

Flow-Induced Corrosion of Aluminum Alloy in Acidic Rain Environment

Olaseinde, Oluwatoyin Adenike

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

Abstract - Flow-induced corrosion test has been carried out on aluminum alloy 6063 in acidic rain environment using a designed test rig. The aluminum alloy was subjected to a simulated flow of acidic rain (pH 2.4) which is dissolution of NO₂ and SO₂ in atmospheric water. Results obtained revealed that the weight loss increased with increasing testing time at a fixed flow rate in both H₂SO₄ and HNO₃ environments. Corrosion rate determined by gravimetric method decreased with increasing testing time.

Keywords: Weight loss, acidic rain, flow-induced corrosion, aluminum alloy.

I. INTRODUCTION

Solar power has continued to expand at a rapid rate, with growth in global capacity averaging almost 55% annually over the past five years. Nigeria is one of such countries making effort to adopt solar energy for power generation. One alloy that is gaining popularity in solar panel construction is Aluminum 6063. There is need, therefore, to study the flow-induced corrosion and erosion-corrosion behavior of the alloy to determine the extent to which acidic rain in some highly industrialized area can affect the use of aluminum alloy 6063 for solar panel construction in Nigeria. Solar energy is used in wide range of industrial, business and residential applications such as electricity generation, water heating, industrial processes, day lighting, heating and cooling. As a consequence of rapid development of the solar power technologies, it is expected that solar systems will provide 12% to 25% of global electricity by 2050 [1] (Abdullah et al., 2010)

Aluminum alloy 6063 find specific applications in solar energy constructions in collector frames, solar reflectors and thermal collectors. Although aluminum alloys are generally resistant to atmospheric corrosion they are still prone to corrosion and flow-induced corrosion [2-4].

Flow-accelerated corrosion is that corrosion reaction assisted by the relative movement of the corrosive fluid and the alloy[5] (Roberge, 2000). Erosion corrosion on the other hand is associated with a flow-induced mechanical (particle, bubble collapse) removal of the protective surface film that results in a subsequent corrosion rate increase via either electrochemical

or chemical processes [5]. The existence of such a phenomenon accelerates the corrosion attack in the metal surface due to the relative motion of a corrosive fluid on the exposed surface [6]

Niu and Cheng [7] investigated the effects of fluid hydrodynamics on aluminum alloy corrosion in ethylene glycol-water solutions by using rotating disc electrode (RDE) technique. It was found that, in the absence of sands, aluminum alloy corrosion is dominated by the oxygen diffusion towards the electrode surface. It was generally found that the total weight-loss of materials in erosion-corrosion media is much higher than those caused by pure corrosion or pure erosion independently.

Several test rig designs have been used by different authors for erosion-corrosion studies. Several authors [4, 8-10] adopted the submerged impinging jet rig to study both flow-induced and erosion-corrosion of several alloys. Rotating cylinder electrode (RCE) was adopted by Miller et al., [11]. Coriolis erosion tester was employed by Das and co-workers [12] while Stack and Abd El Badia [13], Jana and Stack, [14], Rajahram et al., [15] adopted the slurry pot erosion tester. A new rig has however been developed for the purpose of this research. It is the intention of this work to simulate the flow of acidic rain at the angle at which a typical solar panel made of aluminum is tilted, hence the nature of the rig.

II. METHODOLOGY

a) Materials

The sample used for this research is Aluminum alloy 6063 with chemical composition shown in Table 1. The alloy was received as an ingot, it was then melted in an open pit furnace, cast and machined into workable sizes. The sample was grinded with successive grinding paper ranging from grits 240 to 1200, polished with diamond paste of 15 μ m, washed in stream of water and then dried in air prior to examination. The surface morphology was then studied using scanning electron microscopes.

TABLE 1
Chemical composition of Aluminum Alloy 6063

Si	Cu	Mn	Fe	Zn	Mg	Cr	Ti	Al
0.45	0.02	0.04	0.24	0.03	0.5	0.03	0.02	Bal.

b) Test Rig

A test rig was designed for the purpose of this research and subsequently used in the flow-induced corrosion analysis. The design ensures constant corrosive fluid flows manually using the principle of gravity. The corrosion test was carried out using simulated acidic rain media containing 1 M H₂SO₄ and 1 M HNO₃ at pH of 2.4. The medium was allowed to flow against the aluminum alloy coupon placed along the flow path for a period of 30 days. The weight loss result was taken after every 24 hours for 30 days.

