A Study on 3-Body Abrasive Wear Behaviour of Aluminium 8011 / Graphite Metal Matrix Composite

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Abstract. Metals and alloys have found their vital role in many applications like structural, corrosive, tribological, etc., in engineering environment. The alloys/composites having high strength to low weight ratio have gained attention of many researchers recently. In this work, graphite reinforced Aluminium 8011 metal matrix composite was prepared by conventional stir casting route, by varying the weight % of reinforcement. Uniform distribution of Graphite in matrix alloy was confirmed by optical micrographs. Prepared composite specimens were subjected to 3-body abrasive testing by varying applied load and time, the silica particles of 400 grit size were used as abrasive particles. It was observed that with the increase of weight% of Graphite the wear resistance of composite was also increasing and on comparison it was found that reinforced composite gives good wear resistance than base alloy.

Keywords: 3-Body abrasive wear, Aluminium 8011, Stir casting.

1. Introduction
Since last two decades, composite materials have attracted researchers than their counterpart Monolithic materials due to ability to alter their physical properties and mechanical properties by varying filler phase. Based on type of matrix phase, composite are divided into metal matrix (MMC), polymer matrix (PMC), ceramic matrix composites (CMC) [1]. MMCs have good strength, thermal conductivity, damping properties, low coefficient of thermal expansion and lower density. For these reasons it is preferred in tribological applications. Aluminium is used as matrix phase in MMCs, because of its attractive mixture of properties, such as low weight, corrosion resistance, easy maintenance of final product, high strength to weight ratio, low cost and high wear resistance [2]. In particular Aluminium 8011 has properties like cast ability, corrosion resistance and high strength to weight ratio [3]. Abrasive wear can be defined as wear in which hard asperities on one body, moving across a softer body under some load, penetrate and remove material from the softer body, leaving a groove. Abrasive wear can take place in two different forms: two-body and three-body abrasion. In Two-body abrasive wear is caused by hard protuberances or embedded hard particles forced against and moving along solid surfaces. The basic fact in 3-body abrasion is surface wear caused by loose abrasive particle which can freely move (roll or slide) between contact surfaces. These abrasive particles spend 90% of time by rolling and about only 10% of the time by positioning themselves between the solid surfaces. Hence the wear rate in the 3-body abrasion is lower than that of the 2-body abrasion[4,5]. In current years, a lot of research has been conducted to study the wear behaviour of thermoset matrix in composite applications. Yousif et al. [4] learnt the 3-body abrasive wear behaviour of chopped strand mat glass fibres reinforced polyester (CGRP) for different composite fibre orientation and summarised that CGRP exhibited improved wear resistance capacity in parallel orientation. Fillers and fibre reinforcements play a significant role in determining the abrasive wear of...
the polymer matrix composites. Suresha et al. [5] studied the 3-body abrasive wear of silicon carbide (SiC) filled in glass fabric reinforced epoxy (G-E) composites; SiC decreased the specific wear rate of G-E composite. Al-Rubaie et al. [6,7] in their work varied the load applied, SiC Volume fraction and size of the particle so as to investigate their effect on the wear properties of Al-SiC MMC. They proved that the wear rate is directly proportional to abrasive particle size. Ahlatci et al. [8] showed that addition of SiC to the alloy, has positive effect on resistance to wear. Also wear rate increases by increasing particle size of Al₂O₃. Chen et al. [9,10] did an experimental investigation on the wear properties of Al-SiC considering applied load as important parameter. They studied the effect of heat treatment on the fretting wear behaviour of Al-SiC MMC and showed that fretting wear resistance increases by increasing hardness of the material through heat treatment. A study of effect of sliding distance on wear resistance of Al-SiC was performed by Rao and Das[11]. They concluded that as load and sliding speed increase wear rate also increases, and heat treatment positively affects wear resistance. Sharma et al. [12] conducted a wide range of tests to study the effect of SiC reinforcement fraction and inferred that with increase in volume fraction wear rates decrease.

In this present work, the aluminium 8011 is reinforced with graphite to increase the wear resistance capacity. The composite was prepared by two step conventional stir casting rout due to its simplicity and cost-effectiveness. Prepared composite specimens were subjected to 3-body abrasive testing by varying applied load and time.

2. Experimental Procedure

2.1 Material

In this work, as already mentioned, Aluminium 8011 alloy was used as metal matrix composite. In this alloy, magnesium has poor alloying element, hence magnesium was used as wetting agent for proper mixing. The chemical composition and mechanical properties are given in table 1 and 2 [13].

| Material | Fe | Si | Mn | Zn | Cu | Ti | Cr | Mg | Al |
|----------|----|----|----|----|----|----|----|----|----|
| Weight % | 1  | 0.9| 0.2| 0.1| 0.1| 0.08| 0.05| 0.05| 97.5|

| Density | Elastic Modulus | Strength to Weight Ratio | Ultimate Tensile Strength | Thermal Expansion |
|---------|-----------------|--------------------------|---------------------------|------------------|
| 2.72 g/cm³ | 71GPa | 40kN-m/kg | 110Mpa | 21.8µm/m-k |

2.2. Reinforcement

Graphite powder of an average size of 50 microns were used as reinforcement, Graphite powder has physical properties like good electrical and thermal conductivity, high purity, and temperature stability. Graphite is a well-recognized solid lubricant which also has the advantage of low density. In graphite reinforced Aluminium Matrix Composites (AMCs), Graphite serves as a solid lubricating layer between the composite and rubbing surface helping in reduction of composite wear and does not need any additional solid and liquid lubrication [14].

