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Corrosion Behaviour of Al 7075/Al_2O_3/Graphite Hybrid Composite in 3.5% Sodium Chloride Solution

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Abstract- **Metal matrix composites (MMCs) are engineering combinations of two or more materials of which the base material being a metal or its alloy, where tailored properties are achieved by systematic combination of different constituents. Out of the different categories of composite materials, particle reinforced composites are more important because of their isotropic properties and low cost. These materials have a lot of potential to be used in marine, automobile, aircraft, mining and mineral processing industries also, on account of their excellent characteristics like thermal conductivity, wear resistance and corrosion resistance. In order to use these materials in such industries, they are required to withstand high corrosive environments. Thus, there is a need to study the corrosion behaviors of AMCs reinforced with particulate reinforcement. In this investigation, an attempt has been made to develop Al7075/Al_2O_3/Graphite particulate metal matrix composites through stir casting technique using metallic molds and to study the corrosion behaviour. Preheated particles were added to matrix as reinforcement. Corrosion tests were conducted by using weight loss method, Potentiodynamic Polarization method and Electrochemical Impedance Spectroscopy method where 3.5% NaCl solution was used as corrodent. The corrosion rate of metal matrix composites was lower than that of matrix material Al7075 under the corrosive atmosphere.**

Keywords: MMC, Stir Casting, Corrosion Rate, weight loss, Potentiodynamic Polarization method, EIS method

I.INTRODUCTION

Metal matrix composites (MMCs) are gaining considerable importance for their use in a variety of structural applications, which can cover a wide range, starting from components in high temperature gas turbines to wear resistant parts of various complex designs[1,2]. These materials maintain good strength at high temperature, good structural rigidity, dimensional stability and light weight [3-5]. These properties of MMCs enhance their use in automobile engine parts such as drive shafts, cylinders, pistons and brake rotors, which work particularly at high temperature and pressure environments [6,7].

Ceramic particle reinforced Al matrix composites are emerging out as potential materials to replace conventional alloys/metals. MMCs used at high temperature should have good mechanical properties and resistance to chemical degradation in air and acidic environment. For high temperature applications, it is essential to have a thorough understanding of the corrosion behavior of the aluminum composites [8-10].

Most research on alumina-reinforced MMCs has focused on their manufacturing and mechanical properties [11-15]. Relatively little research has been conducted on their corrosion behaviour, and therefore, corrosion mechanisms are not well understood. Conflicting data and interpretations exist regarding fundamental issues, such as corrosion initiation sites and the role of alumina in corrosion susceptibility [16-19].

B. BOBIC et al. [20] studied the Corrosion of Metal-Matrix Composites with Aluminium Alloy Substrate and concluded that the addition of the reinforcement particles could significantly alter the corrosion behaviour of the above materials. The presence of the reinforcing fibres and particles and the processing associated with aluminium MMCs fabrication could cause accelerated corrosion of the metal matrix compared to corrosion of the unreinforced matrix alloy.

H.M. Zakaria [21] studied the Microstructural and corrosion behavior of Al/SiC metal matrix composites and concluded that at room temperature, the Al/SiC composites exhibited better corrosion resistance than the pure Al matrix in 3.5 wt.% NaCl aqueous solution.

Michael OluwatosinBodunrin et al. [22] studied the Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. They have reviewed the different combination of reinforcing materials used in the processing of hybrid aluminium matrix composites and how it affects the mechanical, corrosion and wear performance of the materials.

Zaki Ahmad et al [23] studied the Corrosion Behavior of Aluminium Metal Matrix Composite and concluded that mechanical and corrosion behaviour of fiber, particulate, or whisker reinforced composites were strongly dependent upon the micro-structural parameters, size, shape, orientation and volume fraction of the reinforcement. K. K. Alaneme et al [24] studied the Corrosion Behavior of Alumina Reinforced Aluminium (6063) Metal Matrix Composites and utilized mass loss and corrosion rate measurements as criteria for evaluating the corrosion behaviour of the composites. It was observed that Al (6063)/Al_2O_3 composites exhibited excellent corrosion resistance in NaCl medium than in the NaOH and H_2SO_4 media. The unreinforced alloy exhibited slightly superior corrosion resistance than the composites in NaCl and NaOH media but the composites had better corrosion resistance in H_2SO_4 medium.

