Structural characterization and Corrosion behaviour of AA 2024/SiC-Graphite Hybrid Metal Matrix Composites in 3.5% Nacl

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Abstract--- The present study focuses on the corrosion behaviour of Al 2024 in the presence of silicon carbide, graphite, and their formulations. Hybrid metal matrix composites have been produced using the stir casting method. The influence of combinations of SiC and Graphite volume % on Al 2024 was also tested for corrosion properties. Potentiodynamic polarisation techniques were used to study the corrosion behaviour of the specimens because these methods have a high level of quality and dependability. Finally, corrosion samples were examined and analysed using a scanning electron microscope.

Keywords- Aluminium 2024, Hybrid metal matrix composites, Graphite with SiC, Corrosion

1. INTRODUCTION

The increased demand of light weight materials with high specific strength in the aerospace and automotive industries has led to the development and use of Al alloy-based composites. The metal matrix composites (MMCs) are slowly replacing the general light metal alloys such as aluminium alloy in different industrial applications where strength, low mass and energy savings are the most important criteria. The combination of various properties like electrical, mechanical, and even chemical can be achieved by the use of different types of reinforcements, i.e., continuous, discontinuous, short, whiskers, etc., with the MMCs [1].

Hybrid metal matrix composites (HMMCs) are second-generation composites where more than one type, shape, and sizes of reinforcements are used to obtain better properties. Hybrid composites possess better properties compared with single reinforced composites as they combine the advantages of their constituent reinforcements [2]. Aluminium2024/(SiC + Graphite) - HMMC is one of the composites which have many unique properties over Al/SiC - MMC and Al/Graphite - MMCs. All the data for MMC and HMMC are presented here in sequence to compare the variations.

Aluminium alloy 2024 has good machining characteristics, higher strength and fatigue resistance than both 2014 and 2017. It is widely used in aircraft structures, especially wing and fuselage structures under tension. It is also used in high temperature applications such as in automobile engines and in other rotating and reciprocating parts such as piston, drive shafts, brake rotors and in other structural parts which require light weight and high strength materials [3]. Aluminium is also a ubiquitous element and one of the trace elements with moderate toxic effect on living organism [4]. One of the main drawbacks of this material system is that they exhibit poor tribological properties. Hence the desire in the engineering community to develop a new material with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio led to the development of metal matrix composites [5,6].

Silicon carbide is a compound of silicon and carbon with a chemical formula SiC. Silicon carbide was originally produced by a high temperature electrochemical reaction of sand and carbon. Any acids or alkalis or molten salts up to 800°C do not attack silicon carbide. In air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. Silicon carbide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss. Chemical purity, resistance to chemical attack at temperature and strength retention at high temperatures has made this material very popular as wafer tray supports and paddles in semiconductor furnaces. It is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics and numerous high-performance applications [7].

Graphite is one of the most inexpensive and low density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants. Coal Combustion Products (CCP) is produced in coal-fired power stations, which burn either hard or brown coal. Due to the mineral component of coal and combustion technique, Graphite (FA) is produced [8]. In the US alone each year over 118 million tons of coal combustion products are produced. In India the stature was about 90 million ton during 1995 and is likely to exceed 140 million tons in 2020. Percentage utilization of Graphite differs between countries between 95% in Belgium and the Netherlands and 3% in India in the 1990s [9]. The utilization of Graphite instead of dumping it as a waste material can be both on economic and environmental grounds [10]. There is already a vast body of information on utilization of Graphite (FA) in building/construction, production of aggregates and more recently for agriculture [11].

The challenges and opportunities of aluminium matrix composites have been reported much better to that of its unreinforced counterpart [12]. The addition of reinforcing phase significantly improves the tribological properties of aluminium and its alloy system. The thinking behind the development of hybrid metal matrix composites is to combine the desirable properties of aluminium, silicon carbide and Graphite. Aluminium have useful properties such as high strength, ductility, high thermal and electrical conductivity but have low stiffness whereas silicon carbide and Graphite are stiffer and stronger and have excellent high temperature resistance but they are brittle in nature [13].

In this study, an attempt has been made to fabricate Al 2024/(SiC + Graphite) hybrid metal matrix composites at various proportions. Methods available for the production of hybrid metal matrix composites are powder metallurgy, spray deposition, liquid metal infiltration, squeeze casting, stir casting [14,15]. Though various processing techniques available for particulate or discontinuous reinforced metal matrix composites, stir casting is the technique, which is in use for large quantity commercial production. This technique is most suitable due to its simplicity, flexibility and ease of production for large sized components. Hence stir casting method (also called liquid state method) is used for this study.

The objective of the present work is to form the reinforcing phase within the metallic matrix by reaction of silicon carbide, Graphite and its proportions with aluminium in the metallic melt. To increase the wettability, commercially pure magnesium (1.5%) was added. Corrosion behaviour of the specimens were evaluated. The tested specimens were characterized with the help of scanning electron microscope.

