Experimental Studies on Al (5.7% Zn) Alloy based Hybrid MMC

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Abstract. In this investigation, an attempt is made to disperse SiC (20-25 microns) and Gr (15-20 microns) in the aluminium alloy having Zn, Mg and coper as major alloying elements. The composite is further subjected to mechanical testing to determine various properties like hardness, tensile strength and wear resistance. The alloy and composite samples were tested in the un heat treated conditions. All the tests were done at the laboratory conditions as per ASTM standards. The Pin-On-Disc tribometer is used to test the two-body abrasive sliding wear behaviour in dry conditions. The wear pattern is analysed by the optical images of worn surface taken in an inverted metallurgical microscope. The calculated density is found to be reducing as the SiC and Gr quantity is increased in the base alloy. The as cast Al alloy was found to be having highest hardness. The introduction of SiC tend to increase the hardness and UTS, since Gr is also introduced simultaneously which tends to reduce the hardness and UTS of composite. The composite having highest quantity of Gr showed superior wear resistance which is mainly because the Gr particulates provide an inbuilt lubricating properties to composite. The analysis of images of worn surface showed the abrasive and delamination pattern of wear. The composites developed in the present work can be used in the automobile and aerospace parts that are light in weight and require self-lubricating properties to enhance the wear resistance.

1. Introduction
Metal Matrix Composites are the tailor fit materials produced by combining two or more non-similar materials to produce improved properties. Conventional materials may not always give the desired properties in all service environments [1] hence there is a much scope to explore possible new materials cantered at composites. Of the different matrix materials used aluminium and its alloys are the most favourable materials because of easy processing, broad range, lesser density, superior wear resistance, superior thermal conductivity, heat treatable property, enhanced elastic modulus and strength, stiffness and dimensional stability [2]. Aluminium matrix composites have gained importance and widely preferred because of their higher specific strength and superior wear characteristics. Tribological characteristics of Aluminium based composites have been mostly considered for research because they can be used as bearing material, brushes, contact strips etc. It is found that dispersion of ceramic particles enhances the seizure resistance of the composite at elevated temperature in comparison to base matrix. The investigators observed that the composite showed lesser wear rates in comparison to base alloys confirmed by the dry sliding wear behaviour of composites developed by stir casting method. It is found that wear rate increased with increasing normal force and sliding distance. The wear rate of the composites decreases with the rise in the quantity of Al₂O₃ particles at constant particle size. Also as the particle size increases wear rate reduces at constant volume fraction. Studies for dry sliding wear behaviour of Al/graphite hybrid

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composite has shown that the hybrid composite displayed a better tribological characteristics and lower wear losses [3]. Graphite is one of the most widely used solid lubricant materials. Earlier researchers have already focused their investigation on applications of aluminium graphite composite. There are also earlier reports from some investigators who identified the trend that aluminium graphite composite containing the small amount of graphite exhibit superior wear properties over the base alloys. The limitation with the aluminium graphite composite is in using graphite as a solid lubricant whose introduction results in the loss of strength of the composite [4]. For the Al-Al2O3-Gr composites, graphitic film could have been formed and it was expected to act as a lubricating layer. During abrasive wear process the graphitic layer would be removed first and later hard Al2O3 reinforcement particles takes lead in further reducing of wear process [5]. Importance is given on sliding wear behaviour of hybrid composites i.e. aluminium matrix alloy reinforced with SiC and Gr. It was seen that the addition of Gr to Al-SiC was found to be advantageous in tribolayer formation [6]. It was observed that abrasive wear resistance of SiC reinforced Al alloy increased with increased sliding distance [7]. There is a decrease in friction coefficient because of the increase in bulk mechanical properties because of dispersion of SiC and appearance of graphite film [8]. SiC reinforced AMC’s is observed to have higher modulus, strength and the wear resistance in comparison to alloys which are conventionally obtained [6]. It is found that the rate of wear of the AMC’s reinforced with SiC decreases with increase in volume fraction and reinforcement size [9]. Both mechanical strength and wear resistance of Al alloy increases with introduction of SiC particles. But due to addition of the SiC the hardness increases and makes the machining hard [10]. On the other hand, it is noticed that if Gr particulates are added this makes the machining easy and reduce the wear rate compared to previous [11]. Also on increasing the % of the Gr particulates results in decrease in hardness due to increased porosity [12]. In the present work, an effort is made to produce the Al alloy based hybrid composite by reinforcing SiC and Gr in varying proportions. The developed composite is expected to be a tailor mate material for wear applications with self-lubricating properties.

