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Corrosion Properties of Advanced Materials like Aluminium 6013 Metal Matrix Composites Reinforced with Red Mud Particulates in Acid Chloride Medium

K.N. CHANDRASHEKARA[1,*], B. NARASIMHA MURTHY[2], K. SREENIVASA[1] and P.V. KRUPAKARA[3]

[1]Department of Chemistry, S.J.C. Institute of Technology, Chikballapur-562 101, India
[2]Department of Chemistry, C.M.R. Institute of Technology, Bangalore-560 037, India
[3]Department of Chemistry, Adarsha Institute of Technology, Bangalore-562 110, India

*Corresponding author: E-mail: chandrasjcit2014@gmail.com

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This paper deals with the corrosion characterization of red mud particulate aluminium 6013 alloy metal matrix composites for automobile application owing to their low cost and equivalent or superior performance. Presently, little research is done to study the environmental behaviour of these alloys. Aluminium 6013 alloys have a relative high strength compared with zinc alloys with a low melting point. Hence it was used as the matrix alloy in the present research. Red mud being a ceramic remains inert and is hardly affected by the acidic medium. Red mud particles of size 50-80 μ are used as reinforcement. Experiments were conducted to determine the corrosion rate of the samples in acid chloride medium by static weight loss method. Metal matrix composites are prepared according to ASTM standards by liquid melt metallurgy technique using vortex method. Composites containing 2, 4 and 6 % by weight of red mud and unreinforced matrix were tested using different concentrations of hydrochloric acid at room temperature. Specimens are taken in the form of 20 mm × 20 mm cylinders. Specimens are subjected to scanning electron microscopy to get the microstructures. Corrosion rates of all samples were calculated using the formula 534 W/DAT mpy. The results were computerized and simulation curves were obtained. The composite was found to be more corrosive resistant than matrix alloy. In each test the corrosion resistance of both alloy composites was found to decrease with the exposure time. The decrease in the corrosion rates of composites when compared to that of matrix alloy is due to the physical barrier created by red mud particles.

Keywords: Advanced material, Aluminium 6013, Red mud, Corrosion.

INTRODUCTION

Metal matrix composites are special class of materials, with ceramic or fiber reinforcements incorporated in metal or alloy matrices. Aluminium alloys based metal matrix composites (AMMCs) reinforced with ceramics, fibers and whiskers are commonly used in aircraft, marine and fabrication industries. They provide significantly enhanced properties over conventional monolithic materials, such as higher strength, high stiffness, weight savings, high fatigue strength and abrasion resistance, as well as their excellent performance at high temperatures make alumina reinforced metal matrix composites ideal for applications in aerospace, power utility, automotive and military sectors [1]. Metal matrix composites reinforced with short ceramic particulates show improved corrosion resistance than the matrix metal or alloy. The research work done so far mainly focused on manufacturing of metal matrix composites and studies on mechanical behaviour of the same. Corrosion behaviour of metal matrix composites containing aluminium 6013 as matrix has not been studied so far. Corrosion studies of metal matrix composites is important because the application of the same in different fields like aircraft, automobile and marine industries. The parts are exposed to different media like acid, salt and alkali. Hence there may be corrosion attack on metals and alloys used for the manufacture of the parts. If ceramic particulates are there in the parts in the form of reinforcement then corrosion attack will reduce and the parts will lost long. Hence the study of the corrosion behaviour is important for metal matrix composites.

EXPERIMENTAL

The matrix used for the present research work is aluminium 6013 alloy which is effectively finds application in many fields. It is available commercially. It is procured in the form of ingots. Its composition is confirmed by the supplier. Its composition is given in Table-1.

Reinforcement: The reinforcement used is red mud particulates. Red mud is a waste obtained after the removal of aluminium from its ore. Its EDS analysis reveals the presence of oxides of iron, silicon, titanium, zirconium, *etc*. It behaves

TABLE-1
COMPOSITION OF ALUMINIUM 6013 ALLOY

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.6	0.5	1.1	0.2	0.8	0.1	0.25	0.1	Bal

as a ceramic material. It is obtained from HINDALCO, Renikoot District, UP state, India. 50-80 μ size particulates of red mud are used in this study.

Corrosion testing medium: The medium used for the testing of the corrosion behaviour of the metal matrix composites made up of aluminium 6013 and red mud composites are three different concentrations of hydrochloric acid. 0.025, 0.05 and 0.1 M solutions of hydrochloric acid are used as corrosion mediums.