2.MATERIALS AND METHODS

2.1. Materials

The matrix material used in the present investigation was commercially pure aluminium alloy 2024. Aluminium was purchased from Perfect Metal Works, Bangaluru, Karnataka, India. Silicon carbide, Graphite and magnesium were commercially available.

2.2. Experimental Work: Sample preparation

The Stir casting method is used for hybrid composite materials fabrication, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies. For the present study, Al 2024/SiC, Al

2024/ Graphite, and Al 2024/ (Graphite + SiC) hybrid metal matrix composite was prepared by stir casting route. For this we have chosen 100gm of Al 2024 and desired amount of SiC, Graphite, SiC-Graphite mixtures in powder form. Graphite, SiC and their mixtures were preheated to 300°C for three hours to remove moisture. Aluminium 2024 was melted in a resistance furnace. Then the melt was casted in a clay graphite crucible and it was degassed by purging hexachloro ethane tablets. The melt temperature was raised up to 720°C and then the melt was stirred with the help of a mild steel turbine stirrer. The stirring was maintained between 5 to 7 min at an impeller speed of 200 rpm. To increase the wettability, 1.5% of pure Mg was added with composites. The melt temperature was maintained 700°C during addition of Mg, SiC, Graphite, mixture of SiC-Graphite particles. The dispersion of Graphite and other particles were achieved by the vortex method. The melt with reinforced particulates were poured into the sand casting. The pouring temperature was maintained at 700ºC. The melt was then allowed to solidify in the cast.

Fig.1 Stir Casting

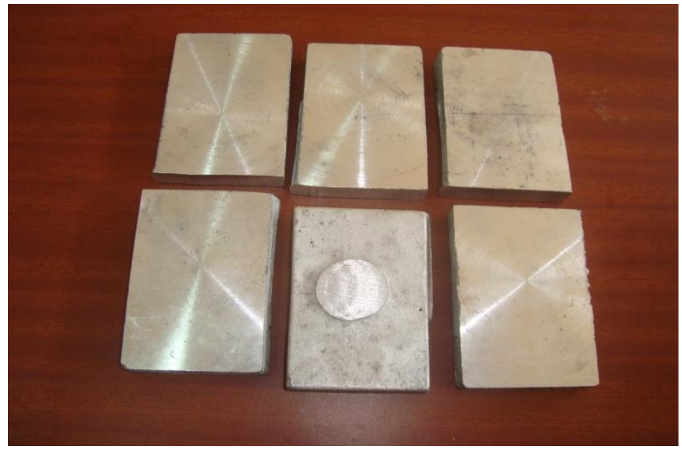


Fig.2 Sample Preparation

3. Corrosion behaviour

Corrosion protection for Al 2024 and their composites reinforced with various spices of different proportions was investigated. Impedance curve interpretation and Potentiodynamic Polarization Technique were used. The materials studied included Al 2024, Al 2024/10%SiC, Al 2024/10% Graphite and Al 2024/(5%SiC + 5% Graphite).

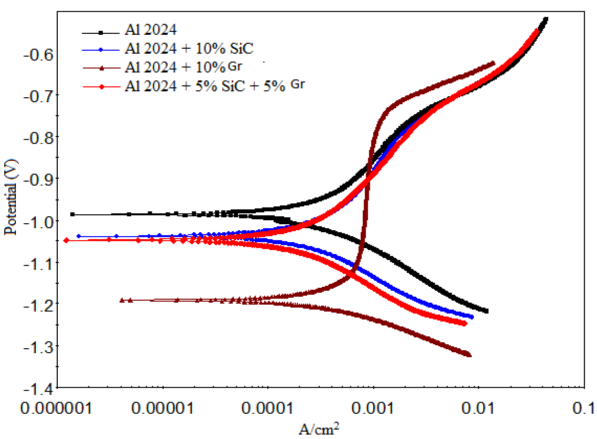
Corrosion Rate Conversion

The polarization curve of base matrix and composites obtained in 3.5 NaCl sodium chloride solution is shown in Fig. 12. The corrosion potential (E_{corr}) and corrosion current current density (I_{corr}) calculated using Tafel extrapolation method is given in Table - 1.

Table-1

S. No.	Percentage variation of differnt reinceforcements	Corrosion potental, E_{corr} (mVvsSCE)	Corrosion current density, I_{corr} (A/m^2)	Corrosion rate (mm/year)
1	Al 2024	-1.0	0.0002	0.618
2	Al 2024 + 10%SiC	-1.04	0.0004	1.806
3	Al 2024 + 10% Graphite	-1.2	0.0009	2.995
4	Al 2024 + 5%SiC + 5%Graphite	-1.05	0.0006	2.426

In all the cases it is observed that the corrosion rate increases in the begining with increase in test duration and remains constant towards to the end due to passivation. It is clear from the graph that the resistance of the composite to corrosion decreases as the exposure time increases. Similarly, referring the graph that with increase in the weight percentage of different reinforcement particles the potentail of the different composites with different weight percentage of reinforcement increases. The initial increase in potential is due to the corrosion process which takes place on the surface of the composites. Also, it is clear from the graph that the percentage variation of reinforcements lead to the decrease in current density. For evidence, the addition of Graphite and SiC particles (5% Graphite + 5% SiC) will diminish the corrosion resistance of Al 2024 alloy since that it is difficult to achieve very good bond-ability between ceramic and metal. Mayyas*et al.* observed the similar results [18].



