Mechanical and Wear Characteristics of $ZrSiO_4$ Reinforced Aluminium Metal Matrix Composite

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***Abstract*— *Aluminum metal matrix composites(MMC) are finding applications in aerospace, automobile and general engineering industries owing to their favorable microstructure and improved mechanical behavior. Aluminium alloy Al-17Si and Zirconium Silicate (ZrSiO4) composites were obtained by stir casting technique. Four different weight percent (3, 6, 9 & 12) of reinforcement materials were added to the base alloy. The specimens were prepared as per ASTM standards and tested. Microstructure revealed a uniform distribution of the ZrSiO4 throughout the matrix. Hardness and wear properties of the composite showed an improvement as compared to the alloy without ZrSiO4 additions. The present paper highlights the salient features of casting technique and characterization of aluminum alloy Al-17Si and ZrSiO4 metal matrix composite.*

Keywords*— MMC, SiC, Zirconium Silicate, Aluminum alloy.

I. INTRODUCTION

Aluminium is a light weight metal used in several industrial application and widely in automobile sector. With silicon addition will give the strength to material with certain limitations. Aluminium alloy will play important role in the enhancing the mechanical properties but with limitations. Therefore, investigation of aluminium based materials is becoming increasingly important [1,2]. Aluminium matrix composites (AMCs) are becoming better substitutes for the conventional aluminium alloys because of characteristics like improved strength to weight ratio, energy savings, better wear resistance etc [3]. AMCs with silicon carbide particles will increase mechanical strength and wear resistance when compared to conventional alloys [4]. SiC particulates were mostly used for reinforcing the various aluminium alloys. The tensile and flexural strength improved up to 10 wt.% of SiCp, beyond which the strength decreased due to agglomeration of SiCp particulates [5]. Garcia et al. [6] have observed Al6061-SiC composites decreases the specific wear rate with increase in the volume fraction and size of reinforcement. Das et al. [7] have deliberated on formation of mechanically mixed layer (MML) consisting of debris and smeared and fragmented SiC particles. SiC needles in MML and in the subsurface region are fragmented into finer particles thus demonstrating the occurrence of surface damage during wear of LM13-SiC composites. Sahin et al.[8] observed with addition of SiC 10% increase in the wear resistance and stable value between 10-55% for Al-SiC composites produced by vacuum infiltration. Krishnamoorthy et al.[9] concluded that addition of SiC particles will improve the hardness which makes the machining difficult for AMCs. Umanath et al.[10] noticed that strengthening of composites depends on particle size, shape, volume fraction and distribution. The composite strengthening depends upon particle closure in the composite matrix. Suresh et al. have observed that one of the important limitations in AMCs is the compatibility of reinforcement in the matrix. This is the prime importance in aluminium composites. Shin et al.[11] studied the strength of Al-6061 alloy reinforced with SiC depends on temperature. The beneficial effect on strength was till temperature of 200˚C, beyond which there is no effect on strength. Sahin found from the worm surface that the small sizes of particles of SiC composites exhibits more wear as compared to large particle size of reinforcement.

It has been found the literature review that number of research carried out to improve the mechanical properties of aluminium alloys reinforced with different materials. But research related zirconium silicate as a reinforcement is found to scanty. In this present investigation zirconium silicate taken as reinforced material to the Al17Si matrix to study the wear properties.

II. MATERIALS AND METHODOLOGY

2.1 Matrix Material:

The material selected as matrix for preparing the composites was commercially available scrap automotive piston whose chemical composition was determined using spectrometer. The chemical composition of scrap piston alloy is given in the Table 1.

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Aluminium-silicon alloy is selected as the matrix material owing to its superior properties such as its high fluidity, ductility, malleability, thermal and electrical conductivities and ease of machining. It has proved its usefulness in automotive applications. The important properties of aluminium-Silicon alloy are listed in Table 2.

Table 1 Chemical composition of Al-Si-alloy (Scrap piston alloy) Silicon alloy

Sl. No.	Element	Composition Wt %
1	Si	17.450
2	Cu	0.880
3	Fe	0.430
4	Mn	0.035
5	Mg	0.723
6	Zn	0.020
7	Ti	0.015
8	Aluminium	80.481

Table 2 Properties of Aluminium-Silicon-alloy (www.encarta.com)

Property	Value
Color	Silver white
Crystallographic Structure	FCC
Density	2.7g/cm^3
Volume change on solidification	4 %
Melting point	660°C
Specific Heat	385 J
Latent heat of fusion	205 J / g
Thermal Conductivity(0 – 1000°C)	399 W/mK
Electrical Conductivity	100-103 IACS
Electrical Resistivity	0.01673 mm^2/m
Hardness	90 VHN
Tensile Strength	115-145

2.2. Reinforcement

2.2.1. Particulate Reinforcement.

Zirconium Silicate (ZrSiO4) of 10-30μm size laboratory grade was used as particulate reinforcements. Properties of ZrSiO4 is shown in table 3.

