Effect of Surface Roughness on the Corrosion Behavior of C45 Carbon Steel in Sea Water

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Abstract

The purpose of this research is to investigate the corrosion rate of C45 carbon steel in saline environment. The influence of surface roughness on corrosion rate was studied in this investigation. Weight loss test of the C45 steel in the lab was conducted to determine the corrosion rate data in stagnant seawater. Results show that the corrosion rate of C45 carbon steel is increased by increasing the surface roughness of samples when abrasive papers used in grades ranged from 80 grit to 320 grit. There was no significant change in the corrosion rate if abrasive papers used in grades ranged from 320 to 1200 grit (the corrosion rate remaining approximately the same). XRD results show that the corrosion product contains FeO(OH) along with NaCl crystals.

Keywords: *corrosion, C45 carbon steel, sea water, surface roughness, XRD.*

1. Introduction

There is a controversy in the literature about the working role of surface roughness condition on the corrosion behavior of carbon steels in marine and other environments, but generally corrosion rate increases by increasing the surface roughness. Hryniewicz et. al. [1] studied the corrosion behavior of C45 carbon steel after mechanical surface finishing in both artificial and natural sea water environments by using the electrochemical impedance spectroscopy (EIS). The results show that the surface state and its roughness considerably affect the corrosion behaviour. After polishing using silicon carbide papers of graininess 4000, the corrosion resistance of the studied C45 steel surface increases almost 3 times in case of using 3% NaCl solution, and 1.6 times in case of using 0.03% NaCl solution. R. B. A. Nor Asma et. al. [2] studied the effect of surface finish on the corrosion of carbon steel in CO2 \ NaCl solution environment in both stagnant and turbulent conditions. Specimens used in the experiments were abraded by using SiC abrasive paper of 60, 240, 400, 600, 800 and 1200 grits. R. B. A. Nor Asma et. al. conclude that the surface roughness affects the hydrodynamic and mass-transfer boundary layer which can influence electrochemical behavior of a surface. Results showed that the corrosion rate increased with increasing surface roughness up to the use of 240 grit SiC abrasive papers either in static or in turbulent flow condition. The corrosion rate results were controversy when the surface prepared by using emery papers between 240 and 600 grits. Generally, the corrosion rate in the turbulent flow was higher than in static condition for all surface finish. Su Kyeng Kim et. el. [3] studied the influence of surface roughness on the electrochemical behavior of carbon steel, it was concluded that the corrosion rate of carbon steel is increased as the surface roughness increases. In addition to the effect of surface roughness of carbon steels on the corrosion rate, there were many other studies on many other materials such as the effect of surface roughness on the corrosion resistance of the oxide layer formed the AZ91 Mg alloy [4]. The specimens in this investigation were prepared by using three different roughness silicon carbide emery papers which are Ra= 0.5, 1.2 and 2.3 μm. The corrosion current density of the oxide layer on AZ91 Mg alloy decreases with increasing surface roughness. M.H. Moayed et al. [5] studied the effect of varying surface roughness conditions on 904L stainless steels in 1 M NaCl by using potentiostatic and potentiodynamic techniques. They conclude that the increasing of the smoothness of the 904L SS samples results in increasing in the critical pitting temperature "CPT" which is defined as the lowest temperature at which the growth of stable pits is possible. W. Li et. al. [6] studied the influence of surface morphology, represented by roughness, on the corrosion of copper metal by using an atomic force microscope and a scanning Kelvin probe as charctrization techneques. Results showed that the corrosion rate increased with an increase in surface roughness. The objective of this research is to study corrosion behavior of a medium carbon steel (C45) in sea water prepared with different emery papers grades (to investigate the effect of surface roughness on the corrosion behavior).

2. Experimental

The experiments in the present work were conducted using one type of medium carbon steels (1045 steel). Materials, equipment, and experimental procedures used in this work are described in the following sections.

Sample Preparation:

Commercial medium carbon steel (C45) samples were cut from 45 mm diameter rod which was 40 cm in length, twenty (20) samples were cut in about 5 mm in thickness. All samples were fixed in the electrolyte bath by hanging them by using a polymeric wires to avoid any undesired electrochemical cells through a small holes in the edge of the specimens. Before fixing the samples in the electrolyte bath, the surfaces of specimens were ground using 80 , 220, 320, 400, and 1200 grit SiC emery papers. Four (4) of these samples were ground up to 80 grit, another 4 samples were ground up to 220 grit, the third group of samples were ground up to 320 grit, another 4 samples were ground up to 400 grit and the last 4 samples were ground up to 1200 grit SiC paper. All samples were cleaned by distilled water before used in the immersion test.