The objectives of the present study were to investigate the corrosion behaviour of Al 7075 alloy reinforced with varying percentage of Al_2O_3 and fixed percentage of graphite in 3.5% NaCl Solution as corrodent. The comparison of performance between the MMC and its monolithic matrix alloy provided evidence that the MMC exhibited inferior corrosion resistance.

II.MATERIALS:

Al7075 was selected as matrix material due to its excellent casting properties, strength, formability, and heat treatable properties. Table 1 show the chemical composition of Al7075 matrix material which was analysed by optical emission spectrometer (OES).

Alumina and Graphite particles sizes of around 20-30 μm and purity of approx 98% were used as reinforcement material in Al7075 matrix material.

Table.1.Chemical Composition of Al 7075 (wt%)

Zn	Cu	Mg	Si	Fe
5.8	1.5	2.4	0.09	0.36
Mn	Cr	Ti	Al	
0.07	0.21	0.05	89.52	

III.EXPERIMENTAL PROCEDURE

A stir casting setup consists of an electric resistance Furnace and a stirrer assembly was used to synthesize the composite. The stirrer assembly consists of a graphite stirrer, which was connected to a variable speed electric motor with range of 800 to 900 rpm by means of a steel shaft. The stirrer was made by cutting and shaping a graphite block to desired shape and size manually. The stirrer consisted of four blades at an angle of 90° apart. Graphite crucible of 1.5 Kg capacity was placed inside the furnace.

Approximately 1 Kg of alloy in solid form (circular rod) was melted at 800°C in the resistance furnace. Preheating of reinforcement (Graphite and Alumina at 500°C) was done for 2 hour to remove moisture, gases and other organic contaminants from the surface of the particulates which will improve the wettability between matrix and the reinforcement material. Once the material is in full liquid condition 1% Mg is added into the melt for increasing the wettability. After that 0.3% Hexachloro ethane (C_2Cl_6) is added for the degassing purpose. The stirrer was then lowered vertically up to 3 cm from the bottom of the crucible (total height of the melt was 9 cm).

The speed of the stirrer was gradually raised to 800 rpm and the preheated reinforced particles were added with a spoon at the rate of 10- 20g/min into the melt through a steel pipe and funnel. The speed controller maintained a constant speed of the stirrer, as the stirrer speed got reduced by 50-60 rpm due to the increase in viscosity of the melt when particulates were added into the melt. During addition of the particle the furnace temperature is maintained at 750-800°C. After the addition of reinforcement, stirring was continued for approx. 10 minutes for proper mixing of prepared particles in the matrix. The melt was kept in the crucible for approximate half minute in static condition and then it was poured in the metallic mould.

IV.CORROSION TEST

The electrodes used for corrosion studies were cut from the cast product having dimensions 10 mm x 10mm x 10 mm (L x b x t). They were polished using 100grit Silicon Carbide paper followed by 220, 400, 600 and 1200 grades of emery paper, degreased with acetone and rinsed with deionised water. The electrochemical measurements were performed using a potentiostat/frequency response analyzer (CH instruments) and a flat cell. A 3.5% NaCl solution was used as the electrolyte. Approx. 1 cm^2 of the sample was exposed to the electrolyte solution.

A Platinum rod and Ag/AgCl served as the counter and reference electrodes respectively. All experiments were performed at room temperature. Potentiodynamic polarization measurements were made at a potential scan rate of 20 mV/min. The corrosion potential (Ecorr) and corrosion current density (icorr) were determined using the CH field machine. Electrochemical Impedance test was also performed on the same apparatus by using AC current and varying its frequency from 0.1Hz to 100000Hz and keeping the potential at 5mV.

