Influence of Cu on Wear and Corrosion Behaviour of Al-Sic-Cu MMC by Powder Metallurgy

[1]Ayaz Ahmed, [2]Jafar Ali. T. N. ,[3]Sheik Mohamed
[1]Assistant Professor,[2] Assistant Professor,[3] Assistant Professor
Department of Mechanical Engineering,
[1]Aalim Muhammed Salegh College of Engineering, Chennai, INDIA

Abstract : Aluminium Metal Matrix composites are widely used in automobiles, aerospace and industrial applications. In this study, Al.85-Cu.05-SiC.10 metal particulate matrix composites was produced by powder metallurgy process. The powders were ball milled and the powder mixtures were pressed uniaxially under a pressure of seven tons to compact the materials and then this compacted sample is kept in a furnace at a temperature of 535℃ and slow cooled to produce the sample. Then the pure Aluminium powder is compacted and sintered and thus the Aluminium sample is also produced. SEM Analysis confirms the presence of Al, SiC, Cu bonding. Then this samples are subjected to wear resistance test and corrosion test. A comparison with the test results reveals that Al alloy composite exhibit better wear and corrosion resistance properties than pure Aluminium.

IndexTerms - Metal Matrix Composites (MMC), Al-SiC-Cu, Wear Resistance, Corrosion Resistance, Powder Metallurgy.

I. INTRODUCTION

Metal Matrix Composites (MMC) have been developed and studied extensively for the last few decades. [1]. The demand for metal matrix composites in the ever-expanding fields of automobiles and aerospace industries and construction applications is increasing rapidly since the past three industrial revolutions. In the recent past, Aluminium (Al)-based composites have potentially grown in engineering and structural applications [2]. Aluminium metal matrix composites (AMCs) are of interest due to the high strength to weight ratio, relatively low co-efficient of thermal expansion and good wear properties of AMCs. These combinations of properties are not available in a conventional metals and alloys. AMCs have potentiality in braking pad application because of their superior strength, light weight, low cost and ease of manufacturing. [6] Ceramic reinforcements such as fly ash, carbon nanotubes, Al_2O_3, SiO_2, $ZrSiO_4$, SiC, TiC, B_4C, AlN, Si_3N_4 and TiB_2 etc. have been used to develop Al or Al alloy composites . On the other hand, Al has been used as an alloying element to improve corrosion and wear resistance of various ferrous or non-ferrous metals. Al alloys were also used as substitutive coatings for toxic Cd coatings to improve corrosion resistance of steels, Mg alloys and NdFeB magnets etc

As far as the processing of AMCs is concerned, liquid processing (stir casting, infiltration, squeeze casting etc.) and solid processing routes (powder metallurgy, additive manufacturing techniques) have been widely used to develop discontinuously reinforced particulate AMCs or continuous fiber reinforced AMCs . Moses et al. produced Al alloy (AA6061) - SiC composites via stir casting route. They studied the effect of SiC reinforcement content on mechanical properties of Al alloy and reported increase in mechanical properties of Al alloy with increasing SiC content (up to 15vol.%) [3]. In another work, Rahman et al [4] reported improvement of mechanical and wear properties of cast Al-SiC composites. The effect of SiC particle size (3,6 and 11 µm) and volume fraction of SiC (up to 15vol.%) on corrosion behavior of sintered and hot extruded Al was investigated by Zakari et al [9]. He observed that Al-SiC exhibited better corrosion resistance than pure Al and it was also found that finer SiC particle size and higher volume fraction of SiC is beneficial in lowering corrosion of Al. It has to be mentioned that corrosion reduces the load sustaining capacity and can results in catastrophic failures. [3] Hence corrosion can limit the application of AMCs in corrosive environments especially in the presence of load.

The enhanced performance from these rather unique materials depends on a careful selection of processing technique/parameters, matrix material and the reinforcing phase. Liquid phase processes, for example, beside their disadvantages are still the most economical processes to synthesize MMCs [6]. However, the commercial utilization of liquid phase processes is still very restricted as a result of limited information available in the open literature regarding the synthesis of these materials. Moreover, MMCs processed using liquid phase processes exhibit coarser microstructure and non-uniform distribution of SIC particulates as a result of sluggish solidification velocity resulting in relatively inferior mechanical properties. [7] In order to circumvent the problems associated with liquid phase processes, partial-liquid phase processes have been investigated and are reported to exhibit an improved combination of micro structural characteristics and mechanical properties. The partial-liquid phase processes, however, have met with limited success [10] and further efforts are required in order to gain further understanding so as to synthesize MMCs with an improved microstructure and enhanced mechanical properties [8]. Accordingly, in the present study metal matrix composites were synthesized using liquid phase and partial-liquid phase techniques in order to gain a further insight into the microstructural evolution as a result of change in certain processing steps [9]. The as-processed composites thus obtained were microstructural~y characterized using scanning electron microscopy and tensile tested using an automated servo-hydraulic Instron testing machine. The mechanical properties thus obtained were correlated with the processing associated micro structural features of the composite materials [11].

