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Effects of Manganese Addition on the Corrosion Behaviour of Aluminium Alloys in Different Media

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ABSTRACT— In *this paper, we report on the effect of manganese addition on the corrosion behavior of aluminium alloys in some different media (H_2SO_4, hydrogen tetraoxosulphate (vi) and HCl, hydrochloric acid). Aluminum alloys containing 1.5%, 2.5% and 3.5% manganese were cast into rods; which were later machined and subsequently cut into coupons averaging a total surface area of 13.33cm^3. The samples were weighed and immersed into beakers containing 0.25M, 0.5M, and 1.0M of H_2SO_4 and HCl solutions respectively. The set up were allowed to stand for 48 hours with the coupons removed every 12 hours for weight loss measurements using the normal procedures. The results show that the corrosion rate decreased with increasing exposure time in the respective media. In particular, at a concentration of 0.5 M H_2SO_4, a step decrease was observed, indicating the possibility of the precipitation of the intermetallic compounds and the amount of intermetallic precipitation increase arising from the manganese addition.*

Keywords— Alloy, aluminum, corrosion, passivation.

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1. INTRODUCTION

Aluminium and its alloys are generally characterized by a high ductility, relatively low density with high electrical and thermal conductivities, and highly resistant to corrosion in different media including water, atmosphere, and brine. According to literature [1-4]. These qualities makes aluminium alloys to be one of the most widely used non-ferrous alloys in different applications including construction materials, automotive components, container and packaging, aerospace industries, electrical industries, marine, aviation, and even in the fabrication of cooking utensils. Corrosion impairs usefulness of materials as a result of the deterioration of its physical properties or appearance. The degradation behavior of corrosion on metals causes adverse consequence when ignored by metal users and fabricators. Corrosion is a natural phenomenon and almost all metals corrode or is expected to corrode or deteriorate with time. The driving force that makes metals corrode is a consequence of their temporary existence in the metallic refined state, or more stable mineral state. The main factor that causes corrosion of metals is the consequence of their temporal existence in the state of higher energy level due to the absorbed energy during extraction from their ores. This eventually makes them quite unstable and certain environments enhance their combination chemically with elements in their environment to form compounds and return to their natural stable ore state with accompanying reduction in the free energy of the system [4]. It is quite clear that corrosion resistant alloys is of little use if parts are designed without the utilization of some basic knowledge of corrosion. It will also be the cheapest and the best if potential corrosion cases can be removed completely at the design stage instead of dealing with symptoms of bad design afterwards. In view of the aforementioned numerous applications of aluminium in a variety of corrosive environments, a variety of approaches have been investigated with the aim of increasing the corrosion resistance of aluminium alloys in different media [5-10]. In the literature [4], it has been reported that Al-Mg based alloys are widely used in aerospace applications because of some interesting properties which includes lightweight and high mechanical features.

It is generally understood that when aluminium surface is exposed to the atmosphere, owing to its strong affinity for oxygen, it forms a passivating oxide (Al_2O_3) which protects the metal from corrosion in many environments. Despite these excellent properties, the stability of these passivating layer is only feasible in aqueous media with pH in the range 4.0 and 8.5 hence in some aggressive media, the passivating layer can be destroyed, and corrosive attack can take place. Al-Mg alloys have been reported as a promising alloy system for investigation due to their low electrode potential, and high current capacity to be used as galvanic anode [6]. In the literature, there are several reports on the studies of corrosion behaviour of Al-alloys in many environments, including saline environment [11], NaCl [12-14], H_2SO_4 [15-16] or in alkaline environments [17]. However aluminum is generally anodic to the rest of other alloys in most normally used media and hence, tend to suffer from localized type of corrosion when it is alloyed since different kind of cathodic precipitates are likely to be formed. Although it has been established [18-22] that aluminum and its oxide films can be protected from corrosion attack by a variety of inhibitors, it has also been reported that some of these inhibitor constitutes serious environmental and health hazards [23-27].

In the present investigation, the major aim of this research work is to investigate the effects of manganese addition on the corrosion behaviour of Al-Mn alloys in different acidic media under varying concentrations with the view to establish the optimized conditions needed for use of these alloys in different applications.

