International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 6, Volume 2 (June 2015) www.ijirae.com

Stress Corrosion Study of Mild Steel in Acidic Media

M. Dauda, L. S. Kuburi, E. C. Okereke, A. A. Alabi
Department of Mechanical Engineering, Ahmadu Bello University Zaria, Nigeria

Abstract - The research investigated the effect of corrosion rate of mild steel in HCl acid. U-Bend method was used for the study. The coupons were stressed to 1.191 X 10^9 N/m^2 and inserted into the corrosive media for 672 hours. The result shows that the corrosion rates of the stressed mild steel in air (SMA), unstressed mild steel in air (USMA), and stressed mild steel in HCl (SMHCL)) were reduced after 672 hours. Highest corrosion rate of 1.0261mm/yr was observed in SMHCL while lowest corrosion rate of 0.000255mm/yr was recorded in USMA. Generally no cracking observed in all cases but pitting corrosion was observed in SMHCL after 672 hours and stress contributes to reduction in lifespan of mild steel structures.

Keywords: Mild steel; corrosion rate; stress; sea water; pitting corrosion

I. INTRODUCTION

Corrosion is an undesirable process which result may not be limited to the damage it does to the materials or engineering properties. Corrosion of metals applies specifically to chemical or electrochemical attack. The deterioration of plastics and other non-metallic materials which are susceptible to swelling, cracking, softening and so on, is essentially physiochemical rather than electrochemical in nature. Non-metallic materials can either rapidly deteriorate when exposed to a particular environment or at the other extreme, being practically unaffected [11], [3].

Stress corrosion cracking is cracking due to a process involving conjoint corrosion and straining of a metal due to residual or applied stresses. The stress level at which failure occurs is well below the stress required for a mechanical failure in the absence of corrosion. The conditions necessary for stress corrosion are: Suitable environment (appropriate temperature and pH values), tensile stress and susceptible material.

Over the years, many alloy–environment combinations have been discovered that have led to SCC. Practically all alloys used for engineering purposes are subject to SCC. However, all alloys are not susceptible to SCC in all environments [6].

Fig.. 1 Effect of SCC on pipelinehttp (Source: www.met-tech.com)

Many researchers have studied the effects of stress corrosion cracking to engineering materials. Reference [5] the corrosion behavior and mechanism for mild steel in hydrochloric acid solutions was studied by chemical (hydrogen evolution, HE & mass loss, ML) and electrochemical (electrochemical impedance spectroscopy & potentiodynamic polarization) methods at 25^{o}C. The chemical results revealed that mild steel corrodes in HCl solutions with a reaction constant of 0.56 and the corrosion rate increases with the increase in acid concentration. Reference [9], investigated the corrosion behavior of mild steel and AISI 304L SS in presence of dissolved Cu ions under different experimental conditions. The results of immersion tests showed a decrease in the corrosion rate of mild steel with increasing Cu concentration. This is attributed to the deposition of reduced Cu on the steel surface which protected the steel efficiently and caused a decrease in corrosion rate. Reference [10] analysed the effect of corrosion on some mechanical properties of mild steel in sea water medium and he observed that the corrosion rate and mechanical properties (i.e. tensile strength and hardness) decreased with increase in time due to the aggressive ions present in the medium. Reference [7], investigated two examples of stress corrosion cracking (SCC) in refinery equipment is studied to highlight the lessons learned to prevent recurrence of such failures. Caustic stress corrosion cracking was confirmed within the heat affected zone of the carbon steel elbow [8].

II. EXPERIMENTAL PROCEDURE

The research work is to investigate the effect of stress corrosion cracking on mild steel HCl acid by the U-Bend method. The choice of HCl acid was due to serious effects of stress corrosion cracking on ships, pressure vessels and offshore engineering. Mild steel was also considered because of its excellent formability, comparatively low cost, availability and their verse usage in engineering applications [10].

The method adopted for this study was the total immersion method. The initial and final weights of the U- bend samples were recorded. The samples were then immersed in standard prepared HCl acid and sea water [2].The samples were left uncovered and observation made daily as experiment proceeded. After every 7 days, a sample was removed from each media and washed thoroughly and the samples were weighed and recorded. The procedure was done for four times making a total of 672 hrs. The weight loss and corrosion rates were also calculated and recorded.

