# Improving performance of epoxy painting by adding some organic

#### inhibitors to decrease corrosion of AISI-1020 Carbon Steel

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### **1. ABSTRACT**

Development of a new environmentally safe painting for corrosion protection of metallic surfaces attracted great interest in material science through the past few years. Smart painting showed promising corrosion protection of metals and alloys in different technological applications due to releasing the active agents of the paint in a controllable manner for preventing cracks propagation in the protective paint. These painting possess passive matrix functionality and actively responds to changes in the local environment which make it prompted great interest from material scientists. Characterization and improving performance of epoxy painting by adding organic inhibitors for AISI-1020 Carbon Steel was done, three organic inhibitors were used (tannic acid, polyethylene glycol, and quaternary amine). The experiments showed that, tannic acid has the most effective results by forming a protective film with substrate and inhibiting the accessible reaction sites exposed to the corrosive media. Thickness was measured for the three samples of different inhibitor content, where the thicknesses were nearly the same because using the same technique of paint application, the thickness was 164  $\mu$ m, also roughness was measured for paintings containing tannic acid, polyethylene glycol, and quaternary amine painting and the result was 15,12 and 13.5 (µm) respectively. Adhesion test was performed on the different three painting and the result was 400, 360 and 340 N/m<sup>2</sup> respectively. Also scratch test in 7 % NaCl was done, salt spray test was done for 6 days and glossy test and spacemen painted by epoxy containing tannic acid shows better condition of corrosion.

Keywords: self-healing, painting, corrosion, metal, polymer,

### **2. INTRODUCTION**

Carbon steel (CS) dominates the world of construction materials, as it is estimated for more than 85% of the worldwide steel production, annually. It is used extremely in applications like metals industries, chemical processing, marine structures, Petroleum/Gas production, refining and transmission [1]. One of the major problems related to CS use is its low corrosion resistance in almost environments. Corrosion failures may lead to release of hazardous materials or can reduce both the performance and reliability of equipment until complete failure [2]. Furthermore, corrosion put at risk the safety of plant employees and the general public and cause severe damage of process units, and in some cases shutdown of operations [3]. So, corrosion is considered one of the main issues in oil and gas industry, as it cost billions of dollars yearly, and efforts should be exerted to control corrosion for safety, business and environmental requirements [4]. Green corrosion inhibitors are becoming more popular as a result of increased environmental awareness and changes in regulations that prohibit the use of traditional corrosion inhibitors due to their toxicity [5]. Natural products are a good source of green corrosion inhibitors because most of their extracts contain necessary elements like N, O, C, and S, which are active inorganic compounds that aid in the absorption of these compounds on metals or alloys to form a film that protects the surface and inhibits corrosion [6]. As we entered into the twenty-first century, search for advanced materials with crack avoidance and long-term durability gained high priority [7]. The challenge for material scientists is therefore to develop new technologies that can produce novel materials with increased safety, extended lifetime and no aftercare or a much smaller amount of repairing costs. Since creation of a perfect material, which would never break, does not seem to be possible, the idea of selfhealing becomes one of the main streams. In self-healing which is defined as "the ability of a material to heal (recover/repair) damages automatically and autonomously, that is, without any external intervention" [8]. In the broadest sense self-healing materials can be distinguished as materials which are able to autonomously (partially) restore (some of) their properties in such a manner that they can serve longer as compared to similar materials without self-healing capabilities. If after rupture at least one property of the material is restored at least partially without any external intervention, one can speak about self-healing capabilities of the material [9]. The main function of painting is the protection of an underlying substrate against an environment-induced corrosion attack. Application of organic painting is the most common and cost effective method of improving the corrosion protection and, thereby, the durability of metallic structures [10]. A wide range of engineering structures, from cars to aircrafts, from chemical factories to household equipment, is effectively protected by painting. The main role of an organic polymer painting in corrosion protection is to provide a dense barrier against corrosive species [11]. Along with these barrier properties, resistance to a flow of charge, electronic and ionic, is also important since corrosion processes involve the transfer of charge [12]. However, defects appear in organic protective painting during exploitation of the painted structures opening a direct access for corrosive agents to the metallic surface. The corrosion processes develop faster after disruption of the protective barrier [13]. Therefore, an active "self-healing" of defects in painting is necessary in order to provide long-term protection. Organic compounds such as tannic acid, polyethylene glycol, and quaternary amine were used as corrosion inhibitors which mixed with epoxy with optimized percentage for painting [14]. The objective of this work is to Characterize and improve the painting properties containing organic inhibitors for AISI-1020 carbon steel.