2. EXPERIMENTAL

The materials used for the experiment were pure Aluminium (Al), Manganese (Mn), Tetraoxosulphate (vi) acid (H_2SO_4), Hydrochloric acid (HCl), Distilled Water, Acetone, Electronic Digital Analytic Weighing Balance (Model X21-001KERN 770-15, 15402301 made in Germany), Beakers, Nylon thread, Paper tape, meter rule, Retort stands, Crucible furnace, Ladle, Tong, Metal mould, measuring tape, hack saw, sand paper, obtained from local suppliers. Each of the alloy were suspended in the beakers containing the various concentrations of H_2SO_4 and HCl and the set up allowed to stand for 48 hours. A set of the coupons was withdrawn every 12 hours, washed with the distilled water, cleaned with acetone and dried in an open air. With the digital analytic weighing balance, the final weight of the test samples was determined.

3. RESULTS AND DISCUSSION

Fig. 1 depicts the corrosion rate profile against the exposure time for the alloys in the 0.25M H_2SO_4 environments. The corrosion rate decreased with increase in exposure time. The corrosion penetration rate (CPR) as the consequence of the physiochemical interactions mostly expressed in mm/year is an important corrosion monitoring index that gives reliable information on the degree of corrosion in a given material. The mathematical computation of CPR is based on the formula;

$$CPR = \frac{K\Delta W}{\rho At} \quad (1)$$

In equation 1, ΔW is the weight loss after the exposure time t, ρ is the density, A is the exposed specimen area and K is a constant with its magnitude depending on the system of units used. However, this estimation is suitable only for uniform corrosion and becomes somewhat erratic with local instability [4, 28].

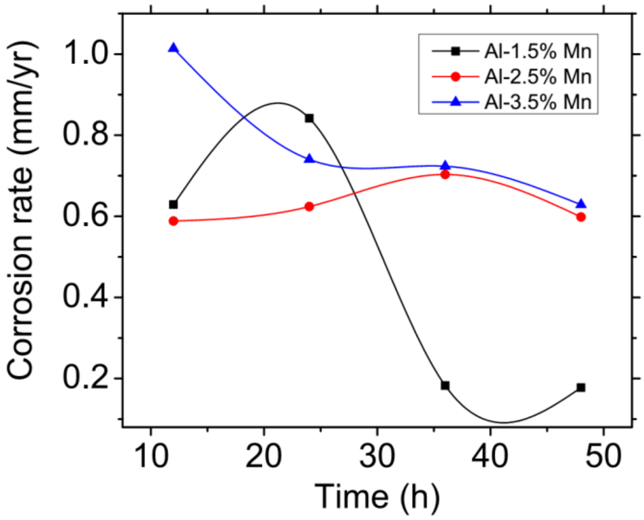

Figure 1: Plots of corrosion rate against time (0.25M H_2SO_4)

As shown on Fig. 1, the corrosion rate decreased steadily with time for the 3.5% Al-Mn binary, while an increase in the corrosion rate was observed for the 2.5% Al-Mn binary to up to an exposure time of 35 hours and then decreased. However, at 1.5%, the increase in the corrosion rate was exponential for exposure time ≤ 25 hours, and then decreased otherwise. This behaviour was attributed to the precipitation of the intermetallic compounds and the amount of intermetallic precipitation increase arising from the manganese addition. Similar behaviour have been reported by other research groups in the literature [6, 29].

Fig. 2 gives the variation of the corrosion rate against time at a concentration of 0.5M H_2SO_4 environment. The corrosion rate were typically low for the Al-Mn binary of 1.5%, higher for 3.5% and also exhibited a sharp decreasing trend with increase in exposure time.

