INTRODUCTION

Metal matrix composites are of wide interest owing to their high strength, fracture toughness and stiffness. The light metals such as Al and its alloys form superior composites suitable for elevated temperature applications when reinforced with ceramic particulates. In the investigation on the wear behavior of Al6061 reinforced with Al2O3 particles it was concluded that a characteristic physical mechanism exists during the wear process. It was found that the matrix hardness has a strong influence on the dry sliding wear behavior of Al2O3 particulate Al6061 MMC. Sliding distance has the highest effect on the dry sliding wear of MMCs compared to load and sliding speed. Addition of 20% reinforcements increases the wear resistance of the composites, but beyond that no improvement was observed. When a sufficiently high load is applied on the contact, the matrix phase is plastically deformed, and the strain is partially transferred to the particulates, which are brittle with small failure strains. It was clearly demonstrated that the effects of applied load and temperature on the dry sliding wear behavior of Al6061 MMCs reinforced with SiC particulates and concluded that, the wear rate decreased as the applied load is increased. At higher normal loads (60N), severe wear and silicon carbide particles (SiC) cracking and seizure of the composite was observed in pin-on-disc test during dry sliding wear of Al2219 alloy MMCs. MMCs having SiC with 15 vol. %, produced by P/M route displayed good wear resistance in sliding. Self-lubricating graphite was incorporated in Al6061 alloy to prepare composites. Al2O3, B4C, Ti3Al, and B2Ti in Al6061, were used to show that Mechanically Mixed Layers (MML) are generated during sliding wear condition.
from mild to severe wear was noticed when the surface temperature reaches about 0.4 times the melting temperature of Al6061 alloy\textsuperscript{11}. Friction coefficient value of the composite was also found to increase due to the presence of hard MML layer and plastic deformation of the steel disc during sliding\textsuperscript{12}. The Al6061-SiC composites have found wide application in industries\textsuperscript{13}. In the investigation of wear behavior of Al6061 alloy filled with short fiber (Saffil) it was concluded that Saffil reinforcement are significant in improving wear resistance of the composites\textsuperscript{14}. In pin-on-disc test a MML produced is six times harder than the bulk material. This layer is responsible for reduction in wear rate of MMCs\textsuperscript{15}. The above literature reveals that the mechanical and wear behavior of the composites are not discussed together, further very little information is available with MMCs of Al6061 reinforced with \textit{Al}_2\textit{O}_3 particulates. Hence the present paper describes the reinforcement effect of \textit{Al}_2\textit{O}_3 particulates on mechanical and wear-resistance properties in Al6061 metal matrix composites.

**EXPERIMENTAL**

The following section highlights the materials used, their properties, methods of composites preparation and tests done.

**Composites composition and properties**

The matrix material used for the present study is Al6061. Table 1 and 2 respectively give the chemical composition and properties of Al6061. The reinforcing material selected was \textit{Al}_2\textit{O}_3 of particle size of 20\textmu m. Table 3 gives the details of the physical and mechanical properties of \textit{Al}_2\textit{O}_3.

**Composites fabrication**

The cast composites were fabricated using the liquid metallurgy route (stir casting technique). The procedure adopted is described below. \textit{Al}_2\textit{O}_3 powder of particle size 20\textmu m and of laboratory grade purity was preheated and was introduced into the vortex of the molten alloy after effective degassing. Mechanical stirring of the molten alloy was done at a speed of 400 rpm by using ceramic-coated steel impeller for duration of 10 min. The molten composite was poured into cast iron moulds at a pouring temperature of 730\textdegree C. The \textit{Al}_2\textit{O}_3 particulates were incorporated in to the matrix alloy in the steps of 2 with a varying wt\% from 2 to 6%. The composites thus obtained contained \textit{Al}_2\textit{O}_3 particles varying from 2 to 6 wt\%. These were made in the form of cylinders of diameter 22mm and length 210mm.