# **3. Experimental Work**

# **3.1 Materials**

3.1.1 A cold rolled – AISI-1020 low carbon steel sheet from EZZ flat steel company (El-sokhna, Suez, Egypt) has been used in this study. Table 1 summarizes the chemical composition of the steel under investigation.

Element	С	Si	Mn	Р	S	Cr	Fe
wt.%	0.20	0.25	0.5	0.012	0.017	0.059	Balance

Table 1: Chemical composition of studied AISI 1020 low carbon steel

3.1.2 Three types of green organic inhibitors were used in this study, namely, tannic acid, a quaternary amine, and polyethylene glycol, all of which had the chemical formula and structure presented in Table 2 each inhibitor was tested in 3%NaCl.

Table 2: Chemical formula and structure of the materials used in this study [15]

Х	Chemical Formula	Structure
Tannic Acid	C <sub>76</sub> H <sub>52</sub> O <sub>46</sub>	A C C C C C C C C C C C C C C C C C C C
Quaternary Amine	C <sub>19</sub> H <sub>42</sub> BrN	Br СН <sub>3</sub> H <sub>3</sub> C(CH <sub>2</sub> ) <sub>15</sub> <sup>+</sup> №—СН <sub>3</sub> СН <sub>3</sub>
Polyethylene Glycol	$C_{2n}H_{4n+2}O_{n+1}$	H <sub>3</sub> C (o) CH <sub>2</sub> n O CH <sub>2</sub> cH <sub>3</sub>

3.1.3 Polyamide epoxy that was delivered from Alpha Egypt.With mixing ratio 3 epoxy :1 hardener with 5 mm thinner

# **3.2 Methods**

# **3.2.1 Specimens preparation**

There were different sizes of specimens which used, for testing and Characterization the painting layer performance on AISI-1020. Carbon steel specimens of (20mm  $\rightarrow$ 20mm  $\rightarrow$ 1mm) and (50mm  $\rightarrow$ 50mm  $\rightarrow$ 1mm) were used, the painting layer was prepared by mixing the polyamide epoxy with optimum percentage of each inhibitor (tannic acid, a quaternary amine, and polyethylene glycol). The optimum percentages are (40, 75, and 250 ppm. respectively) with inhibition efficiencies of 77.14%, 65.67%, and 73.14%, respectively without inhibitor [14].

# **3.2.2** Application of Paint

After painting preparation with specific percentage of inhibitors, spin coater was used for painting AISI-1020 low carbon steel specimens with constant regime of 1000 rpm for 1 min. and 3000 rpm for 3 min. then, the paint leaved to dry for 3 hours in air at room temperature [16].

# 3.3 thickness measurement

The thickness of the paint for three samples of different inhibitor content (tannic acid, a quaternary amine, and polyethylene glycol) was measured using DeFelsko Digital thickness Tester (Model: PosiTest AT-M, DeFelsko Corporation), according to the ASTM A956 standard

# 3.4 Adhesion test

The Adhesion force between the paint layer and the substrates was measured using DeFelsko Digital Pull-off Adhesion Tester (Model: PosiTest AT-M, DeFelsko Corporation). Each sample was stuck to 20 mm diameter dollies by a selective adhesive (epoxy) (ResinLab L.L.C., Germantown, MD), then the combination (dolly + sample) was fitted inside the tester and a force is applied to separate them. According to the ASTM A956 standard.

