Fabrication and Tribological Behavior of Al3003-SiC Reinforced MMCs

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Abstract. The world is moving in the direction of development of novel materials, there must be an alternative for everything which makes utilization of resources efficiently. In this domain, the significance of Aluminium (Al) Metal Matrix Composites (MMCs) use increased in many industrial segments. This paper mainly focuses on the tribological behavior of Al3003 alloy with is reinforced with Silicon Carbide (SiC) powder of 25μm size. The Al3003-SiC MMCs were fabricated by using liquid metallurgy technique stir casting process. The SiC reinforcements were incorporated 0 to 4.5% in the phases of 1.5% weight percent (wt%). The obtained MMC specimens were subjected to investigative studies related to density, optical and tribological properties. All the studies and experimental work were carried out in accordance to the ASTM standards. The Al3003-SiC composites theoretical and practical evaluated density values are in line with each other and increased with increase in SiC amount in Al3003 matrix material. The optical micrographs of the Al3003-SiC MMCs showed respectable bonding between matrix and reinforcement particle with minimal casting defects. The sliding wear tests have been done on Pin on Disc tribology meter at different loads varying 10 to 40N in the strides of 10N by maintaining other tribological parameters constant. The wear test outcomes showed that higher resistance to wear was shown by Al3003-SiC composites compared to unreinforced alloy and the composite contain higher SiC amount showed highest resistance to wear.

Keywords: Aluminium, Al3003, Silicon Carbide, Density, Microstructure, Wear.

1. Introduction
As time progress the engineering community is looking to upgrade and develop new type of materials which are durable and highly useful in various industrial applications. So as growing needs are being increased the importance and significance of particulate reinforced MMCs usage and applications are increased. There are many methods to fabricate the particle reinforced MMCs like liquid and powder metallurgy techniques, of which liquid casting metallurgy route is most widely adopted because to its easy to fabricate and economics. The choice of fabrication process depends on its property requirement, cost of production, reliability, and future application [1]. More recently hybrid MMCs with particulate reinforcement are widely adopted in engineering applications with the combination of minimum two types of reinforcement materials with added advantage of their properties to get the better mechanical and physical properties [2]. This will allow a better degree of freedom to design that different material combinations material in any applications. The improvement in the properties of
reinforced material or alloy depends on their intrinsic properties of composites like shape, volume fraction, size, orientation, and distribution of reinforcement phase in MMCs [3]. Many scholars or research had shown applicability and usage of hard fibres/whiskers/particles as a ceramic reinforcement in various Al alloy MMCs as a main material in the automobile engines, cylinder liners, marine and aircraft applications etc, there are certain techniques other than traditional casting have been developed by scientists to fabricate MMCs, some of them are stir casting, rheo-casting, die casting, spray forming etc [4]. Among these, the stir casting process has its own advantages like less cost of production coupled with economical, better flexibility ability to fabricate various composites, suitable for mass production, we can get good matrix reinforcement compatibility and near net shapes. Al-based MMCs have superior mechanical properties to all other MMCs [5-7]. The wear rate of an Al6061-Titanium Dioxide composite is affected by several factors, including load, rpm, sliding size, and reinforcement [8, 9]. Wear of the modules causes most system breakdowns [10, 11]. When Al6061-Al2O3 composites were subjected to a dry sliding wear inspection, very different mechanisms were observed [12]. Temperature and load also influence the wear rate of Al6061-Silicon Carbide (SiC) composites. According to reports, Al6061-SiC composites would have a lower wear rate as load increases [13]. It was discovered that composites of Al6061 and short fibresaffil fillings had increasing wear resistance when tested [14]. The MMCs with 15% SiC particulates as reinforcement and manufactured using powder metallurgy technique have strong wear tolerance, according to the publications [15]. The microstructure, sliding speed, sliding distance, and load applied all have significant impact on wear of composite. It was discovered that as applied load increased to Al2219-SiC composites, wear, and cracking of SiC particles increased [16]. Sliding wear is one of the causes for the composite's maximum wear when exposed to various loads and speeds [17]. When dry sliding, there is a transition in wear rate from mild to extreme as temperature of Al6061 alloy rises [18]. The properties of Al6061-Albite and Al6061-Graphite (Gr) were investigated, and it was discovered that as percentage of Gr filler increased, properties like elongation, modulus, and strength increased, while hardness decreased. Increased Albite content in Al6061-Albite composites resulted in increased stiffness and decreased ductility [19]. The key goal of this project is to create composites with Al3003 alloy and SiC micro-powder as reinforcement. It also entails the use of different experiments to investigate the composites' physical, optical, and tribological properties.

