Characterization of aluminum metal matrix-composite based on silicon carbide (SiC) Particles and Lubricated with molybdenum disulphide (MoS_2)

Mohd. Arif[1*], Rohit Sahu[1]

[1] *Department of Mechanical Engineering, GLBITM Greater Noida, India*

ABSTRACT

Achieving a uniform distribution of reinforcement within the matrix is still a challenge despite of one of the oldest technique of Metal Forming. It directly affects the properties and quality of composite material. In present paper a modest attempt has been made to develop aluminium based silicon carbide particulate MMCs which is lubricated with molybdenum disulphide (MoS_2) particulates with an objective to develop a conventional and low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material with lesser wear rate. The problem of wettability associated with ex-situ composite synthesis has been overcome by the use of Magnesium. To achieve these objectives Stir Casting technique has been adopted and subsequently property analysis has been made. Aluminum (99.99 %) and SiC has been chosen as matrix and reinforcement material respectively with Molybdenum disulphide (MoS_2) as lubricant and Magnesium (Mg) as binding element.

Keywords – Aluminium, Metal matrix composites MMC's, Microstructure, Molybdenum disulphide (MoS_2),Silicon Carbide SiC.

I INTRODUCTION

Composite materials, often shortened to composites, are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. The properties of composite materials can be tailored according to the requirement of applications by changing amount or orientation of the reinforcement material [1]. Metal matrix composites are materials with metals as the base and distinct, typically ceramic phases added as reinforcements to improve the properties. They offer superior combination of properties in such a manner that today no existing monolithic material can rival. Metal Matrix Composites (MMC's) have very light weight, high strength, and stiffness and exhibit greater resistance to corrosion, oxidation and wear, which is desired for applications like aerospace, automobile etc. Composite materials reinforced with ceramic particles/fibers (e.g. SiC, Alumina) are being extensively used in many applications. Important metal matrices that are widely used are aluminum alloys, titanium alloys, magnesium alloys, copper etc. However, aluminum based composites have found wide applications in aerospace and automotive industry due to their light weight, high strength, low cost (as it is the 3rd most abundant element found in earth crust), and sufficient mechanical strength. Aluminum is the most popular matrix for metal matrix composites because of its low density, low cost, its capability to be strengthened by precipitation, good corrosion resistance, and high thermal and electrical conductivity etc. In metal matrix composites [2, 3]. Generally, matrix is usually a ductile or tough material while reinforcing materials are strong with low densities. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. The various possible strengthening mechanisms include i) load transfer mechanism ii) matrix strengthening due to grain size reduction iii) increase in dislocation density due to geometrical and thermal mismatch [4]. Reinforcement of aluminum alloys with SiC has generally been observed to improve wear and abrasion resistance. It was observed that SiC reinforcement along with incorporation of solid lubricants (like Molybdenum disulphide, graphite, etc) enhanced the wear performance of Al composites. Several materials with lamellar structure result low values of friction under certain conditions, and are therefore of interest as solid lubricants. Molybdenum disulphide (MoS_2) is a good lubricant characterized by its hexagonal structure [5, 6]. The use of MoS_2 at high temperature is limited by decomposition or oxidation in air [6, 7]. Main problem encountered in ex-situ self-lubricating composites is poor wettability and non-uniform distribution of reinforcement as reported in may studies. To overcome this difficulty Magnesium or its alloys have been used as a binding element. In stir casting different process variables like holding temperature, stirring speed, heating rate etc. may affect the properties of composites.

II EXPERIMENTATION

2.1 Material and Setup

The raw materials used for synthesis of composites are 99% pure Aluminum (Al) ., Silicon carbide (SiC) powder of 99% purity with average size particle of 25μm and 99% pure molybdenum disulphide (MoS2) powder of 25 μm average particle size.