Among the various ceramic reinforcements, SiC has been extensively used to improve mechanical, tribological, corrosion and high temperature properties of Al or Al alloys. Subsequently corrosion tests were performed on the Al composites that exhibited better density and hardness in 3.5% NaCl solution at room temperature to realize the potential of Al composites for marine applications. [12].

II. EXPERIMENTAL PROCEDURE

2.1 BALL MILLING PROCESS

A ball mill is a type of grinder used to grind and blend materials for use in mineral dressing processes, paints, pyrotechnics, ceramics and selective laser sintering. It works on the principle of impact and attrition: size reduction is done by impact as the balls drop from near the top of the shell.

A ball mill consists of a hollow cylindrical shell rotating about its axis. The axis of the shell may be either horizontal or at a small angle to the horizontal. It is partially filled with balls. The grinding media is the balls, which may be made of steel (chrome steel), stainless steel, ceramic, or rubber. The inner surface of the cylindrical shell is usually lined with an abrasion-resistant material such as manganese steel or rubber. Less wear takes place in rubber lined mills. The length of the mill is approximately equal to its diameter.

Figure-1: Ball Milling Machine

2.2 COMPACTION PROCESS

Compaction of ceramic powders is a specific forming technique for ceramics. It is a process in which ceramic granular materials are made cohesive through mechanical densification, involving (hot pressing) or not (cold forming) temperature exposition. The process permits an efficient production of parts ranging widely in size and shape to close tolerances with low drying shrinkage. Traditional (for instance: ceramic tiles, porcelain products) and structural (for instance: chip carriers, spark plugs, cutting tools) ceramics are produced. Cold compaction of ceramic powders ends up with the realization of the so-called green piece, which is later subject to sintering.

Figure-2: Compaction Machine

2.3. SINTERING PROCESS

Sintering is a heat treatment applied to a powder compact in order to impart strength and integrity. The temperature used for sintering is below the melting point of the major constituent of the Powder Metallurgy material.

After compaction, neighboring powder particles are held together by cold welds, which give the compact sufficient “green strength” to be handled. At sintering temperature, diffusion processes cause necks to form and grow at these contact points.

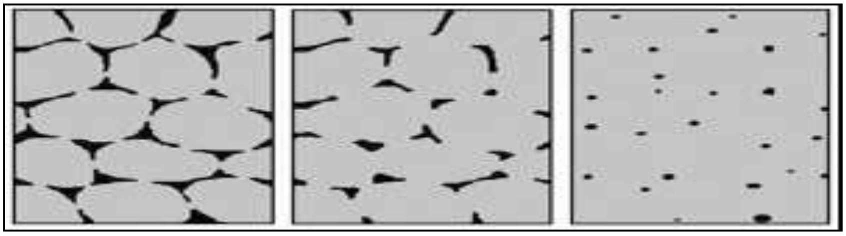


Figure-3: Initial, Intermediate, Final

There are two necessary precursors before this “solid state sintering” mechanism can take place:-

- Removal of the pressing lubricant by evaporation and burning of the vapours.
- Reduction of the surface oxides from the powder particles in the compact.

These steps and the sintering process itself are generally achieved in a single, continuous furnace by judicious choice and zoning of the furnace atmosphere and by using an appropriate temperature profile throughout the furnace.

Figure-4: Sintering Furnace

2.4. SCANNING ELECTRON MICROSCOPY

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electron. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image. In the most common SEM mode, secondary electron emitted by atoms excited by the electron beam are detected using an Everhart-thornley detector. The number of secondary electrons that can be detected, and thus the signal intensity, depends, among other things, on specimen topography. SEM can achieve resolution better than 1 nanometer.

Specimens are observed in high vacuum in conventional SEM, or in low vacuum or wet conditions in variable pressure or environmental SEM, and at a wide range of cryogenic or elevated temperatures with specialized instruments.

