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Effect of Al_2O_3 Particles on Mechanical and Wear Properties of 6061al Alloy Metal Matrix Composites

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Abstract

Particulate reinforced aluminium matrix composites are being considered for their superior mechanical and tribological properties over the conventional aluminium alloys, and therefore, these composites have gained extensive applications in automotive and aerospace industries. In this investigation, the fabrication of 6061Al composites with different weight percentage of Al_2O_3 particles up to 0-9% was processed by liquid metallurgy route. For each composite, reinforcement particles were preheated to a temperature of 200°C and then dispersed in steps of three into the vortex of molten 6061Al alloy rather than introducing all at once, there by trying to improve wettability and distribution. Microstructural characterization was carried out for the above prepared composites by taking specimens from central portion of the casting. Microstructural characterization of the composites has revealed fairly uniform distribution of Al_2O_3 particulates. XRD analysis revealed the presence of Al_2O_3 and other phases. The tensile strength and hardness of the resultant composites were examined. It was revealed that the 6061Al- Al_2O_3 composites have a higher tensile strength than 6061 aluminium alloy with reduced ductility. It was found that an increase in the Al_2O_3 content in 6061Al alloy contributed in enhancing the hardness of the composites. The wear test was conducted using computerized pin on disc wear tester with counter surface as EN31 steel disc (HRC60) and the composite pin as specimens, demonstrated the superior wear resistance property of the composites.

Keywords: 6061Al alloy; Al_2O_3 particulates; Tensile strength; Hardness; Metal matrix composites; Stir casting

Introduction

The composites posses improved physical and mechanical properties such as superior strength to weight ratio, good ductility, high strength and modulus, low thermal expansion coefficient, excellent wear resistance, corrosion resistance, high temperature creep resistance and better fatigue strength [1,2]. Metal-Matrix Composites (MMCs) are most promising in achieving enhanced mechanical properties.

Aluminium-Matrix Composites (AMCs) reinforced with particles and whiskers are widely used for high performance applications such as in automotive, military, aerospace and electricity industries because of improved mechanical properties [3]. Aluminium alloy 6061 possesses very high corrosion resistance and excellent extricable in nature and exhibits moderate strength and finds much applications in the fields of construction like building and highway, automotive and marine applications [4]. The composites formed out of aluminium alloys are of wide interest owing to their high strength, fracture toughness, wear resistance and stiffness. Further these composites are of superior in nature for elevated temperature application when reinforced with ceramic particle [5]. Several authors reported that particulate reinforced composites exhibit superior mechanical properties compared to unreinforced alloys.

Particulates such as SiC, TiC, and TiB_2 fly ash have been used to reinforce Al alloys to improve their mechanical properties and wear resistance [6]. Mahendra et al. reported a higher tensile strength and hardness for Al-4.5% Cu alloy-fly ash based composites. kumar et al. [4] in a study on Al7075-Al_2O_3 metal matrix composites concluded that the tensile strength properties of composites are found higher than that of base matrix Al7075 alloy and also hardness of the composites increased with increased filler content. Long et al. [7] reported the tensile strength of the Al6061-T6 alloy was increased by 20% by the reinforcement with 15 vol% of Al_2O_3 fibers. Sahin et al. [3] and Mahdavi et al. [8] in their studies on properties of SiC_p reinforced aluminium alloy composites reported that, wear properties of the Al alloy improved significantly by the addition of SiC particles into the matrix alloy. Straffelini et al. [9] reported that the matrix hardness has a strong influence on the dry sliding wear behaviour of 6061Al-Al_2O_3 composites. It has been found that reinforcement has a great influence on the properties of the aluminium metal matrix. The addition of ceramic particles results in increasing the dislocation density and decreasing the grain size of the metal matrix [10].

In the present work, an effort has been made to fabrication of 6061Al-Al_2O_3 metal matrix composites containing various weight percentages of particles and to study their mechanical properties.

Experimental Details

Materials

Metal matrix composites containing various weight percentages of Al_2O_3 particles were produced by liquid metallurgy route. For the production of MMCs, a 6061Al alloy was used as the matrix material while Al_2O_3 particles with an average size of 125 μm was used as the reinforcement. The chemical composition of the 6061Al alloy is shown in table 1 and properties of matrix and reinforcing materials is shown in table 2.

