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Corrosion Characterization of Al6061/Red Mud Metal Matrix Composites

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Abstract

Metal matrix composites are heterogeneous systems containing matrix and reinforcement. Their physical and mechanical properties can be tailored according to requirement. They are used in automobile, aircraft and marine industries because of their increased corrosion resistance. In this paper weight loss corrosion test, open circuit potential test and potentiostat test are conducted on AL6061/ Red Mud metal matrix composites in different concentrated neutral chloride solutions like sodium chloride solutions. Composites are prepared by liquid melt metallurgy technique using vortex method. Composites containing 2, 4 and 6 percent of red mud are prepared according to ASTM standards. Specimens are machined and made ready by standard metallographic methods. Weight loss corrosion studies, open circuit potential studies and potentiostat studies, are carried out in 0.035, 0.35 and 3.5% solutions of sodium chloride. The corrosion rate decreases with increase in the exposure time for all specimens in all corrodents in all the methods of testing. Corrosion rate also decreases with the increase in reinforcement content of the composites. Hence the composites can be used for the manufacture of the equipments used in marine environment so that they lost long.

Keywords: AL6061/ Red Mud metal, corrosion characterization, liquid metallurgy technique, metal matrix composites.

Introduction

Metal matrix composites (MMCs) reinforced with ceramic particulates, whiskers, have received increasing attention due to their potential high fracture toughness and strength [1-5]. Particle reinforced aluminium MMCs find potential applications in several thermal environments, especially in the automobile engine parts, such as drive shafts, cylinders, pistons, and brake rotors [6], and in space

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applications. With the exception of noble metals, no metal and alloy is stable in air at room temperature, tending to form oxides. Most of the metals in the solid or liquid state are morphologically unstable in air at any temperature. An investigation relating to the temperature profiles of the piston area in a diesel engine has shown that the temperature can reach as high as 200- 600 ºC in certain regions of the piston [7]. As the piston and cylinder areas are exposed to high temperature environment, the MMCs used here should have sufficient stability as well as good mechanical and chemical strength (oxidation). Oxidation occurring at grain boundaries in alloys and at the interface between particle and matrix in MMCs usually increases intergranular fracture, resulting in premature failure and severe brittleness [8-10]. Therefore, in high-temperature applications, it is essential to have a thorough understanding of the oxidation behaviour of the aluminium MMCs.

Experimental Procedure

Material selection

In the present study, liquid metallurgy technique is adopted and Al6061, which exhibits excellent casting properties and reasonable strength, used as the base alloy with good strength, being suitable for mass production of lightweight metal castings. The chemical composition of the Al6061 alloy is given in Table I.

Table 1. Chemical composition of Al6061 alloy.

Mg	Si	Fe	Cu	Ti	Pb	Zn	Mn	Sn	Ni	Al
0.8-1.5	10-12	1	0.7-1.5	0.2	0.1	0.5	0.5	0.1	1.5	82.1-85.6

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 as a ceramic material. It is obtained from HINDALCO, Renikoot district, UP. 50-80 µm size particulates of red mud are used in this study.
The testing corrodent medium selected is 0.035, 0.35 and 3.5% solutions of sodium chloride.

Composites preparation

The liquid metallurgy route using vortex technique [11-12] is employed to prepare the composites. The weight percentage of red mud used was 2-6 weight percentages in 2% steps. Matrix was also casted in the same way for comparison.

Specimen preparation

For weight loss corrosion test the composites along with matrix were cut into cylindrical shaped specimens of dimension 18 cm x 18 cm, and for open circuit potential and potentiostat tests specimens of 20 mm x 10 mm x 1mm size were machined. Dimensions of all specimens were noted down using vernier gauge.

Corrosion test

The corrosion tests were conducted at room temperature using the conventional weight loss method. Weighed specimens were immersed in the corrodents and taken out at 24, 48, 72, and 96 h. Weight loss was calculated and converted into corrosion rate and expressed in mils penetration per year (mpy) [13].