Composite preparation: The metal matrix composites containing aluminium 6013 as matrix and red mud particulates as reinforcement are manufactured by liquid melt metallurgy technique using vortex method adopted by Krupakara [2]. Before the manufacture of the composites the reinforcement particulates must be pre heated. Hence the red mud particulates are pre heated in a muffle furnace at 400 °C and maintained at that temperature till it is added. Pre heating is necessary in order to improve the wetting between the matrix and reinforcement. The matrix alloy procured in the form of ingots are subjected to degreasing and pickling in order to remove oil, grease and corrosion products present on them. Then the ingots are washed with double distilled water and in ethyl alcohol or acetone and air dried. The ingots are introduced in to graphite crucible fitted in to a bottom pouring furnace. The bottom pouring furnace used for the preparation of the metal matrix composites basically contains an electrically heated 3 phase resistance coil thus the furnace is fitted with three pairs of 14 gauge kanthal, which are A_1 grade heating coils. The temperature range of the furnace is 1200 °C with a temperature control accuracy of ± 1 °C. It is fitted with seven segmented light emitting diode, to read out temperature and fitted with a partially integrated differential digital temperature controller. The heating capacity of the furnace is 500 °C/h. The furnace is fitted with a graphite crucible at its center with opening provision at bottom, which enables to pour the melt directly into mould. A stainless steel impeller or stirrer coated with aluminite was used to stir the molten metal and created a vortex. The aluminite coating is necessary in order to prevent the migration of ferrous ions from the stirrer material to the melt and hence to prevent contamination of the melt. The impeller used for stirring was of centrifugal type, three blades welded at 45 and 120 °C apart. The stirrer was rotated at a speed of 500 rpm and a vortex was 60 % of the height of the molten metal from the surface of the melt. The above parameters were obtained from the optimization studies as explained above. Then the reinforcement was red mud particulate which was preheated in the furnace was introduced into the vortex at the rate of 120 g/min. Composite melt could be degassed using degassing tablet, which containing hexachloroethane. Thus during degassing process hydrogen absorbed was removed from the melt. Degassing was done to reduce blow holes and minimize porosity in the casting. Then the melt is poured directly in to the pre heated cast iron moulds kept at the bottom. Cylindrical castings can be taken out for alloy and composites in the same way. Composites containing 2, 4 and 6 weight percent of red mud were casted in the method explained above. Alloy is also casted in the same way for comparison.

Specimen preparation: For the study of static weight loss method the cylindrical rod castings of alloy and composites are subjected to machining using lathe. Cylindrical specimens of 20 mm diameter and 20 mm length are fabricated. Before the conduction of the static weight loss corrosion test the specimens are subjected to microstructure studies to find out the distribution of the particulates.

Corrosion test: The static weight loss corrosion test was conducted according to ASTM standard G1. The experiment is conducted at room temperature around 25 °C using static weight loss method. The experiments were conducted in 0.025, 0.05 and 0.1 molar solutions of acid chloride like hydrochloric acid. The specimens are subjected to standard metallographic techniques before taking them for weight loss corrosion test. The specimens were weighed accurately. The specimens are immersed in 200 cm^3 corrodent solution. In the beginning tests are conducted in 0.025 molar solution of the acid. Then the experiment is repeated in 0.05 and 0.1 molar solution of hydrochloric acid.

After the corrosion test, the specimens were immersed in acetone solution for 10 min and gently cleaned with a soft brush to remove adhered scales. After drying thoroughly, the specimens were reweighed to determine the percentage weight loss, weight loss per area of exposure. Corrosion rates were computed using the equation:

$$\text{Corrosion rate} = 534\ W/DAT\ \text{mpy}$$

where W is the weight loss (g), D is density of the specimen (g/cc), A is the area of the specimen (cm^2) and T is the exposure time in hours. Corrosion rate is expressed in mils per year (mpy) [3].

RESULTS AND DISCUSSION

Figs. 1-3 show the results of the corrosion tests conducted in 0.025, 0.05 and 0.1 M solutions of hydrochloric acid solution. The graphs are drawn by taking the corrosion rate on y axis and time of exposure in hours on x axis.

Corrosion behaviour: The graphs presented in Figs. 1-3 show that for each composite as well as for unreinforced aluminium 6013 alloys, the corrosion rate is found to decrease during the corrosion tests. The decrease in corrosion rate is

