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CORROSION RESISTANCE OF AUSTENITIC Cr-Ni STAINLESS STEEL IN 1 M HCl

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The corrosion resistance of austenitic stainless steel grade 316 were performed in 1 M hydrochloric acid solution using the electrochemical potentiostatic polarization method. The result showed the more active corrosion reactions in presence of chloride ion results in pitting corrosion observed on the metal surface. The potential range of passivity was shortened and both the pitting potential and protection potential shifted towards the active direction. Potentiostatic polarization method was used for the pitting corrosion investigation. The electrochemical corrosion reactions exhibited both the passive and active corrosion reactions characteristics. The acids at the intermediate concentrations show more obvious active corrosion reactions; while in the concentrated form they were relatively passive—the passivity that was associated with the oxidizing nature of the concentrated acids.

Keywords: Pitting corrosion, AISI 316 stainless steel, Hydrochloric acids, Pit nucleation

INTRODUCTION

Grade 316 has excellent corrosion resistance when exposed to a range of corrosive environments and media. It is usually regarded as "marine grade" stainless steel but is not resistant to warm sea water. Warm chloride environments can cause pitting and crevice corrosion. The existing demand for materials with high functional properties, a definite geometrical shape, a high resistance to the destructive effect of a aggressive environments, produced in compliances with a valid ecological standards, motivates the manufacturers to a continuous improvement in the engineering process, in particular the steelmaking and plastic forming processes. Stainless steels fulfil enough above requirements and characterized excellent corrosion resistance combined with high mechanical and plastic properties. The most

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common stainless alloys are austenitic steels, well-known as 18/8 types and usually contain between 16 and 18%wt. Cr, 6-8%wt. Ni and 0.03-0.1%wt. C (Lamb, 2001; and Baron *et al.*, 2006).

Stainless steels are iron alloys that have thin, transparent and durable chrome oxide passive layers on the surface. The stability of passive film and the corrosion resistance of stainless steel increase with increasing chrome content in the alloy. Although the costs of the stainless steel are higher than those with similar mechanical characteristics, the primary justification for its common usage is improved corrosion resistance. Stainless steels have a large range of applications. Over 1/3 of produced stainless steels are used in structural applications for chemistry and power engineering industries. These applications include nuclear reactor canals, heat converters, tubes that are used in oil industries, chemistry applications, paper industries components, and as the pieces of boilers and furnaces that are used in nuclear reactors (Kajzer *et al.*, 2007).

Corrosion resistance of stainless steels depends on various metallurgical and processing variables (Opiela *et al.*, 2009). The austenitic grade is considered to be most resistant to industrial atmospheres including aggressive aqueous and non-aqueous acid media (Surowska and Weroski, 1995).

However, as conditions become more severe, addition of several alloying elements is useful in promoting corrosion resistance and hence is desirable. Chromium >12%wt., for instance, improves the passivity of iron alloys, and molybdenum (>2%wt.) promotes resistance to pitting corrosion (Zor *et al.*, 2009).

The exorbitant amount spent on corrosion and protection of engineering components, structures/facilities annually has created a lot of interest in continually seeking for techniques and methods to efficiently combat corrosion. This is of particular interest to corrosion scientists and engineers worldwide, to gain more knowledge about the corrosion phenomenon and its control, and with the aim of finding appropriate and better utilization of austenitic stainless steels and other alloys (Loto, 2012).

The austenitic stainless steels comprise a large and varied group of iron-based alloys containing 18% or more chromium and sufficient nickel to assume a fully austenitic metallurgical structure. The most common group is referred to as "18-8" stainless steel 18%Cr and 8%Ni of which Type 316 stainless steel belongs. These alloys are of major importance in the chemical process industries and in other industrial applications. They are the alloys of choice for many of the applications which require a higher level of corrosion resistance than the type 304 stainless steel. In composition, type 316 consists of about 2% Mo to improve the resistance to pitting attack by strengthening the passive film and imparting improved corrosion resistance in reducing acids.

Austenitic Stainless steels are used as construction materials for key corrosion-resistant equipment and due to their strength in most of the major industries, and especially in chemical, petroleum, offshore drilling marine shipping, water desalination, processing, and

power generation plants. The high corrosion resistance of this material arises from the formation of a passive layer on its surface. This passive film or layer is very thin, which is self healing in a wide variety of environments, provides their corrosion resistance. Due to environmental concerns, there has recently been an increase in the demand for ethanol as a road vehicle fuel. There is therefore, a greater need for studies of the corrosion resistance of materials used in alcohol production plants, and in transportation and storage facilities (Pardo *et al.*, 2008).