# **3.5** Surface roughness Test

The roughness test was carried out on the paint surface for three samples with different inhibitor content (tannic acid, a quaternary amine, and polyethylene glycol) using DeFelsko Digital roughness Tester (PosiTector SPG Surface Profile Gages), average surface roughness has been taken to each specimen, according to the ASTM A956 standard

### 3.6 painting hardness measurement

painting hardness test was carried out on the paint surface for three samples with different inhibitor content (tannic acid, a quaternary amine, and polyethylene glycol) using DeFelsko Digital hardness Tester (PosiTector HT hardness test), according to the ASTM A956 standard.

### 3.7 Salt Spray test

Salt Spray Tester Chamber provides a high-saline fog environment to measure the corrosion resistance of products, paints, coatings, and etc. over a predetermined amount of time. The test was carried out by Alpha+ Salt Spray testing equipment. Test conditions (according to ASTM B117). Time = 6 days, Chamber temperature=  $35 \,^{\circ}$ C, PH = 6.5 to 7.2, It uses a 5% sodium chloride aqueous solution

### 3.8 Gloss test

According to ASTM D523, Gloss is determined by projecting a beam of light at a fixed intensity and angle onto a surface and measuring the amount of reflected light at an equal but opposite angle. After calibration of the glossmeter, it's placed on the sample. The gloss degree value of the sample is displayed on the screen.

#### 3.9 Corrosion rate measurement

Potentiodynamic polarization technique, was used to study the electrochemical behavior of AISI 1020 carbon steel in 3% NaCl solution. All electrochemical experiments were conducted using a conventional three-electrode 250 ml cell assembly, with the counter electrode made of platinum and saturated calomel electrode (SCE) as a reference electrode. A copper wire, 3 mm diameter, was mounted to the rear side of the samples as an electrical connection. The electrodes were degreased with acetone, air dried and embedded in two-component epoxy resin and mounted into a glass tube. The exposed surface of the specimen was flat with cross section area of 4 cm<sup>2</sup>. These were used as the working electrode during the electrochemical experiments. Prior each test, the flat surface of the electrode for bare specimen was wet polished with silicon carbide abrasive papers up to 2000 grits, rinsed with ethanol, and air dried. The test medium was 200 ml 3% NaCl, employed as the blank for all tests. Potentiodynamic polarization experiments were carried out using Versastat 3 Princeton/Applied Research (Potentiostat /Galvanostat Model). It is controlled from any suitably equipped PC by a Universal Serial Bus (USB) interface using the Versa Studio Electrochemistry software package. All potentials were measured with respect to the SCE. The potentiodynamic current – potential curves were recorded by changing the electrode potential automatically from -2500 mV to +2500 mV with scan rate of 1 mV.S-1 and the corresponding current were recorded.

# 4. RESULTS AND DISCUSSION

# 4.1 Potentiodynamic Technique Results

Polarization curves for bare steel, bare in 40 ppm tannic acid, painting without inhibitor and painting with 40 ppm tannic acid in 3% NaCl solution at 25 °c using potentiodynamic polarization technique. As shown in Figure 1 and Table 3 sample Scratched painting with 40 ppm tannic acid have the minimum corrosion rate of 0.87 mpy, this is duo to formation of passive layer formed between interaction of inhibitor and the material.





Table 3 Corrosion rate for AISI-1020 carbon steel using potentiodynamic technique at four different conditions in 3% NaCl

Condition	Corrosion Rate	
	(mpy)	
Bare	12.53	
Bare in 40 ppm tannic acid	2.863	
Scratched painting without inhibitor	1.96	
Scratched painting with 40 ppm tannic acid	0.87	

# 4.2 thickness measurement

According to the ASTM A956 standard the average thickness of samples was (163.66  $\mu$ m ± 3).

# 4.3 Adhesion test

According to the ASTM A956 standard the results of adhesion test ranged from 340 to 400  $(N/m^2)$  as shown in Figure 2

Painting with tannic acid showed best adhesion between paint and substrate.