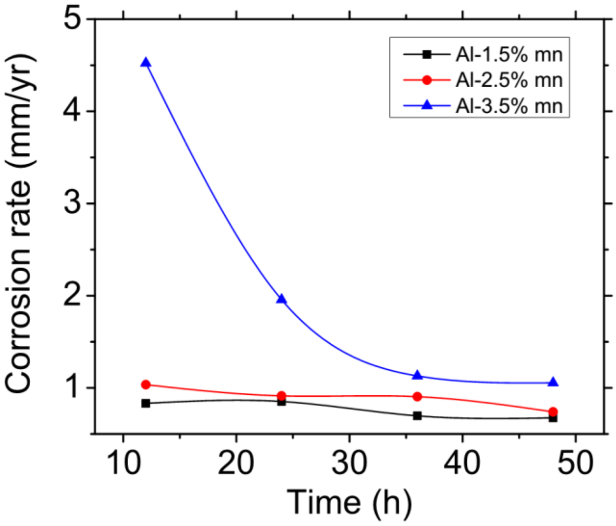

Figure 2: Plots of corrosion rate against time (0.5M H_2SO_4)

This observation as indicated in Fig 2, is in line with the reports of other authors [6]. Vuelvas et al [6] , noted that an increase of mangenese in Al-Mg alloys significantly increases the strength of the alloy without reasonable impact on formability, and also observed that an increase in the Mg contents leads to increase in the presence of Al_3Mg2 and Mg_5Al_8 particles in the alloy. The authors argue that these are anodic as compared to the surrounding aluminum matrix, and represents the places where initial corrosion attack takes place in the alloy.

Fig. 3 show the change of the corrosion rate with time at the highest concentration investigated in the study for the H_2SO_4 environment. The results (Fig. 3), indicate that a sharp decrease of the corrosion rate with exposure time was observed compared to the former. The decrease was relatively uniform, and indicate that formation of the protective passivating oxide (Al_2O_3) were more rapid at the highest concentration of the H_2SO_4 environment.

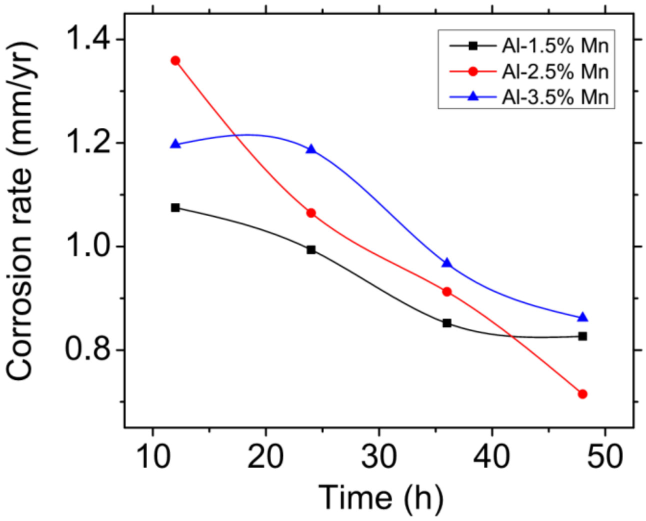

Figure 3: Plots of corrosion rate against time (1.0M H_2SO_4)

Fig. 4 show the variation of the corrosion rate against exposure time in the HCl environment at a concentration of 0.25M. The behaviour exhibited by the plot of the 3.5% Al-Mn binary in Fig. 4, is close to that indicated in Fig. 1 for the 1.5% Al-Mn binary. However, a relatively uniform decreasing trend was observed for other case as shown on Fig. 4. Similar behaviour has been reported in the literature [11-12]. For instance, Vrsalovic et al [30], reported that the susceptibility towards localized type of corrosion for Al-2.5Mg alloy is higher than that for Al-0.8Mg alloy in 3.5M NaCl solution while the reports of Baldwin and co-workers [31] showed that for a saline environment, an increase of the Mg content from 2-20% in an Al-Mg alloy, resulted to a corresponding increase of the corrosion current density.

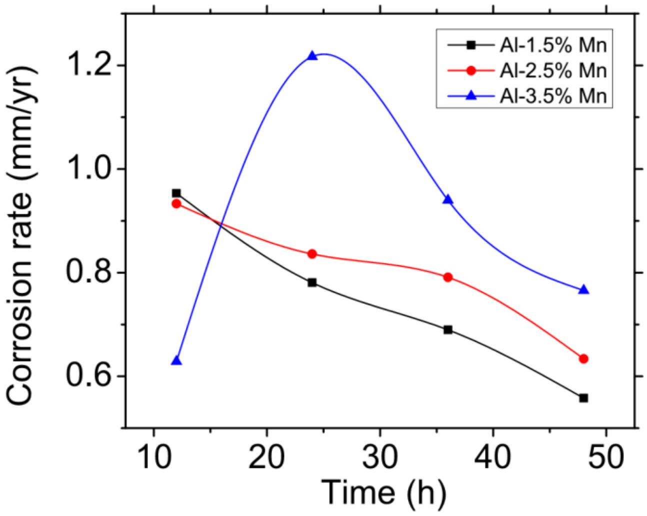

Figure 4: Plots of corrosion rate against time (0.25M HCl)