2. Experimental details

2.1. Matrix material

In this investigation, Al alloy having Zn, Mg and Cu as major constituents is used as matrix material. The chemical components of this alloy have been given in table 1.

| Table 1. Chemical composition of Al alloy matrix. |
|-----------------------------------------------|
| Element: | %wt.  |
| Al      | 89.8  |
| Zn      | 5.7   |
| Mg      | 2.24  |
| Cu      | 1.59  |
| Fe      | 0.294 |
| Cr      | 0.223 |
| Mn      | 0.022 |
| Others  | Rest  |

2.2. Reinforcements

To produce hybrid composite SiC and Gr particles are used. SiC particles were in the range 20-25 microns and Gr particles were in the range 15-20 microns. SiC particles exhibits high hardness and low coefficient of thermal expansion. Also, these are highly wear resistant and has good mechanical properties such as high temperature strength and thermal shock resistance [13]. Gr is used as another reinforcement in the present work owing to its layered structure and very good lubricating
properties. Particle shape of SiC and Gr has been shown in figure 1. The SiC particles are diamond shaped with sharp edges and Gr are flaky in nature.

![Image of SiC and Gr particles](image1.png)

**Figure 1.** Optical image (200X) of (a) SiC and (b) Gr particles.

### 2.3. Casting of specimens

The conventional motorised stir casting was used to cast the alloy and the composite specimens. The set up used has been depicted in figure 2.

![Stir casting process](image2.png)

**Figure 2.** Stir casting process

The crucible before loading was subjected to stepped annealing by heating to 100\(^{\circ}\) C for 2 hours, subsequently by 2 hours heating at 300\(^{\circ}\) C and 1 hour at 500\(^{\circ}\)C with subsequent furnace cooling to room temperature. The crucible was cleaned and kept inside the furnace at 750\(^{\circ}\)C. The molds are cleaned with wire brush, coated the mold cavity with mixture of graphite power and water emulsion. Assembled molds are preheated to 450\(^{\circ}\)C before pouring the melt into them. Reinforcement materials were also (SiC and Gr) preheated in the muffle furnace to remove volatile material. About 1 kg of aluminium alloy was kept in the crucible for melting. Material was heated till it melts, slag remover (alkaline powder) was used to remove slag from the matrix material. \(\text{C}_2\text{Cl}_6\) (Hexa chloroethane) was added to remove entrapped gas. A constant stirring speed of 120 rpm is maintained. When the vortex is formed in the melt SiC and Gr are added in varying proportion to produce the composite. The melt mixture is continued to stir for 5 minutes and then the melt is poured in the preheated molds to allow for solidification, table 2 shows the types of specimens casted and their coding.
Table 2. Details of specimen casted.

| Specimen code | Composition |
|---------------|-------------|
| #1            | As cast alloy |
| #2            | 2 SiC+0.5Gr   |
| #3            | 2 SiC+1Gr     |
| #4            | 4 SiC+0.5Gr   |
| #5            | 4 SiC+1Gr     |

2.4. Density of specimens

The density is calculated by measuring the actual dimensions of diameter and length of all specimens. The variation of density for different specimens has been shown in figure 3.

![Figure 3. Variation of density of as cast alloy and composite specimens.](image)

2.5. Hardness test

The hardness test was done by Vickers hardness tester using a diamond indenter and 100 kg load applied for 15 s. The 400, 600, 800, and 1000 grit emery paper was used to polish the test specimen to decrease the machining scratches and the effects of surface defects on the sample. The test was done at ambient weather (30°C) and the hardness was measured at five spots on the surface of each sample to calculate the average VHN. The unpolished specimen is shown in figure 4. The graphical variation of hardness of different specimens has been depicted in figure 5.

![Figure 4. Specimen for hardness measurement.](image)

![Figure 5. Variation of hardness of specimens.](image)
2.6. Tensile test
The tensile strength of alloy and the composite were determined by tensile testing machine as per ASTM-E8M standard. The figure 6 depicts the tensile specimens prepared by CNC turning.

![Tensile test specimens](image1.png)

**Figure 6.** Tensile test specimens.

**Figure 7.** Variation of true UTS of composite.

The variation of true UTS and the % elongation have been depicted in figure 7 and figure 8 respectively.

![Variation of true UTS and % elongation](image2.png)

**Figure 7.** Variation of true UTS of composite.

**Figure 8.** Variation of peak displacement (%) for specimens.

2.7. Wear test
To understand wear pattern of aluminium alloy and composite specimens in unlubricated conditions, testing was done in pin-on-disc type wear and friction monitor [DUCOM, India make; Model: TR-201CL] supplied with data acquisition system as shown in figure 9. The wear tests were conducted as per ASTM G-99 standards.

![Pin-On-Disc machine](image3.png)

**Figure 9.** Pin-On-Disc machine used for wear testing.
Pin type specimens of 8 mm diameter and 30 mm length were used for testing wear behaviour of the material. A hardened steel disc (En31) was used as the counter surface in the wear test. The test was conducted with various loads of 2 kg, 3 kg and 4 kg at a disc speed of 300 rpm for the constant sliding distance of 60 mm. The test was carried out at room temperature (30°C) with a relative humidity of 60–65%. The initial weight of the specimen was measured in an electronic weighing machine. The wear test was conducted after the initial run in period of 5 min up to 20 min for each 2, 3, 4 kg when the pin specimens were entirely in contact with the disc surface. At the end of each trial, the specimen was washed with acetone, dried and then weighed to know the loss in mass because of wear. The results of wear test have been plotted for different normal loads and have been shown in figures 10-12.

