

Corrosion Protection of Structural Steel by Surfactant Containing Reagents

D. Erdenechimeg, T. Bujinlkham, N. Erdenepurev

Abstract—The anti-corrosion performance of fatty acid coated mild steel samples is studied. Samples of structural steel coated with collector reagents deposited from surfactant in ethanol solution and overcoated with an epoxy barrier paint. A quantitative corrosion rate was determined by linear polarization resistance method using biopotentiostat/galvanostat 400. Coating morphology was determined by scanning electronic microscopy. A test for hydrophobic surface of steel by surfactant was done. From the samples, the main component or high content iron was determined by chemical method and other metal contents were determined by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) method. Prior to measuring the corrosion rate, mechanical and chemical treatments were performed to prepare the test specimens. Overcoating the metal samples with epoxy barrier paint after exposing them with surfactant the corrosion rate can be inhibited by 34-35 $\mu\text{m}/\text{year}$.

Keywords—Corrosion, linear polarization resistance, coating, surfactant.

I. INTRODUCTION

CORROSION is generally iron oxidation process, or change in the metal composition due to environmental effects. Precise identification of causes of corrosion and selection of an appropriate protection method against corrosion becomes important not only in Mongolia but also globally. By conducting a corrosion-prevention study of steel structures, their metal erosion can be reduced to 15-35%. It is equivalent to 375-875 billion dollars worldwide [1]. Velocity of corrosion process and types of corrosion depend on both internal and external factors. Internal factors include metal composition, surface state, internal deformation and voltage. The external factors of an environment which surround the metal, are relative humidity, temperature, sulfur dioxide and chloride [2].

From iron oxides, +2, +3 are more stable than -2, -1, 0, +1. In acids, iron is in Fe^{2+} , Fe^{3+} ion and in the alkaline environment iron forms $\text{Fe}(\text{OH})_2$, $\text{Fe}(\text{OH})_3$ and HFeO_2^- as a product [3]. This variety of oxidation properties is highly dependent on acid and alkaline environments [4]. In industrial practice it is important to protect metals from corrosion, especially in acidic and alkaline environment. There are many corrosion researches, such as coating metals with polyaniline [5]-[7], coating metals by producing fatty-acid-metal-ion complex [8] and researches on Titanium Nitride Physical

Vapor Deposition (TiN PVD) coating [9]. Electrochemical methods are used widely in corrosion researches [5], [8]-[11]. Passivation of metal corrosion reagents is different depending on environmental conditions (air, acidic, alkaline, neutral). Anodic inhibitors include substances that have oxidizing properties with respect to metals (reducers), they can be nitrite salts, chromates, etc. There are also anode film-forming inhibitors. These include surfactants that passivate corrosion [12].

In this study, authors aimed to investigate the chemical composition of steel samples and the corrosion rate dependence on their chemical compositions. Characterizing mechanism of protection of steel against corrosion with differing chemical compositions was studied with the help of surfactants.

II. MATERIAL AND METHODOLOGY

A. Preparation of Electrodes

The electrodes were mechanically treated prior to use and chemically cleaned to remove the external mixtures. When preparing electrodes, it is best to make a rectangular shape which is suitable for testing. Cutting process used rotating persecutor 150 mm and manual cutter AG7108 INCO. Prior prepared electrode surface was polished with 80, 120, 180, 320, 500, 1000 mm emery paper by using Knuth Rotor 2. After mechanical cleaning, for the purpose to separate samples from other mixtures, chemical treatment was carried out to prepare the electrodes for experiment. Electrode surfaces which were mechanically clamped by the clamps were wiped by organic solvents and acetone, P-646, benzene and toluene. Reference or counter electrode was prepared before each test. In order to cleanse reference electrode 3M an anion containing potassium chloride solution was used, which is later heated to boil and rinsed again. Before the use of the counter electrode for electrochemical measurement, metal has to be rinsed by non-soluble acid for metals and removed the acid residue by distilled water.

B. Corrosion Rate Experiment

Out of many methods, the electrochemical polarization method is the most common and widely used method to determine corrosion rate. Therefore, the corrosion rate was determined by galvanostatic polarization techniques using $\mu\text{rta} 400$ that was connected to the computer with the Drop view 2.0 software by USB. This is a computer controlled electrochemical measurement system. It consists of data-acquisition system and a potentiostat/galvanostat. 3 electrode system was applied to perform linear sweep voltammeter and

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working electrode was as the sample, which was prepared and polished for the experiment. The reference electrode was silver chloride electrode (3M KCl). The corrosion rate of steel determined by Tafel polarization was relatively easier and faster than traditional methods [5], [6], [13].

C. Hydrophobic Surface of Steel Sample

The samples were oxidized with oxidizing reagent in low setting. Then, the samples were exposed by fatty acid 4-24 hours and were coated with epoxy barrier paint after the drying process in room temperature.

