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Investigating Pitting Resistance of 316 Stainless Steel (316 SS) in Ringer's Solution using Cyclic Polarization Technique

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Abstract

Cyclic polarization is a DC electrochemical technique that gives us information about the corrosion rate, corrosion potential and susceptibility to pitting corrosion of a metal. The aim of the present research work was to evaluate the pit nucleation resistance of ground/polished and passivated surfaces of 316 stainless steels (316 SSs) in Ringer's solution. The electrochemical cyclic polarization results showed that better pitting resistance for polished surface as compared to ground surface and passivated polished surface gave better pitting resistance than ground surface after passivation.

Keywords: Cyclic polarization, Pitting resistance, 316 Stainless steels, Ringer's solution, Passivation

Introduction

Stainless steels are widely used as biomaterials and materials of construction [1]. The main reason for the demand of the stainless steels is their good corrosion resistance to corrosion. Chromium, main alloying element in stainless steel should be at least 11%. Although chromium is a reactive element but it passivates and exhibit excellent resistance to many environments [2].

The resistance of stainless steel to corrosion is due to the formation of a thin oxide film on its surface, known as passive film. A number of different properties of this passive film, such as chemical composition, electronic properties, thickness, etc. determine the capability of the stainless steel to resist pitting. However, the passive/protective nature of the passive film is generally attributed to the presence of Cr-oxide. Therefore, an increase in chromium content in the passive film results in an increased resistance of the stainless steel to pitting corrosion [3-6]. It has also been reported that molybdenum also plays a positive role in pitting corrosion resistance [7,8]. Merello et al. [9] claimed that presence of Mo in stainless steel in the amount higher than 1 wt% results in a considerable improvement in their pitting resistance. On the other hand, the presence of some inclusions on the stainless steel surface, such as sulfide inclusions cause a major problem to passivation tendency due to their acceleration to pitting corrosion [10-12].

The published literature has emphasized a effect of surface characteristics on pitting behaviour in different conditions. [3,5,13]. Significant efforts have been made to develop methods to modify the stainless steel surface and/or its passive films in order to improve the material's pitting corrosion resistance. These methods have been focused mainly on the removal of surface inclusions [3, 13], the modification of chemical properties/composition and element distribution in the passive film [14-16], or the increase in the Cr/Fe ratio in the film [3-6]. Some improvement in pitting resistance has been reported using these methods [3, 5, 17, 18].

A lot of research work has been carried out using oxidizing and non-oxidizing environments to study the corrosion resistance particularly pitting corrosion. A non-oxidizing environment such as H2SO4, the resistance against corrosion is increased by alloying elements in stainless steel [19]. Oxidizing environments particularly containing HNO3 are largely used for passivation [19, 20-24].

Experimental

1. Chemical Composition of Material

The chemical composition of 316 Stainless Steel (316 SS) under investigation as given by the supplier is shown in table 1.

Table 1. Chemical composition of 316 SS (in wt.%)

Elements	C	Cr	Ni	Mo	Si	Mn	S	P	Fe
Composition	0.04	17.5	10.17	2.95	0.70	0.93	0.02	0.03	Balance

2. Sample Preparation

The metal samples were cut from a 316 SS sheet into 1 x 1 x 0.3 cm size and then cold mounted. The samples were ground using silicon carbide papers 120, 320, 400 and 600 grit sizes and polished on velvet cloth with alumina abrasive to produce scratch-free and mirror-like surface. The samples were washed thoroughly with distilled water, rinsed, and then degreased with acetone.

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3. Surface Treatment

The samples were passivated in 20 vol% of HNO_3 at 60°C for 30 minutes, the samples were then washed with running distilled water and dried in air.

4. Electrochemical Testing

The electrochemical testing was carried out by using Gamry Potentiostat PC/750 connected to a three electrode cell system. The graphite electrode was used as a counter electrode, saturated calomel electrode (SCE) as a reference electrode and 316 SS samples as working electrode of 1 cm^2 exposed area. The electrochemical measurements were carried out in a Ringer's solution (NaCl=8.60 g/l, $CaCl_2.H_2O$=0.66 g/l and KCl=0.60 g/l). The potentiodynamic cyclic polarization study was selected to investigate the pitting resistance of 316 SS samples. The parameters selected for cyclic polarization testing are shown in table 2.

