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Corrosion Behaviour of Annealed 2205 Duplex Stainless Steel in Sulphuric Acid Environment

Victor A. Adedayo[1,2*]

[1]*Department of Materials Science and Engineering; Obafemi Awolowo University, Ile-Ife, Nigeria*

[2]*Department of Metallurgical Engineering; Kwara State Polytechnic, PMB 1375, Ilorin, Nigeria*

Abstract: *This paper presents a study that investigates the corrosion behavior of annealed 2205 duplex stainless steel in sulphuric acid environment. Duplex 2205 stainless steel black bar in ASTM A276 was obtained and annealed in solite furnace for 45 minutes. A control sample which was not heat treated was also prepared. The annealed and the control samples which were metallographically prepared were then analyzed for corrosion behavior in sulphuric acid using potentiodynamic test/analysis. The potentiodynamic polarization plot generated showed that the annealed samples exhibit less corrosion resistance than the untreated samples, indicating that annealing heat treatment reduces the corrosion resistance of 2205 duplex stainless steel in sulphuric acid.*

Keywords; *Corrosion, corrosion behavior, stainless steel, duplex stainless steel*

I. Introduction

Duplex Stainless Steels (DSS) are relatively new important materials with attractive properties for engineering applications. Such properties include excellent corrosion resistance, resulting from a thin and protective passive film, which prevents the metal from reacting with corrosive environments (Escrivá Cerdán et al., 2013). Normally, DSS consists of almost the same percentage of austenite and ferrite phases in the base metal. These stainless steel materials combine the properties of austenite with the properties of ferrite. Majorly, austenite phase is very sensitive to stress corrosion cracking; however, the ferrite phase is almost immune to stress corrosion cracking (Nilsson, 2017). Ferrite is somewhat brittle while austenite is particularly tough. The effect of work hardening is much less pronounced in ferrite than in austenite owing to the difference in atomic structure. Austenitic stainless steels are readily weldable, while ferritic stainless steels are much difficult to weld. The combination of ferrite and austenite in DSS leads to complementary properties in the steel. Many of these properties sometimes synergistically interact, leading to surprising properties that cannot be predicted from the properties of the constituent phases alone.

Stress corrosion resistance and mechanical strength are examples of such synergism exhibited by DSS (Saadawy, 2012; Kotecki, 1989). Despite that austenitic phase is sensitive to stress corrosion; DSS materials are almost insensitive to it (Nilsson, 2017). This has been explained by the fact that the conditions for stress corrosion cannot be fulfilled in both phases simultaneously. Moreover, the mechanical strength is typically twice that of the constituents mainly because of the small effective grain size, which is difficult to obtain in a single-phase material.

Also, the heat treatment of DSS material is important because of many reactions that accompany the heat treatment procedures. By virtue of its high ferrite content, high chromium, and usually molybdenum in ferrite, DSS is sensitive to Alpha prime and Sigma prime embrittlements. By exposure to elevated temperatures around 475°C, a chromium-rich BCC phase, known as "alpha prime," precipitates in the BCC iron-rich ferrite, causing marked hardening and embrittlement. At temperatures of about 700°C, complex intermetallic compound that is approximately 50% iron-50% chromium, known as "sigma phase," forms from ferrite, causing marked embrittlement. Molybdenum tends to accelerate formation of both alpha prime and sigma phases, while nitrogen seems to have some beneficial effect in slowing formation of these phases. The direct implication of formation of these precipitates and intermetallic is that they can be areas of pitting or selective attacks for corrosive environment (Blasco-Tamarit et al., 2011), or lead to depletion of chromium in certain areas of the base metal, leading to reduced corrosion resistance in the areas. Because fabrication of DSS materials almost always involve some elevated temperature procedures, it becomes important to understand how these elevated temperature processings may affect the important properties of DSS, particularly corrosion resistance. Hence, in this study, corrosion behaviour of 2205 DSS in sulphuric acid environment is presented.

II. MATERIALS AND METHODS

Duplex 2205 stainless steel black bar in ASTM A276 (12 mm diameter) was obtained from Shanghai Bozhong Group, in China and sectioned to appropriate sizes for further analysis/testing. Chemical composition of 2205 DSS is presented in Table 1.

