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Analysing the Mechanical Behaviour of Aluminum Reinforced with Silicon Carbide Composites (AlSiC)

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Abstract- **This study describes the erosion behavior of AL6063 aluminum alloy matrix filled with different weight proportions (10 wt. %, and 20 wt. %) of silicon carbide (SiC) particles and the composite being fabricated by using a widely accepted stir casting technique. Different sizes of angularly shaped alumina (Al2O3) particles are used, and the tensile and hardness tests are performed. Aluminium Metal Matrix composites is a relatively attractive material for automobile, aerospace and other engineering application due to its mechanical and tribological properties. To improve wear resistance and mechanical properties has led to design and selection of newer variants of the composite. The present investigation deal with the study of wear behavior of Al-SiC MMCs for varying reinforcement content, applied load, sliding speed, and distance. Aluminium MMCs reinforced with two different percentage of reinforcement prepared by stir casting method. An analysis of variance is employed to investigate the influence of controlling parameters, SiC content, Normal load of the composites.**

I. INTRODUCTION

Composite materials are important engineering materials due to their outstanding mechanical properties. Composites are materials in which the desirable properties of separate materials are combined by mechanically or metallurgically binding them together. Each of the components retains its structure and characteristic, but the composite generally possesses better properties. Composite materials offer superior properties to conventional alloys for various applications as they have high stiffness, strength and wear resistance. The development of these materials started with the production of continuous-fiber-reinforced composites.

The high cost and difficulty of processing these composites restricted their application and led to the development of particulate reinforced composites. Aluminium and its alloys possess excellent properties such as low density, good plasticity and ductility and good corrosion resistance. They find extensive applications in aeronautics, astronautics, and automobile and high speed train fields. However, low hardness and poor impact resistance results in their limited application in heavy duty environments. Like all composites, aluminium-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, the reinforcement material, the volume and shape of the reinforcement, the location of the reinforcement, and the fabrication method can all be varied to achieve required properties. Regardless of the variations, however, Al composites offer excellent thermal conductivity, high shear strength, excellent abrasion resistance, high temperature operation, non-flammability, minimal attack by fuels and solvents, and the ability to be formed and treated on conventional equipment.

Silicon carbide (SiC) is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. SiC is not attacked by any acids or alkalis or molten salts up to 800 $^{\circ}$C. In air, SiC forms a protective silicon oxide coating at 1200 $^{\circ}$C and is able to be used up to 1600 $^{\circ}$C.

The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. SiC ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600 $^{\circ}$C with no strength loss.

Metal matrix composites (MMCs), such as SiC particle reinforced Al, are one of the widely known composites because of their superior properties such as high strength, hardness, stiffness, wear and corrosion resistance. SiC particle reinforced Al based MMCs are among the most common MMC and available ones due to their economical production. They can be widely used in the aerospace, automobiles industry such as electronic heat sinks, automotive drive shafts, or explosion engine components.

Metal Matrix Composites (MMCs) have emerged as a class of material capable of advanced properties, aerospace automotive, electronic, thermal management and wear application. The MMCs have many advantages over the conventional metal including higher specific modules, higher strength to weight ratio, better properties at elevated temperature, and lower coefficients of thermal expansion and better wear resistance.

Aluminium composites are widely employed in the aerospace industry, automotive application and structural application.

2. EXPERIMENTAL PROCEDURE

In this study, an attempt has been made to fabricate aluminum (Al-6063)/SiC (Silicon carbide) MMCs by STIR casting process. The MMCs plates were prepared with varying the reinforced particles by weight fraction of 10% and 20%. The average reinforced particles size of SiC was 325 mesh respectively. The stirring process was carried out at 200rev/min rotating speed. Stir casting can be regarded as a popular process for manufacturing AMCs for research applications. The process is usually carried out in a stir casting furnace with the matrix and reinforcements added to the furnace and then stirred continuously. A stir casting machine consists of mainly the following parts.

