

Corrosion behaviour of low carbon steel in acidic and acidic-chloride solutions

Olaseinde O. A, Adewuyi B. O

Department of Metallurgical and Materials Engineering, Federal University of Technology Akure, Ondo- State, Nigeria

ABSTRACT

An investigation of the corrosion behaviour of low carbon steel in 0.5M sulphuric acid, 1M sulphuric acid, 0.5M sulphuric acid with 10% sodium chloride and 1M sulphuric acid with 10% sodium chloride were using conventional weight loss method and potentiodynamic method. The microstructure of the alloy was revealed by optical microscopy and scanning electron microscopy. It was observed that the increase in concentration of the acid caused the corrosion potential to move to more negatives values. Addition of chloride to the sulphuric acid reduces the corrosion potential, increases the current density and corrosion rates of the low carbon steel.

Keywords: Carbon steel, Acidic, Acidic-chloride, Corrosion

I. INTRODUCTION

Steel has remained the most widely used material for infrastructural development. This is because of its good weldability, adequate ductility, moderately high strength. It is relatively cheap and readily available [1-5]. These qualities have made it stand out in the midst of other materials for selection as the major constructional material in different fields of engineering. The use of materials exposes them to different environments. It is used in environments that require optimization of its excellent properties, some of which are low and high pressure boilers and vessels, fossil fired power plant, fuel gas desulphurization equipment, evaporator tubing, super heater reheating tubing and steam heaters and pipes to mention but a few. The low carbon steels are produced in greater quantities than all other steels. These generally contain less than about 0.25 wt% C and are unresponsive to heat treatments intended to form martensite; strengthening is accomplished by cold work. Microstructures consist of ferrite and pearlite constituent. These alloys are relatively soft and weak, but have outstanding ductility and toughness; they are machinable, weldable, and inexpensive to produce. Typical applications include automobile body components, pipelines, buildings, bridges, marine, petroleum

production and refining, construction and metal processing equipment.

Corrosion of carbon steels is a problem of huge practical importance. Carbon steel pipes and vessels are often used for transportation of water or are submerged in water to some extent. Many structural alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to certain substances. Acidic and chloride environments are constantly encountered in the industry, such as oil and gas, construction, pulp and paper etc [5-7]. The behaviours of materials in these environments need to be studied from time to time since the environment keeps changing. The objective of the present work is to investigate the corrosion behaviour of low carbon steel in acidic, acidic-chloride and chloride environments and to compare the effect of environments on the corrosion behaviour of low carbon steel [6].

II. METHODS AND MATERIAL

The chemical composition of the steel was obtained by spark spectroscopy analysis. The tests were done in triplicate and the average was recorded. The samples were mounted onto bakelite in order to leave only one uncovered surface and it was polished using successive grade emery papers from 60 down to 1200 grit to

acquire a good surface finishing and wet polishing was done with the use of polishing machine. The exposed surface was etched using nital solution, Microscopy analyses were carried out with the optical microscope and scanning electron microscope. The solutions for corrosion tests were prepared from sulphuric acid and sodium chloride analytical grade reagent. 150mL of the corrosives solution was used for electrochemical tests and for conventional weight loss methods. For the weight loss test each sample was cut and ground to 600grits Silicon Carbide paper on all faces, rinsed with distilled water, degreased with acetone and dried, and weighed in an analytical balance PJ electronics balance model LSPJ-P20 with a precision of 0.0001g before immersion. Weight was measured by the same analytical weighing balance and recorded daily for each samples in the different medium for 60 days. The weight loss is calculated by subtracting the weight after each day from the initial weight. The difference between the initial and final weights divided between the initial areas was the mass loss. The potentiodynamic tests were made using an electrochemical cell constituted by the working electrode which is the steel sample, a graphite rod as auxiliary electrode and an Ag/AgCl as the reference electrode. An over-potential from -200 mV to 1200 mV was applied to the electrochemical cell at a sweep rate of 1 mV/s. The over-potential was applied when a constant corrosion potential was obtained. Both techniques were performed through an potentiostat equipped with NOVA software. The electrochemical tests were performed at room temperature $\pm 25^{\circ}\text{C}$. The corrosive environments were 0.5 M H_2SO_4 and 0.5M $\text{H}_2\text{SO}_4 + 10\%$ NaCl, 1 M H_2SO_4 and 1M $\text{H}_2\text{SO}_4 + 10\%$ NaCl

III. RESULTS AND DISCUSSION

The chemical composition of the alloys is shown in Table 1 below. It shows that the total alloying elements is less than 2wt%. The balance is Iron.