Table 3 Properties of Zirconium Silicate

Product Name : - ZIRCONIUM SILICATE EXTRA PURE
Mol. Formula : - $ZrSiO_4$
Mol. Weight : - 183.30

Sl. no.	Tests	Specifications	Results
1	Description	Off white powder	Off white powder
2	ZrO2 (+HfO2)	Min. 64.0%	64.11%
3	SiO2	Max. 0.40%	0.32%
4	Fe2O3	Max.0.13%	0.12%
5	TiO2	0.08 – 0.13%	0.11%
6	Mesh size	Min. 96% passing through 325 mesh	Complies

2.3 Melting Furnace

Fig. 1 shows the Electrical resistance furnace used for preparing the composites. The specifications of the furnace are given below:

Crucible capacity : 6kgs.
Max Temperature : 900 °C
Power : 7.5 kW, 3 phase, 420V.

Fig.1: Electrical Resistance Furnace

2.4 Mould Details

The mould used for producing the castings are permanent type made of cast iron as shown in Fig. 2. The overall dimension of the mould is 450 mm x 300 mm.

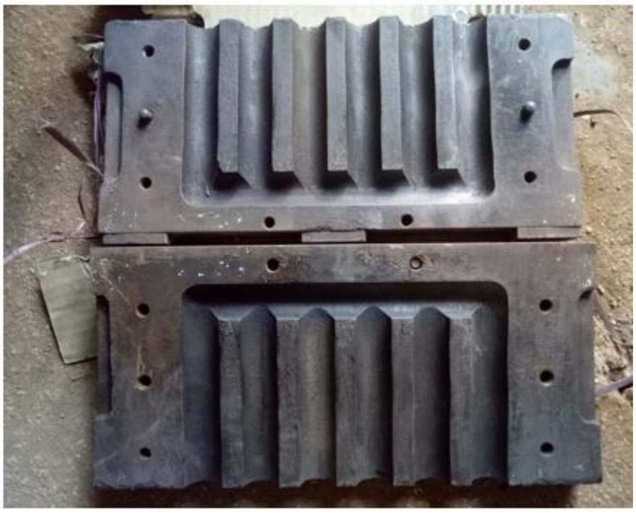

Fig.2: Cast Iron Mould

2.5 Composite Preparation

A batch of 3 kg of commercially available scrap pistons were melted in an electrical resistance furnace. The molten metal was degassed using commercially available hexa choloro ethane tablets. The molten metal was agitated by use of mechanical stirrer rotating at a speed of 75–100 rpm to create a fine vortex. Preheated dispersoids (preheated to 500 °C for 2 hours) were added slowly into the vortex while continuing the stirring process. The stirring time adopted was 5-7 minutes. The composite melt maintained at a temperature of 780°C was then poured into a metallic mould as shown in Fig 2. Dispersion of Zirconium Silicate was varied from 3 to 12 vol% to prepared composite.

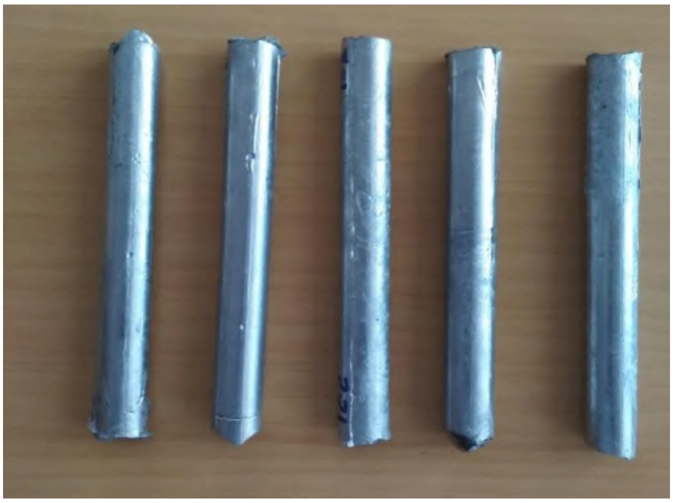

Fig.3: Casted composites of different percentages of Zirconium

2.6 Preparation of Samples

Samples were prepared from solidified cast composite whose photograph is shown in Fig 3. Specimens for hardness, sliding wear and microstructure were machined to required dimensions from the cast composite. The photographs of the prepared samples for different tests are shown in Fig 4.