Corrosion rate is calculated using the following formula

$$\text{Corrosion rate in mpy} = 534W/DAT \tag{1}$$

where W is the weight loss in grams, D is the density of the specimen (gm/cc), A is the area of the specimen (inch^2), and T is the exposure time in hours.

For open circuit potential test the specimen was coupled with a calomel electrode and connected to a multi meter, then dipped in corrodent solutions and the potential developed was noted down every hour.

For potentiostat test the equipment used is a potentiostat-Galvanostat (model CL95) in connection with a function generator and graphic plotter. These devices are interfaced with a personal computer in order to simulate the results obtained. Corrosion rate in mpy is directly obtained in the computer.

Results and discussion

Microscopy

Microstructures of as cast matrix, 2, 4 and 6% red mud reinforced composites are shown in Fig. 1 to 4, respectively. The polished specimens of the both mentioned above are etched with Keller's reagent and microstructures are taken. The microstructures of the composites demonstrate uniform distribution of the reinforcement with good bonding between matrix alloy and reinforcement.

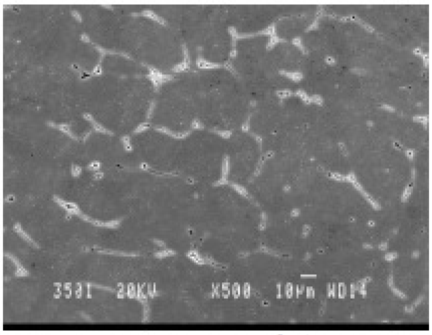

Figure 1. Microstructure of the matrix.

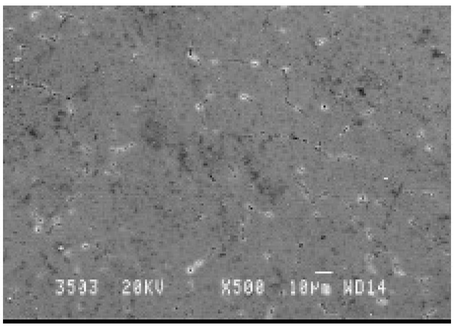

Figure 2. Microstructure of 2% composite.

Fig. 5 to 7 give the corrosion rate of composites by conventional weight loss method and Fig. 8 to 10 show the simulation curves for open circuit potential with different percentages of Red mud in MMCs and matrix in different concentrated solutions of sodium chloride. Fig. 11 to 13 are the simulation curves for potentiostatic studies of the MMCs in comparison with matrix.

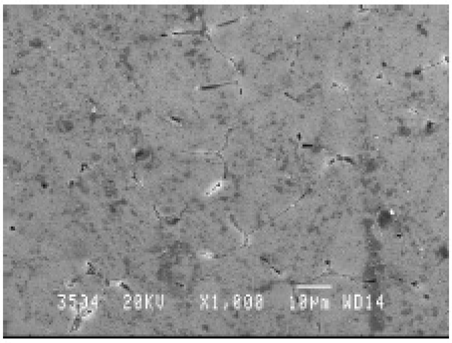

Figure 3. Microstructure of 4% composite.

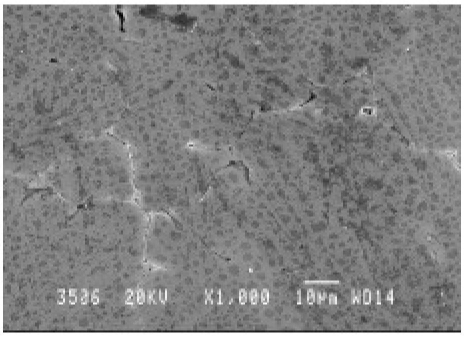

Figure 4. Microstructure of 6% composite.