Table1: Chemical composition of low carbon steel

	C	Si	Mn	P	S	Cr	Co	Ni	Al	Cu	Nb	Ti	Fe
Wt%	0.125	0.285	1.300	0.017	0.003	0.017	0.002	0.022	0.034	0.021	0.045	0.003	Bal.

The metallography examination was carried out using optical microscopy and scanning electron microscope to reveal the phases present in the steel sample. The optical microscopy of the samples understudy is shown in Figure 1. It revealed ferrite and pearlite phases. The dark part is the pearlite while the brown part is the ferrite phase. This agreed with the Scanning electron microscopy results (Figure 2)

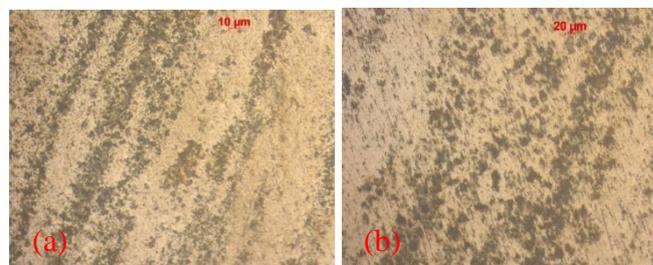


Figure 1. Optical micrograph of low carbon steel showing ferrite and pearlite phases at (a) 50 (b) 100 magnifications

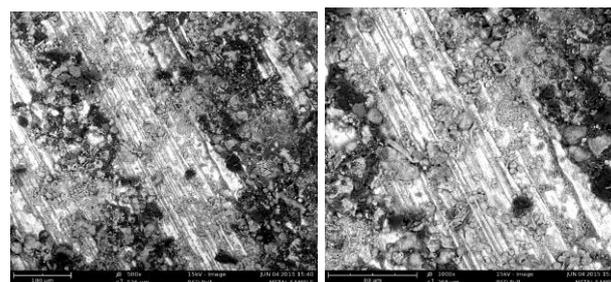


Figure 2. The scanning electron micrograph of low carbon steel at 500 and 1000 magnifications

Figure 3 showed the potentiodynamic corrosion curves of low carbon steel in 0.5M and 1M sulphuric acid solution. These plots showed that the corrosion potentials are very close to each other. The corrosion potential of alloy in the two solutions -407 for 0.5M sulphuric acid and -409 for 1M sulphuric acid (Ag/AgCl reference electrode).

It has been studied that the corrosion potential is more negative as concentration of the acid increased [8-9]. Active dissolutions were observed for the curve in the two solutions. There is similarity in the shape of the curve of 0.5M and 1M sulphuric acid.

The potentiodynamic curves of the alloy 0.5M H_2SO_4 and 0.5M $\text{H}_2\text{SO}_4 + 10\%$ NaCl is shown in Figure 4. The

corrosion potential of 0.5 M sulphuric acid is -407mV, which was nobler than for the sample containing chloride solution. It was observed that addition of chloride to the 0.5M H₂SO₄ shifted the corrosion potential to a less noble figure. There is an increase in the current density of the sample containing the chloride solution than without. This shows that chloride increases the passage of current and thereby increases the corrosion rates of samples in the chloride environments.