Additionally, chromium content in the steel enhances its corrosion resistance. The passive film is constituted by an iron and chromium oxy-hydroxide layer and water containing-compounds which is formed at the metal/solution interface, and an underlying film formed by chromium oxide. However, under certain circumstances, the passive state may be lost, and most stainless steel-based equipment failures are caused by pitting corrosion due to chloride ions (Fontana and Greene, 1967).

Hydrochloric acid remains the main source of the aggressive chloride ions. Pitting corrosion is one of the most dangerous forms of localized corrosion especially for steels in chloride media (Aldahan, 1999). On the other hand, sulphuric acid is very corrosive for stainless steels too, and constitutes one of the basic raw materials encountered in the chemical industry. Despite the number of publications about stainless steel corrosion and passivation, the kinetics of the various complex processes involved has been investigated less extensively in concentrated solutions of these acids. Therefore, it is

interesting both from the fundamental and practical standpoint to study the influence of acidity, chloride and sulphate ions on those processes. The presence of such ions imposes the use of inhibitors to avoid destruction of either the material surface or the passive layer in contact with the aggressive solution (Ait Albrimi, 2011).

Electrochemical studies of pitting corrosion have found the existence characteristic potentials. Stable pits form at potentials noble to the pitting potential, Ep, and will grow at potentials nobler than there passivation one, ER, which is lower than Ep. During upward scanningin a potentiodynamic polarization experiment, a stable pit starts growing at Ep, where the current increases sharply from the passive current level and, upon reversal of the scan direction, repassivates at ER where the current drops back. It is generally considered that materials exhibiting higher values of Ep and ER are more resistant to pitting corrosion, and potentiodynamic polarization experiments are commonly used for this purpose.6, Ep is in many cases a function of experimental parameters such as potential scan rate. Furthermore, so-called metastable pits initiate and grow for a period at potentials well below the pitting potential, which provides evidence in contradiction to the definition of the pitting potential as being the potential above which pits initiate. Metastable pits initiate and grow for a limited period before repassivating. Large pits can stop growing for several reasons, but metastable pits are typically considered to be those of micron size at most, with life times on the order of seconds or less.

In the present investigation, the corrosion behaviour of AISI 316 stainless steel exposed

to hydrochloric acid solution has been investigated with special focus on the characterization of the pitting susceptibility of the steel in these environments. The influence of various factors such as the nature of the acidic media and its concentration, potential cycling, potential scan rate, and the addition of Cl- ions were considered.

EXPERIMENTAL METHOD

Austenitic stainless steel AISI 316 plates have been used. Table 1 provides its nominal chemical composition. The composition of steels as analyzed by optical emission spectrophotometer is given in the Table 1.

Austenitic stainless steel-SS 316 samples in cylindrical form (20 mm dia. and 6 mm long) used for this investigation. The surface finishing procedure recommended by ASIM was replaced by the polishing procedure used as standard practice in metallographiy laboratories, i.e., wet grinding successively with grades 80, 120, 180, 220, 320, 400, 600 and 800 silicon carbide papers and then cloth polishing with alumna. The finishing was checked under the optical microscope at 100x. This finishing permits a clearer resolution of the metallic surface structure. The samples were immediately kept in desiccators for subsequent corrosion experimental studies.

Electrochemical studies were carried out in a conventional three-electrode single-compartment Pyrex glass cell (Model NOVA 1.18, serial no. 12800817 Pyrex cup, 300 ml volume, with the cover model AUTOLAB one

channels/openings, software NOVA 1.8.17). Sample was used as the working electrodes by putting only one side of the specimen in contact with the electrolyte (1 cm^2).

The remaining sides were covered with a non-reactive and non-conductive varnish. The electrical contact with the test electrode was made using a crocodile clip attached on a small strip of the sample.

Potentiodynamic experiments were performed using each of the cylindrical specimens in turns, in which 1 cm^2 surface area of the specimen was exposed to the test solution at room temperature. The experiments were performed using a polarization cell of three – electrode system consisting of a reference electrode (saturated-AgAgCl/KCl 0.197V), a Working Electrode (WE); and a Counter Electrode (CE) made of platinum mesh. The experiments were conducted in 1 Mole HCl solution for stainless steel sample.

