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Mechanical characterization of aluminum-based hybrid metal matrix composites

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ABSTRACT

Metal Matrix Composites (MMC) are characterized by light weight, better specific strength and wear resistance properties. Due to their superior properties, MMCs have good potential for application in the automotive and aerospace industries. Among many types of MMCs, the most popular types are aluminum alloys reinforced with Al_2O_3 and MgO particulates since they provide favorable properties with only a minimum increase in density over the base alloy. The basic purpose of adding reinforcement into the metal matrix is to increase the yield strength, tensile strength, and hardness at ambient temperatures.

Many of the components made out of MMCs are operated in applications, where they are subjected to relative sliding and rolling motion with respect to the surfaces of the mating components. The sliding wear of the composites is a complex process involving not only mechanical but also thermal and chemical interactions between the surfaces in contact. The Al 6061 Hybrid composites prepared by stir casting liquid metallurgy route with the percentage of 2% wt of Aluminium Oxide and 2% wt of Magnesium Oxide and the combination of 1% wt of Aluminium Oxide and 1% wt of Magnesium Oxide for Hybrid material. Hence, composites with Al2O3 and MgO with Al-6061 as reinforcement are likely to overcome the cost barrier as well as the different physical and mechanical properties for widely used in the automotive and space craft applications.

Keywords: *MMC, Stir Casting, Al 6061, MgO, Al_2O_3, Hybrid Composite.*

1. INTRODUCTION

Metal matrix composites are attractive materials because of their tailored properties by addition of suitable reinforcements. In recent days the particulate reinforced metal matrix composite are used due to their specific strength and stiffness at room or elevated temperatures. The combination of the metal matrix into ceramic materials forms a composite material which results in an excellent combination of physical and mechanical properties which cannot be obtained with monolithic alloys [1]. Aluminum 6061 has good cast ability which makes it a logical choice for intricate and complex castings where lightweight, pressure tightness and excellent mechanical properties are needed. However, the main weaknesses of aluminum alloys are their poor high-temperature performance and wear resistance

In the last two decades, research has shifted from monolithic materials to the composite material. Composites are materials in which two phases are combined, usually with strong interfaces between them. They usually consist of a continuous phase called the matrix and discontinuous phase called the reinforcement. Considerable interest in composites has been generated in the past because many of their properties can be described by a combination of the individual properties of the constituent phase and the volume fraction in the mixture.

Composite materials are gaining wide spread acceptance due to their characteristic of behavior with their high strength to weight ratio. The interest in metal matrix composites (MMCs) is due to the relation of structure to properties such as specific stiffness or specific strength. Like all composites, aluminum matrix composites are not a single material but a family of materials whose stiffness, density, thermal and electrical properties can be tailored. Composites materials are high stiffness, high strength, low density, high-temperature stability, high electrical and thermal conductivity, the adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc. The matrix holds reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

2. EXPERIMENTATIONS AND TESTING ANALYSIS

2.1 Work Material Details: The details of the material selected for present investigation are as discussed below. Aluminum (Al6061) based metal matrix composite with aluminum oxide (2% volume fraction, 5µm) are used. Particulates of MgO (magnesium oxide) with an average particle size of <150µm are added and the combination of 1% wt of Aluminium Oxide and the combination of 1% wt of Aluminium Oxide and 1% wt of Magnesium Oxide for Hybrid material to improve the tribological behavior of MMCs.

Table 2.1 specifies the percentage composition of Aluminum - 6061 used for the present investigation

Elements	Percentage
Silicon	0.4 - 0.8
Iron	0.7
Copper	0.15 – 0.4
Manganese	0.15
Magnesium	0.8 – 1.25
Chromium	0.04 - 0.35
Zinc	0.25
Titanium	0.15
Aluminum	95.85 – 98.56

2.2 Stir Cast Processing Details: The casting unit consists of a graphite crucible of about 5 kg capacities, which is heated by electrical resistance type heating coils. The temperature level of the heating unit is controlled by thermocouple activated controlling unit. Duration of heating is determined based on the quantity of material to be melted. The furnace used in the present work is of bottom pouring type, which is regulated using a valve operated from the bottom. A motor operated stirrer is provided at the top, for mixing the particulate reinforcement with the molten metal. The mechanical stirrer used for stirring the molten alloy during fabrication of composites is made of steel blades coated with Alumina powder and sodium silicate mixture to withstand high temperature and to avoid iron pickup by the melt. The arrangement is made at the bottom of the crucible for exact positioning of the split mould below the valve.

Figure2.1 shows the schematic representation of electrical furnace used, Figure 2.2 and Figure 2.3 shows the split mould and cast specimens respectively.