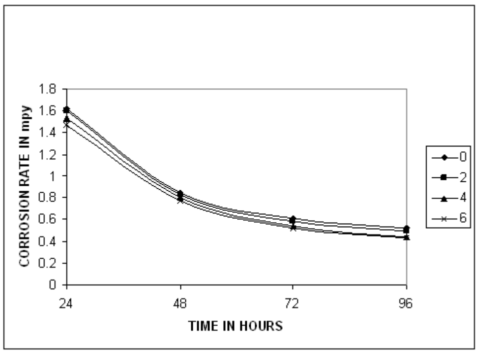

Figure 5. Weight loss corrosion in 0.035% sodium chloride solution.

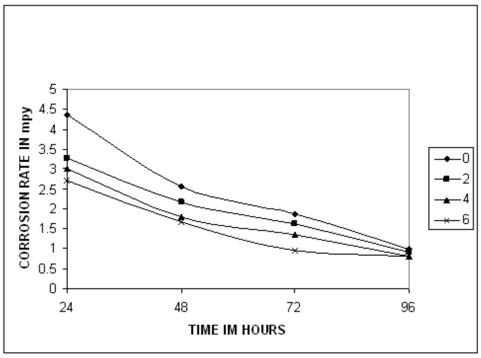

Figure 6. Weight loss corrosion in 0.35% sodium chloride solution.

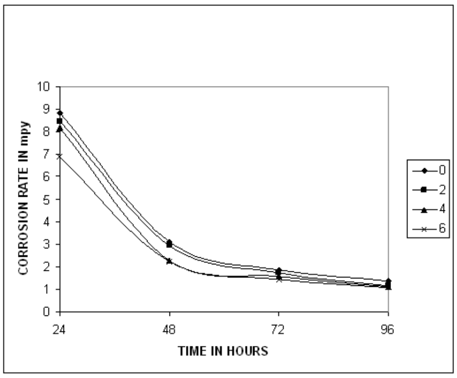

Figure 7. Weight loss corrosion in 3.5% in sodium chloride solution.

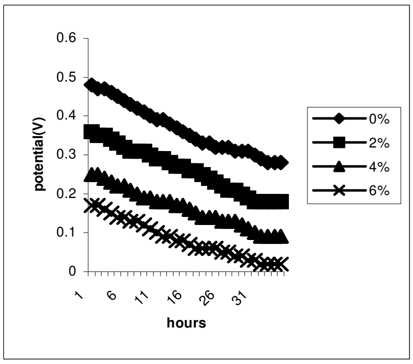

Figure 8. Open circuit potential test in 0.035% sodium chloride solution.

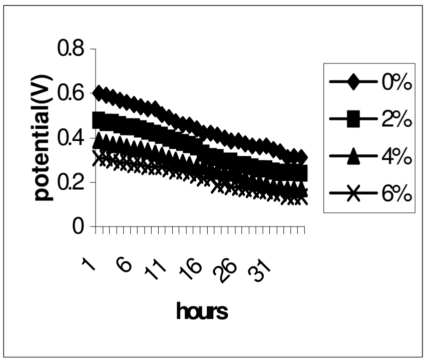

Figure 9. Open circuit potential test in 0.35% in sodium chloride solution.

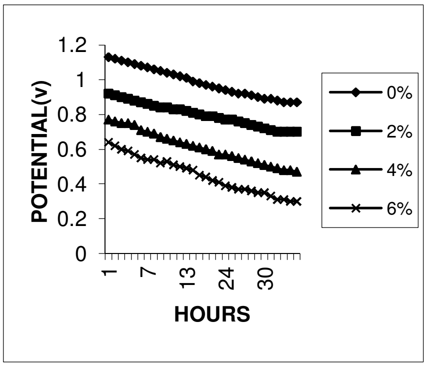

Figure 10. Open circuit potential test in 3.5% sodium chloride solution.