The corrosion rate CR (from the mass loss) was calculated using the following equation by weight loss method .

$$CR = \frac{K \times W}{A \times D \times T}$$

where CR is the corrosion rate (mm/year), K is a constant (8.766×10^4), T is the time of exposure (h) to the nearest 0.01 h, A is the area (cm^2), W is the weight loss in the nearest 1 mg and D is the density of the material (g/cm^3).

V.RESULTS AND DISCUSSION

The electrochemical measurements were performed using a potentiostat/frequency response analyzer (CH instruments). The test system is a 3-electrode system, the sample was the working electrode, and the reference electrode was a saturate Ag/AgCl electrode and a platinum plate serves as the counter electrode. The corrosion medium was 3.5wt% NaCl neutral solution, prepared by analytical sodium chloride and distilled water. Fig.1 show the samples before and after the corrosion respectively. One surface of the sample was exposed to electrolyte i.e. 3.5% NaCl Solution and other surfaces was covered with waterproof m-seal followed by electric tape.

A.Weight Loss Method: Samples of Al 7075 and different reinforcement samples of hybrid composite were dipped in 3.5% NaCl Solution for 4 weeks. Weight of samples was measured using chemical balance before dipping into solution and every week weight loss of the samples were examined. According to loss in weight, corrosion rate were calculated every weak according to the formula whose graphical representation has been shown in Figure 2.

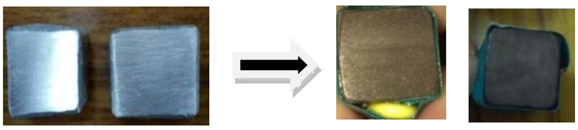

Fig.1.Surface before and after corrosion (Presence of a black film covering the surface after corrosion)

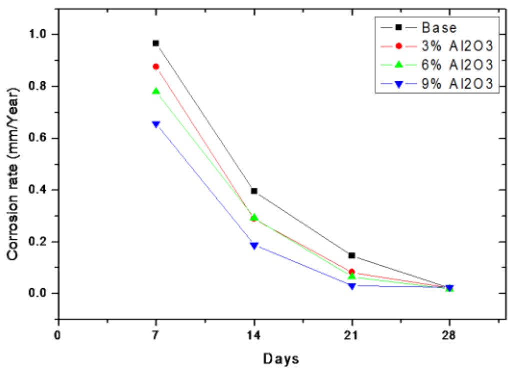

Figure.2.Corrosion rate of Al7075 and Al7075/Al_2O_3/Graphite Hybrid Composite

B.Potentiodynamic Polarization Test: The polarization curve of base matrix and hybrid composites obtained in 3.5% sodium chloride solution has been shown in Fig.3. The corrosion current density (Icorr) and corrosion rate was calculated using Tafel extrapolation method which has been shown in Fig.4 and Fig.5 respectively.

$$\text{Corrosion rate (mil/year)} = \frac{(I_{corr}/A) \times 0.129 \times \text{equivalent weight}}{\text{Density}}$$