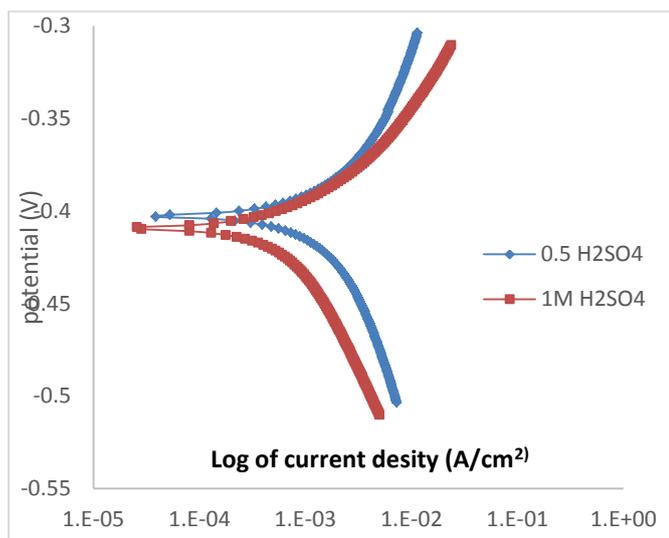


Figure 3. Potentiodynamic curves of carbon steel in 0.5M H₂SO₄ and 1M H₂SO₄

The electrochemical behaviour of low carbon steel in acidic chloride environment was done and the comparative study of the effect of increased concentration of sulphuric acid was presented in Figure 5. The corrosion potential of the sample in solution of 1M sulphuric acid with chloride moved to a more negative potential. The shapes of the curves were the same, higher current density of $1.3 \times 10^{-3} \text{ A/cm}^2$ was observed in the solution, containing higher concentration of sulphuric acid (1M sulphuric acid). While the current density of $8.0 \times 10^{-4} \text{ A/cm}^2$ was observed for the solution of 0.5M sulphuric acid (Figure 5). The corrosion rates of the sample immersed in 1.0M sulphuric acid with 10% sodium chloride is higher than for the sample in 0.5M sulphuric acid with 10% sodium chloride.

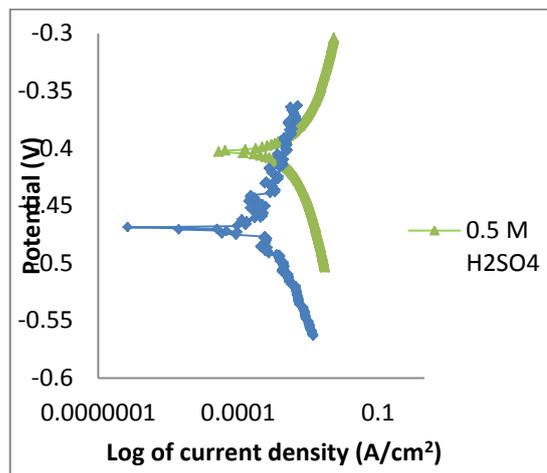


Figure 4. Potentiodynamic curves of carbon steel in 0.5M H₂SO₄ and 0.5M H₂SO₄ + 10% NaCl

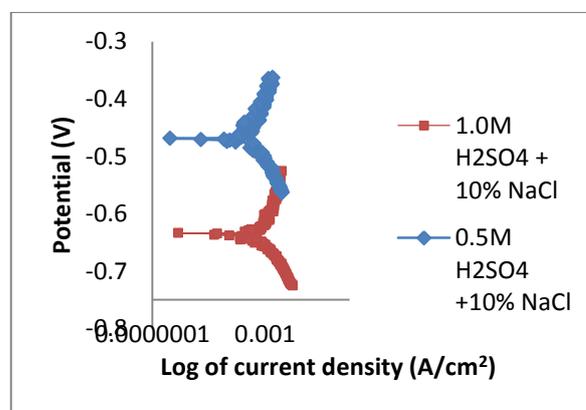


Figure 5. Potentiodynamic curves of carbon steel in 1.0M H₂SO₄ + 10% NaCl and 0.5M H₂SO₄ + 10% NaCl

Figure 6 showed the polarization curves of low carbon steel in 1M sulphuric acid and 1M sulphuric acid with 10% sodium chloride. Like it was previously observed for the samples in 0.5M sulphuric acid and 0.5M sulphuric acid with 10% sodium chloride, the addition of chloride moved the corrosion potential from -409mV to -638mV. The shift of corrosion potential to more negative value was more in solutions of 1M sulphuric acid and with 1M sulphuric acid as compared to the 0.5M sulphuric acid and 0.5M sulphuric acid with 10% sodium chloride -402mV and -475mV respectively.

Table 2. Cumulative weight loss of samples immersed in solution for 60 days

Solution	Cumulative weight loss (mg)
----------	-----------------------------

0.5M H ₂ SO ₄	6.7305
1M H ₂ SO ₄	16.1812
0.5 H ₂ SO ₄ + 10% NaCl	0.8036
1 H ₂ SO ₄ + 10% NaCl	1.4961

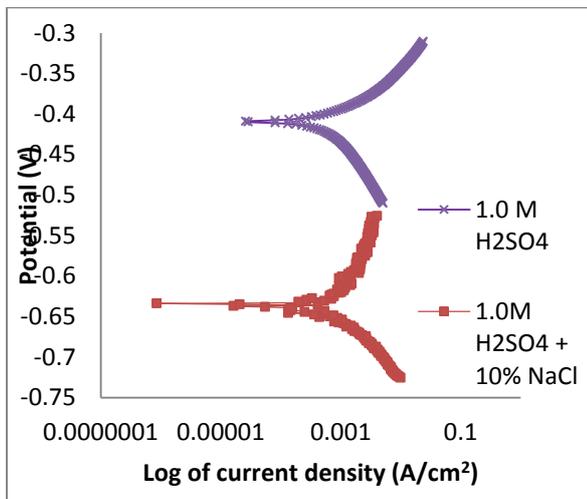


Figure 6. Potentiodynamic curves of carbon steel in 1.0M H₂SO₄ + 10% NaCl and 1.0M H₂SO₄ + 10% NaCl