2. Fabrication, Matrix and Reinforcement Material Details

2.1 Matrix Al3003 and SiC Reinforcement Material Details

Like other aluminium series alloys, Al3003 also has good corrosion resistance, moderate strength but not heat treatable and generally develops strengthening from mainly cold working Al3XXX series is an alloy of Al and Manganese (Mn) commonly utilized in sheet metal applications such as kitchen and gas pipeline applications, downspouts, gutters, food processing units, roofing, and siding. In the current studies Al3003 was selected as matrix material and obtained from Mallinath Metal, Mumbai, Maharashtra, in the form of sheets as shown in Figure 1. The reinforcement of SiC laboratory grade of 25µm was procured from Parshwamani Metals Mumbai, Maharashtra, as shown in Figure 2. The composition of Al3003 alloy is shown in table 1, and properties of matrix and reinforcement particulates are shown in table 2.

| Chemical composition | Si  | Fe  | Cu  | Mn  | Zn  | Others | Al  |
|----------------------|-----|-----|-----|-----|-----|--------|-----|
| Al6061               | 0.60| 0.70| 0.10| 1.30| 0.10| 0.1 to 0.5 | Bal |

Table 1. Chemical composition of Al3003 alloy by wt%.
2.2 Fabrication of MMCs

The Al3003-SiC composites were made using the stir casting process system of liquid metallurgy techniques. The Al3003 alloy was heated to 710°C in a container of SwamEquip’s computerized bottom pouring style stir casting furnace in Chennai, TN. Coverall powder was applied to improve wettability, remove gases from molten metal, and form a protective barrier between molten material and atmosphere after securing molten alloy catalyst such as Magnesium chips and degassing tablets Hexachloroethane.

Table 2. The base matrix and reinforcement materials properties.

| Material | Density (g/cc) | Hardness (HB500) | Elastic Modulus (GPa) | Tensile Strength (MPa) |
|----------|----------------|------------------|----------------------|-----------------------|
| Al3003   | 2.73           | 35               | 70-80                | 125                   |
| SiC      | 3.1            | 2800             | 410                  | 3900*                 |

At a stirrer speed of 400rpm, a steel stirrer coated with graphite was used to stir the molten alloy. The micro particulates of SiC powder were preheated to 350°C using a muffle furnace after sufficient degassing was assured, before being added into the vortex created by stirring.
Stirring was continued for another 10-12 minutes to ensure uniform SiC reinforcement distribution. The molten MMC was then poured into a cylindrical mold box with a length of 180mm and diameter of 30mm. Adding various weight percent (0 percent to 4.5 percent) of SiC micro particulates resulted in four castings. Figure 3 to 4 shows the different photographs of the casting details of the Al3003 and its SiC filled MMCs.

2.3 Experimental details

The stir cast castings were machined to the necessary specifications using CNC lathe machines from Hytech Automation Pune, Maharashtra, in accordance with ASTM standards. After that, properties including microstructure, density, and wear resistance were investigated on the test samples. The density was calculated using the rule-of-mixtures algorithm, and the results were compared to measurements taken in the field. Microstructural photographs of Al3003-SiC MMC specimens were obtained using an NIKHON model 150 ECLIPSE metallurgical microscope from Japan. The wear height loss of the composites was measured using a computerised Pin-on-disc tribometer made by Ducom, Bangalore, under various loads ranging from 10 to 40N. The cylindrical MMC specimens used in this study were 15mm in length and diameter. The Al3003 alloy and Al3003-SiC MMC specimens were made to dry slide against a 60 HRC coated high carbon hardened EN31 steel counter surface disc. Wear height loss in cylinder-shaped Al3003 alloy and Al3003-SiC composites samples was measured every 30 seconds in the test using a 1.0m precision LVDT transducer to draw graphs of wear height loss and sliding speed. The disc was set to spin at 500rpm and had a 3.0km sliding distance. To investigate the form of wear, SEM photographs of worn-out Al3003 alloy and Al3003-SiC composites surfaces were taken.

3. Results and discussions

3.1 Density of Al3003-SiCMMCs

The theoretical density of the four different compositions, namely 0%, 1.5%, 3%, and 4.5% weight percentage compositions, was determined using the law of mixtures, and experimental densities were measured using weight to volume ratios. Then, using the X, Y Scatter graph seen in figure 7, the theoretical and experimental densities were compared.

