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Research Article

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

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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

Introduction

Duplex Stainless Steels are special type of ferrous alloys having a two-phase microstructure consisting of grains of ferritic and austenitic stainless steel. These families of steels have been identified to possess many attractive properties which include: enhanced tensile properties and greater resistance to pitting and crevice corrosion, and they are twice the strength of austenitic stainless steels. Their lighter weight also makes duplex stainless steels cheaper to transport and assemble. The tensile properties DSS are essentially governed by the ferritic matrix, while the good impact resistance properties of the alloy is considered to be by the austenitic phase content, which retards the cleavage fracture of ferrite [1]. Despite these attractive properties of DSS, their use is limited, owing to their susceptibility to the formation of dangerous intermetallic phases, such as σ- and χ-phase, which form after ageing the material in a temperature range over 600°C [1-2]. The critical temperature range at which these intermetallics form depend on the steel's composition. At certain temperatures the precipitation can be very fast, occurring only after 3-5 minutes of ageing treatment. While mechanical properties of DSS are strongly affected by susceptibility to intermetallic formation, this susceptibility can equally affect corrosion behaviour of these materials. Particularly, it can affect corrosion behaviour in specific environment, and specific temperature of heat treatment. Because duplex steels are commonly subjected to different kinds of hot forming and used in different types of severe environments, the understanding of effect of heat treatment (solution annealing) and acidic environment on corrosion behaviour of the material becomes important. Herein, the rationale for the study is identified

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 [3-4]. 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 hydrochloric acid environment was carried out by potentiodynamic tests. 0.1M hydrochloriic acid was adopted to simulate mild corrosive environment, while 3M hydrochloric 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.

Results and Discussion

The results of the electrochemical corrosion of the test samples by potentiodynamic test are presented as potentiodynamic polarization curves in Figures 1, 2, 3 and 4 that follow.