2.3. Composite preparation

The Al-Gr composite was fabricated by two step mixing stir casting method, stirring speed was gradually increased up to 300rpm and it was done for about 300sec. When compared to conventional stirring, double stir casting results in more uniform microstructure [1]. The Al 8011 alloy ingots, were cut into small pieces using hand press, placed in graphite crucible and heated in a resistance furnace.
up to 750°C above its melting point (660°C), the maximum temperature level of furnace being 1200°C. Degassing tablet was used to remove entrapped gases. To facilitate easy circulation of particles into the alloy during melting and wettability between alloy and graphite, 2 wt.% of Magnesium was added. Graphite was preheated to a temperature of about 300°C in a preheater and then added to molten metal and continuously stirred using zebrine coated steel stir. The graphite percentage was varied from 2% to 8% by weight with the increment of 2%. Uniform distribution of Graphite in Aluminium matrix alloy was confirmed by Optical Micrographs. The composite was then poured in a prepared mould box of mild steel material with dimension of 150mm length, 25mm width, 8mm thick, and then it was cooled in air. It was then cut according to ASTM G-65 Standard, to the dimension of 75mm× 25mm× 8mm and then carried for testing. The wear characteristics of the composites were studied by using a 3-body abrasive wear tester. The wheel used in the tester is made up of chlorobutyl rubber wheel of dimensions, length -130 mm, width -10 mm and rotating at a speed of 200rpm. The sample was placed on the platform of wear machine so that flat surface of the sample will be touching the rubber disk while rotating, the silica of 400 grit size was poured in between wheel and specimen through nozzle. The load is applied in the range of 10, 20 and 30kgs for different duration of time 10, 20, and 30 min. The rubbing action between wheel, specimen, and silica results in loss of weight. When each sample was completed the specimen was removed and then cooled in air. The mass of each specimen was measured before and after wear test by electronic precision balance. The mass difference when divided by sliding distance gives wear rate [15]. Figures 1a and 1b show test specimens before and after wear test respectively.

![Figure 1 a. Specimens before wear test.](image1)

![Figure 1 b. Specimens after wear test.](image2)

3. Result and discussion

In 2-body abrasion process, particles are rigidly attached to the second body, where as in 3-body abrasion process, wear is caused by loose abrasive particles which can freely move between contact surfaces. The wear rate in the three-body abrasion is lower when compared two-body abrasion [16]. The results of 3-body abrasive wear test for various combinations of applied load and time were tabulated.

3.1. Microstructure

Figure 2(a) shows optical micrograph of Al alloy 8011 with 2% reinforcement, at 30 magnification scale. Similarly figures 2(b), 2(c) and 2(d) show micrographs of 4%, 6% and 8% reinforcement in Al alloy 8011 respectively. The microstructures show that uniform distribution of graphite particles throughout the aluminium alloy. This indicates that there is good bonding between the alloy and reinforcement particles resulting in good wear resistance.
Hence it can be concluded that the two step stir casting is a fairly reliable process to produce Al-Gr composites.

3.2 Wear behaviour
It is observed that out of all composite series, the base alloy gives greater wear in comparison to the composite containing graphite. The presence of graphite will help to reduce the wear rate of the composites by providing a solid lubricating layer between the composite and the rubbing hard counter surface [14]. Results of this wear test are shown in table 3 and depicted in figure 3. These graphs reveal that the wear resistance of composite increases when Graphite content is increased from 2% to 8%. They also show that reinforced composite gives good wear resistance than base alloy.

| Sl. No | Time (min) | Load (kg) | Base (Metal) Wear rate | Al+2% Gr. Wear rate | Al+4% Gr. Wear rate | Al+6% Gr. Wear rate | Al+8% Gr. Wear rate |
|--------|------------|-----------|------------------------|---------------------|---------------------|---------------------|---------------------|
| 1      | 30         | 10        | 1.6892                 | 1.5593              | 1.3987              | 1.1681              | 0.7839              |
| 2      | 30         | 20        | 2.4876                 | 2.2513              | 2.0819              | 1.7295              | 1.5947              |
| 3      | 30         | 30        | 2.8695                 | 2.6132              | 2.4613              | 2.1163              | 1.9372              |
4. Conclusion

3-Body Abrasive wear behaviour of Al 8011 AMC reinforced with Graphite was studied in this work. The samples were subjected to wear test by varying the load in the range of 10-30 kgs for various durations of time at constant speed of 200 rpm. From the experimental investigation following main conclusions are drawn:

- Successful fabrication of 8011 Aluminum composite reinforced with Gr is possible by simple two-step stir casting process.
- On comparison it is found that reinforced composite gives good 3-D wear resistance than base Al alloy.
- It is observed that with the increase of weight% of Graphite the wear resistance of composite is also increased.
- Also the wear loss of composite increases with increase in load.

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