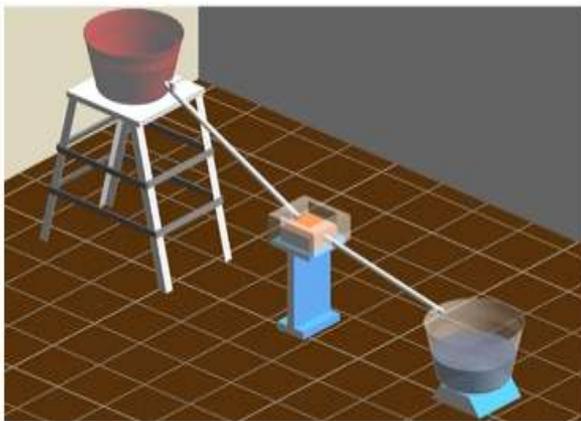


Figure 1: The designed flow-induced corrosion rig

III. RESULTS AND DISCUSSION

a) Surface Morphology of Aluminum 6063 as received

Surface morphology and microstructure of the as-received sample was examined using scanning electron microscopes as shown in Figure 2.

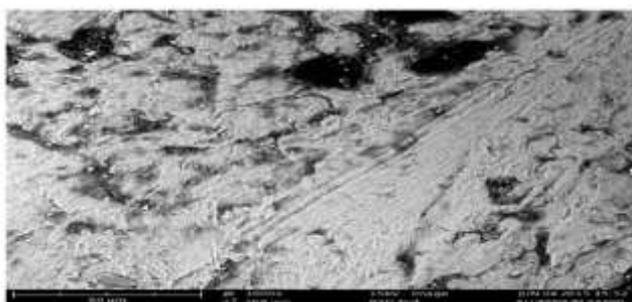


Figure 2: SEM Micrograph of the aluminum alloy 6063 showing α phase and β phases formed at the grain boundaries etched with carpenter 300 series etchant

b) Flow-Induced Corrosion Behaviour of Aluminum Alloy 6063 in HNO₃ and H₂SO₄ Environments

Figure 3 shows the weight loss (g) for the alloy in both media after 30 days while Figure 4 shows the corrosion rate in g/mm²/year. Figure 3 shows that a very pronounced increase in weight loss was recorded within the fifth and seventh days (HNO₃) while a relatively uniform increase in the weight loss was observed between the seventh and fifteenth testing days. There is a sharp rise in the weight loss around seventeenth and the twentieth testing days. An averagely uniform weight reduction was noticed till the thirtieth day. The rate at which the sample corrodes under the influence of flow in HNO₃ is also shown in Figure 4. It is noticed that the corrosion rate reduced with increasing testing time. This can be attributed to the formation of protective film on the surface of the aluminum alloy. This is seen in the weight reduction from day to day as revealed in Figure 3.

There is a relative increase in weight loss with increasing testing time for the alloy in H₂SO₄ as shown in Figure 3. The weight loss increase is steady through the testing time and produced an almost uniform weight loss difference as the exposure time increased. Figure 4 also describes the corrosion rate behavior of the alloy in H₂SO₄ medium. The curve reveals that there is a relatively undulated relationship between the corrosion rate and increasing testing time. A sharp decrease in the corrosion rate is observed within the second and the fourth testing days with the alloy losing weight at a fairly steady state till the sixteenth day of exposure. The undulated curve is thought to be due to the formation and removal of protective films (depassivation and repassivation mechanism) on the surface of the alloy at intervals due to the rate of flow of the corrosive medium.

A comparison of the behavior of the alloy in the two media shows that weight loss is higher and more pronounced in the HNO₃ medium compared to the H₂SO₄ medium. This is thought to be due to the difference in the aggressiveness of the two media under the flow conditions. Although H₂SO₄ is more aggressive acidic medium in static conditions and should effect more corrosion rate on the sample. This does not seem to be so under the influence of the flow as HNO₃ seems to behave more aggressively. However, the aggressiveness of H₂SO₄ can be seen in the first few days as the weight loss in the medium surpasses that of HNO₃.