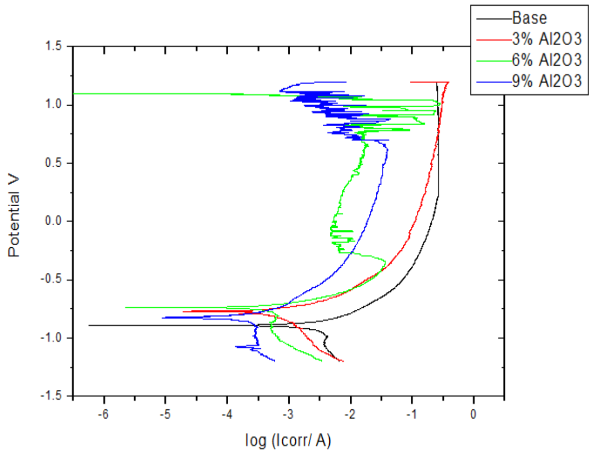

Fig.3. Polarization curves of Base metal and different composition of Hybrid MMC

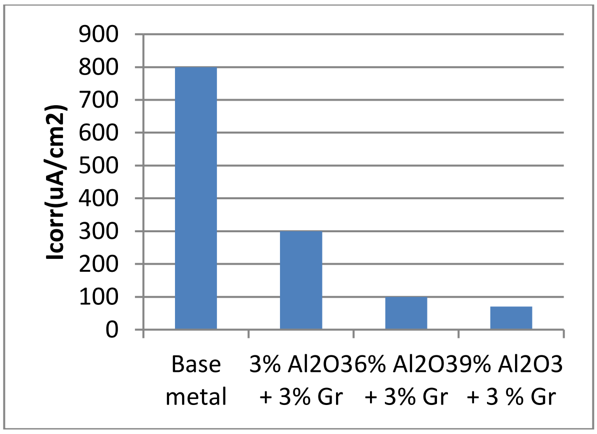

Fig.4.Corrosion current density for base metal and different composition of Hybrid MMC.

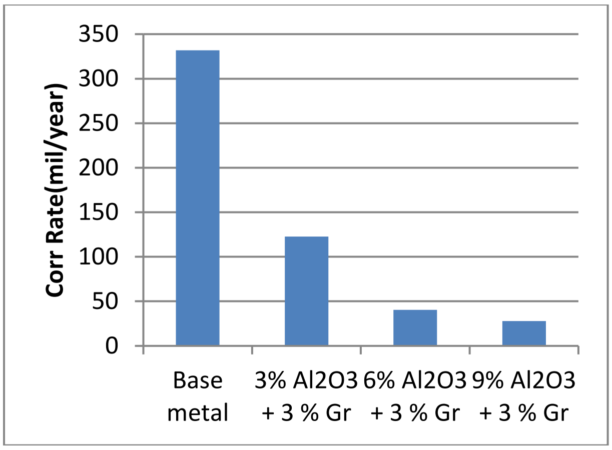

Fig.5.Corrosion rate for base metal and different composition of Hybrid MMC.

From Fig.3 it is observed that the corrosion rate and the potential decreases in the beginning with increase in test duration and remains constant towards the end due to passivation. It is clear from the figure that the resistance of the composite to corrosion increases as the exposure time increases.

The phenomenon of gradually decreasing corrosion rate and potential indicates the possible passivation of the matrix alloy. Visual inspection of the specimens after the tests revealed the presence of a black film covering the surface and that might have retarded the corrosion. In case of base alloy the strength of the media used induces crack formation on the surface, which eventually leads to the formation of pits, thereby causing the loss of material.

It is clear from the Fig.4 that the percentage variation of Al_2O_3+3% Graphite as reinforcement lead to the decrease in corrosion current density. From the fig.4 it can also be clearly seen that the ceramic reinforcement particles act as insulator and remain inert in the corrosion medium during the test. Thus the corrosion current density decreases with increase in the percentage of different reinforcement contents.

It is clear from the fig.5 that the corrosion rate decreases with increase in the percentage of different reinforcement contents. Less exposure of the MMCs area to corrosive environments in corrosion testing led to lesser pitting as well as corrosion than that of the matrix alloy. Since the lesser surface area is provided by the MMCs as compared to the matrix alloy lesser is the corrosion rate.

Al_2O_3 being the ceramic material remains inert and is hardly affected by corrosion medium during the test and is not expected to affect the corrosion mechanism of the composites. The results indicate that there is an improvement in corrosion resistance as the percentage of Al_2O_3 particulates increased in the composite which shows that Al_2O_3 particulates directly or indirectly influence the corrosion property of the composites. Al_2O_3 particulates act as a physical barrier to the initiation and development of corrosion pits and also modifies the micro structure of the matrix material and hence reduces the corrosion rate as well as the potential.