- Control and Display Unit
- Stirring mechanism
- Main Casting furnace
- Pre-heating furnace

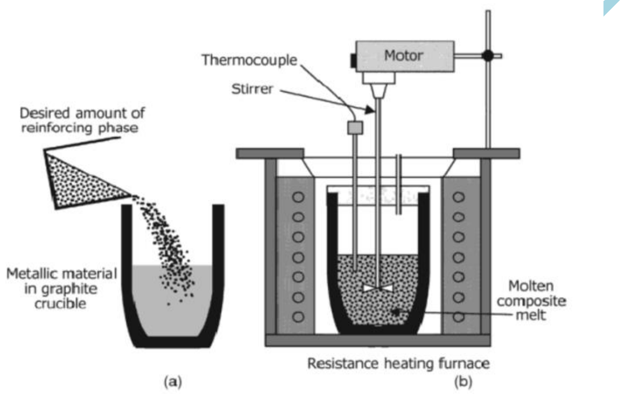
The dimensions of the mold used for casting was 100x100x10 mm. The raw material requirements were as follows:

- Metal matrix- Aluminum alloy -Al-6061)
- Particle reinforcement - Silicon carbide particles (500 mesh)
- Surfactant- Magnesium powder
- Degassing Tablets
- Crucible- Graphite (size no. 6)

Composition of samples chosen for the study

Al-SiC composites have been prepared by varying the SiC weight percentage from 10 to 20%. The weight of sample taken is 400 grams and the percentages are varied accordingly.

Sample No.	Aluminium (Grams)	Silicon Carbide (Grams)	Remarks
1	360	40	Al-10%SiC
2	320	80	Al-20%SiC



Stir casting experimental setup

The stir casting experimental setup used for fabricating Al-SiC MMC is shown in Figure 1. It consists of furnace for heating the metal, Stirrer and motor for mixing of particles. First of all, the SiC particles are preheated in a separate muffle furnace at 900 $^{\circ}C$ for 2h in order to remove the volatile substances and impurities present and to maintain the particle temperature closer to melting point of aluminium alloy. The preheating of SiC particles leads to the artificial oxidation of the particle surface forming SiO2 layer. This SiO2 layer helps in improving the wettability of the particle.

Thereafter, Al6061 billets were charged into the furnace and melting was allowed to progress until a uniform temperature of 750 $^{\circ}C$ was attained. The flux is added to Al alloy during melting to prevent oxidation of the aluminium. The melt was then allowed to cool to 600 $^{\circ}C$ (slightly below the liquidus temperature) to a semi-solid state and silicon carbide preheated mixture was added to the melt in fragments and manual stirring of the slurry was performed.

Thereafter, small amount of Mg less than 1% of the total weight is added to improve the wettability between the reinforcement and the alloy. After performing 5min of manual stirring, rest amount of SiC is added along with the hexachloroethane tablets for degassing the molten metal and to prevent porosity in the cast composites.

After the manual stirring, the composite slurry was reheated and maintained at a temperature of $750^{\circ}C \pm 10^{\circ}C$ (above the liquidus temperature) and then mechanical stirring was performed. The stirring operation was performed for 10 minutes at an average stirring rate of 150rpm. Platinum-Rhodium thermocouple was utilized in all cases to monitor the temperature readings of the furnace.

The permanent cast iron mould is preheated at a temperature of $350^{\circ}C$ before the pouring of composite mixture in to it. After that the composite is solidified, dried and taken out from the permanent mould.

3. Metallographic and micro structural analysis

Characterization by optical microscope

The micro-structural characterization was performed by an optical microscope. The sample was prepared by polishing with emery paper. After that, it was further polished in a fine grade wheel polisher. Afterwards, when the surface became scratch free, it was cleaned with acetone and investigated under optical microscope.

Micro structural analysis

The micro structural investigation of the stir casted Al6063/10%SiC and Al6063/20%SiC MMC has been carried out by optical microscope. The Optical microstructures are shown in Figure 2 & 3 at 100x and 200x. The optical micrographs of the as-cast composite revealed that the agglomerations of SiC particles are uniformly distributed in the matrix. It is apparent from the microstructure that the distributions of reinforcement particles become more uniform in the matrix as their weight percentage increases.