Fig.4: Hardness, Microstructure and Wear Testing Specimens

2.7 Friction and Wear Test

The friction and wear behavior of cast Al-17Si-alloy (scrap piston) and the developed composites before and after heat-treatment were evaluated at room temperature using a computerized pin-on-disk wear test rig whose photograph is shown in Fig. 5.

The sample pins were of diameter 8mm and height 30mm. The load was varied from 20N to 50N in steps of 10N, while the sliding velocity was varied from 0.42m/s to 2.09m/s. A hardened steel disc of 60 HRC was used as the counter disc. The frictional force was measured using load cell of accuracy 0.1N while the wear loss was measured in terms of height loss as indicated by LVDT of accuracy 1μm. The wear rates were calculated from the height loss data in terms of volumetric wear loss per unit-slid distance. The coefficient of friction was calculated using the frictional force data.

Fig.5: Pin-on-disk Wear test rig.

III. RESULTS AND DISCUSSION

In this section Al17Si reinforced with Zirconium silicate (3%, 6%, 9% and 12% by weight) composites are taken to study the wear and hardness properties.

3.1 Effect of wear rate

Figure 6 shows the effect of wear rate for different compositions of zirconium silicate at 200 rpm for different load conditions. From the wear rate result it can be found that as the load increases the wear rate also increases linearly for all compositions of composites. This is because the fact that at higher loads there is a tendency for large plastic deformation which promotes the extent of wear debris formation leading to higher wear rates. The wear mechanism alters from mild to severe delaminating mode at higher loads. As the percentage of zirconium silicate increases it can be seen that wear rate is decreases. This resistance to wear is catered by harder zircon sand particle reinforced in the softer Al–Si alloy matrix offering more obstacles for the dislocations to propagate through the matrix. Hence decreases in wear rate are observed for the zirconium silicate reinforcement.

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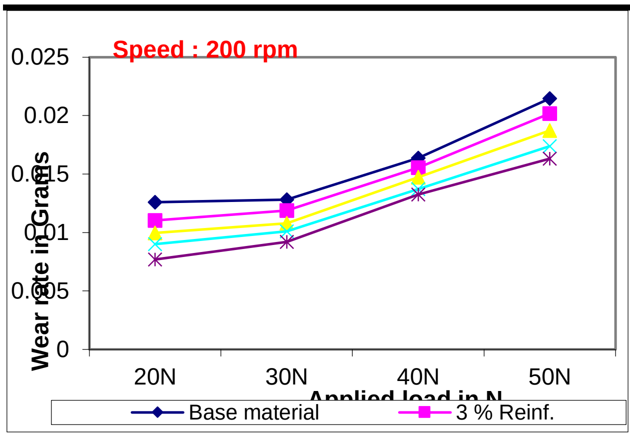

Fig.6: Effect of applied load on wear rate for different wt. % of reinforcement at 200 rpm.

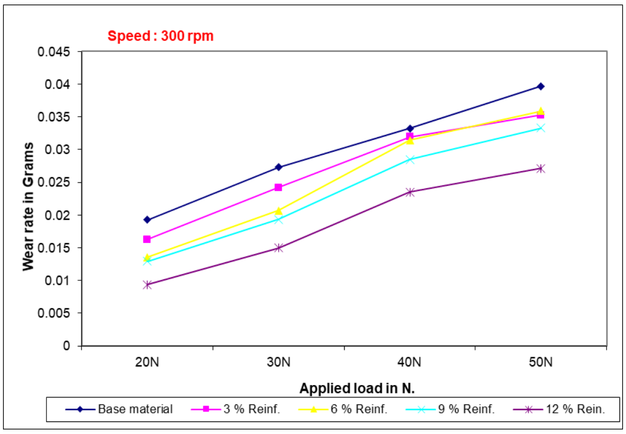

Fig.7: Effect of applied load on wear rate for different wt. % of reinforcement at 300 rpm

Figure 7, 8 and 9 shows the effect of wear rate for different compositions of zirconium silicate for different speeds (300rpm, 400 rpm and 500 rpm). Similar trends were obtained for wear rate for all compositions of zirconium silicate at higher speed. As the speed increases the wear rate also increases for all composition of zirconium silicate along with base material composite. This is because good interfacial bonding of reinforcement with the matrix and higher hardness as possessed by composite a results better wear behavior is observed. From the wear rate study we can conclude that 12% reinforcement of zirconium silicate to the base metal will improve the wear resistance properties.