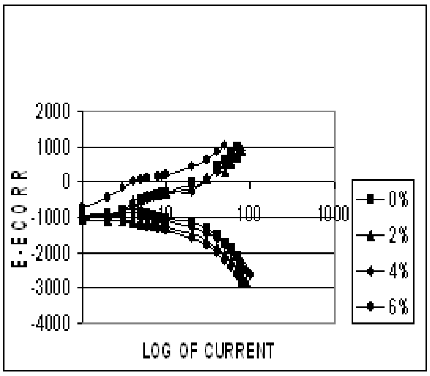

Figure 11. Potentiostat test in 0.035% in sodium chloride solution.

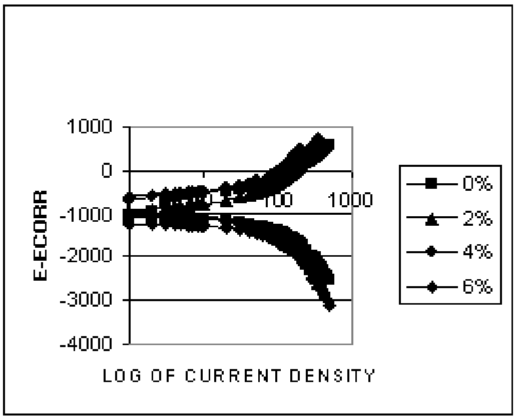

Figure 12. Potentiostat test in 0.35% in sodium chloride solution.

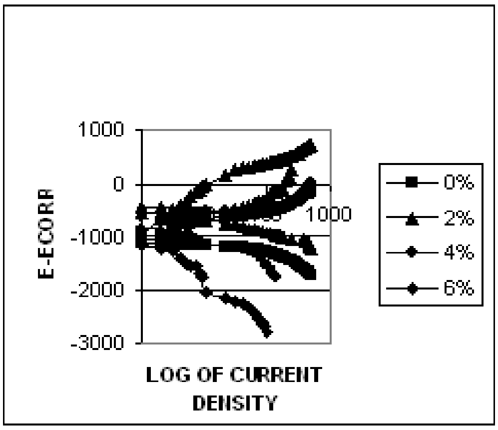

Figure 13. Potentiostat test in 3.5% in sodium chloride solution.

Effect of exposure time

In weight loss corrosion tests (Fig. 5-7) it is observed that MMCs and matrix exhibit a decrease in corrosion rate with increase in test duration in all concentrations of sodium chloride solutions. It is clear from graphs that the corrosion resistances of the composites are higher when compared to that of matrix in all media. The same trend is also observed in open circuit potential tests (Fig. 8-10), where the potential developed for MMCs and matrix go on decreasing with exposure time and become constant after thirty hours of exposure. The potentials experienced by MMCs are less when compared to that of matrix. In both tests there will be a black deposit development on the specimens. The phenomenon of gradually decreasing corrosion rate indicates a possible passivation of the matrix alloy. De Salazar et al. [14] explained that the protective black film consists of hydrogen hydroxy chloride film, which retards the forward reaction. Castle et al. [15] pointed out that the black film consists of aluminium hydroxide compound. This layer protects further corrosion in acid media. But the exact chemical nature of such protective film is still not established.

Corrosion morphology

Fig. 14-17 are the SEM micrographs of the matrix, 2, 4 and 6 % composites.

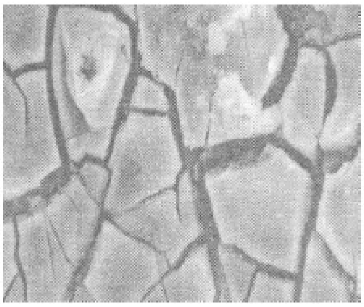

Figure 14. Microstructure of the corroded matrix.

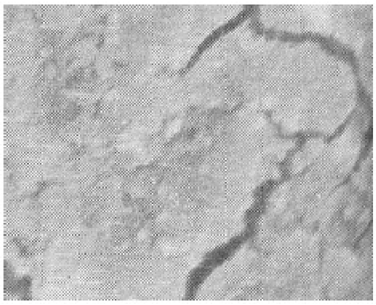

Figure 15. Microstructure of the corroded 2% composite.