Optical microstructures of Al-10% SiC composite at 100x and 200x magnification

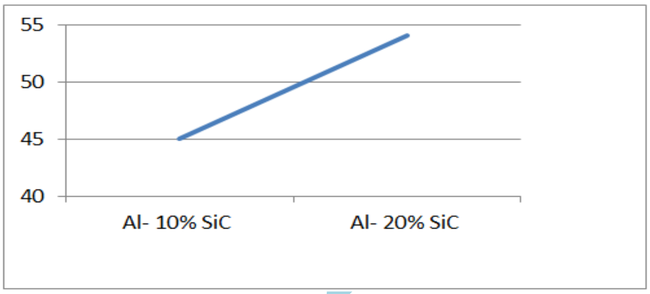
Optical microstructures of Al-20% SiC composite at 100x and 200x magnification

Hardness testing

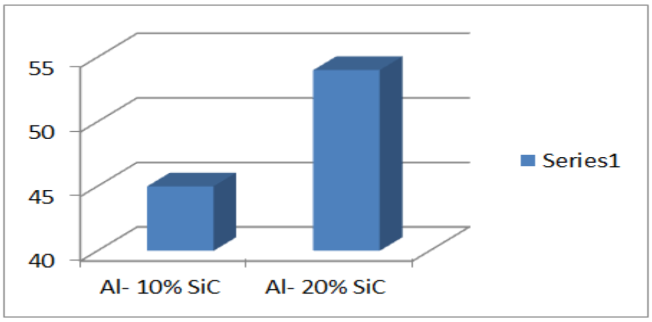
The resistance to indentation or scratch is termed as hardness. Among various instruments for measurement of hardness, Brinell's, Rockwell's and Vicker's hardness testers are significant. Vickers hardness value of Al-SiC MMCs taken at 10Kgf load and 10sec dwell time using micro indenter of diamond is shown in Table 2 and also in Figure 4 & 5.

Vickers Hardness value of Al-SiC

S. No.	Samples	Hardness (HV10)
1	Al- 10% SiC	45
2	Al- 20% SiC	54



Graph between hardness value and percentage of SiC



Bar chart diagram of hardness on increment of SiC content.

Wear Test

The Wear test was performed in a unidirectional pin-on-disk apparatus. It used to measure the wear behavior of Al-Sic under dry non lubricated condition. Samples (sizes 10 mm diameter, 20 mm height) are pressed against rotating steel roller (diameter 80mm, thickness). The setup is placed in such a way that the rotating roller serves as the counter face material and stationary plate serves as the test specimen. A 3:2:1 ratio loading lever is used to apply normal load on top specimen. The loading lever is pivoted near the normal load sensor and carries a counter weight at one end while at the other end a loading pan is suspended for placing the dead weight. The wear rate is measured in terms of displacement with the help of linear voltage resistance transducer. The wear displacement sensor allows obtaining direct measurement of the loading lever's deflection, which corresponds to the wear of the specimen plate plus the wear of the counter face. It may be noted here that wear behavior is normally expressed as weight loss while in the present experimental set up, wear is measured in terms of displacement results for wear are compared with weight loss and it shows almost linear relationship for the range of test parameters considered in the present study.

Wear mechanism

Microstructure study of the wear tracks are carried out to analyze the wear mechanism that the composites undergo during tribological testing. Wear tracks of samples having three different volume fraction of reinforcement, Al-3%SiC, Al-6%SiC and Al-9%SiC. From the SEM micrographs, it can be observed that the warm surface mainly consists of longitudinal grooves and partially irregular pits. The presence of grooves indicates micro cutting and micro ploughing effect. Thus wear mechanism is found to be dominated by abrasive wear. Also presence of pits and prows can be observed in the micrographs, thus occurrence of adhesive wear is also visible. So, from overall microstructure study it can be concluded.

That mostly abrasive wear has taken place with some traces of adhesive wear. In the present investigation the effect of four process parameters weight fraction, applied load, sliding speed and distance on the wear behaviour of Al-SiC particulate composite is studied. Apart from these, other factors like heat treatment, temperature change and particle size of reinforcement are assumed constant during this experimental study.

Wear testing

Wear resistance testing was done on Pin-On-Disc machine at load of 15N and rotational speed of disc of 400rpm. Standard cylindrical pin wear testing sample was prepared on the lathe machine having dimensions of 8mm diameter and 1inch length as shown in Figure 6.