**Composites testing**

The cast composites were machined to prepare the specimens as per ASTM standards. These specimens were used for the measurement of hardness, micro structural studies as well as for mechanical and wear behavior. The Hardness of the composites was measured using Brinell hardness tester. After polishing the specimens using standard polishing machine, the microstructure studies were accomplished with the help of a metallurgical microscope of Lobo make, with 1000X maximum magnification attached with Pentax camera. The mechanical properties were evaluated using Akash make computerized universal testing machine of 40-ton capacity. Magnam make computerized pin on disc wear testing machine with test material as pin and high carbon EN31 steel (HRC60) as counter-surface, equipped with LVDT and digital display system served to record the wear height loss.

**RESULTS AND DISCUSSION**

The test results and inferences of Al6061 and its composites containing \textit{Al}_2\textit{O}_3 at various weight percentages are presented in these sections.

**Composites characterization**

Microphotographs of the Al6061-\textit{Al}_2\textit{O}_3 filled composites were taken to present the results of the composite characterization. The specimens of Al6061 and Al6061- \textit{Al}_2\textit{O}_3 composites are subjected to micro structural studies by an optical microscope. The microstructure samples were ground using abrasive Silicon Carbide papers of grade 300 to1200 grit sizes. After emery polishing the samples were carefully washed, dried and polished on a velvet cloth using alumina paste. To obtain a highly polished mirror finished surface a diamond paste of grade 3\textmu was used. The highly polished surface was observed under Triumph make microscope and photographs were captured. Figures 1 to 4 shows the microphotographs of both the Al6061 and its composites in cast conditions.
The microstructure clearly indicates the homogeneity in the distribution of reinforcement in the matrix alloy. They reveal minimal porosities in cast composites and good bond exists between the matrix and the particle reinforcement. It is clearly shown in the Figs. 1-4 that the reinforcement particle distribution in the composite increases as the amount of reinforcement increases.

**Effect of reinforcement**

The mechanical properties such as hardness and tensile strength test results, and also the wear behavior of Al6061 and its composites containing various percentages of Al$_2$O$_3$ are presented in these sections.

**Figs. 1-4: Microphotographs of the Al6061 - Al$_2$O$_3$ composites**

**Fig. 1: 0% Al$_2$O$_3$ 50 µm & 100X**

**Fig. 2: 2% Al$_2$O$_3$ 50 µm & 100X**

**Fig. 3: 4% Al$_2$O$_3$ 50 µm & 100X**

**Fig. 4: 6% Al$_2$O$_3$ 50 µm & 100X**

**Fig. 5: Variation in the Hardness of Al6061 with different wt% of Al$_2$O$_3$**

**Fig. 6: Variation in Tensile Strength of Al6061 with increasing wt% of Al$_2$O$_3$**
**Hardness**

The variation in the hardness of composites with increased content of reinforcement is shown in figure 5. The figure represents the variation in hardness evaluated at a load of 500kg with increasing percentage of $\text{Al}_2\text{O}_3$ in Al6061. It is observed that the hardness of Al6061 composites increases with increased content of the $\text{Al}_2\text{O}_3$. Improved hardness results in decrease in wear rate\textsuperscript{16}. Finer the grain size better is the hardness and strength of composites. This increase in hardness of the composite may be due to the reason that the reinforcement material is much harder than that of the matrix material and it is also due to the good bonding between the matrix and reinforcement materials.

Fig. 7: Variation in the % elongation of Al6061 with different wt% of $\text{Al}_2\text{O}_3$

Fig. 8a: Wear rate Vs Sliding distance for Al6061-$\text{Al}_2\text{O}_3$ composites at 10N applied load

Fig. 8b: Wear rate Vs Sliding distance for Al6061-$\text{Al}_2\text{O}_3$ composites at 20N applied load

Fig. 8c: Wear rate Vs Sliding distance for Al6061-$\text{Al}_2\text{O}_3$ composites at 30N applied load

Fig. 8d: Wear rate Vs Sliding distance for Al6061-$\text{Al}_2\text{O}_3$ composites at 40N applied load