Table 2. Input parameters for cyclic polarization testing

Parameters for Cyclic Polarization	
Initial Potential	-500mV vs. SCE
Apex potential	1500mV vs. SCE
Final Potential	-500 mV vs. SCE
Forward Scan Rate	5.0 mV/s
Reverse Scan Rate	2.5 mV/s
Apex current density	10mA/cm^2

Results and Discussion

Cyclic polarization scan of ground and polished samples is shown in figure 1 and the values of E_{corr}, E_{pit} and pitting resistance (E_{pit} - E_{corr}) are given in table 3. It can be observed that E_{corr} of polished sample is more positive than ground sample and also E_{pit} is higher for polished sample as compared to ground sample which clearly shows that ground surface is more potent to pitting than a polished surface because uneven surface facilitate localized corrosion. The corrosion species can accommodate in the crevices produced due to

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grinding. It can be observed that pitting resistance of ground surface is lower than the polished surface.

Table 3. Characteristics results of potentiodynamic cyclic polarization scan of ground and polished surfaces

Sample	E_{corr}	E_{pit}	Pitting resistance (E_{pit} – E_{corr})
Ground Surface	-273.7	91.56	365.26
Polished Surface	-238.4	131.6	370

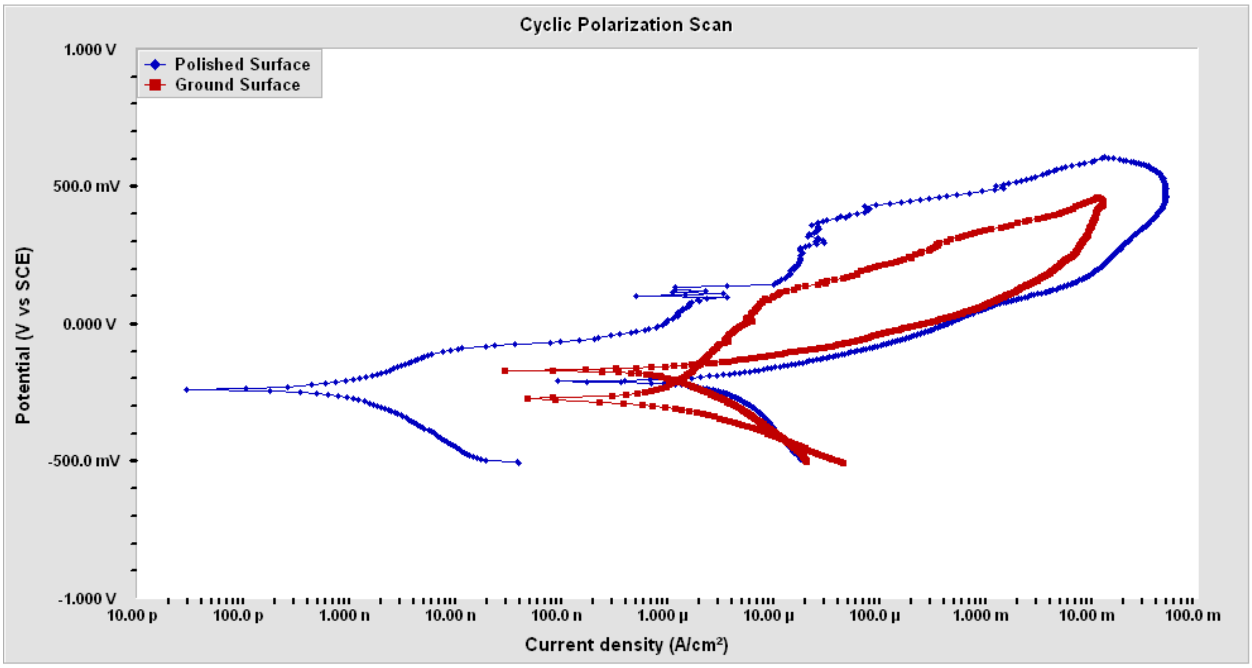

Figure 1. Cyclic polarization scan of ground and polished surfaces

The cyclic polarization scan for the passivated polished and ground surfaces is shown in figure 2 and the values of E_{corr}, E_{pit} and pitting resistance are given in table 4. It is observed that E_{corr} of passivated polished surface is more positive than the passivated ground surface showing relative inertness of polished surface. Similarly E_{pit} of passivated polished surface is higher than that for passivated ground surface. It can be inferred that the passivated ground surface is more prone to localized attack. Similarly the pitting resistance of passivated polished surface is higher than the passivated ground surface. The lower values of E_{pit} and pitting resistance may be due to the partial passivation on ground surface causing differential passivation on crest and trough of a scratch.