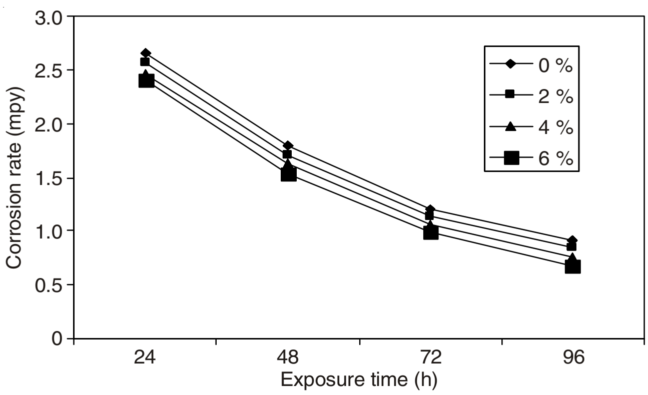

Fig. 1. Static weight loss corrosion test in 0.025 M hydrochloric acid solution

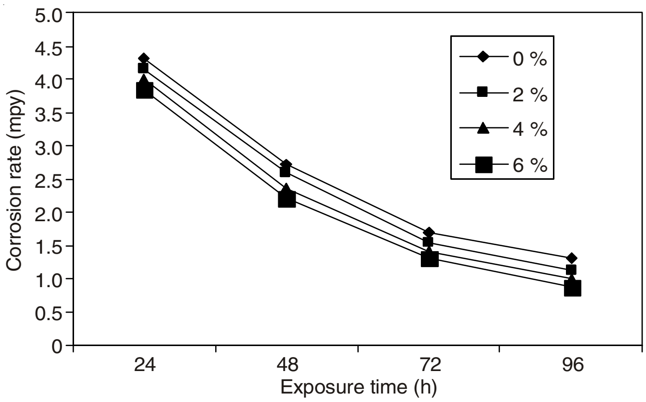

Fig. 2. Static weight loss corrosion test in 0.05 M hydrochloric acid solution

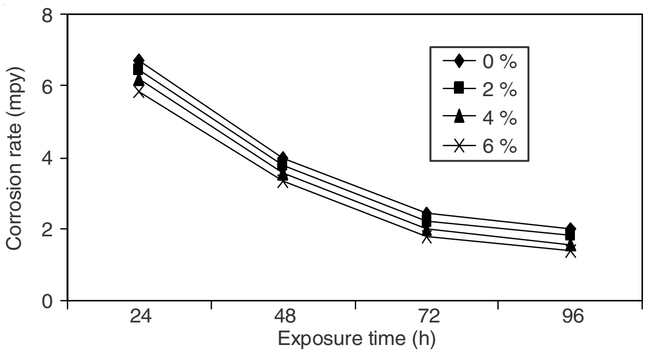

Fig. 3. Static weight loss corrosion test in 0.1 M hydrochloric acid solution

due to passivity of the matrix alloy. Visual inspection of the specimens after the corrosion tests revealed the presence of a black film, the composition of black film is $Al(OH)_3$, which covered the surface. Thus $Al(OH)_3$ acts as the passive layer. Since the passive layer acts as a barrier between the fresh metal surface and the corrosive media, it avoids the direct contact between the specimen and the corrosive media, thus further dissolution of the metal alloy would not takes place. Corrosion rate depends on the stability, nature and thickness of the passive layer. After a specific duration, the film may be stable but it contains porosities and micro cracks through which solution may come in contact with the specimens surface and hence oxygen drifting might take place through these defects in the passive layer, Such passive layer reduces the contact between the specimens surface and corrosion media hence it leads to drastic reduction in corrosion rate.

According to Trzaskoma [4] if specimen is exposed to saturated media at very high temperature and for a long time, the corrosive chemical reaction would stopped due to exhaust of conducting media.

Effect of reinforcement: From Figs. 1-3, it is apparent that for all the tested specimens, there is a decrease in corrosion rate with increase in reinforcement content. The corrosion rate in the unreinforced matrix alloy is higher than those in the ceramic reinforced composites, because in alloys there is a direct contact between the alloy surface and the corrosive media, thus alloy dissolution increases, as alloy does not exhibit much resistance to the action of acid medium.

Reinforcements like red mud, when it is added to the alloy matrix, it binds the matrix surface and thus it avoids the direct contact of the alloy matrix surface with the acid media and red mud being ceramic, remains inert and unaffected during the tests. Thus the reinforcement helps in protecting the metal from corrosion.

Ohsaki *et al*. [5] obtained similar results in glass fiber reinforced ZA-27 alloy composites and also reported that the corrosion resistance increases with increase in reinforcement.

Jianxin *et al.* [6] in their work on corrosion characteristics of aluminium based particulate reinforced metal matrix composites, state that the rate of corrosion is affected to a significant extent by the presence of SiC particulates in aluminium, thus the particulates definitely play a secondary role by acting as physical barrier.

Effect of concentration of the hydrochloric acid: It is observed that as the concentration of hydrochloric acid solution increased, corrosion rate decreased. The corrosion loss increases monotonically with increase in the concentration of hydrochloric acid solution for both the red mud particulate reinforced composite as well as cast aluminium 6013 alloy. The red mud particulate reinforced composite exhibited lesser corrosion loss than that of as cast aluminium 6013 alloy. It is well known that the chemical reaction depends on the concentration ofsolution, area of the reaction surfaces, *etc*. The intensity of the corrosion attack increased with increase in concentration. On the same line some researchers [7-10] attributed this trend to the intensity of chloride concentration of the solution, which is mainly responsible for corrosion

Conclusions

• The aluminium 6013/red mud particulate reinforced composites containing 2, 4 and 6 weight percentages of red mud are successfully casted using liquid melt metallurgy technique using vortex method.

• Aluminium 6013/red mud particulate metal matrix composites were found to corrode in 0.025, 0.05 and 0.1 M hydrochloric acid solutions.

• The corrosion rate of metal matrix composites in all concentrations of hydrochloric acid solutions decrease withtime, probably because of the formation of stable oxide layer over the specimens

• The rate of corrosion of both the alloy and composite decreased with increase in time duration.

• Use of metal matrix composites containing aluminium 6013 alloy as matrix and red mud particulate as reinforcement is more preferred than aluminium 6013 alloy.

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