The chloride addition had an effect over the corrosivity of the environments. This was observed in Figures 4 and 6 where the addition of the chloride to the sulphuric acid moved the corrosion potential to a more negative value, increased the current density and also increased the corrosion rates. It was studied that the addition of chloride to acidic environments increases the corrosion rates, the current density and moved the corrosion potential to a more negative values. Active dissolutions were observed in the samples [5-9].

Passivation was not observed in all the polarization curves obtained. This shows that there is active dissolution of the samples.

The cumulative weight loss for the sample immersed in solutions for 60days was calculated and presented in the Table 2. The weight losses increase by factors of 10 as the concentration increases. Higher amount of weight loss were observed for samples immersed in solutions without chloride as compared to the samples immersed in solutions with chloride.

IV.CONCLUSION

According to the experimental results obtained for carbon steel to 0.5M H₂SO₄, 1M H₂SO₄, 0.5M H₂SO₄ + 10% NaCl and 0.5M H₂SO₄ + 10% NaCl solutions .

- Optical images and scanning electron microstructure of carbon steel revealed ferrite and pearlite phases.
- The corrosion rates increased with increased concentration of the acid and acidic-chloride solutions
- The addition of chloride to the acidic solutions shift the corrosion potential to a more negative values, increased the current density and also increased the corrosion rates

V. ACKNOWLEDGEMENTS

Regional Initiative in Science and Education, New Jersey, USA.

VI. REFERENCES

- [1] H. Hänninen, J. Romu, R. Ilola, J. Tervo and A. Laitinen. 2001. Effects of processing and manufacturing of high nitrogen – containing stainless steels on their mechanical corrosion and wear properties, *Journal of Materials Processing Technology*, 117, 424-430.
- [2] H. D. Solomon and T. M. Devine. Duplex Stainless Steels. *Proceedings of Conference on Duplex Stainless Steels*, Metal Park, 1983, pp. 693-756.
- [3] J.O. Nilsson, P. Kangas, T. Karlsson and A. Wilson. 2000. Mechanical properties, microstructural stability and kinetics of σ phase formation in a 29Cr-6Ni-2Mo-0.38N super duplex stainless steel, *Metallurgical and Materials Transactions A*, 31A, 35-45.
- [4] A.K. Iversen .2006. Stainless steels in bipolar plates – surface resistive properties of corrosion resistant steel grades during current loads", *Corrosion Science*, 48, 1036-1058.
- [5] S.S.M. Tavares, V. Moura, V.C. da Costa, M.L.R. Ferreira and J.M. Pardal . 2009. The Microstructural changes and corrosion resistance of AISI 310S steel exposed to 600-800°C, *Materials Characterization*, 60 (6) 573-578.
- [6] H. Möller, E.T. Boshoff, and H. Froneman The corrosion behaviour of a low carbon steel in natural and synthetic seawaters. The South African Institute

of Mining and Metallurgy, 2006. SA ISSN 0038–223X/3.00 +0.00.

- [7] P.A. Olubambi, J.H. Potgieter and L.A Cornish. 2008. Corrosion behaviour of super ferritic stainless steels cathodically modified with minor additions of ruthenium in sulphuric and hydrochloric acids, *Materials and Design*, 30 (5) 1451-1457.
- [8] O. A.Olaseinde, L. A.Cornish, J.W van der Merwe and P. A. Olubambi, 2011. Electrochemical Behaviour of 2101 DSS with Ruthenium and 316 SS, 18th International Corrosion Congress, Perth, Australia. Paper 450, 2, 1541-1548 ISBN 9781618393630
- [9] O. A. Olaseinde, J.W van der Merwe, L.A Cornish, 2014. Characterization and Corrosion Behaviour of Selected Duplex Stainless Steels in Acidic and Acidic-Chloride Solution, *Advances in Chemical Engineering and Science*, 2014, 4, 89-93. <http://dx.doi.org/10.4236/aces.2014.41012>