Table 4. Characteristics results of potentiodynamic cyclic polarization scan of passivated ground and polished surfaces

Sample	E_{corr}	E_{pit}	Pitting resistance (E_{pit} – E_{corr})
Passivated Ground Surface	-228.2	426.7	654.9
Passivated Polished Surface	-193	692	885

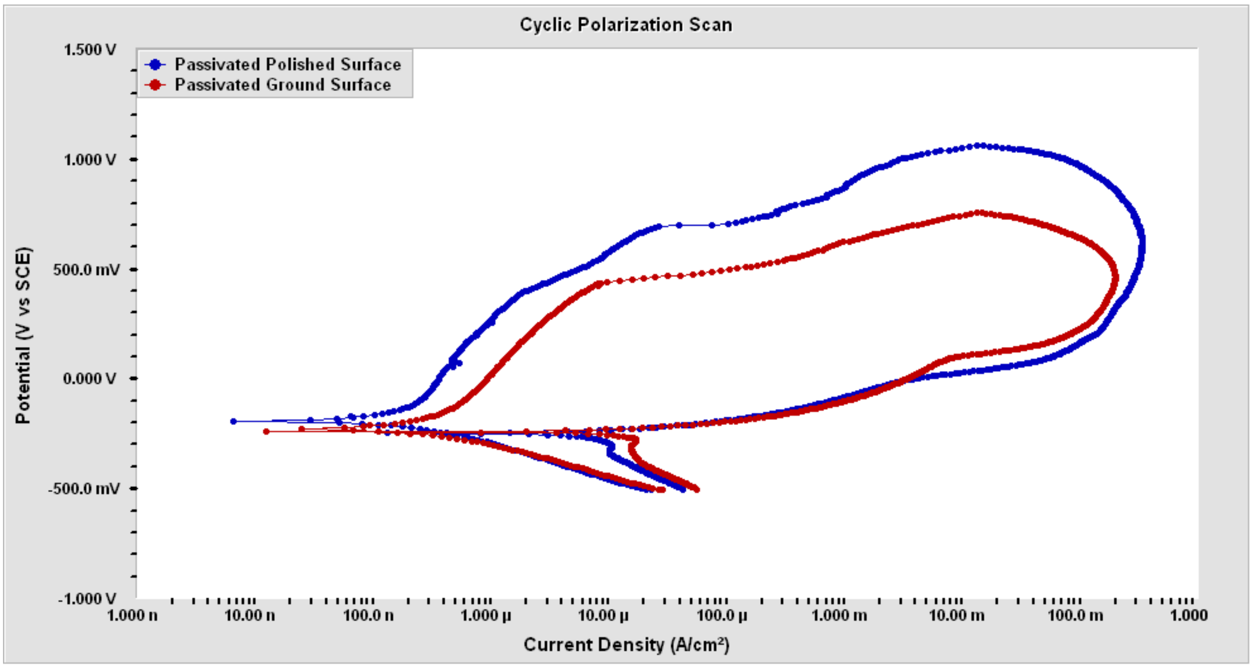

Figure 2. Cyclic polarization scan of passivated ground and polished surfaces

The cyclic polarization scans of passivated and non-passivated ground surfaces are compared in figure 3. It can be observed that E_{corr} of passivated ground surface is more positive than non-passivated surface. On the other hand E_{pit} and pitting resistance of passivated ground surface is double than that of non-passivated ground surface. It can be inferred that although the ground surface shows more tendency to pitting however passivation can decrease the tendency of pitting.

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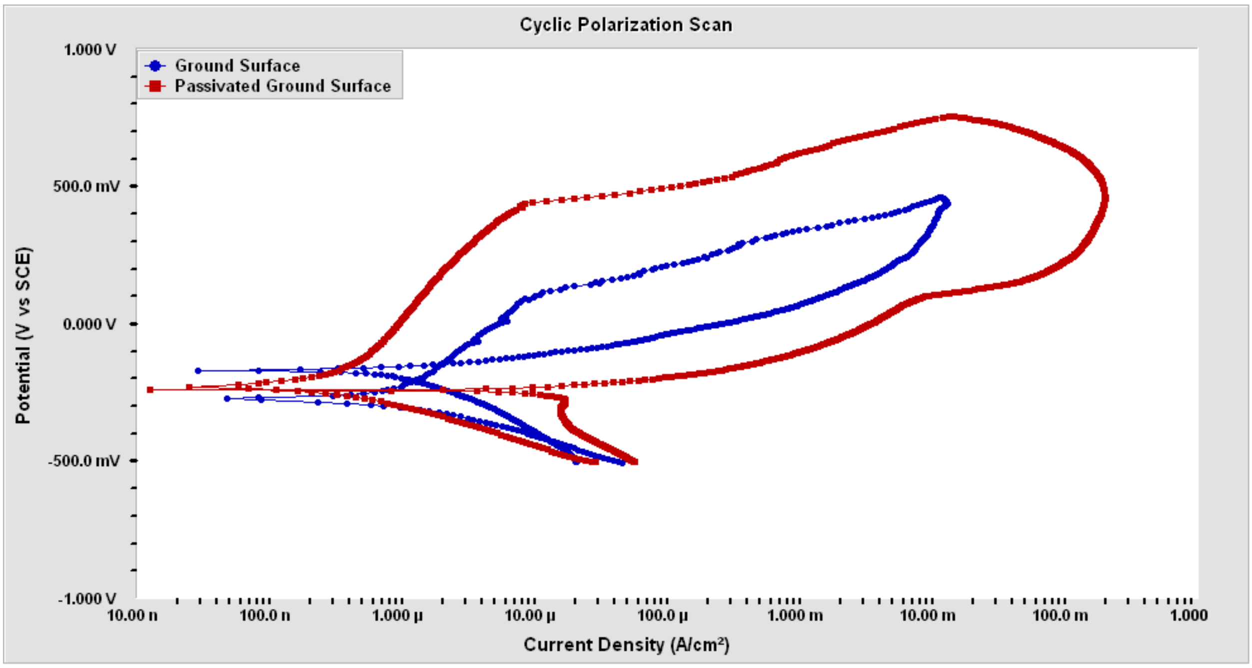

