-out test on the samples coated with primer on the surface of atmospheric corrosion rust layer and coated with primer after rust conversion are shown in Figure 5. It can be seen from the figure that when zinc phosphate primer is coated on the surface of the sample after rust conversion, its adhesion is more than twice that of the sample without rust conversion. The adhesion of zinc rich primer coated on the surface after rust conversion is nearly twice that of the sample without rust conversion. The above results show that rust conversion solution can significantly improve the adhesion of primer.

![Fig. 5 adhesion of atmospheric corrosion rust layer coated with primer and rust transfer solution plus primer, adhesion with zinc phosphate antirust primer (a), with rust conversion solution and zinc phosphate antirust primer (b), with zinc rich primer (c), with rust conversion solution and zinc rich primer (d).](image)

In view of the excellent conversion ability of the rust conversion solution, it was applied on site in combination with zinc rich anticorrosive paint. It is applied to the side cabinet plate and lower cabinet plate of distribution network cabinet equipment.
Fig 6. Field application of rust conversion solution and zinc rich anticorrosive paint in rust resistance of cabinet equipment

4 Conclusion
In this paper, the rust conversion solution with acrylic resin as the main component is developed, and the universality, corrosion resistance and adhesion to primer of the rust conversion solution are tested. The following conclusions are drawn:

(1) Rust conversion solution has strong universality, which can convert atmospheric corrosion, salt spray corrosion and damp heat corrosion rust layer;
(2) Rust conversion solution has good corrosion resistance, which can significantly improve the corrosion potential of corroded surface and reduce the corrosion current density;
(3) Rust conversion solution can significantly improve the adhesion and corrosion resistance of primer coating.

References
[1] YH. Wu. Correlation Between Steel Corrosion and Coating Wet Adhesion[J]. Synthetic Materials Aging and Application, 31 (2002) 28-31.
[2] X. Lu, Y. Zuo, X. Zhao, et al. The influence of aluminum tri-polyphosphate on the protective behavior of Mg-rich epoxy coating on AZ91D magnesium alloy[J]. Electrochimica acta, 93 (2013) 53-64.
[3] D. Xie, J. Hu, S. Tong, et al. The development of Zinc-Rich paints[J]. Journal of Chinese Society for Corrosion and Protection, 24 (2004) 314-320.
[4] I. Gonzalez, D. Mestach, J.R. Leiza, et al. Adhesion enhancement in waterborne acrylic latex binders synthesized with phosphate methacrylate monomers[J]. Progress in Organic Coatings, 61 (2008) 38-44.
[5] F. Deflorian, L. Fedrizzi. Adhesion characterization of protective organic coatings by electrochemical impedance spectroscopy[J]. Journal of adhesion science and technology, 13 (1999) 629-645.
[6] C. Peebles, J. Garcia, A.P. Tornheim, et al. Chemical “Pickling” of phosphite additives mitigates impedance rise in Li ion batteries [J]. The Journal of Physical Chemistry C, 122 (2018) 9811-9824.

[7] V. Guillaumin, D. Landolt, Effect of dispersion solution on the degradation of a water borne paint on steel studied by scanning acoustic microscopy and impedance [J]. Corrosion science, 44 (2002) 179-189.

[8] X. ZU, J. HU, F. WANG, et al. Research progress of environment-friendly anti-rust coatings [J]. Chemical Industry and Engineering Progress, 9 (2008).

[9] V. Vetere, M. Deya, R. Romagnoli, et al. Calcium tripolyphosphate: An anticorrosive pigment for paint [J]. Journal of Coatings Technology, 73 (2001) 57-63.

[10] N. Li, H. Lv, W. Fu, et al. Preparation and Performance of a New Waterborne Rust Converting Agent [J]. Contemporary Chemical Industry, 47 (2018) 56-59.

[11] J.-M. Yeh, K.-C. Chang. Polymer/layered silicate nanocomposite anticorrosive coatings [J]. Journal of Industrial and Engineering Chemistry, 14 (2008) 275-291.

[12] L. Ning, Y. Chen, K. Yang, et al. Research and Application of a Highly Adaptable Anticorrosion Coating for Transmission Tower [J]. Corrosion Science and Protection Technology, 2019(2) 149-154.

[13] K. Xu, J. Fang, B. Lian. Study on Preparation and Properties of High Performance Surface-Tolerant Epoxy Coating [J]. Paint & Coatings Industry, 2019(4):27-33.

[14] Singh D D N, Bhattacharya D. Performance and mechanism of action of self-priming organic coating on oxide covered steel surface [J]. Progress in Organic Coatings, 2010, 67(2):129-136.

[15] Li J, Ge S, Wang J, et al. Water-based Rust Converter and its Polymer Composites for Surface Anticorrosion [J]. Colloids and Surfaces A Physicochemical and Engineering Aspects, 2017:S0927775717309408.

[16] Feng L, Yuan P. Corrosion protection mechanism of aluminum triphosphate modified by organic acids as a rust converter [J]. Progress in Organic Coatings, 140(2020): 105508.