Table 1: Chemical Composition of 2205 Duplex Stainless Steel

Element	Fe	C	Cr	Ni	Mo	N	Mn	Si	P	S
Percentage	Rest	<0.03	21-23	4.5-6.5	2.5-3.5	0.8–2	<2	<1	<0.03	<0.02

The sectioned materials were then solution annealed at a temperature of 1000°C in a solite furnace for 45 minutes, after which the samples were removed from the furnace and quickly quenched in water. Normally, annealing heat treatment of DSS is carried out at temperatures between 900 -1200°C for a soaking time long enough to ensure that the part is heated thoroughly throughout its section to the required temperature, 30 minutes per 25mm of section is normally used as a guide (Beartech Alloys, Inc., 2018; IMOA, 2009). An un-heat treated was also kept to serve as control specimen. The prepared samples were then metallographically prepared.

The electrochemical response of the duplex stainless steel in 0.1 and 3M Sulphuric acid environment was carried out by potentiodynamic tests. 0.1M sulphuric acid was adopted to simulate mild corrosive environment, while 3M sulphuric acid was used to simulate aggressive corrosion environment. The samples were made the working electrodes for potentiodynamic tests. Counter electrode is Platinum, and reference electrode is Ag/AgCl. The scan rate for the potentiodynamic test is 1mV/s from potentials of -250mV to +250mV. The polarization responses of the study materials were evaluated with potentiostat equipped with VERSASTAT4 software, and the entire electrochemical tests were performed at room temperature.

III. RESULTS AND DISCUSSION

The results of the electrochemical corrosion of the test samples by potentiodynamic test are presented as potentiodynamic polarization curves in the figures that follow. Figures 1; 2; 3 and 4 present the potentiodynamic polarization curves which show the corrosion behaviour of the test samples in their respective environments.

Figure 1 is the potentiodynamic polarization curve which shows the corrosion behaviour of annealed 2205 DSS in 3M sulphuric acid environment. This polarization curve has both anodic and cathodic domains (Blasco-Tamarit et al., 2011). The cathodic domain includes potentials below the corrosion potential (E_{corr}), where current density determined by the cathodic reaction shows a continuous increase in the current density of the cathodic branch as the potential decreases (Saadawy, 2012). The polarization curve indicates that solution annealed 2205 DSS has distinctive active-passive corrosion behaviour in 3M sulphuric acid environment. For this system, corrosion potential (E_{corr}) is -0.26mV and passive potential (E_{pa}) of about -0.21mV. At the passive range, the current density of about 10^{-5}mAcm^{-2} decreased gradually as the potential increased. This is indicative of better corrosion resistance, which can be due to thickening of the passive film on the 2205 DSS as the potential increased. Normally, Composition and thickness of the passive film are functions of potential and solution composition (Michigan State University, 2018).