### 4.4 Surface roughness Test

According to the ASTM A956 standard, the average roughness results were shown in Figure 3. paint with tannic acid content had the smoothed surface





### 4.5 painting hardness measurement

According to the ASTM A956 standard average surface hardness has been taken to each specimen, the average hardness results were shown in Figure 4. paint with tannic acid content had the highest surface hardness

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#### Figure 4 Hardness surface result

### 4.6 Salt Spray test

The result of salt spray test is quantitative method, and the result showed that the paint of tannic acid content had the best condition than the others after 6 days under testing as shown in Figure 5.



Figure 5: samples after 6 days in salt spray test

Macrographic examination after salt spray test was carried out using the optical microscope (OPTIKA) with magnification of 50 X. As showing in Figure 6 macrostructural examination of painting with tannic acid content have less corrosion and plastering content due to the formation of chemical compound between tannic acid and the substrate.

(a) blank

(b) free painting



(d) quaternary amine





Figure 6 Macrostructural examination after salt spray test

Blisters or bubbles appear when a layer of paint does not adhere perfectly to its underlying surface. Blistering of painting was determined by phase analysis technique by optical microscope (OPTIKA) as shown in Figure 7.









Figure 7 (a): Tannic acid

Figure 7 (b) Quaternary Amine

Figure 7 (c) Quaternary Amine

Figure 7 (e): blank

Addition	40ppm Tannic acid	75 ppm Quaternary Amine	250 ppm polyethylene glycol	blank
Blistering %	2 %	5 %	15 %	55 %

#### Table 4 Blistering % after salt spray test

### 4.6.1 Scratch test of paint in salt spray test

Scratch test was carried out on painted samples of different inhibitor content of 40 ppm tannic acid, 250 ppm Polyethylene Glycol, 75 ppm polyethylene glycol and blank without inhibitor, sample of tannic acid content showed that best condition as shown in Figure 8.

#### (a) Tannic acid



Figure 8 (a) Sample Before Salt Spray Test.

(b) Quaternary Amin

Figure 8 (b) Sample After Salt Spray Test. Figure 8 (c) Sample After Salt Spray Test.



Figure 8 (a) Sample Before Salt Spray Test.



Figure 8 (b) Sample After Salt Spray Test.



Figure 8 (c) Sample After Salt Spray Test.

(c) polyethylene glycol



Figure 8 (a) Sample Before Salt Spray Test

Figure 8 (b) Sample after Salt Spray Test.

Figure 8 (c) Sample After Salt Spray Test.









Figure 8 (b) Sample after Salt Spray Test.



Figure 8 (c) Sample After Salt Spray Test.

# 4.6.1.1 Performance rating of scratched painting.

According to ASTM B117, samples were rated as shown in Table 5.

Sample type	Test result : Performance rating
Tannic acid	(Rp / RA) 8 VS G
Quaternary Amine	( <b>Rp / RA</b> ) 5 M G
polyethylene glycol	(Rp / RA) 3 X G
blank	( <b>Rp / RA</b> ) 1 X G

Table 5 Rating of types of	of painting deterioration
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### 4.7 Gloss test

The gloss test was carried out on surfaces of samples of different inhibitor content (tannic acid, a quaternary amine, and polyethylene glycol), the result was 67, 55, 50 GU, where sample without inhibitor was 35 GU, The sample with tannic acid content showed highes value of glossy. As the value of glossy increased, the amount of reflected heat increased and lead to decrease the absorbed heat.



### 5. Concolusion

Smart paintings are an area of development and commercialization that promises to change the expectations of what can be accomplished with paintings. Addition of inhibitors to paint leads to increase corrosion resistance due to formation of passive layer due to reaction between inhibitor and substrate in case of paint scratch. The experiments proved that, addition of organic inhibitors (tannic acid, a quaternary amine, and polyethylene glycol). The optimum percentages are (40, 75, and 250 ppm. respectively) with inhibition efficiencies of 77.14%, 65.67%, and 73.14%, respectively. Addition of tannic acid (40 ppm) increased the adhesion between paint and substrate to  $400 \text{ (N/m}^2)$ , the glossy increased to 67 GU, hardness also increased to 80 HL and the rating performance of scratched painting was (Rp / RA) 8 VS G.

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