Figure 2.1: Schematic Diagram of Electrical Heating Furnace

Figure 2.2: Split Mould

Figure 2.3: Casted Specimens

2.3 Mechanical Properties

2.3.1 Tensile Test: The tensile test specimens are prepared as per the ASTM standard as shown in Figure 2.4.

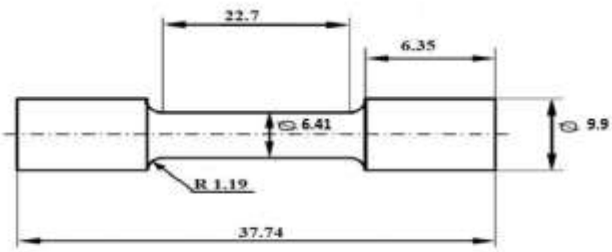


Figure 2.4: Specimen dimensions in mm

Figure 2.5: Tensile Specimen

2.3.2 Compression Test: The UTE type Universal Testing Machine serves for conducting tests in tension, compression, shear and transverse for metals and materials. The test machine is operated hydraulically drive is performed with the help of an electric motor.

The compression test specimen of the diameter of 20mm and length 30mm specimen are prepared as per standard as shown in Figure 2.7.

Figure2.6: a Universal testing machine for compression test

Figure2.7: Compression test specimen

2.3.3 Hardness Test: In Brinell hardness test, a steel ball of diameter (D) is forced under a load (F) on to a surface of the test specimen. Mean diameter (Di) of indentation is measured after the removal of the load.

2.3.4 Wear Test: The wear test specimens of 30mm length and 8mm diameter are prepared as per the ASTM standard as shown in Figure 2.9. The wear test was conducted at different loads, with increments of load 2kg and constant velocity of 400rpm. After every 15 min, the specimen was removed, cleaned, dried and weighed to calculate the mass loss.

Table 2.2: Specification of Wear & Friction Test Rig

Rotational Speed	Up to 8000 rpm
Track Diameter	10-380 mm
Load Range	2Kg
Disc Size	Dia 100 mm ×Thickness 8mm
Wear measurement	Up to 2mm
Pin Size	8 to 30 mm
Frictional Force	Up to 100 N

Figure 2.8: Wear test machine

Figure 2.9: Wear Testing Pins

3. RESULTS AND DISCUSSION

3.1. Microstructural Study:

Scanning Electron Microscopy

Figure 3.1 shows the SEM image of Alumina (Al6061+2% 5µm AL2O3), Figure 3.2 indicates SEM image of Al6061 reinforced with 2% MgO. Figure 3.3 shows the SEM image of composite material (Al6061+1% 5µm AL2O3 with 1% MgO particles). From the figures, it can be seen that the reinforcement particles are uniformly distributed in the matrix material, the presence of reinforcement particles in the matrix material yields in the higher strength of the composite materials.

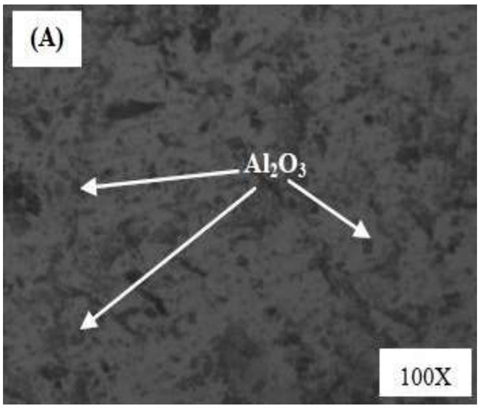


Figure 3.1: Al-6061+2% 5µm AL2O3 Particles

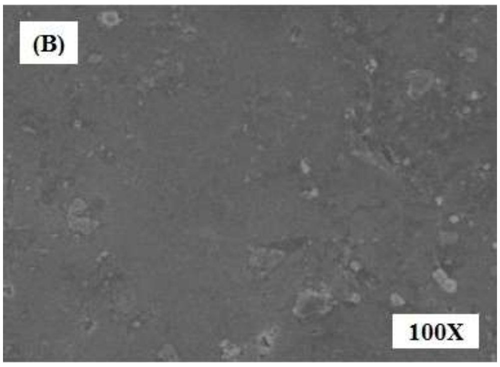


Figure 3.2: Al-6061 + 2% <150µ MgO

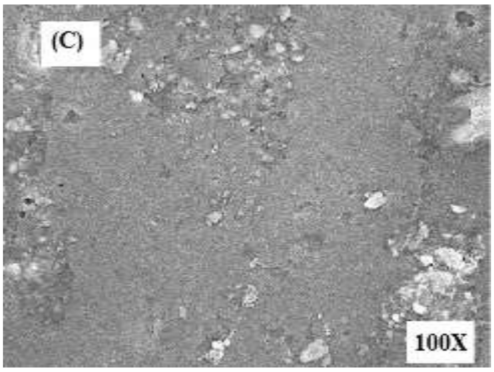
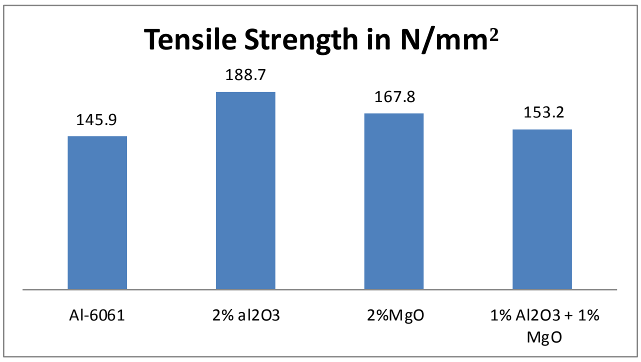


