



Study of the corrosion protection behavior of neutral water-based rust remover on carbon steel

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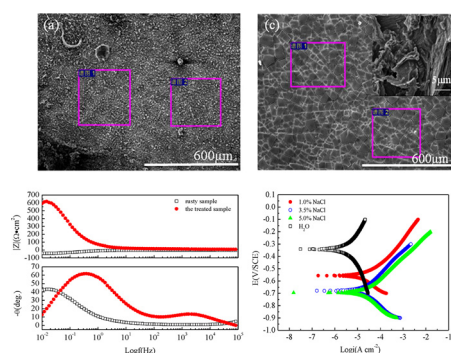
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GRAPHICAL ABSTRACT



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ABSTRACT

The purpose of this work was to study the corrosion protection behavior of neutral water based rust remover on carbon steel. The reaction between rust remover and steel was explored by X-ray diffraction (XRD), FT-IR, energy dispersive spectrometer(EDS), scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy(XPS). Tests revealed that the surface of low-carbon steel treated with neutral rust remover was relatively smoother and the rust was capable of reacting with rust remover by forming a Fe-O-P and Fe-O-C chelate film. Besides, the rust-removing samples with a larger impedance value showed a better corrosion resistance than the rusty samples. Corrosion resistances of the film were investigated in sodium chloride solution of different concentrations by using Tafel polarization technique and electrochemical impedance spectroscopy. The results demonstrated that the film of carbon steel was highly susceptible to solution with chloride, which was characterized by the decreasing corrosion potential (E_{cor}) of the samples and the increasing corrosion current density with the addition of chlorides. Meanwhile, the film formed during a 1-hour immersion time had a better corrosion resistance (a larger impedance value) than other samples, but other samples with different immersion times in the rust remover had no significant difference owing to the strong penetrating power of chloride ions.

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1. Introduction

Carbon steel, as an important structural material, has been applied widely owing to its good comprehensive performance and low price [1]. Corrosion protection and prevention are remarkably significant since a large amount of carbon steel is consumed annually for corrosion [2] such as chemical corrosion [3] and electrochemical corrosion [4], which will reduce physical mechanical properties in application [5], as well as cause huge economic losses [6]. Therefore, there is a need for investigating and developing novel protection techniques to prevent corrosion. Many protection methods such as organic coatings [7] or nano-coating [8] and electrochemical protective [9] have been frequently reported. In order to improve the corrosion resistance and adhesion of organic coatings, the surface pre-treatment on metals with rust are applied [10]. Hand scraping and abrasive blasting [11] are considered promising among surface cleaning technologies, but the application is limited by labor intensity, poor efficiency and the location or geometry of the equipment [12]. Furthermore, the rust can be removed by reacting with chemical rust removal. Nevertheless, traditional chemical rust removal involves use of high concentrated acids which will have negative influence to human health and environment. Besides, the waste solutions must be neutralized and it results the increase of cost.

Aiming to find economical and environmentally friendly methods, the research, which inhibit the corrosion on carbon steel by tannic and phosphoric acids, also attracted some attentions [13]. The resistance of tannin conversion coatings is obviously affected by coating thickness type and stability of emulsion, thus strict control is necessary to improve efficiency in corrosion protection, while tannates could be harmful to the environment because of their high chloride content [10]. Up to now, it is considered that adding corrosion inhibitors in high concentrated acids is the most effective and economic method for avoiding corrosion in actual application [14].

As mentioned, the high concentrated acids are harmful to environment and operators due to the toxicity, strong volatility and must be combined with environment-friendly corrosion inhibitors. Therefore, it's important and significant to develop new rust remover to solve the risk of environment and operators, [15] as well as avoid the damage on the substrate plate caused by high concentrated acids.

In this paper, a novel neutral water-based rust remover was prepared creatively to avoiding the negative impacts including acid evaporation, over corrosion, hydrogen embrittlement caused by traditional acid rust remover. The neutral rust remover has the advantages of neutral pH, mild reaction conditions and good safety. Its corrosion protection mechanism was observed and analyzed when using to treat rusty carbon steel, while the rust-removing electrochemical behavior occurred on the surface was explored. This neutral rust remover will play a positive role in chemical corrosion protection owing to its green, environmental-friendly, efficient and sustainable.