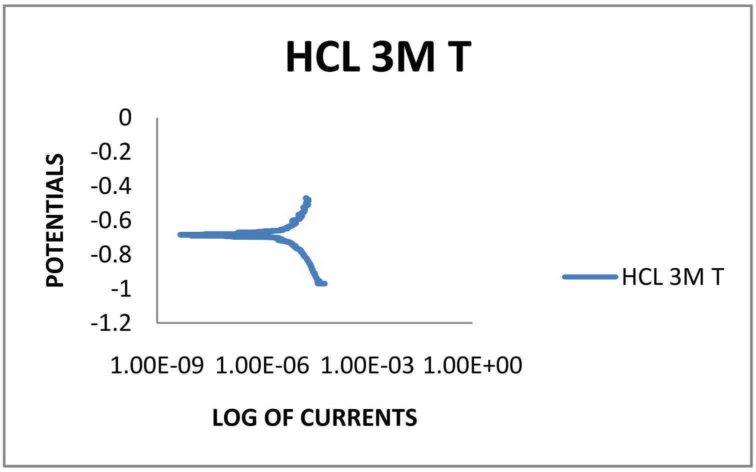

Figure 1: Potentiodynamic polarization curves of annealed 2205 DSS in 3M HCl

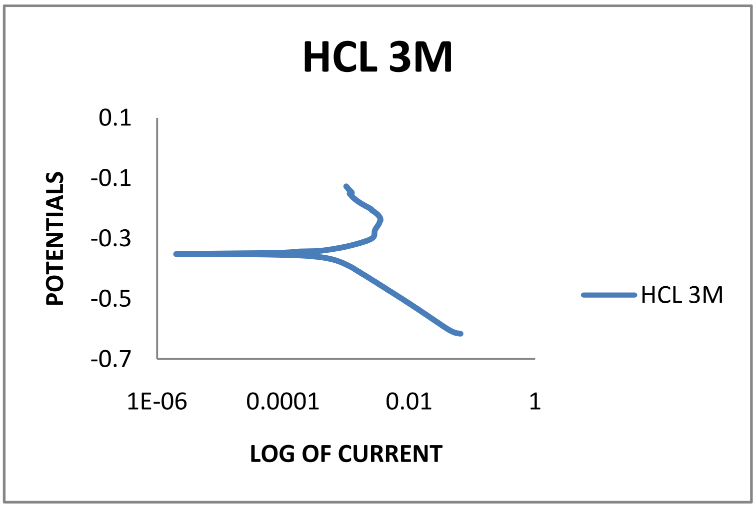

Figure 2: Potentiodynamic polarization curves of untreated 2205 DSS in 3M HCl

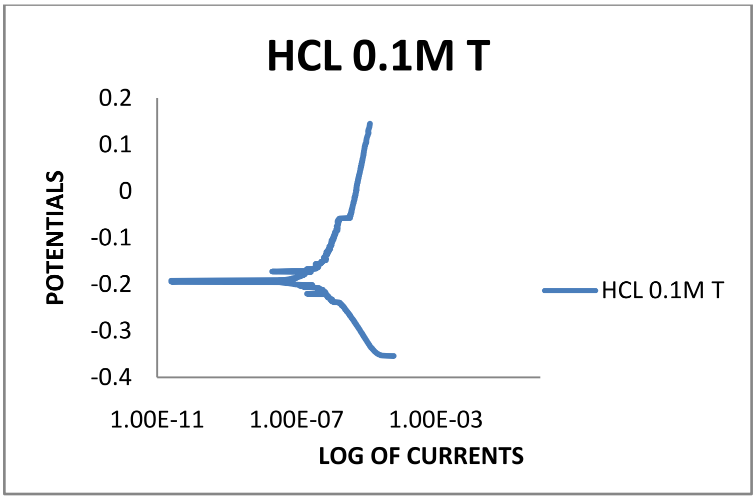

Figure 3: Potentiodynamic polarization curves of annealed 2205 DSS in 0.1M HCl

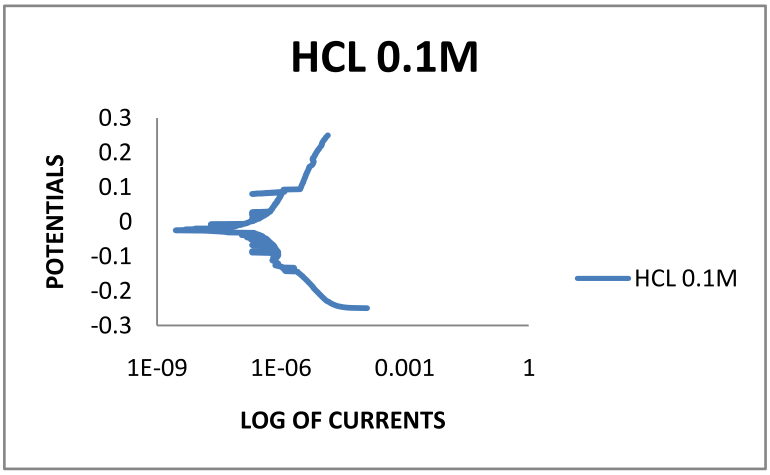

Figure 4: Potentiodynamic polarization curves of untreated 2205 DSS in 0.1M HCl

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 ($E_{corr.}$)	-0.69mV	-0.35mV	-0.19mV	-0.02mV
Pitting potential ($E_{pitt.}$)	-	-	-0.06mV	0.09mV
Corrosion current (I_{corr})	-31.872 µA	-785.477 µA	-43.642 nA	-440.805 nA

Figure 1 gives the result of potentiodynamic polarization of annealed 2205 DSS in 3M hydrochloric acid. The curve shows an active corrosion behaviour with corrosion potential (E_{corr}) of -0.69mV. The cathodic branch of the polarization curve includes potentials below the corrosion potential, where current density determined by the cathodic reaction shows a continuous increase in the current density of the cathodic branch as the potential decreases [5]. This polarization result indicates that this curve has both anodic and cathodic domains [6]. On the cathodic branch, the potential decreases from the E_{corr} value till a potential of about -1.0mV. From the anodic branch, the current increased rapidly with potentials till current density of about 10^{-5}mA where the curve is tending to passivation.

Figure 2 is the potentiodynamic polarization plot of un-annealed 2205 DSS in 3M HCl. The curve indicates both anodic and cathodic branch. On the cathodic domain, the corrosion potential is -0.35mV, and as this potential decreased, the current density on the cathodic branch increased till a value of about 10^{-1}mA. On the anodic branch, the corrosion potential increased with current density until critical current density (i_{crit}), where there is primary passivation at a potential (E_{pp}) of about -0.25mV. The system of un-annealed 2205 DSS in 3M HCl shows active-passive corrosion behaviour.

Comparing corrosion behaviour of annealed and un-annealed 2205 DSS in 3M HCl, the annealed sample shows active corrosion behaviour for the potential range used for the potentiodynamic polarization study, where as the un-annealed sample shows active-passive behaviour for the potential range used for the polarization study. The corrosion potential (E_{corr}) for annealed 2205 DSS is lower than the corrosion potential for untreated 2205 DSS material, indicating that the untreated 2205 DSS possessed the best corrosion resistance in 3M HCl.

Potentiodynamic polarization plot of Figure 3 shows the corrosion behavior of annealed 2205 DSS material in 0.1M HCl. The polarization plot shows active behavior, which has both anodic and cathodic domains. The potential decreased with increasing current density on the cathodic domain. The anodic branch of the polarization plot shows corrosion potential (Ecorr) is about -0.19mV, with a pitting potential (P_{pit}) at about -0.06mV.

Figure 4 presents the potentiodynamic polarization plot of un-annealed 2205 DSS sample in 0.1M HCl. The figure shows both anodic and cathodic branch with active behavior. On the cathodic domain, the polarization curve includes potentials below the corrosion potential, where current density determined by the cathodic reaction shows a continuous increase in the current density of the cathodic branch as the potential decreases. The Ecorr from the plot is -0.02mV, with a pitting potential (P_{pit}) of about 0.1mV at current density of 10^{-5}mA.

Comparing behavior of both annealed and un-annealed sample in 0.1M HCl, the un-annealed sample shows a higher Ecorr of about -0.02mV. This shows that the untreated sample has better corrosion resistance in 0.1M HCl as compared with the annealed sample. The pitting potential (P_{pit}) of un-annealed sample is about 0.09mV and is higher than that of the annealed sample. This shows that un-annealed sample also has better pitting resistance. Overall, untreated 2205 DSS sample has the highest corrosion potential (E_{corr}), indicating that un-annealed 2205 DSS in 0.1M HCl exhibit the best corrosion resistance.

Conclusion

The study has revealed that 2205 duplex stainless steel exhibits active-passive corrosion behavior in hydrochloric acid environment. The annealed samples showed lower corrosion potentials (Ecorr.) as compared to the untreated samples. This indicates that annealing weakens corrosion resistance of 2205 duplex stainless steel in hydrochloric acid environment.

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