Electrolytes:

Natural seawater was used as an electrolyte in the immersion test baths. Sea water collected from the Mediterranean Sea from the region of Tripoli city in Libya. The electrolyte was chemically analyzed and the pH of the electrolyte was also measured.

Immersion Test:

A 15-liter glass container with a diameter of 40 cm was used as an immersion test bath. The working samples were hold by using a polymeric wire. All of the immersion tests were carried out in stagnant condition and at temperature of 298 oC for a period of 840 hours. At the end of the immersion time, samples were dried and all of them kept in a desiccator to reduce further chemical and electrochemical reactions as much as possible. Both corrosion product forms (the corrosion products in a powder form collected from the electrolyte and the corrosion products located on the corroded surfaces) were examined by using X-Ray Diffraction (XRD) and an optical microscope to investigate the nature of these corrosion products.

3. Results and Discussion

Sea water sample was chemically analyzed by using evaporation, deposition and titration techniques and the results are shown in Table 1. The results show the amount of sulphate is slightly different from the results of others [7, 8] because the composition of water is depending on location, time, sea water streams, temperature, and many other factors. The amount of chloride ions and sulphate ions were recorded to be about 2218 ppm and 3442 ppm respectively. The pH of the sea water was about 8.04. The microscopic examination also show that the corrosion products cover the whole surfaces of all tested samples. Figure 1 shows the corrosion scale formed on a sample surface which was ground up to 220 grit emery paper. The thickness of the corrosion product was different from location to another. The topography of all corrosion products of all conditions looks the same and there were no significant differences among them.

Table 1.1 The chemical analysis of sea water samples.

species in Sea water	(ppm)

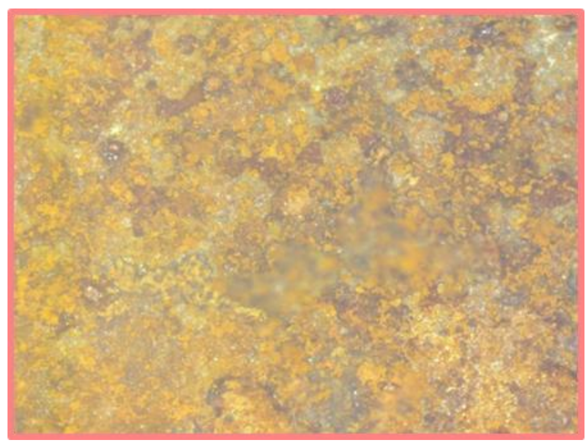


Figure 1.1 Corroded surface of C45 sample prepared by using 220 SiC emery paper with a magnification of 100 X

Corrosion rates of the carbon steel were calculated based on the weight loss data. Table 2 shows the average of the corrosion rates of carbon steel. All corrosion rates were calculated based on the following formula [9]:

$$mpy = 534W / DAT$$

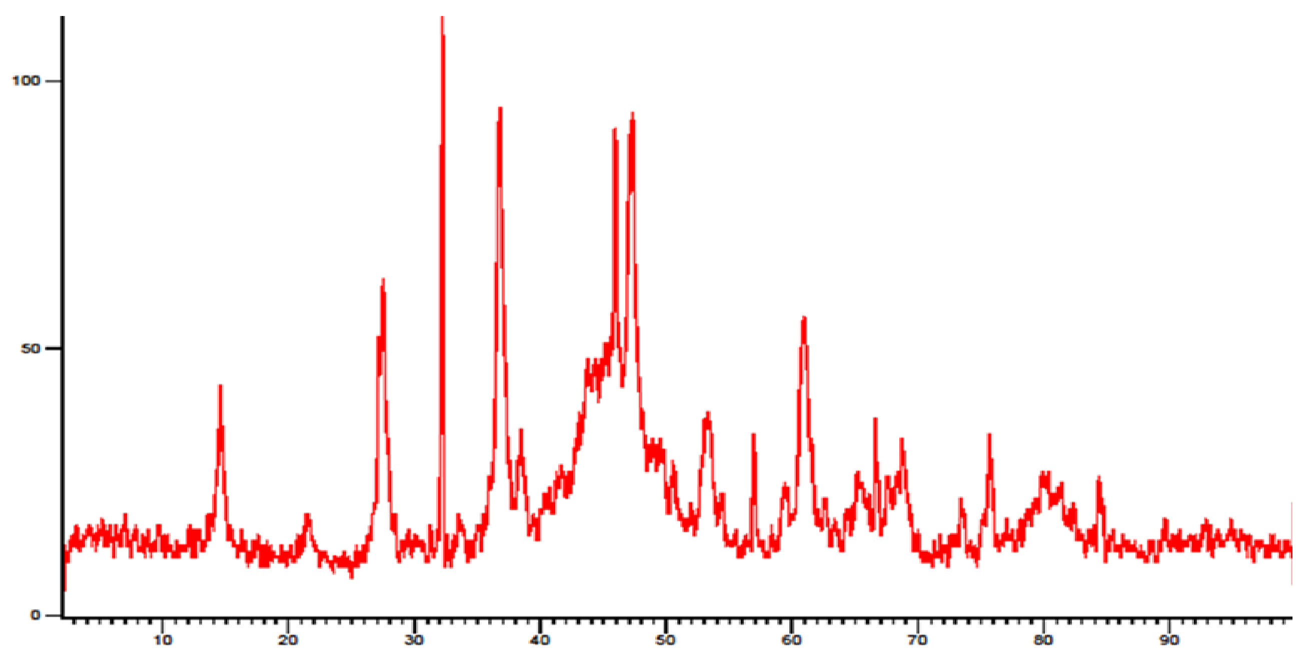
Where
mpy = the corrosion rate in mils penetration peryear (0.001 in/year).