2.2 Experimental Set-up for Synthesis of Composites

Setup for Stir casting was made to cast the Matrix, in which a threaded arrangement was made and the integrated with the electric furnace. The induction furnace whose upper limit temperature was fixed at 1100℃ surrounded with electric coil inserted in muffle from three sides was used as the heating source. The stirrer used here was made of mild steel bar integrated with electric motor whose speed can be varied from 200 to 600 rpm by the speed controller. The melting was carried out in a clay-graphite crucible placed inside the resistance furnace. An induction resistance furnace with temperature regulator cum indicator was utilized for synthesis of aluminum metal matrix composites. Silicon Carbide (SiC) powder of average particle size 25μm, 10% of aluminium weight was used for casting of Al/SiC MMCs by melt-stir technique. In another casting 4% Molybdenum disulphide (MoS2) by weight was mixed to study the effect of solid lubricant on the composite.

Mechanical and tribological properties of the cast MMC are determined to study the effect of solid lubrication. To avoid the problem of poor wettability in composites, 4% Magnesium (Mg) was added which act as binding element.

Table 1 composition of composites

S.No.	weight of pure Al (gm)	weight of SiC (gm)	weight of MoS2(gm)	weight of Mg (gm)
1.	550	55	-	-
2.	520	52	20.8	-
3.	560	56	22.4	22.4

SiC particulates were preheated at 400°C for 20 minutes to improve the wetness properties by removing the absorbed hydroxide and other gases. The 520 gm Al was melted at 700^0C and when the temperature reached 680^0C then the weighed SiC and MoS_2 was added into the melted Al wrapped by Al-foil with the help of tongs and then waited until the 700^0C is reached with intermittent stirring. Then it was cooled down to just below the melting temperature to keep the slurry in a semi-solid state. This composite slurry was then stirred for 10 min at 400 rpm average stirring speed. In the final stage of mixing, the furnace temperature was controlled within 700 ± 10. Molds (size 25×35×200mm) made of 5 mm thick steel sheet were preheated to 450°C for 1 hours before pouring the molten Al/SiC -MMC. The prepared permanent mould made of steel sheet utilized for casting of 25mm ×35mm×200mm long bar. Then fabrication of composite was followed by gravity casting. Similar process was adapted for preparing the other composite with addition of solid lubricant molybdenum disulphide (MoS_2) and magnesium (Mg).

2.3 Metallographic Examination

The microstructure of the entire composite was taken to study the distribution of all phases in the aluminum matrix. Samples were first polished by surface grinder and the surface on which the microstructure is to be taken is made plane. Then, the samples are polished by four grade emery paper of increasing fineness (i.e.-1/0, 2/0, 3/0, 4/0) in such a manner that scratches of previous polishing are removed from the surface for 20 min and washed thoroughly with water. Now, the surface was seen at 10X to see any irregular scratches, if found, was again polished to make surface free from aligned scratches. Then, sample was finally polished to cotton cloth wrapped around a rotating flat disc with the mixture of brass powder and kerosene oil. Then the sample was etched by Keller's reagent which contains 1.5% HCl, 2.5% HNO_3, and 1% HF, 95% H_2O for 1 minute and immediately washed thoroughly with water. The sample was mounted over the glass plate and the microstructures are taken by a microscope integrated with the computer on 100X and 200X.

2.4 Hardness Test

To find the change in the mechanical strength of the composite manufactured, Brinell macro hardness test was carried out on the Brinell Hardness Testing machine. The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter. The test uses a 10 millimetres diameter steel ball as an indenter. The load used for the Brinell hardness is 500 kgf and six indentations are taken to the polished samples on plane faces, three on each.The load was applied for 15 seconds and the indented diameter was measured by the portable microscope having the least count of 0.01 mm. The final hardness value of a specimen was estimated by taking the average value of hardness obtained for all six indentations and the same is reported The BHN (Brinell hardness number) is calculated by the following formula

$$\mathbf{BHN= 2P/\pi\, D(D-(D^2 - d^2)^\wedge 1/2)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)}$$

Where:
P = applied force (kgf); 500 kgf in case of Aluminum.
D = diameter of indenter (mm),
d = diameter of indentation (mm).