A. Test Conditions

The experiment was conducted at ambient temperature during the start of the rainy season. The supporting device and container used to hold the solution were plastic materials. These were chosen because they are chemically inert and are neither affected by the solution nor cause contamination to the test solution, and then a white thread was tied to the bolt of each sample to avoid galvanic corrosion [2].
The test specimens were prepared according to equation 1 below [1].

$$\in = \frac{t}{2r} \quad \text{when } t < r \qquad (1)$$

where, t = specimen thickness
r = radius of curve at the point of interest

The strain applied to the U-bend samples used in this experiment was calculated using equation 1 above.
Thickness of specimen (t) = 1.7mm
Radius of bend (r) = 1.5cm = 150mm
Hence the strain ($\in$)on the U-bend specimen = 0.00567
And the corresponding stress was obtained using equation 2 below.

$$E = \frac{stress}{strain} \qquad (2)$$

Where, E is the Young's modulus (210GPa)

$stress = E \times strain$

$= 0.00567 \times 210 \times 10^9$

= 1190700000

= 1.191$\times 10^9\ N/m^2$

Hence for strain value of 0.00567, the stress obtained is approximately 1.2GN/m^2. The strain was kept constant by maintaining the distance between the two legs of the U-bend at 3cm apart using nut and bolt [1]. Figure 2 to 4 below shows the samples used in the experiment.

Fig. 2 Prepared U Bend Sample Used in the Experiment

Fig. 3 Corroded U Bend Sample Used in the Experiment

Fig. 4 Prepared Sample before U Bend

B. Corrosion Rate Calculation

The rate of material removal as a consequence of the chemical action, or the corrosion rate, is an important parameter. This can be expressed as the corrosion penetration rate (CPR), or the thickness loss of material per unit time. It is expressed mathematically as [3].

$$CPR = \frac{KW}{A\rho T} \quad (mm/yr) \qquad (3)$$

Where;
CPR = Corrosion Penetration Rate
W = Weight Loss (mg) = Wi − Wf
Wi = Initial weight of specimen (g)
Wf = Final weight of specimen (g)
ρ = Density of mild steel constant = 7.85 g/cm^3
A = Total surface area of specimen = $52.1 cm^2$
T = Time of exposure of specimen in test solution (hrs)
K = Constant = 87.6

Equation 3 above was used to calculate the corrosion rates of the coupons used in each of the corrosive media tested.

III. RESULTS

Table 1: CORROSION RATES OF MILD STEEL IN CORROSIVE MEDIA FOR 672 HOURS

Exposure Time (hrs)	Corrosion Rate of UMSA (mm/year)	Corrosion Rate of SMA (mm/year)	Corrosion Rate of SMHCL (mm/year)
168	0.000765	0.01594	0.771
336	0.00121	0.007523	1.0261
504	0.0006375	0.00289	0.8513
672	0.000255	0.001944	0.6798

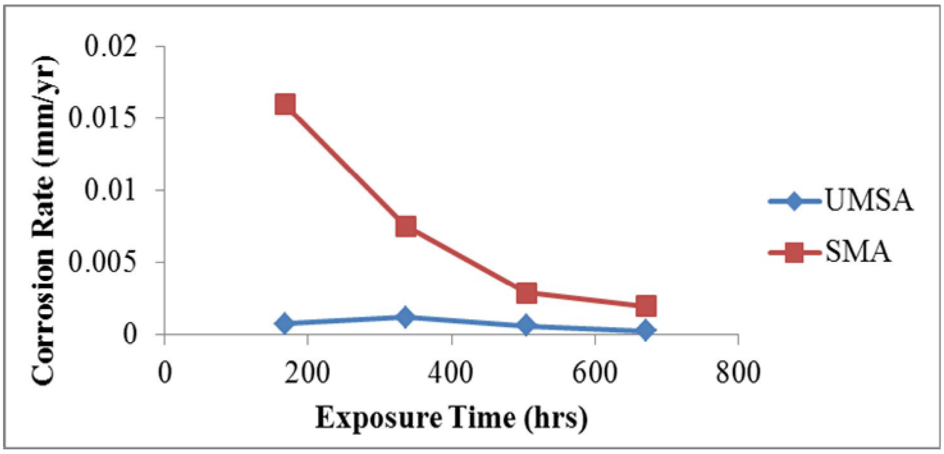

Fig. 5 Effect of Stress on Corrosion Rate of Mild Steel against Exposure Time in Air