![Figure 10. Wear behaviour of specimens for 2 kg normal load.](image1)

![Figure 11. Wear behaviour of specimens for 3 kg normal load.](image2)

![Figure 12. Wear behaviour of specimens for 4 kg normal load.](image3)

3. Results and discussion

3.1. Density
Increase in the amount of reinforcements has led to the decrease in density of the composites. This could be due to increase in the porosity level with higher quantity of reinforcements. The entrapment of gas while stirring, release of hydrogen, the shrinkage during solidification and existence of air pockets in the molten alloy could decrease the density of composite [14]. But certain amount of porous structure is unavoidable during the fabrication composites. The similar nature of variation in density is noticed by some researchers in their work [15-21]. There will be always a tendency to increase density of composites due to ceramic reinforcing particles (SiC), but however there will be reduction in density because of dispersion of light weight reinforcements (Gr) in the hybrid composites.

3.2. Hardness test
Hardness of the composite tends to increase with the addition of SiC above the alloy hardness. It may be because of hard SiC particles present in the matrix alloy. But since the Gr particles are also present
in the composite, they try to decrease the hardness as compared to base alloy [5]. This decrease in hardness could be due to low hardness of graphite particulates than the base alloy [15], [22], [23]. Further the brittle characteristic of Gr due to higher quantity makes the composites to undergo plastic deformation. Similar behaviour is noticed by the previous researches also [4], [13], [24-28]. Due to lubricating property of Gr, an easy movement of grains along the slip planes takes place and hence material deforms easily while indenting [29].

3.3. Tensile test
Reduction in UTS could be due to existence of graphite reinforcement particles which due to their low hardness and brittle nature imparted brittleness in the composites because of which composites shows low resistance to the tensile stress produced [25], [30], [31]. Also, the peak displacement (%) has found to be decreased with increasing quantity of graphite particles in the matrix. The variations of these for specimens have been depicted in figure 7 and figure 8. The peak displacement (%) has increased with the reduction in hardness of the composite. The brittle behaviour of the reinforcing particles (Gr) performs a momentous protagonist in reducing the ductility since graphite as an indulgent reinforcement is brittle in behaviour and enlarged the brittleness in the aluminium matrix composites that has lowered ductility [16]. Also, the hard SiC phase in the matrix alloy offer protection to the softer alloy matrix. Thus, limiting the deformation [32].

3.4. Wear tests
The variation of mass loss of different composites has been shown in the figures 10-12. The graphite particles in the hybrid composites has set a trend to reduce the mass loss during wear test and this is probably because of thin layer of graphite on the rubbing surface [33] which in turn prevents the direct metal to metal contact [28], [29], [34-40] The governing wear mechanism is found to be the abrasion and delamination. The graphite in the hybrid composite also would resulted in decrease of coefficient of friction of the composite and this is attributed to release of graphite which acted as a solid lubricant during the wear process. Images of the worn surfaces of composite specimens were captured at 200X magnification by using an inverted metallurgical microscope. Typical images have been shown in figure 13. For the specimen #2 having 2% SiC and 0.5% Gr the wear tracks were fine with delamination at few spots. For the specimen #3 the wear tracks are wider compared to the previous specimen. Here also at some spots the surface damage has taken place may be because of hard SiC particles at the interface. The grooves appear to have grown further deeper and wider for specimens #4 and #5. As seen in the micrographs the grooves are not regular but have grown irregularly with ploughing at some of the spots. The analysis of images of worn surface indicates that the abrasive and delamination wear pattern are more dominant in the composites produced.

![Figure 13. Wear track macrographs of composite specimens at the end of 20 mins. with 4 kg, normal load.](image-url)
4. Conclusions

- Simple and cost effective vortex stir casting can be used to produce the composites with uniform distribution of particles.
- Generally, increase in the quantity of SiC alone will lead to increase in the composite hardness but since the composites in the present case are also reinforced with Gr particles, which eventually reduced the hardness in comparison to base alloy.
- The tensile strength of the composites is found to be reducing as the Gr particles quantity is increased.
- The presence of graphite in the hybrid composites has set a trend to reduce the mass loss during wear test and this is probably due to the formation of thin layer of graphite on the rubbing surface. The governing wear mechanism is found to be the abrasion and delamination.
- The graphite in the hybrid composite also would resulted in decrease of coefficient of friction of the composite and this is attributed to the release of graphite which might have acted as a solid lubricant during the wear process.
- The wear rate is less at lower load but it has increased with increase in the load. The wear surface has undergone surface damage in some cases which is probably because of hard ceramic particles entrapped in the groves in the direction of sliding.
- The composites tested showed similar type of variation in the properties as that of composites having same quantity of reinforcements but replaced by Al2O3 instead of SiC.

5. References

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