Fig. 8: Wear rate Vs Sliding distance for Al6061-$\text{Al}_2\text{O}_3$ composites at different applied loads
Tensile Properties
This section represents the variation in the tensile strength with varying percentage of Al₂O₃ in Al6061. From the figure 6, it can be seen that the tensile strength increases with increasing percentage of Al₂O₃. It can be observed further that the tensile strength of the composites is higher than that of the matrix alloy. Further, from the graph, the trends of the tensile strength can be found to be increased with increase in Al₂O₃ content. This improvement in tensile strength may be attributed to the fact that the filler Al₂O₃ possesses higher strength and also may be due to the better bonding strength due lower fineness of dispersed Al₂O₃ particulates\(^\text{10, 16, 17}\). Further it can be seen that the % elongation is decreasing with the increasing % of Al₂O₃ content from figure 7. This is due to the higher brittleness of the reinforcing material. Hence it is clear that the composite material is becoming more and more brittle as the Al₂O₃ content is increasing in the matrix material, in other words the matrix material is losing its ductility due to the influence of the reinforcement material.

Wear Properties
Cast pins of 10mm diameter and 25mm length were the specimens for the wear test. The wear rate is defined as the ratio of wear volume to the product of applied load and sliding distance. The test parameters, sliding distance (3KM), sliding speed (500 rpm) and applied load (10-40N in steps of 10N) are varied with respect to material parameter (filler content). The figures 8a to 8d are presented with the wear rate of the cast Al6061 and its composites. From the figures it can be noticed that cast Al6061 base alloy has the higher wear rate than that of the Al6061-Al₂O₃ composites. Further as the sliding distance and applied load increases, the wear rate also increases. Also the figures it can be observed that as the Al₂O₃ content increases the wear rate decreases. This is mainly attributed to the fact that the Al₂O₃ possesses higher hardness and wear resistance than that of the base material hence it imparts the same into the composite material. The composite Al6061-6wt% Al₂O₃ shows improved wear resistance performance than the other composite systems studied.

CONCLUSIONS
The significant conclusions of the studies carried out on Al6061-Al₂O₃ composites are as follows.
1. Cast Al6061-Al₂O₃ composites were prepared successfully using liquid metallurgy techniques.

| Table 1: Chemical composition of Al6061 BY Wt% |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Composition (%) | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|----------------|---|----|---|----|----|----|----|----|----|
| 0.62 | 0.23 | 0.22 | 0.03 | 0.84 | 0.22 | 0.10 | 0.01 | Bal |

| Table 2: Physical and mechanical properties of Al6061 |
|----------------|----------------|----------------|----------------|----------------|
| Property | Elastic Modulus (Gpa) | Density (g/cc) | Poisson's Ratio | Hardness (HB500) | Tensile Strength (Mpa) |
| Value | 70-80 | 2.7 | 0.33 | 30 | 115 |

| Table 3: Physical and mechanical properties of Al₂O₃ |
|----------------|----------------|----------------|----------------|----------------|
| Property | Elastic Modulus (Gpa) | Density (g/cc) | Poisson's Ratio | Hardness (Kg/cm²) | Compressive Strength (Mpa) |
| Value | 375 | 3.89 | 0.22 | 1440 | 2600 |
2. The micro structural studies revealed the uniform distribution of the particles in the matrix system, with minimal porosities in cast composites.

3. Hardness of the composites found increased with increased Al₂O₃ content. Finer the grain size better is the hardness and strength of composites leading to lowering of wear rates.

4. The tensile strength of the composites increased with increase in reinforcement content.

5. The percentage elongation of the composites decreased with increase in reinforcement content.

6. The Al₂O₃ contributed significantly in improving the wear resistance of Al₆0₆1-Al₂O₃ composites. Al₆0₆1-6 wt.% Al₂O₃ composite exhibits superior wear resistance among the composites tested.

7. From the studies, in overall, it can be concluded that Al₆0₆1-Al₂O₃ exhibits superior mechanical and wear resistance properties.

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