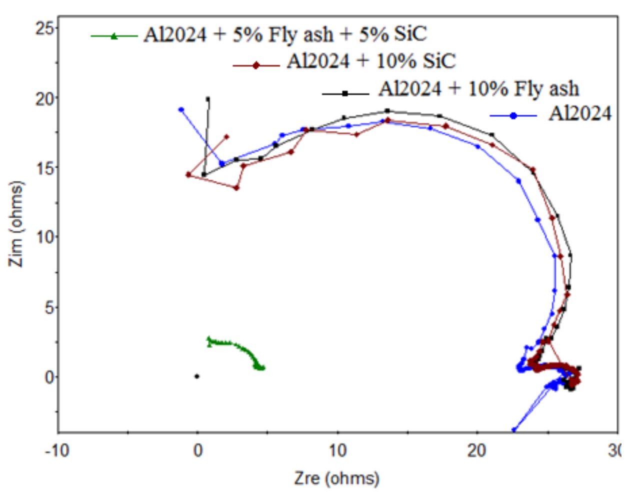


Fig. 4

4. Microstructural Characterization

The worn out surface of some selected /typical specimens after the wear test and corrosion test are observed under scanning electron microscope. Results were compared with earlier studies [23,24].

Scanning electron micrograph of the Al 2024 and Al 2024/(5%SiC + 5% Graphite) composites are visualised after subjecting to the corrosion test are shown in Fig. 16 and Fig. 18 respectively. The scanning electron micrographs of corroded samples of matrix and composites reveal more severe pitting and cracks development in unreinforced matrix than in reinforced composites alloy. Greater degree of surface deterioration in composites as observed from SEM images indicates the higher corrosion rates for matrix alloy than for composites. The SEM micrographs show a complete deterioration of the smoothness of the surface of composites, suggesting the penetration of chloride ions into the material surface forming corrosion spots.

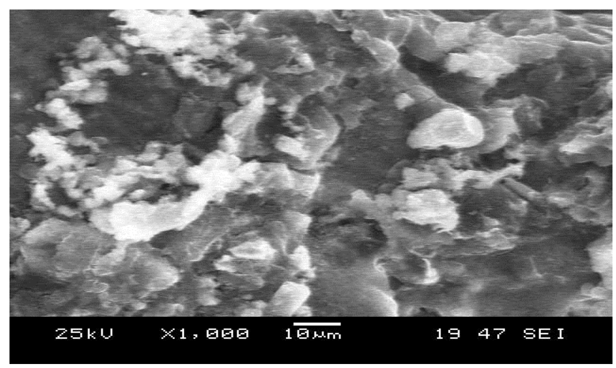


Fig. 5. SEM image of the corroded Al 2024 alloy

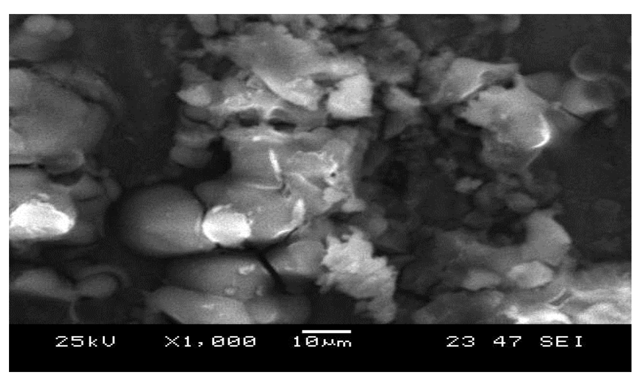


Fig. 6 SEM image of the corroded Al 2024/ (5%SiC/5%Graphite)

5. CONCLUSIONS

Al 2024/10% SiC, Al 2024/10% Graphite, Al 2024/(5% SiC + 5% Graphite) composites were fabricated by stir casting process. Wetting of reinforcements with the aluminium matrix was further improved by the addition of magnesium (1.5%). The test results infer that the corrosion rate offered by the AA 2024-Gr, AA 2024-Gr-SiC is higher compared to the unreinforced AA 2024. SiC reinforcement particles were not affected the corrosion resistance of the AA2024 considerably compared to Graphite particles. It may be due to the inertness of the SiC particles in the 3.5%NaCl solution. The morphological study validated the test results inferred. The presence of the reinforcement materials reduces the corrosion resistance.

5. REFERENCES

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