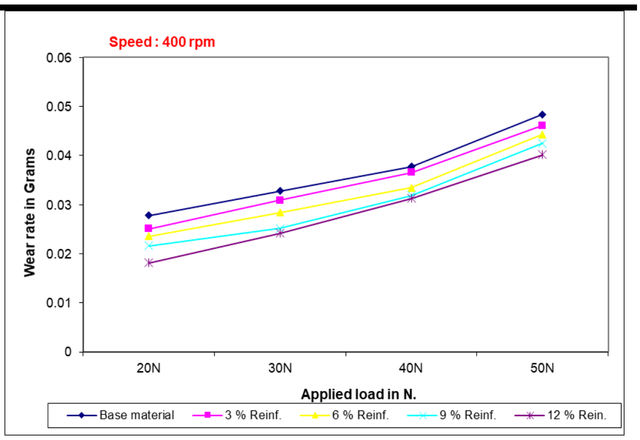

Fig.8: Effect of applied load on wear rate for different wt. % of reinforcement at 400 rpm.

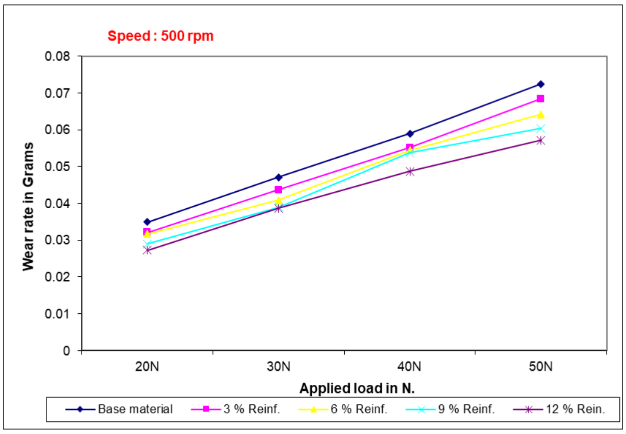

Fig.9: Effect of applied load on wear rate for different wt. % of reinforcement at 500 rpm.

3.2 Effect of Hardness

Hardness test has been conducted on each specimen using a load of 250 kg and a ball indenter of diameter 5 mm. The diameter of the impression made by indenter has been measured by Tool maker microscope. The corresponding values of hardness (BHN) were calculated from the standard formula. In the Brinell hardness test, a hardened ball indenter is forced into the surface of the metal to be tested. The standard loads are maintained as a constant for 5-10 seconds. Figure 10 shows the values of hardness for different compositions of zirconium silicate. It can be seen from the result, as the percentage of reinforcement increases the value of hardness decreases till 6% thereafter slightly increases. Since the base material is having 17% of silicon particles which is having higher hardness value. Hence any addition of reinforcement will lead into the decreased value of hardness. After 6% of reinforcement there is a tendency of increase in the hardness. Finally we can conclude that3% of reinforcement have better wear and hardness properties.

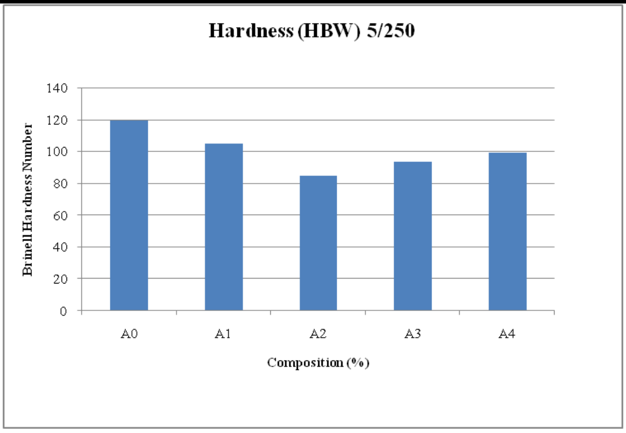

Fig.10: Effect of Brinell hardness number for different wt. % of reinforcement

IV. CONCLUSION

Experiments are conducted on different percentage of zirconium silicate as reinforcement to the Al-17-Si composites to study the mechanical and wear properties. From the research following conclusion can be made.

- As the percentage of reinforcement increases wear rate decreases at all load conditions when compared to the base material. From the result it can be seen that 12% of reinforcement will have better wear resistance properties compared to all other percentage of reinforcement.
- As the speed increases it is found that wear resistance also increases and 12% reinforcement shown better wear properties.
- Brinell hardness result shown that 3% reinforcement will give the better hardness property when compared to other percentage of reinforcement.

From research work it can be concluded that 3% of zirconium silicate as a reinforcement to the Al-17-Si composite will have the better mechanical and wear properties.

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