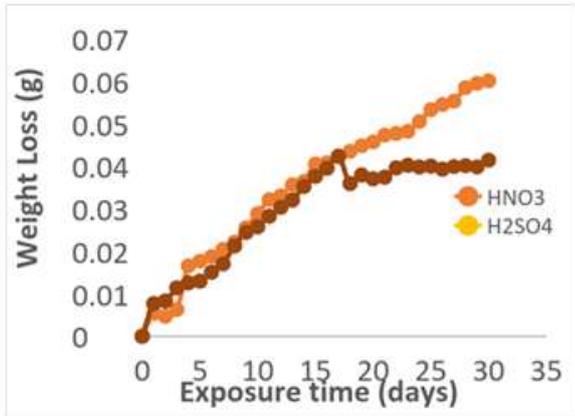


Figure 3: Weight loss against exposure time for both media

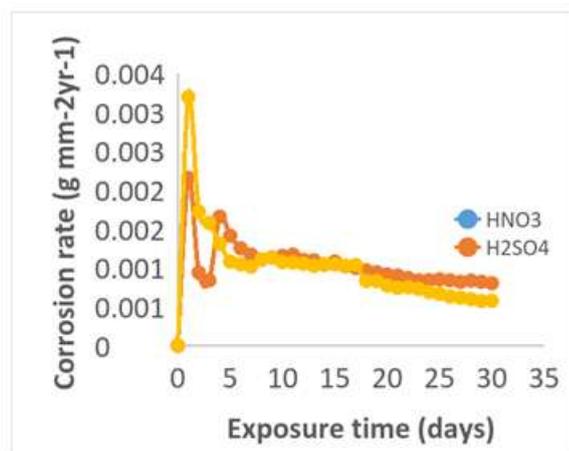


Figure 4: Corrosion rate against exposure time for both media

c) Static Corrosion Behavior of the Alloy

The flow-induced corrosion rate result and that of the Tafel polarization plots were compared for 1 M HNO₃ and 1 M H₂SO₄. For the sample in 1 M HNO₃ and 1 M H₂SO₄ under the flow conditions, it has been shown (Figures 3 and 4) that HNO₃ has a more severe corrosion effect on the alloy. However, contrary to this result, the potentiodynamic test (static conditions) affirms the aggressiveness of H₂SO₄ compared to HNO₃ medium. This is seen in the higher corrosion current exhibited by the alloy in H₂SO₄ environment (Figure 5). It is thought that this disparity between the flow induced and static corrosion behavior may be due to the behavior of the passive films formed on the aluminum alloy. Aluminum alloy reacts in the two media to form passive oxides according to the following equations:

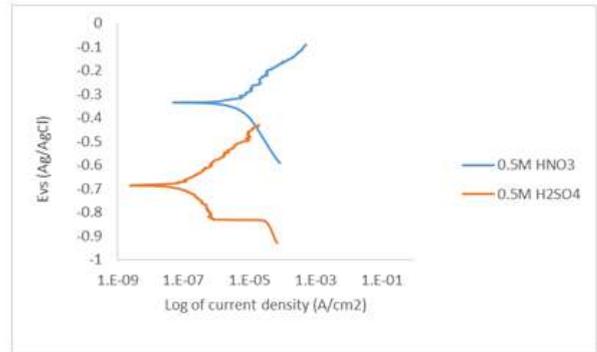
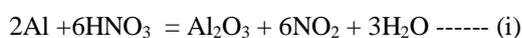


Figure 5: Tafel plots in static conditions for the alloy in 0.5M of acid

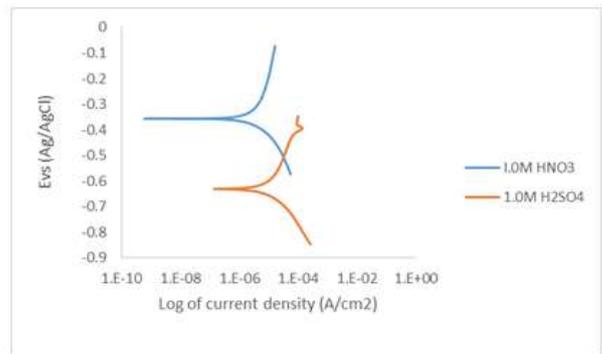


Figure 6: Tafel plots in static conditions for the alloy in 1M of acid

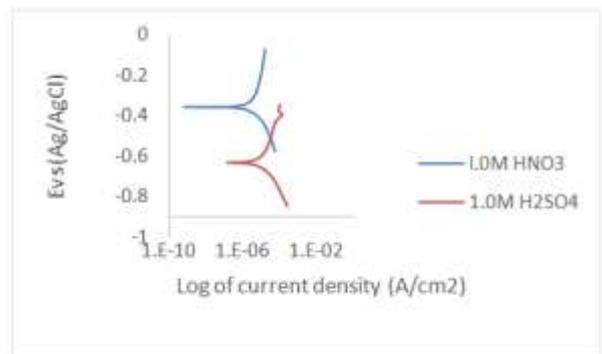


Figure 7: Tafel plots in static conditions for the alloy in 0.5M of acid

The aluminum oxide film formed on the alloy in the HNO₃ does not adhere properly and could be easily eroded under the flow conditions. This is in contrary to the sulphide film formed on the alloy surface in the H₂SO₄ medium with more adherence. This explains why the alloy is more resistant in H₂SO₄ under the flow conditions. More so, the static corrosion test was run for a short period while the flow-accelerated test was run for 30 days. Behaviour of the passive film over a long period of time may be different from the passive film form for a short period of time.