2.5 Tensile Testing

Tensile testing is a fundamental material science test. Tensile testing has been performed to all the three composites and pure Al at ambient temperature having a standard dimension according to ASTM specification. Tensile strength for each composite was found out by testing three tensile specimens for each percentage of composite and average of all three values is taken as the final value. The tensile tests have been performed on a universal testing machine (**INSTRON-1342)**.The diameter and the gauge length of each specimen are measured prior to and after the tensile test. The ultimate tensile strength of the specimens has been estimated by dividing the maximum tensile force by the initial cross sectional area of the specimens in units of MN/m^2 MPa. After fracture of the specimen, the increase in gauge length was measured and the engineering fracture strain has been estimated as a change in gauge length per unit initial gauge length.

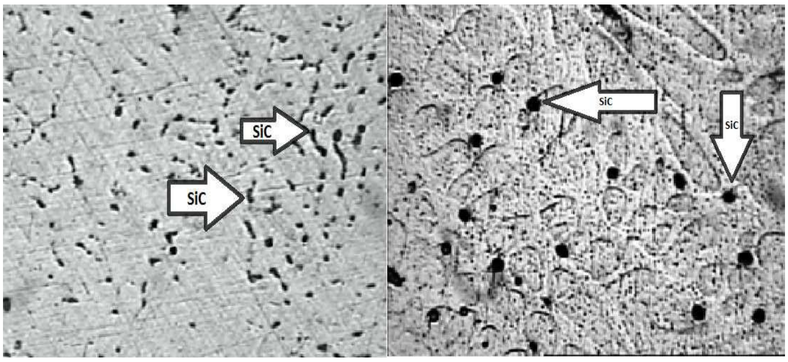
Figure 1 (a) Tensile Specimens, (b) Indentation on specimen after hardness test

III RESULT AND DISCUSSION

The composites synthesized are tested further and microstructural analysis, hardness testing, tensile testing are carried out. The various testing results are discussed below.

3.1 Microstructural Characterization

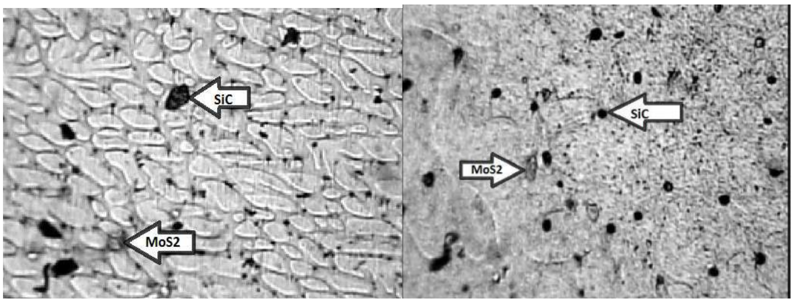
Figure 2 shows the microstructures of the Al/SiC composite at 100X and 200X obtained by addition of 10% SiC by weight. Microstructure shows the distribution of SiC particles in Al metal matrix uniformly while some of SiC particles get agglomerated to interstices of grain boundaries of aluminum metal matrix and a slight macro-segregation of particles at some places. In present study no porosity was observed. The distribution of SiC is affected by the interfacial bonding and wettability of SiC with molten metal matrix as reported by V.S.Aigbodion [8].



(a) **(b)**

Figure 2 Optical micrograph of Al+10% SiC composite (a) 100X (b) 200X

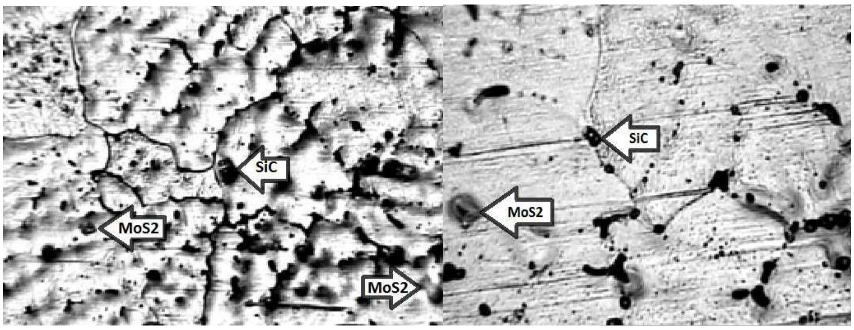
The reinforced SiC particulates are shown by black phase while metal phase is white. SiC reinforcements are shown by arrows.