Table 1: SEM Specification

ACC voltage	0.3 to 30 kV
Magnification	5X to 300000X
Resolution	3.0nm (30kW HV mode)
Standard Detectors	SE, BSE
Vacuum system	TMP/RP based
Specimen stage	Fully motorized, 100/50 XY movements
PC	Latest PV
Coating unit	Ion sputter coater with gold target
Chamber viewing	IRCCD camera
EDS Detector system	LN2 free, peltier cooled, 139eV
EDS software	Qualitative and quantitative analysis, X-ray spectral mapping, multipointing analysis

2.5. PIN ON DISC APPARATUS

For the pin-on-disk wear test, two specimens are required. One, a pin with a radiused tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk center. In either case, the sliding path is a circle on the disk surface. The plane of the disk may be oriented either horizontally or vertically.

Figure-5: Pin on Disc

III. RESULTS AND DISCUSSION

The primary results that are derived from this work are as follows:

- Wear resistance of Aluminium composite is better than Aluminium.
- Corrosion resistance of Aluminium composite is better than Aluminium

3.1 Wear Test

Wear test is conducted on a Pin-on-disc apparatus with samples as pin and EN31 steel as a disc. Wear results are given by

Table 2: Sample Comparison - Wear

Samples	Initial weight g	Final weight g	Wear loss in g
Al composite	2.759	2.753	0.006
Aluminium	1.448	1.438	0.01

SEM IMAGES:

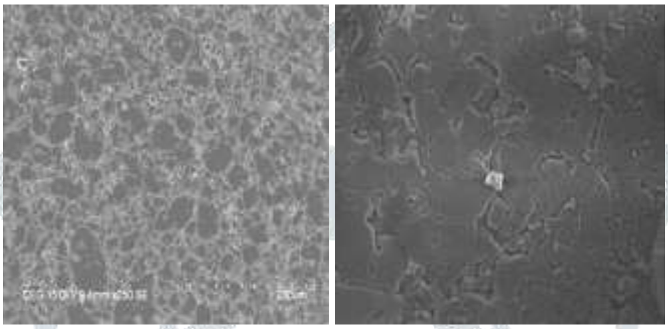


Figure-6 (i) Al-MMC (9.4mm X 250 SE) (ii) Al (9.4mm X 250 SE)

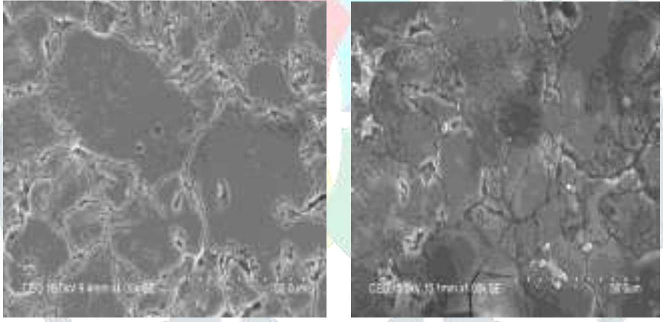


Figure-7 (i) Al-MMC (9.4mm X 1.00K SE) (ii) Al (9.4mm X 1.00K SE)

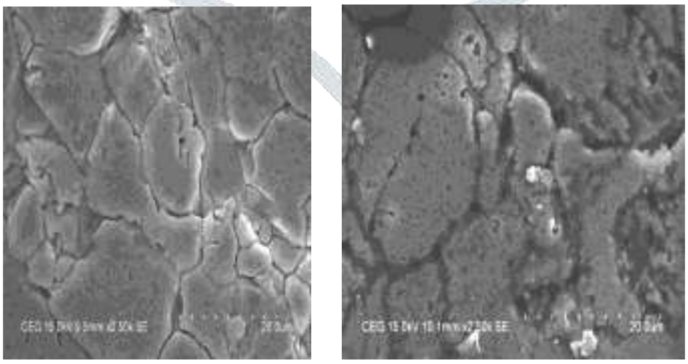
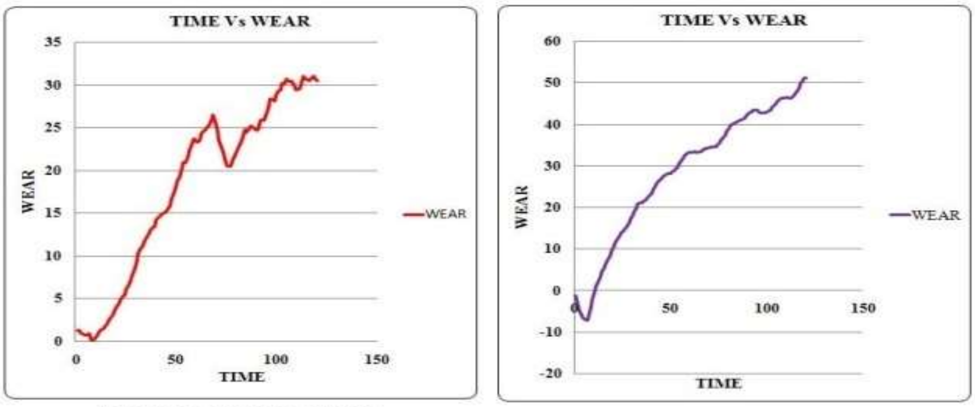