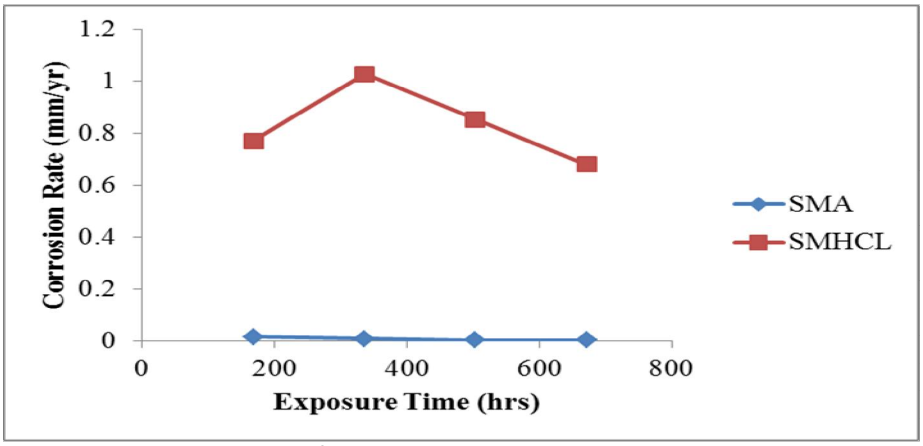

Fig. 6 Corrosion Rates Of Stressed Mild Steel against Exposure Time in Corrosive Media

IV. DISCUSSION

The corrosion of mild steel samples as observed in the experiment appears to be uniform in all the corrosive media with pitting corrosion on the coupon exposed in HCl for 672 hrs. The result in table 1 and figure 5 above shows the effect of stress on the corrosion of mild steel exposed to the natural environment. Corrosion rates of stressed mild steel in air (SMA) and unstressed mild steel in air (UMSA) reduced continuously due to initial layer formed on the surface of the material. The stressed sample appears to be attacked more because the reaction took place faster than the unstressed sample. Table 1 and figure 6 shows the effect of corrosive media on the corrosion of mild steel. The stressed mild steel in HCl acid (SMHCL) has higher corrosion rate than the stressed mild steel in air (SMA). (SMHCL) corroded more than the stressed mild steel in air (SMA) because HCl is more corrosive than air. (SMHCL) in figure 6 shows a slight increase in the first week of the exposure and then reduced drastically because the chemical reaction took place faster than in the other corrosive media. The corrosive agents formed reduced further attack until the surface is further exposed. It is generally observed that stress has influence in the corrosive media investigated.

V. CONCLUSION

i. *The corrosion rate of stressed mild steel in HCl acid is observed to be higher than in air.*
ii. *Strain is observed to be contributing to the degradation and failure of mild steel in corrosive media.*
iii. *It was also concluded that exposure time is an important factor in determining the failure of stressed or unstressed mild steel. This is also a very important factor to consider in shipping, construction and loading underground oil piping.*
iv. *Pitting corrosion was observed on the surface of the sample exposed to HCl for 672 hrs.*
v. *Crack was not observed even in the HCl acid which means mild steel is less susceptible to stress corrosion cracking.*

REFERENCES

[1]. W. H. Ailor, *Handbook on Corrosion Testing and Evaluation*, American Society for Testing and Materials, New York: John Wiley, 1971.
[2]. ASM Handbook, *Corrosion: Materials*, Vol. 13B, 1987.
[3]. W. D. Callister, *Material Science and Engineering: An Introduction*, 4th edition, New York. 2001.
[4]. C. LeRose, The Collapse of the Silver Bridge,' West Virginia Historical Society Quarterly Vol. 6, No 4, 2001.
[5]. A. N. Ehteram and H. A. Aisha, Corrosion Behavior of Mild Steel in Hydrochloric Acid Solutions. Int. J. Electrochem. Sci., 3, 806-818, 2008.
[6]. J. Gao, Experiments to Explore the Mechanisms of Stress Corrosion Cracking,' PhD Thesis, Materials Science Program, Art, Sciences and Engineering, Edmund A. Hajim School of Engineering and Applied Sciences. University of Rochester, New York, 2011.
[7]. R. L. Graham, (2002) Stress Corrosion Cracking: Case Studies in Refinery Equipment the 6th Saudi Engineering Conference, KFUPM, Dhahran, Vol. 5. 17, 2002.
[8]. http://www.met-tech.com/preheater-tube-failure
[9]. M. Mobin and H. Shabnan, Corrosion Behavior of Mild Steel and SS 304L in Presence of Dissolved Copper. Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.12, pp.1113-1130, 2010.
[10]. S. Muhammad, Corrosion Protection with Eco- Friendly Inhibitors, School of Chemical and Materials Engineering,' National University of Sciences and Technology, Journal of Corrosion Protection with Eco- Friendly Inhibitors. Islamabad, Pakistan, 2011.

[11]. R. H. Perry, and D. W. Green, *Perry's Chemical Engineers' Handbook*, 8th Edition, McGraw-Hill, Singapore, 1997.
[12].M. Shaaba, Effect of Corrosion on some Mechanical Properties of Mild Steel in Sea Water Medium,' Unpublished, B.Eng Final Year Project, Department of Mechanical Engineering Ahmadu Bello University, Zaria, Nigeria, 2012.