W = the weight loss or weight gain in milligrams.
D = the density.
A = the area in square inches.
T = the time in hours.

Table 2 The corrosion rate results of C45 carbon steel sea water

Abrasive Paper 80	Abrasive Paper 220	Abrasive Paper 320	Abrasive Paper 400
0.75	0.64	0.52	0.53

paper of 80 grit, which was the higher corrosion rate by comparing it to the other conditions. This can be explained by that the rough surface disturb the surface structure leading to disarrangement in the metal crystal lattice and consequently leading to getting more locations on the surface to consider as stagnant condition locations (the corrosion rate s usually increased in the case of stagnant conditions). Also, the surface area is increased by increasing the surface roughness, which lead to increasing of both anodic and cathodic areas and result in increasing the corrosion rate. The corrosion rate was decreased when the roughness of the surface decreased (by using abrasive paper 220) to be about 0.64 mpy. The corrosion rate decreases to 0.52 mpy when using abrasive paper 320 and remaining approximately the same when abrasive papers of 400 and 1200 grits were used.



The results obtained in table 2 indicate that the surface roughness considerably affects the corrosion rate of the medium carbon steel in sea water. No significant changes can be observed in the corrosion rates measured on sample surfaces prepared with varying paper grits ranged from 80 up to 1200. Results from table 2 show that the corrosion rate was 0.75 mpy when samples were ground by using abrasive

X-ray diffraction was used to identifying the corrosion products in a powder form which collected from the electrolyte. Using X-ray diffraction was successful to some extent, probably because the corrosion products was enough. The reason is because that 35 days (840 hours) was a good time to produce enough amount of corrosion product to be investigated. Figure 2 shows the intensity count versus the 2-theta diffraction angle for the corrosion product in a powder form produced from C45 carbon steel, which collected from the electrolyte. The peaks appeared in the spectrum can be attributed to FeO(OH) and some of the peaks were attributed to NaCl (which is available in the sea water and were precipitates in the bottom of the test container along with corrosion product). It was not possible to estimate the corrosion reactions from the results of XRD alone, and other electrochemical techniques should be made such as the cyclic voltammetry electrochemical technique, but the expecting reactions could be as following:

The reduction reaction is the oxygen reduction reaction

$$O_2 + 4e^- + 2H2O \rightarrow 4OH^-$$

The oxidation reaction

$$Fe \rightarrow Fe^{2+} + 2e^-$$

The following reaction are also expected to take place:

$$4Fe^{2+} + O_2 \rightarrow 4Fe^{3+} + 2O^{2-}$$

$$Fe_3+ + 3H_2O \rightleftharpoons Fe(OH)_3 + 3H^+$$

$$Fe(OH)_3 \rightleftharpoons FeO(OH) + H_2O$$

Conclusion

The corrosion resistance of C45 steel was increased with decreasing the roughness grade of the surface up to the use of abrasive paper of 320 grit. There was no significant change in the corrosion rate if abrasive paper grade of 400 and 1200 were used and the corrosion rate remaining the same as in the case of using abrasive paper grade of 320. Optical microscopic examination show that the topography of the corroded surfaces in all conditions was approximately the same and XRD results show that the corrosion product is mainly FeO(OH).

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