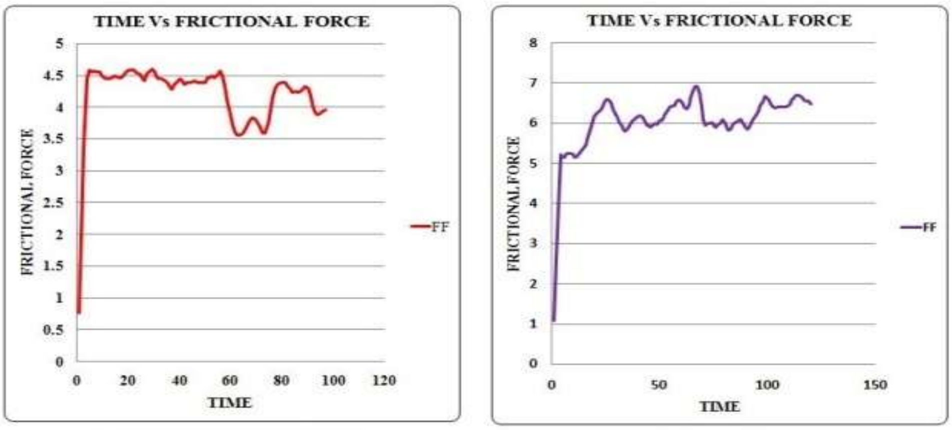
Figure-8 (i) Al-MMC (9.4mm X 2.50K SE) (ii) Al (9.4mm X 2.50K SE)

WEAR TEST GRAPH OBSERVATIONS



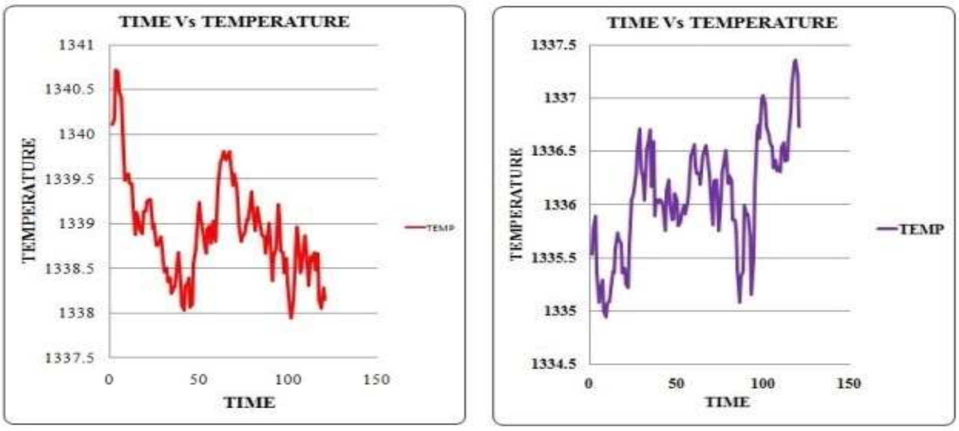
ALUMINIUM COMPOSITE (Al MMC) ALUMINIUM (Al)

Figure-9 : Time vs Wear



ALUMINIUM COMPOSITE (Al MMC) ALUMINIUM (Al)

Figure-10 : Frictional Force



ALUMINIUM COMPOSITE (Al MMC) ALUMINIUM (Al)

Figure-11 : Time vs Temperature

3.2 Corrosion Test

The salt spray (or salt fog) test is a standardized and popular corrosion test method, used to check corrosion resistance of materials and surface coatings. Usually, the materials to be tested are metallic (although stone, ceramics, and polymers may also be tested) and finished with a surface coating which is intended to provide a degree of corrosion protection to the underlying metal. Salt spray testing is an accelerated corrosion test that produces a corrosive attack to coated samples in order to evaluate (mostly comparatively) the suitability of the coating for use as a protective finish.

Table 3: Sample Comparison - Corrosion

Samples	Initial weight g	Final weight g	Corrosion loss in g
Al composite	36.464	36.325	0.139
Aluminium	30.281	30.027	0.254

CONCLUSION

- The Wear resistance of Al MMC is considerably higher than its counterpart Al which suggests that it has excellent Wear properties.
- The Corrosion results also conclude that Al MMC has remarkable Corrosion resistance.

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