The density of the composites of varying Wt% of SiC from 0, 1.5, 3, to 4.5 in Al3003 alloy were observed to increasing, it is because the SiC has better density than the Al3003 alloy, so when added with the Al3003 alloy the density will be increased according to rule of mixture [20]. But when it comes practical, we may not see that the same results as in case of theoretical densities. It is due to some other external factors like porosity, casting defects, inclusion of foreign particles (dust), but in both the cases it was observed increase in the densities as weight fraction of SiC percentage increases [21]. This increase in density will lead to increase in the mechanical characteristics.
3.2 Optical Studies on Al3003-SiC MMCs

The reinforcement grain size is the most important aspect when it comes to mechanical and metallurgical characteristics of MMCs. It plays a very important role in enhancing physical and mechanical characteristics in Al MMC’s, which can be identified by destructive and non-destructive testing like tensile, hardness, compressive and dry sliding wear tribological tests. In the present investigative work, the Al3003-SiC MMCs samples were subjected the after disc polishing under Optical Microscope to view the grain size and distribution of reinforcement particles to compare how its microstructure growth influences the wear properties of the composites for different compositions. After Disc Polishing of the specimens the samples subjected for etching with using Kellar solution for around 30 sec. So that it will give better understanding of grain distribution. For all four compositions samples, images were taken for the 500X Magnification in the 10 μm square area. The image samples for all 4 Compositions are shown in figure 8a to 8d.
From the OM images of all four samples, we can observe that the grain boundary distribution and size vary as the SiC composition changes which effects the hardness, strength of the material. Infer that the grain borders are in the shape of dendrite regions based on the photographs. These dendrite regions show a uniform distribution of SiC reinforcements with low porosity and good bonding between the Al3003 matrix and the SiC reinforcement materials. The photographs show that the Al3003-4.5 percent SiC composite has extra dendrite regions due to the inclusion of SiC reinforcements in greater quantities.

3.3 Wear studies on al3003-Sic

Wear tests were done on Pin on Disc (POD) machine to analyse rate of wear, volume loss, and friction for all the four different compositions of Al3003-SiC MMC's. The technical parameters of the POD were given in table 3. The specimens of size 15mm both diameter and height in the shape of cylindrical pins were undergone into testing for all samples varying load from 10N, 20N, 30N, and 40N with other parameters like Sliding distance = 3000m, sliding rotation speed = 500rpm are remains same. During the POD test the sliding disc rotates, the pin surface in contact with disc, so when disc rotates in opposite direction there will be a friction generated which results in wear, which gives the height loss against sliding distance values in the digital monitor. The dry sliding wear experiments were executed according ASTM-G99 standards [22]. Further the figure 9 and 10 shows the POD machine set up.

Table 3: Pin on Disc set up parameters and specifications.

| S.No | Parameters Name       | Specifications of the Setup parameters                      |
|------|-----------------------|-------------------------------------------------------------|
| 1    | Disc Dimensions       | Range from 8 to 12 mm thickness and up to 160mm dia         |
| 2    | Dimensions of the Pin | Ranges from 10 to 50 mm length and 3 to 15 mm diameter      |
| 3    | Wear Track diameter   | Ranges from 20 mm to 120 mm                                 |
| 4    | Sliding Velocity      | Ranges from 0.5 to 26 m/s                                  |
| 5    | Load Applied          | Maximum 200N load                                          |
| 6    | Disc rotational speed | 100 to 2000rpm                                            |

A pin-on-disc tribometer was used to test the MMC's wear resistance. In last 25 years, numerous studies on Al-MMCs have been carried out to determine the wear properties of these composites, and numerous reports have been submitted on the topic. The MMCs are subjected to a dry sliding wear test at room temperature in this paper. The sliding velocity is kept constant to 3.14ms⁻¹.

Figure 9. POD experimental set up.
Figure 10. Cylindrical pins.
In general, either the volume loss or wear volume loss may be used for obtaining the wear rate. Using a pin-on-disc tribometer, the wear resistance of MMCs was investigated. In the last 25 years, several studies on Al-MMCs have been carried out to determine the wear properties of these composites, as well as numerous papers. At room temperature, the MMCs are subjected to a dry sliding wear test in this paper.

The figures 11a-d characterizes height loss at different sliding distances when 04 different loads were applied. It can be deduced from the statistics that wear height increases as sliding distance increases. This is because as the sliding distance rises, the frictional force changes, causing temperature of MMCs sliding surfaces to rise. As the temperature rose, the contact materials weakened, resulting in increased wear loss in height.