Fig. 5 show the corrosion rate against time at a concentration of 0.50 M HCl while Fig. 6 is for the highest concentration in the HCl media. A critical scrutiny of both graphs (Figs. 5 and 6) indicate that a relatively uniform decreasing trend were exhibited in all cases, except Al-1.5% Mn in 0.50 M HCl which show an increase in the corrosion rate for exposure time ≤ 25 hours and then decreased thereafter. The decreasing trend observed herein is explained on the basis of the fact that with increasing manganese content, the amount of these precipitates increases, thus limiting the corrosion rate.

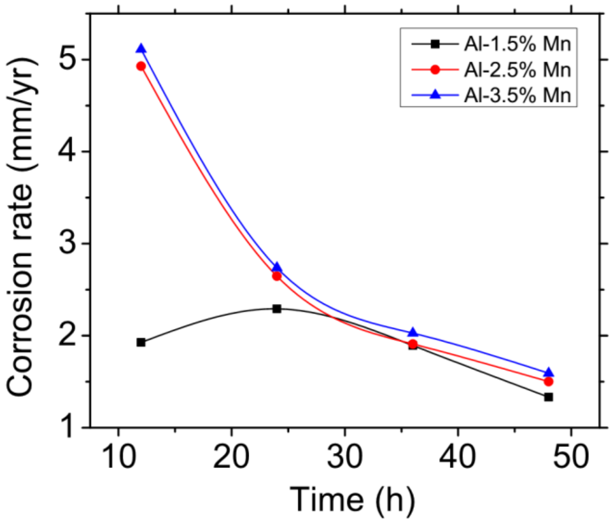

Figure 5: Plots of corrosion rate against time (0.50M HCl)

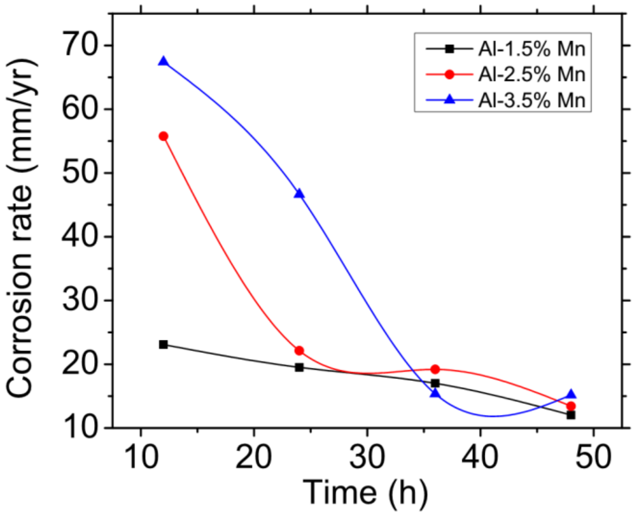

Figure 6: Plots of corrosion rate against time (1.0M HCl)

4. CONCLUSION

In this study, the effect of manganese addition on the corrosion behaviour of Al-Mn binary alloy in different acidic environments (hydrogen tetraoxosulphate (vi) and hydrochloric acid) at different concentrations is investigated. The results show a general trend of decreasing corrosion rate with the exposure time in all cases. In particular the decrease was more relatively sharp at the higher concentration independent of the acidic media. The increase in the corrosion rate at exposure time ≤ 25 hours at Al-1.5% Mn in 0.50 M HCl and at Al-1.5% Mn in 0.25 M H_2SO_4 respectively, was attributed to the initial corrosion attack due to the formation of Al_3Mg_2 and Mg_5Al_8 particles in the alloy while the decreasing trend was due to the adsorption of the formed oxide layer on the metal surface, thus resulting in the decrease of the corrosion rate.

5. ACKNOWLEDGEMENT

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