Figure 3.3: Al-6061+ 1% AL2O3+1% MgO

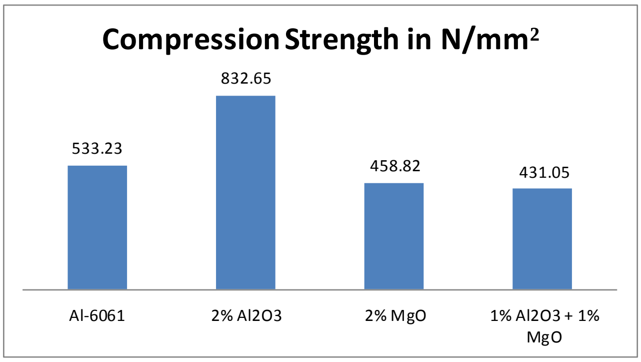
3.3 Tensile Strength Test:



Graph 3.1: Tensile strength of composite samples

By graph 3.1 it is evident that the addition of Al_2O_3 and MgO particulates has increased the Tensile strength of the composite materials compared to that of the base alloy. Test results also indicate the progressive increase in tensile strength when the base alloy is combined with 2% of Al_2O_3.

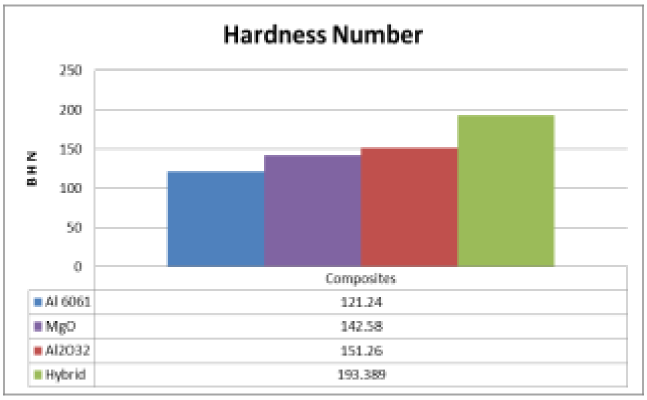
3.2 Compression Test:



Graph 3.2: Compressive strength of composite samples

By graph 3.2 it is evident that the addition of Al_2O_3 and MgO particulates has increased the compressive strength of the composite materials compared to that of the base alloy. Test results also indicate the progressive increase in compressive strength when the base alloy is combined with 2% of Al_2O_3.

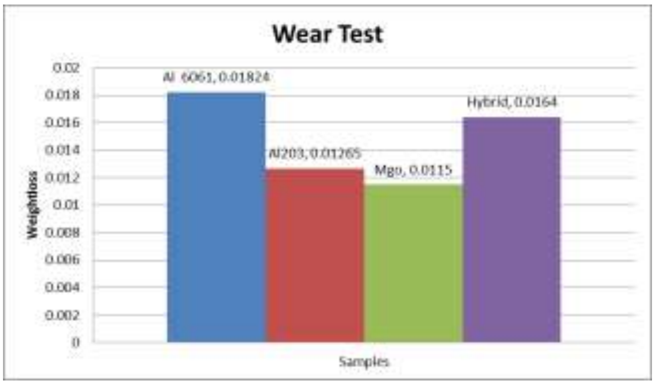
3.3 Hardness Test:



Graph 3.3: Hardness Number of composite samples

Graph 3.3 illustrates the variation in Brinell Hardness Number (BHN) of composite test specimens with reinforcements. It can be observed that the addition of Al_2O_3 and MgO particulates has increased the hardness of the composite materials compared to that of the base alloy. Test results also indicate the progressive increase in hardness of the composite sample when base materials combined with 1% of Al_2O_3 and 1 % of MgO.

3.4 Wear test:



Graph 3.4: Weight loss of composite samples

By graph 3.4 it is evident that the addition of Al_2O_3 and MgO particulates has decreased the weight loss of the composite materials compared to that of the base alloy. Test results also indicate the progressive decrease in wear loss is obtained when the base alloy is combined with 2% of MgO.

4. CONCLUSIONS

The Effect of Incorporation of Aluminum oxide and magnesium oxide particles on Mechanical Properties of Al 6061 has been investigated. Based on the results the following conclusions can be done

• Significant Improvement in the tensile properties wear properties and hardness of the material with the incorporation of Aluminium Oxide and Magnesium Oxide Particles.

• The Test results ensure that as the Aluminium Oxide Percentage is increased the mechanical properties of this composition are also increasing positively.

• The Al-6061 Alloy Reinforced with 2% Aluminium Oxide Shows a significant improvement in the hardness, tensile strength, compressive strength compared to other weight percent composition, Hence this combination can be used for light weight and high strength applications.

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