2. Experimental

2.1. Materials

1-hydroxyethylidene-1,1-diphosphonic acid (HEDP, 60%) was purchased from Shandong Yousuo Chemical Co., Ltd, Shangdong, China. Sodium hydroxide (NaOH, 96%) and sodium citrate ($\geq 99\%$) were supplied by Tianjin Damao Chemical Co., Ltd, China. Sodium gluconate ($\geq 99\%$) was purchased from Tianjin Fengchuan Chemical Co., Ltd, China. Polyethylene glycol (PEG400), sodium chloride (NaCl) and sodium dodecyl benzene sulfonate were purchased from Tianjin Jiangtian Chemical Co., Ltd, China. Distilled water was used throughout the experience.

2.2. Preparation of the neutral water-based rust remover

HEDP (10.0 g) and distilled water (50.0 g) were added into a reactor equipped with agitator. After that, added the remaining HEDP (10.0 g)

into the reactor and stirred until the solution was clear and transparent. Then sodium hydroxide was added slowly to make the solution pH is neutral. The solution was stirred to make them react completely. After 1 h continuous agitation and reaction, the system was naturally cooled down to room temperature. Subsequently, sodium gluconate (2.5 g), sodium citrate (1.0 g), polyethylene glycol (PEG400, 0.5 g) and sodium dodecyl benzene sulfonate (0.05 g) into the solution system, respectively. When they were dissolved completely, we should put the remaining distilled water and continue stirring 1 h to get the neutral rust remover.

2.3. Samples preparation

Low carbon steel (Q235) (the compositions of the steel plates are listed as follows (wt%): C: 0.130; Si: 0.020; Mn: 0.380; P: 0.014; S: 0.031; Fe: balance.) of 50 mm \times 25 mm \times 2 mm and 10 mm \times 10 mm \times 2 mm were degreased with acetone, then cleaned them with alcohol. After that, all these steel plates were exposed to air (the average temperature and humidity were about 25 °C and 65%, respectively.) for 60 days to rust. The rusty plates were only roughly cleaned to remove the floating rust with metallic brush. Subsequently, these rusty steels of different specifications were put into the neutral rust remover at 60 °C for 1 h until the rust disappeared, then rinsed them with distilled water and dry at 60 °C for 4 h. Up to now, the samples for testing were obtained. These samples of 10 mm \times 10 mm \times 2 mm were used for surface morphology analysis and X-ray photoelectron spectroscopy analysis. For electrochemical measurements, samples of 50 mm \times 25 mm \times 2 mm were used. Solutions of electrochemical measurements were prepared with 0, 1.0%, 3.5%, 5.0% NaCl concentrations using deionized water, respectively. All the above electrochemical tests were carried out at 25 °C.

2.4. Characterizations and tests

2.4.1. Rust layer analysis

X-ray diffraction analysis was a modern scientific method for analyzing the structure and composition of materials [13,16]. By X-ray diffraction, the diffraction patterns of materials were analyzed. Meantime, while the formation of materials including the composition, the structure impacted by morphology of molecules was obtained. To evaluate corrosion products, the rust powder was collected from the surfaces of the rusty samples at 50 mm \times 25 mm \times 2 mm. Then the crystallographic informations of rust powder were characterized by XRD (Shimadzu 6100, Japan) using a Cu-K α radiation ($\lambda = 1.540 \text{ \AA}$, 40 kV) [17,18]. The scan speed was 5°/min in 2 θ range of 5°–80°.

2.4.2. FT-IR analysis

The powder samples before and after rust removed were collected with an approximate 0.5 g, and the changes of absorption peak removed were investigated by FT-IR and compared. The FT-IR spectra of these samples were analyzed by a Tensor 27 FT-IR spectrometer (Tensor27, Germany) in the range of 4000–400 cm $^{-1}$ using the KBr method and a background spectrum was included [19]. The FT-IR measurements were all carried out with two parallel samples.

2.4.3. Surface morphology analysis

To study the mechanism of how the rust remover acts on the steel, the surface morphology and chemical compositions of steel were investigated which were sampled before and after treated with rust remover. And then they were observed by Ultra Plus scanning electron microscopy (JSM-IT300LV, Japan) equipped with an energy dispersive spectrometer [20].

2.4.4. X-ray photoelectron spectroscopy analysis

In order to further study the mechanism of how the rust remover acts on the steel, XPS of steel surface was investigated. X-ray

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