(a) **(b)**

Figure 3 Optical micrograph of Al+10% SiC+4%MoS2 composite (a) 100X (b) 200X

Figure 3 (a) and (b) shows the microstructure of the Al/10%SiC/4%MoS2 composite. The micrographs indicate that the SiC particles and second phase of MoS_2 particles are uniformly distributed in the matrix through there is poor wettability between reinforcements and metal matrix. SiC particles are black in color while MoS_2 particles are lighter in color which is shown by arrow.



(a) (b)

Figure 4 Optical micrograph of Al+10% SiC+4%MoS2+4%Mg composite (a) 100X (b) 200X

Figure 4 (a) and (b) shows the microstructure of the Al/10%SiC/4%MoS2+4%Mg composite. Magnesium is added to increase wettability and grain refinement, which is evident from microstructure. From the optical micrographs, it can be seen that there is good bonding between the matrix and the reinforcement particulates resulting in better load transfer from the matrix to reinforcement material and lower porosity as reported by G.B. Veeresh Kumar *et al*. [9].

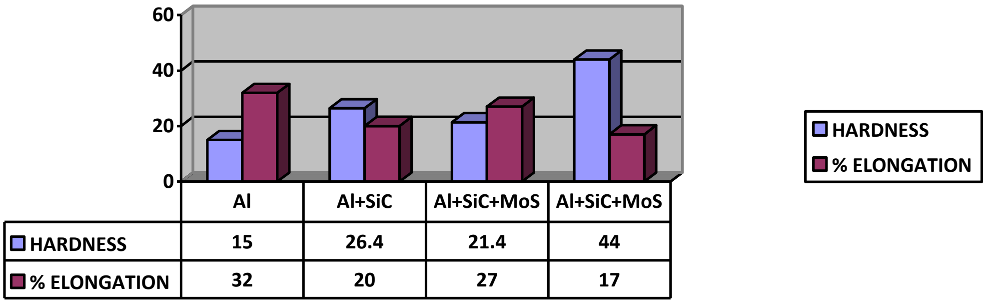


Figure 5 - Variation of hardness and % Elongation with the composition of the composites

The variation in the Hardness and % Elongation in pure Al and as well as Al metal matrix composite are shown in figure 5. The hardness values increases as Silicon carbide (SiC) added in aluminum to a value of 26.4 BHN. This is due to increase in the percentage of the hard and brittle phase of the ceramics body in the aluminum. [8] Hardness value of Molybdenum disulphide (MoS_2) added composite decreases due softer nature of Molybdenum disulphide (MoS_2) to value of 21 BHN while with addition of Magnesium (Mg), which results in good wettability hardness value increase to 44 BHN.

Table 2. Mechanical properties of Aluminum and composites

Composition	UTS (MPa)	% elongation	BHN
Pure Al	58	32	15
A l+10%SiC	92	20	26.4
A l+10%SiC+4MoS2	73	27	21.4
Al+10%SiC+4MoS2+4%Mg	200	17	44

IV CONCLUSION

The present investigation on ex-situ synthesis of Al/SiC, Al/SiC/MoS2,Al/SiC/MoS2/Mg composites and their mechanical and tribological analysis can be concluded as follows-

1. It is possible to generate ex-situ Al/SiC, Al/SiC/MoS2 and Al/SiC/MoS2/Mg composites through a simple and cost effective in melt reaction route.
2. The mechanical properties of the composite get improved as compared to that of pure aluminium and also with the reinforcement of SiC, MoS2 and Mg the mechanical strength of composite increases.
3. The metallographic study shows more uniform distribution of SiC and MoS2 is seen in the aluminum matrix, while addition of Mg results in good binding of reinforcements and aluminum matrix.

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