IV. CONCLUSIONS

- The combined effect of corrosion and flow is always more severe than static corrosion in the same medium.
- Mechanism of flow-assisted corrosion of the alloy in the acid rain medium seems to be different from the behaviour in static conditions.
- Flowing acidic rain containing HNO₃ seems to be more aggressive than acidic rain containing H₂SO₄.
- A locally designed flow-induced corrosion rig has been successfully adopted to simulate a flow-assisted corrosion condition.

ACKNOWLEDGEMENT

I acknowledge the contribution of my B.Eng. student Mr.Oyewole T.S (2015/2016) for this study.

REFERENCES

- [1] Abdullah Al Ashraf, Abdullah Al Aftab “Aluminium Alloys in Solar Power - Impact on Renewable Energy to Reduce Global Carbon Footprint,”2010
- [2] M.M. Khan and Gajendra Dixit.“Erosive wear response of SiCp reinforced aluminium based metal matrix composite: Effects of test environments”, *Journal of Mechanical Engineering and Sciences* vol11, No1, pp. 2401-2414, March 2017
- [3] F Djevanroodi, OM Irfan, FA Al-Mufadi,“Erosion-Corrosion Behavior of Al 6066 Aluminum Alloy. *International Journal of Mechanical Engineering (IJME)*,vol3 No1, pp 15–24, 2014.
- [4] M. AAhmed, “Study of Erosion- Corrosion Behavior of Aluminum Metal Matrix Composite,”*Eng. &Tech.Journal*,32(3), pp 406–417, 2014.
- [5] P. Roberge, (2004) Corrosion testing made easy, erosion-corrosion. NACE International, ISBN 1-57590-173-0, pp.1-2. 2004.
- [6] E. A. M., Hussain andM. J., Robinson. “Erosion-corrosion of 2205 duplex stainless steel in flowing seawater containing sand particles”, *Corrosion Sci.* 49, pp. 1737-1744, 2007.
- [7] L., Niu and Y.F., Cheng, “Erosion-corrosion of aluminum alloy in ethylene glycol-water solutions in the absence and presence of sand particles”, *Corrosion Eng. Sci. Tech.* 44, pp. 389-393, 2009
- [8] H., Meng, X., Hu, A.,Neville, “A systematic erosion-corrosion study of two stainless steels in marine conditions via experimental design”, *Wear* 263, pp. 355-362, 2007.
- [9] V. A. D.,Souza and A. Neville, “Aspects of microstructure on the synergy and overall material loss of thermal spray coatings in erosion-corrosion environments”, *Wear* 263, pp. 339-346, 2007
- [10]S, Aribo, R. Barker, X. Hu, and A. Neville, Erosion–corrosion behaviour of lean duplex stainless steels in 3.5% NaCl solution. *Wear*; vol. 302: 1602-1608, 2013.
- [11]W. S.Miller, I. Zhuang, J. Bottema, A.J. Wittebrood, P.A. De Smet, A. Haszlerand A. Vierregge, "Recent development in aluminium alloys for the automotive industry". *Mater Sci Eng*, A 280, pp. 37-492000
- [12]S. Das, D. P. Mondal, , O. PModi., and Dasgupta, R., “Influence of experimental parameters on the erosive-corrosive wear of Al-SiC particle composite”, *Wear* 231 (2), pp. 195-205.1999
- [13]M.M Stack M.M., and T.M. Abd-El Badia, "Mapping erosion-corrosion of WC/Co-Cr based composite coatings: particle velocity and applied potential effects", *Surface and Coatings Tech*, 201, pp. 1335-1347. 2006.
- [14]D. Jana and M.M Stack, “Modeling impact angle effects on erosion-corrosion of pure metals: construction of materials performance maps”, *Wear* 259,pp. 243-255, 2005
- [15]S.S.Rajahram,T.J.Harvey, and R.J.K., Wood “Erosion-corrosion resistance of engineering materials in various test conditions”, *Wear* 267, pp. 244-254, 2009.

Citation of this article:

Olaseinde, Oluwatoyin Adenike, “Flow-Induced Corrosion of Aluminum Alloy in Acidic Rain Environment” Published in *International Research Journal of Innovations in Engineering and Technology (IRJIET)*, Volume 3, Issue 4, pp 1-4, April 2019.