The electrochemical measurements were performed using a computerized potentiostatic electrochemical set AUTOLAB model PGSTAT 3210 potentiostate. The corrosion behaviour of the stainless steel was investigated 1 mole HCl acid solution, at room temperature, using potentiodynamic polarization technique. Test environment were 1 M HCl (33.6 ml) 266.4 ml distilled water.

Potentiodynamic polarization measurements were performed at a scan rate of 0.5 mV/s, initial potential-0.25 V final potential 1.6 V,

| Table 1: Chemical Composition of Grade 316 Austenitic Stainless Steel											
Elements	C	Mn	Si	P	Cr	Ni	Mo	V	Cu	Sn	Al
Wt%	0.08	0.44	0.019	0.009	16.67	9.86	2.09	0.070	0.49	0.013	0.042

step height 0.5 mV, step time 1 mV and measured open circuit –300.572 mV with respect to the corrosion potential (Ecorr) and scanning back to the starting potential when the samples reached a current density value of 104 I A/cm².

RESULTS AND DISCUSSION

1 Mole Hydrochloric Acid (1 M HCl) Environment

The potentiostatic polarization curves and table of measurement results for the test specimen recorded in 1 M HClare presented in Figure 1 and Table 2 respectively. Figure 1 shows the polarization corrosion curve of the 316 stainless steel in 1M HCl alone. The Open Corrosion Potential (OCP), Ecorr was –0.305 V. The specimen can be described to be protected with this potential value throughout the experimental period. This medium serves as the control for the subsequent experiment. A summary of the overall result data is presented in Table 2.

Results summary for the test in 1M HCl presented in Table 1 showed that the corrosion rate is 42.514 mm/yr and the corrosion polarization resistance (Rρ) is 11.034 Ω. The corrosion current density of 0.003659 A/cm² was low and the corrosion current is 0.003659 A which was also very low. All these results data confirmed the corrosion of the test specimen 1 M HCl to be very high.

Figure 1: Potentiodynamic Polarization Curves 316 Austenitic Stainless Steel in 1 M HCl
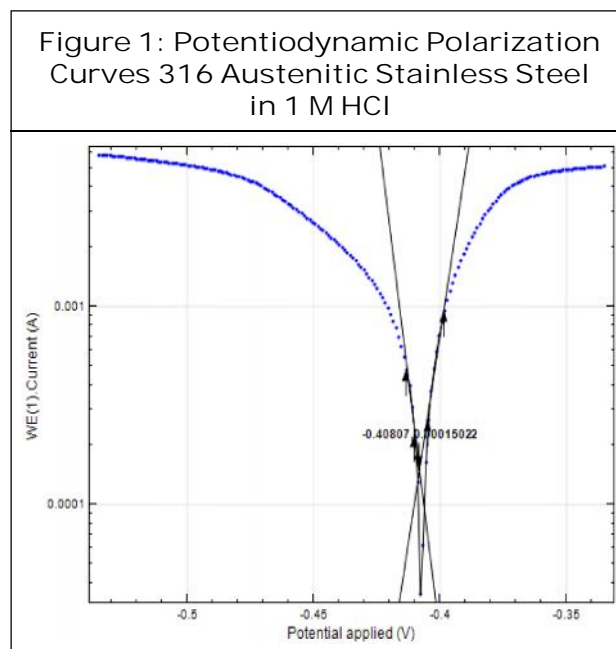
CONCLUSION

The electrochemical behaviour of type 316 austenitic stainless steel in acidic solutions depends considerably on the concentration of hydrochloric acid environment. The presence of acid concentration produces and enhancement of metal corrosion through the passive layer, and decreases the passivity breakdown potential. Pit nucleation and growth involves a number of contributions which can be distinguished through the analysis of current transients at constant potential.

The corrosion polarization behaviour for the tests performed in hydrochloric acid showed active corrosion reactions behaviour at all the used concentration (1 M). Theless corrosion resistance of the test electrode as indicated by the obtained results data.

Table 2: Electrochemical Parameters Estimated from the Polarization Tests in 1 M HCl										
Conc. (M)	Icorr (A)	Icorr (A/ Cm²)	bc (V/ dec)	ba (V/ dec)	Rp (Ohm)	Ecorr Reference (V)	Ecorr Calc (V)	Ebegin (V)	Eend (V)	Corrosionrate (mm/year)
1	0.003659	0.003659	0.08779	–1.5819	11.034	–0.4073	–0.4080	–0.4130	–0.3981	42.514

The overall corrosion resistance performance of this alloy in the test environments can be rated as fair to good. ◍

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