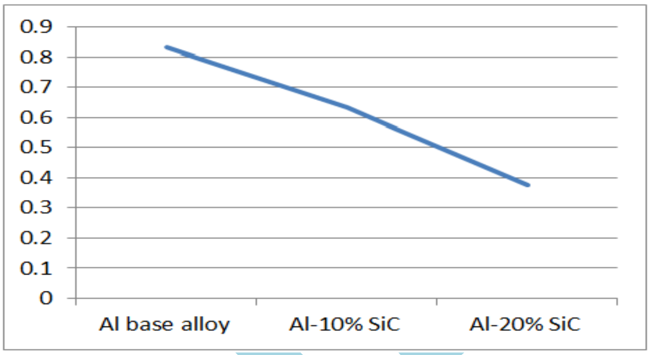
Standard wear testing sample

Wear testing parameters

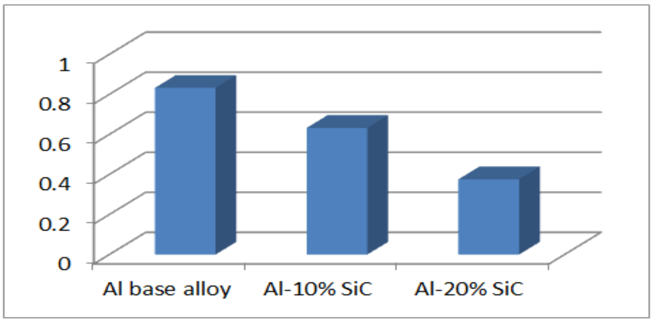
Following parameters were used to perform wear test:
Load (N)-15 Newton, Disk Rotation speed-400rpm.
Track radius-60mm, Time-60 minutes
Wear testing results of Al-SiC MMCs on pin-on-disc setup at 15N load and 400rpm speed are shown in Table 3 and Figure 7 giving the trends in wear resistance value on increment in SiC content

Wear Rate of Al-SiC MMCs

Al- SiC Composites of Varying Amounts of SiC	**Wear Rate (mm^3/m)**
Al base alloy	0.832475
Al-10% SiC	0.632448
Al-20% SiC	0.375677



Graph between wear resistance and percentage of SiC



Bar chart diagram of wear resistance and percentage of SiC

A. The dry sliding wear behaviour in the base alloy and composites were investigated against emery papers of 400 grits. The SiC particulate phase is found to reduce the wear rate (expressed in terms of gm/m, mm3/m etc) significantly in the composites. The volumetric wear rate (mm3/m) in 20 % SiC composite is reduced by 62-66% for 400 emery sliding with respect to the base alloy. In case of 10% SiC composite the corresponding reduction in the wear rate is 15-25%.

B. The wear rate is found to increase with load in all the materials studied. The increase in wear rate with load is steeped in the base alloy as compared to that of the composites. The increasing load is known to produce heating effect leading to thermal softening and seizure. Also it brings more area into sliding contact and thereby causes enhanced wear.

C. The micro mechanism of wear against the coarse abrasive emery paper was found to be characterized by deep wear tracks along with fragmented SiC particulates in the 10% SiC composite. Fine cracks were also noticed. In 20% SiC composite wear was followed by limited extent of cutting and plowing marks keeping the overall surface smooth.

4. EXPECTED CONCLUSION

Mechanical behaviour of Al-SiC-Cu metal matrix composite is studied for varying reinforcement content, applied load and analysis. It is observed that parameter wt, i.e. weight % of reinforcement is the most significant parameter influencing the wear behaviour while parameters L (applied load) and S (sliding speed) are also significant within the specific test range. Sliding distance has smallest influence on wear property of the composite. From the analysis the optimal combination of process parameter for minimum wear is found on the level, highest level of weight % of reinforcement along with the lowest levels of applied load, sliding speed and sliding distance. From the present study it is revealed that a proper control of process parameters can result in improved design of the Al-SiC composite for tribological applications. From the microstructure study of worn surfaces, it is observed that mostly abrasive wear mechanism has occurred on the wear tracks with some traces of adhesive wear mechanism.

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