D. Determination of Chemical Composition of Steel

Chemical analysis of steel was performed by Thermo Fisher's iCAP 6300 ICP-OES. The iron content of steel was obtained by volume method according to ISO 2597-1:1994 methodology. By hydrochloric acid and nitric acid, steel samples were transferred to the solution form. After that, ammonia was added to the three oxidants in the solution and then filtered out the formed precipitation. Iron content was measured by titration or volumetric method using diphenylamine sulfonate as an indicator, added diluted hydrochloric acid in order to dissolve filtered precipitation [14], [15].

III. RESULTS AND DISCUSSION

A. Determination of Corrosion Rate

Corrosion rate was measured by using μ Stat400 biopotentiostat/galvanostat instrument using linear sweep voltammetry and the result was calculated by linear polarization resistance method [13], [16]. The results are shown in Table I.

TABLE I
THE RESULTS OF CORROSION RATE OF STEEL SAMPLES

No	Samples	Corrosion rate ($\mu\text{m}/\text{year}$)
1	IS- industrial steel	36.96
2	IBSF- industrial black steel floor	22.59
3	IGSF industrial grey steel floor	33.25

It can be clearly seen that the corrosion rate depends on the metal designation and chemical composition. The corrosion rate is used to assess the corrosion resistance of metals. The speed of corrosion is expressed in $\mu\text{m}/\text{year}$, which is the numerical value of the metal loss per year. Table II shows the numerical value of the first annual corrosion rate for the standard metal (carbon steel, zinc, copper, and aluminum) for each ratio [17].

TABLE II
MNS ISO 9223:2004 CORROSION RATE OF METALS PER YEAR

MNS ISO 9223:2004 CORROSION RATE OF METALS PER YEAR					
Classification of metals*	Corrosion rate of metals (r_{corr})				
	Unit	Carbon steel	zinc	copper	aluminum
C ₁	μm/year	(r_{corr}) ≤ 1.3	(r_{corr}) ≤ 0.1	(r_{corr}) ≤ 0.1	little
C ₂	μm/year	1.3 < (r_{corr})	0.1 ≤ (r_{corr}) ≤ 0.7	0.1 ≤ (r_{corr}) ≤ 0.6	(r_{corr}) ≤ 0.6
C ₃	μm/year	25 < (r_{corr}) ≤ 50	0.7 ≤ (r_{corr}) ≤ 2.1	0.6 ≤ (r_{corr}) ≤ 1.3	0.6 ≤ (r_{corr}) ≤ 2
C ₄	μm/year	50 < (r_{corr}) ≤ 80	2.1 ≤ (r_{corr}) ≤ 4.2	1.3 ≤ (r_{corr}) ≤ 2.8	2 ≤ (r_{corr}) ≤ 5
C ₅	μm/year	80 < (r_{corr}) ≤ 200	4.2 ≤ (r_{corr}) ≤ 8.4	2.8 ≤ (r_{corr}) ≤ 5.6	5 ≤ (r_{corr}) ≤ 10

*C₁-excellent metal quality, C₂-good quality, C₃-medium quality, C₄-poor quality, C₅-very poor quality

According to Table II, the corrosion rates of the steel samples were 22.59-36.96 $\mu\text{m}/\text{year}$ which means steel samples included in the classification C3 (medium quality) as "MNS ISO 9223:2004 standard - Metal and alloy corrosion - Corrosion classification in air" [17].

B. Determination of Chemical Composition of Steel

Type and chemical composition of steel have effect on the corrosion rate. Content of the chemical elements in the steel was described using iCAP 6300 ICP-OES (Thermo Fisher). The results are shown in Table IV of appendix. From the table, the contents of Si, Mn, P, Cr, Ni and Ti were higher in IBSF, and Zn was higher in IGSF. As Cr and Ni content increases the corrosion resistance of the steel increases and therefore corrosion rate decreases. High content of Cr, Ni, Si, Al and Mn also improves heat-resistant quality [18]. The content of the key elements of steel samples shall meet the requirements of G 3112: 2004 of the PRC.

C. SEM Morphology Inspection

The IS samples were covered by protective layer were inspected by Scanning electronic microscopy (SEM) analysis. SEM (shown in Fig. 1) revealed many micro and nano

structures on the carbon steel surfaces coated by monocarboxylic fatty acids, sodium oleate and thiourea, which were essential for affording the hydrophobic properties.