Figure 3. Cyclic polarization scan of passivated and non-passivated ground surfaces

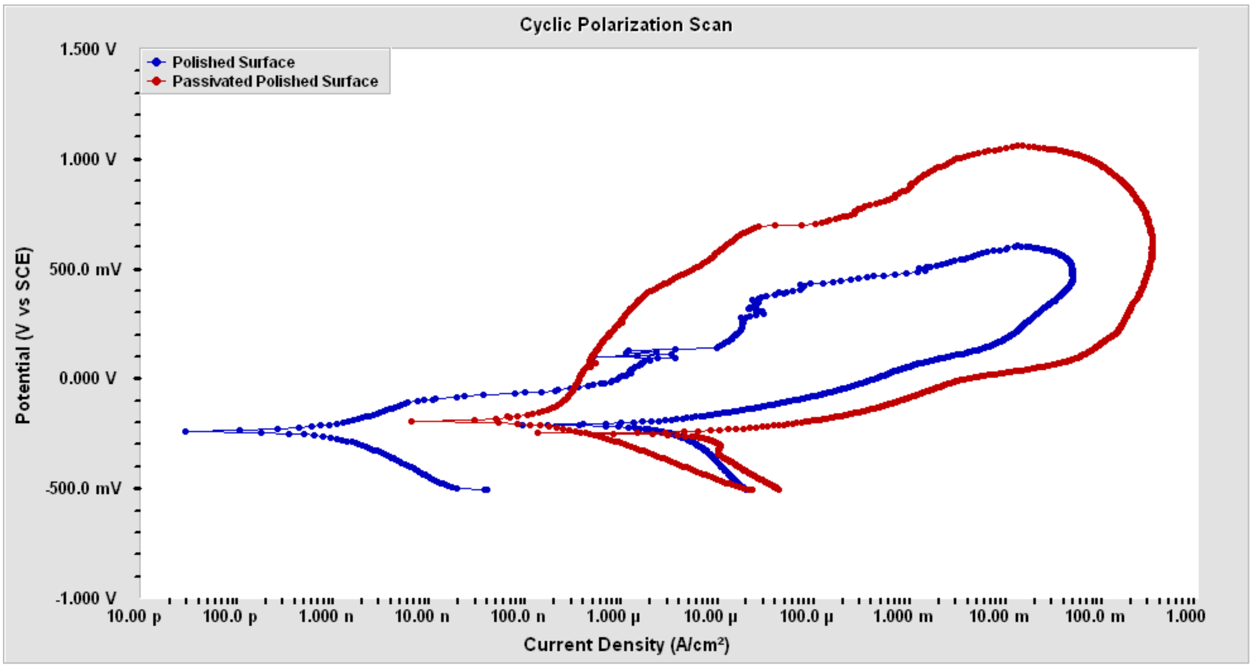

Figure 4. Cyclic polarization scan of passivated and non-passivated polished surfaces

Similarly cyclic polarization scans for passivated and non-passivated polished surfaces are shown in figure 4. It is concluded that passivation has a significant effect in this case. The E_{corr} of passivated polished surface is more positive than non-passivated polished surface. Similarly E_{pit} is increased 5 times while pitting resistance increased about 3 times showing effective passivation on the surface.

Conclusion

The surface condition has a profound effect on the degree of passivation and pitting resistance of stainless steel in Ringer's solution. The pitting resistance of polished surface in passivated and non-passivated state is higher than the ground surface in passivated and non-passivated state.

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