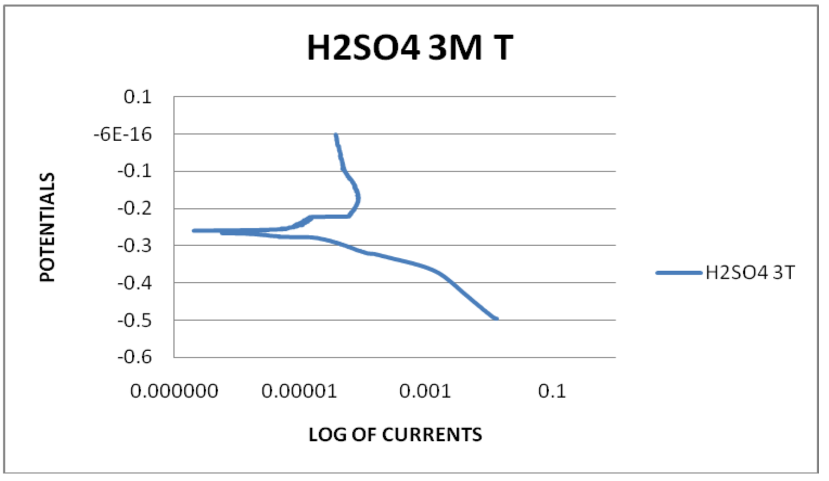

Figure 1: Potentiodynamic polarization curves of annealed 2205 DSS in 3M H_2SO_4

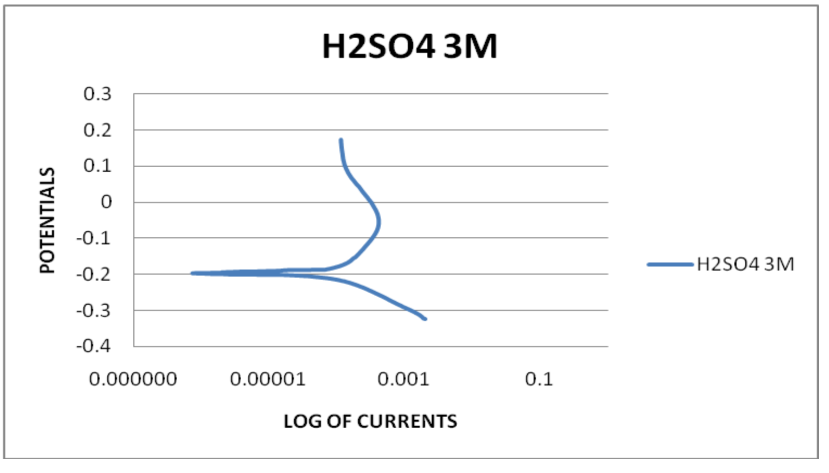

Figure 2: Potentiodynamic polarization curves of untreated 2205 DSS in 3M H_2SO_4

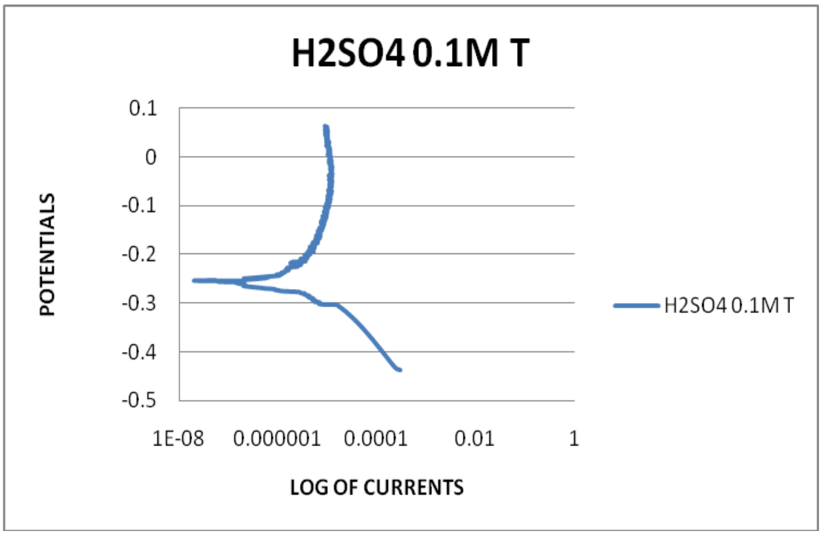

Figure 3: Potentiodynamic polarization curves of annealed 2205 DSS in 0.1M H_2SO_4