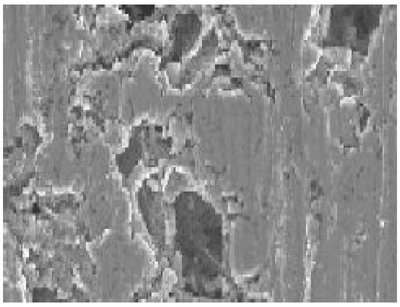

Figure 16. Microstructure of the corroded 4% composite.

Figure 17. Microstructure of the corroded 6% composite.

Virtual examination of the specimens after the corrosion experiment showed few deep pits, flakes and cracks formed on the unreinforced matrix alloy and the cracks are perpendicular to the axis of the matrix specimen. Whereas wide spread of the superficial pitting was observed, a few of no cracks were seen on the surface of the reinforced composites.

The formation of pits and cracks on the surfaces of the composites decreases with increase in the content of the reinforcement in the composite, which is a clear indication of the decrease in corrosion.

Effect of red mud content

From Fig. 5-7, it can be clearly observed that for MMCs, the corrosion rate decreases monotonically with increase in red mud content. In the present case, the corrosion rate of the composites as well as the matrix alloy is predominantly due to the formation of pits and cracks on the surface. In the case of the base alloy, the severity of the base used induces crack formation on the surface, which eventually leads to the formation of pits, thereby causing the loss of material. The weight loss in the case of un-reinforced alloy is higher than in the case of the composites. Same explanation can also be adopted to the open circuit potential test.

Potentiostat test results in different concentrations of sodium chloride are shown in Fig. 11-13 and the corrosion rates are given in Table 2. For all specimens irrespective of percentage of red mud reinforcement the corrosion rate increased with increase in normality of NaCl solution. Ceramic reinforcement particles act as insulator and remain inert in the acidic medium during the test. Hence the corrosion rate decreases with increase in red mud content in MMCs, which may decrease the area of exposure of the alloy with increase in the reinforcement. Less exposure of the MMCs area to aggressive chloride environments in corrosion testing led to lesser pitting as well as corrosion than that of the matrix alloy. Reinforcements in the MMCs decrease the corrosion density, which further decreases with additional reinforcement [16-17]. The pits on the matrix alloy were more when compared with those of MMCs. This may be due to the exposure of less matrix alloy surface in MMCs than matrix alloy, by the addition of reinforcement.

Table 2. Corrosion rate for different concentrations of sodium chloride solutions for matrix alloy and its composites.

Percentage reinforcement →	0	2	4	6
Conc. Of NaCl ↓	Corrosion rate in 10^4mpy			
0.035 %	1.3289	0.985	0.7502	0.073
0.35%	1.8004	1.8004	1.7361	1.5218
3.5%	3.6009	3.6009	3.2365	2.3577

From Table 2 it can be clearly seen that the ceramic reinforcement particles act as insulator and remain inert in the acidic medium during the test. Hence the corrosion rate decreases with increase in red mud content in MMCs, which may decrease the area of exposure of alloy with increase in the reinforcement. Less exposure of the MMCs area to aggressive chloride environments in corrosion testing led to lesser pitting as well as corrosion than that of the matrix alloy.

Conclusions

Al 6061 based MMCs reinforced with 2, 4 to 6% of red muds were successfully produced by liquid melt metallurgical technique.

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

The potential developed by both the alloy and composite decreased with time duration.

Normality of NaCl plays a significant role in the corrosion of MMCs. Corrosion rate of the alloy and MMCs increased with increase in the concentration of NaCl solutions. The cathodic polarization curves were function of the normality of NaCl and reinforcement concentration with hydrogen reduction increasing with increase in reinforcement.

The corrosion rate of the composites was lower than that of the corresponding matrix alloy.

The corrosion by weight loss of the composite decreased with increase in the weight percentage of the reinforcement.

The use of MMCs in bearing applications in marine environment is more suitable than the matrix alloy.

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