Figure 11a to d. Height Loss Vs Sliding Distance Al3003 and its SiC MMCs.

The wear volumetric loss vs sliding distance for the compositions and 10 to 40N loads is seen in Figure 12a to d. When a 10N load was applied, the volumetric wear loss decreased progressively as the percent sum of SiC reinforcement was increased. This indicates that the stiffness has increased. Similarly, 12b to 12d describe the same for 20, 30, and 40N loads, indicating that as the stiffness of Al3003-SiC MMCs rises, so does the resistance to slipping wear [23]. The load added has a major impact on the wear rate of Al3003 and its SiC composites [24]. As four graphs are compared, it can be shown that the wear rate increases as the applied load increases from 10N to 40N. These improved wear properties of Al3003-SiC MMCs could be attributed to the SiC reinforcement's increased stiffness. The sliding dry wear under both composites obtained showed promise with the SiC reinforcement Al3003 composites and demonstrated superior sliding wear resistance [25, 26].
Figure 12a to d. Wear volume loss Vs sliding distance in meters for Al3003-SiC MMCs.

3.4 SEM Analysis of Fractured Surface

The Scanning electron microscope is also known as SEM is used to identify and analyse the wear and its mechanism of SiC particles in matrix Al3003. Through scanning the sample with a directed beam of electrons, SEM creates images of the sample. Electrons communicate with atoms in the sample and provide a variety of signals that provide knowledge about the polished surface structure of the sample. In most cases, the electron beam is scanned in a raster scan pattern, and the direction of the beam is coupled with the observed signal to create an image [27]. SEM analysis is used to determine the distribution and orientation of reinforcement particles in MMCs. Following the POD inspection, the samples were subjected to SEM for pictorial wear recognition after slipping at 3km at 40N. At 500x magnification, the worn-out surface of pins for all four combinations of SiC from 0% to 4.5 percent is found, as seen in figures 13a to d.

a. Al3003 alloy.  
b. Al3003-1.5% SiC MMCs.
c. Al3003-3.0% SiC MMCs.  

Figure 13a to d. SEM images of worn-out surface of Al3003-SiC MMCs.

The SEM images of MMCs are taken following dry sliding them for distance of 3.0km with 500rpm constant speed. Figure 13a to d, characterizes the SEM micrographs of Al3003, Al3003-1.5% SiC, Al3003-3.0% SiC and Al3003-4.5% SiC composites correspondingly. From SEM images it is very much clear that the Al3003-SiC MMCs with 4.5wt.% reinforcement has undergone lesser wear in comparison to other samples in current study. SEM photographs show that the number of grooves and pits is higher in the composite with 1.5wt.% SiC reinforcement and lower in the MMC with 3.0wt.% SiC reinforcement. However, in the SEM picture of the MMC with 4.5 percent SiC reinforcement, there are more tracks with smaller pits and grooves.

The behaviour of wear in reinforced specimens, as well as physical and mechanical characteristics, are the most important considerations in tribology.

Extrinsic to undergoing material interactions at surfaces level like effect wear normal load at the triboscopic contact, sliding velocity, sliding wear distance, environment, temperature, reinforcement orientation, counterpart materials and surface finish, factors inherent to material undergoing interactions at the surface level are distribution of the filler, shape, size and reinforcement type, matrix microstructure and volume fraction of reinforcement [28, 29].

4. Conclusions

The project was attempted to fabricate Al3003-SiC MMC’s by Stir Casting Process under fixed four different weight percentage of SiC reinforcement and then finding the Microstructure Growth and also evaluated the Tribological Properties of the fabricated composites.

- The Stir Casting technique was successfully implemented for all the four percentage of Silicon Carbide Reinforcement (0%, 1.5%, 3%, 4.5% of SiC) in the Al3003 matrix.
- As the percentage of reinforcement SiC in Al3003 alloy was increased from 0%, 1.5%, 3% up to 4.5% the densities of the fabricated composites were observed increasing because of adding high density ceramic particles.
- Uniform distribution of the reinforcement was observed by using OM images for all the compositions of Al3003-SiC MMCs.
- Wear Volume loss was decreased as the SiC reinforcement percentage increases in the MMC of Al3003-SiC and the composite contain higher SiC filler content showed excellent resistance to wear in comparison to other materials considered in the current studies.
- Further the excellent resistance to wear sample was inferred by the SEM images of the worn-out surfaces of Al3003-4.5% SiC filled MMCs with formation of the lesser pits and grooves.
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