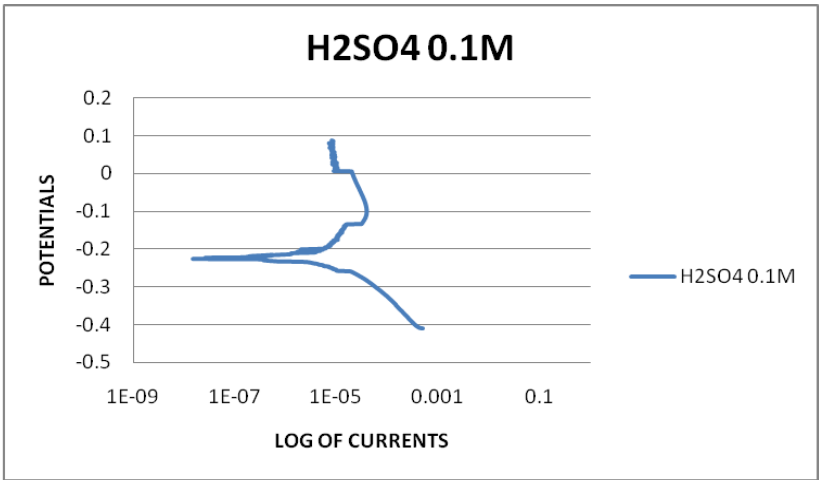

Figure 4: Potentiodynamic polarization curves of untreated 2205 DSS in 0.1M H_2SO_4

Table 1: The corrosion and pitting potential in potentiodynamic polarization curves of 2205 DSS samples.

Samples	*3M (Treated)*	*3M (Untreated)*	*0.1M (Treated)*	**0.1M (Untreated)**
Corrosion potential ($E_{corr.}$)	-0.26mV	-0.20mV	-0.25mV	-0.22mV
Pitting potential ($E_{pitt.}$)	-	-	-	-0.12mV
Corrosion current (I_{corr})	-8.968 µA	-158.157 µA	-1.985 µA	-4.171 µA

The potentiodynamic polarization curve showing corrosion behaviour of untreated 2205 DSS sample in sulphuric acid environment is presented in Figure 2. The cathodic domain show potential trends where the corrosion potential (E_{corr}) decreased from -0.20mV, and the current density shows a continuous increase in the current density of the cathodic branch till current density of about 10^{-3}mA. The untreated 2205 DSS materials also show active-passive corrosion behaviour in 3M sulphuric acid environment. In this case, the corrosion potential (E_{corr}) is -0.20mV and passive potential (E_{pa}) is about 0.1mV. The potentiodynamic polarization plot for the untreated 2205 DSS sample indicates a critical current density (i_{crit}) of about 10^{-3}mA.

Comparing the potentiodynamic polarization curves for treated and untreated 2205 DSS; it is clear that the untreated sample presents a higher corrosion potential. Normally, higher corrosion potential indicates better corrosion resistance, thus untreated 2205 DSS offers better corrosion resistance in 3M sulphuric acid environment.

Figure 3 presents the potentiodynamic polarization curve of corrosion behaviour of annealed 2205 DSS sample in 0.1M sulphuric acid environment. The cathodic branch of the plot show potential trends where the corrosion potential (E_{corr}) decreased from -0.25mV, and the current density shows a continuous increase till current density of about 10^{-4}mA. This plot indicates a spontaneously passive behaviour (Michigan State University, 2018), which predicts that annealed 2205 DSS material will be spontaneously passive in 0.1M sulphuric acid environment. The passive potential (E_{pa}) is -0.10mV with a passive current density of about 10^{-6}mA.

Figure 4 shows the polarization plot of potentiodynamic corrosion test of untreated 2205 DSS in 0.1M sulphuric acid environment. Cathodic branch of the plot showed a decrease in corrosion potential (from -0.22mV) lead to increase in current density till a current density of about 10^{-3}mA. Unlike the annealed 2205 DSS sample which exhibits spontaneous passivity, the untreated sample shows active-passive corrosion behaviour with pitting potential at about -0.12mV. The plot showed that, from about -0.10mV; there is decrease in current density. At 0.0mV, there is repair/thickening of passive film which indicates better corrosion resistance.

By comparing the polarization plots of annealed and unannealed DSS samples, the untreated sample showed a higher corrosion potential (-0.22mV), indicating that the untreated 2205 DSS sample possessed the better corrosion resistance in 0.1M sulphuric acid environment.

Conclusion

The study has revealed that 2205 duplex stainless steel exhibits active-passive corrosion behavior in sulphuric acid environment. The annealed samples showed lower corrosion potentials (Ecorr.) indicating that annealing weakens corrosion resistance of 2205 duplex stainless steel in sulphuric acid environment. The study also shows that untreated 2205 duplex stainless steel shows increased passivation in sulphuric acid with increased molarity of the sulphuric acid environment.

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