C.Electrochemical Impedance Spectroscopy

Electrochemical impedance is the response of an electrochemical system (cell) to an applied potential. The frequency dependence of this impedance can reveal underlying chemical processes.

The response of electrochemical systems is vary nonlinear. Small amplitude (~10 mV) AC ripple on top of the controlled DC polarization potential. The complex response of the system is usually displayed in Nyquist format, with the reactance inverted (since such systems are inherently capacitive). A process that depends on diffusion of reactants toward or away from the surface has a particular low-frequency character. ("Warburg" impedance).

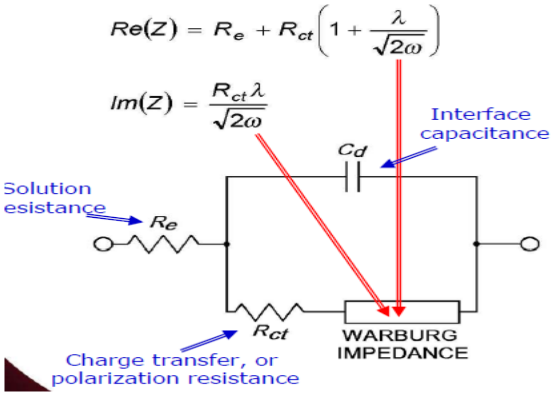

Fig.6. Electrochemical Impedance circuit

$$\lambda = K / \sqrt{D}$$

Where, k = chemical reaction rate and D = diffusion coefficient

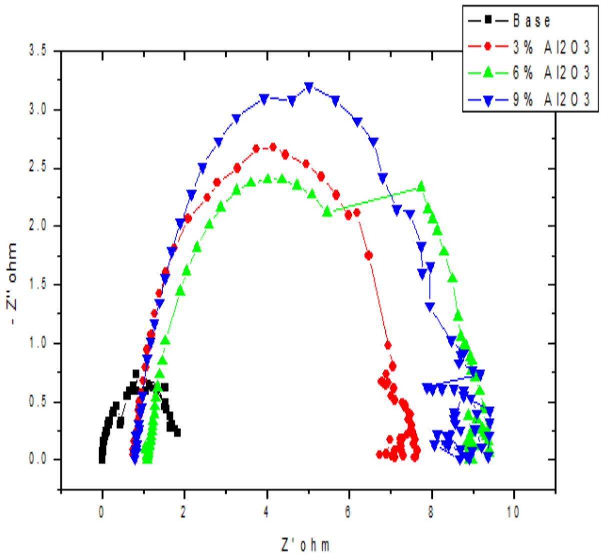

Fig.7. Comparison of Nyquist plot of base metal with varying composition of Hybrid MMC.

From the Nyquist plot of Fig.7 can be clearly concluded that impedance of the circuit is increasing with the increasing wt% of reinforcement. Hence, due to increase in circuit impedance, corrosion rate is decreased or we can say resistance for corrosion has been increased with increase in wt% of reinforcement.

VI.CONCLUSION

Based on the experimental results the following conclusions may be drawn:

1. Al 7075 alloy matrix composites reinforced with Alumina particles, and Graphite particles can be successfully synthesized by the stir casting method.

2. Corrosion behaviour of Al7075 and Al 7075/ Al_2O_3/Gr MMCs was tested by weight loss, potentiodynamic polarization and Electrochemical Impedance method. Increase in the percentage of Al_2O_3 particles will reduce the potential, corrosion current density and corrosion rate.

3. The Al_2O_3 content in Al 7075 alloys plays a significant role in the corrosion resistance of the material. Increase in the percentage of Al_2O_3 will be advantageous to reduce the density and increase the strength of the alloy. However, there is a significant reduction in the potential and corrosion rate.

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