D. The Results of Surfactant Covered Steel Samples' Corrosion Rate

The corrosion rate (current) data can be obtained by the Tafel extrapolation method, where large cathodic and anodic polarizations provide the cathodic and anodic polarization curves for the respective corrosion processes [7]-[11]. Extrapolation of these curves to their point of intersection provides both the corrosion potential and the corrosion current. Fig. 2 shows the configurations of Tafel measurements of three samples after 24 hours exposure, drying in room temperature and then overcoating with an epoxy barrier paint. Table III summarizes the corrosion rates obtained from the Tafel measurements. From these results it is concluded that the coating method decreases metal corrosion rate by 34-35 $\mu\text{m}/\text{year}$.

IV. CONCLUSION

The corrosion rate of the samples was 22.59-36.96 $\mu\text{m}/\text{year}$, it shows that our tested samples can be included in the

classification C3 (medium quality) of MNS ISO 9223: 2004 – “Corrosion of metals and alloys. Classification of Corrosion into Air”.

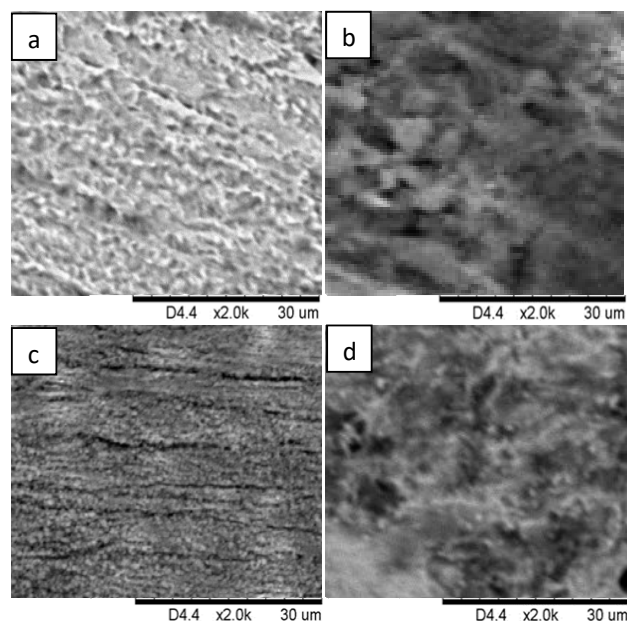


Fig. 1 (a) SEM image of uncoated carbon steel; (b) SEM image of monocarboxylic fatty acids coated; (c) SEM image of sodium oleate coated; (d) SEM image of thiourea coated.

From the study it is concluded that the corrosion rate decreases with the increase of contents of the chemical elements such as Si, Mn, P, Cr, Ni, Ti. The corrosion rate was shown to be inhibited by 18 times or decreased from 36.96 $\mu\text{m}/\text{year}$ to 1.48-2.41 $\mu\text{m}/\text{year}$, when overcoating the metal samples with epoxy barrier paint after exposing them with surfactant.

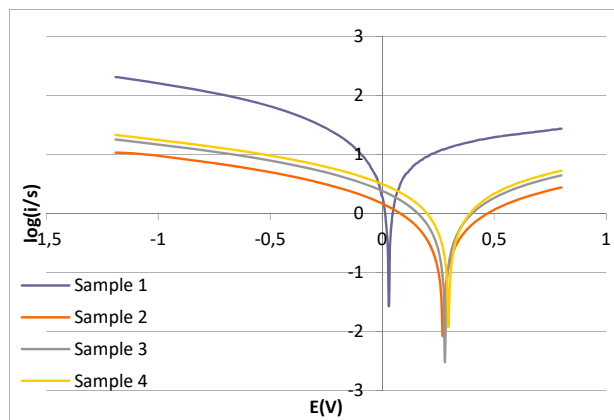


Fig. 2 Current density potential curves of coating with protection layer structure and reference uncoated carbon steel; Sample 1: Uncoated carbon steel, Sample 2: Monocarboxylic fatty acids coated, Sample 3: Sodium oleate coated, Sample 4: Thiourea coated

TABLE III
CORROSION RATE ($\text{CR}_{\mu\text{m}}/\text{YEAR}$)

No	Samples	$\text{CR}_{\mu\text{m}}/\text{year}$
1	Uncoated carbon steel	36.96
2	Monocarboxylic fatty acids coated	1.48
3	Sodium oleate coated	2.19
4	Thiourea coated	2.41

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APPENDIX

TABLE IV
CHEMICAL COMPOSITION (WT %) OF STEEL USED AS ELECTRODE

No	Samples	Si,%	Mn,%	P,%	Mo,%	Cr,%	Ni,%	Cu,%	Ti,%	Zn,%	Fe,%
1	IS	0.088	0.217	0.0080	<0.05	0.027	0.008	<0.0005	0.002	0.006	97.11
2	IBSF	0.222	0.599	0.0270	0.011	0.131	0.080	0.281	0.005	0.017	97.49
3	IGSF	0.175	0.344	0.0140	<0.05	0.040	0.023	<0.0005	0.002	0.268	96.67

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