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Si	Cu	Fe	Mn	Mg	Zn	Pb	Ti	Sn	Al
0.62	0.23	0.22	0.03	0.84	0.22	0.10	0.01	0.01	BAL

Table 1: Chemical Composition of 6061Al alloy by Weight percentage.

Material/ Properties	Density gm/cc	Hardness (HB500)	Strength (Tensile/ Compressive) (MPa)	Elastic modulus (GPa)
Matrix – 6061 Al	2.7	30	115 (T)	70-80
Reinforcement Al_2O_3 Particle	3.69	1175	2100 (C)	300

Table 2: Properties of 6061Aland Al_2O_3.

Composite preparation

A liquid metallurgy route has been adopted to fabricate the cast composites. Liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production and generally can be classified into four categories: pressure infiltration, stir casting, spray deposition and *in situ* processing [11]. Compared to other routes, melt stirring process has some important advantages, e.g. the wide selection of materials, better matrix particle bonding, easier control mixture structure, simple and inexpensive processing, flexibility and applicability to large quantity production and excellent productivity for near net shaped components [12].

6061Al has been chosen as matrix alloy. Pre heated Al_2O_3 particulates of size 125 μm were introduced into the vortex of the effectively degassed 6061Al molten alloy in steps of three to improve wettability and distribution. The molten alloy was stirred for duration of 10 min using a mechanical stirrer processing ceramic coated steel impeller. The speed of the stirrer was maintained at 300 rpm. The melt at 720°C was poured into the cast iron molds. The addition of the alumina particles in the matrix alloy was varied from 3-12 wt% in steps of 3 wt%. The cylinders of 15mm X 125mm cast composites of Al6061-Al_2O_3 were obtained as shown in figure 1.

Mechanical properties

The tensile tests were conducted on the samples according to ASTM E8 at room temperatures, using a universal testing machine (INSTRON). The specimens used were of diameter 9mm and Gauge length 45mm, machined from the cast composites with the gauge length of the specimen parallel to the longitudinal axis of the castings as shown in figure 2.

The compression tests were conducted as per ASTM E9-95. The specimens used were of diameter 15mm and length 20mm machined from cast composites.

Hardness measurements were carried out on a Brinell hardness testing machine. A load of 600 N was applied on the specimen for 30 seconds using 5 mm ball indenter and the indentation diameter was measured using a micrometer microscope. The mean values of least five measurements conducted on different areas of each sample were considered.

Results and Discussion

The tensile properties of the 6061aluminium alloy and the 6061Al-Al_2O_3 composites were evaluated according to the ASTM-E8M standard. The tensile properties such as tensile strength (UTS), yield strength (Ys), elastic modulus (E) and elongation (%EL), were extracted from the stress-strain curves. A thermal mismatch between the metal matrix the reinforcement is a major mechanism for increasing the dislocation density of the matrix and, therefore, increasing the composite strength.

Tensile strength

Figure 3 shows the tensile strength property of 6061Al and composites containing Al_2O_3 as a function of percentage weight.

From figure it can be observed that the tensile strength of the composites is higher than that of their base matrix also it can be observed that the increase in the filler content contributes in increasing the tensile strength of the composite.

Percentage elongation

From the study of figure 4 it can be seen that the % elongation decreases with increasing percentage of Al_2O_3. From the figure, it can be observed that the % elongation of the composites is lesser than that of the matrix alloy. Further, from the graph, the trends of the % elongation can be found to be decreased with increase in alumina content in the composites. This considerable decrease in ductility is due to the alumina additions.

Figure 5 shows an increase in hardness with the increase in the percentage of Al_2O_3, when compared with the unreinforced 6061Al alloy. For instance, the hardness was found to be 72 BHN for 3% alumina (an increase of 7.5% over the base alloy). A significant increase in hardness of the alloy matrix can be seen with addition of Al_2O_3 particles. A hardness reading showed a higher value of hardness indicating that the existence particulates in the matrix have improved the overall hardness of the composites. This is true due to the fact

Figure 1: Composites prepared by liquid metallurgy route.

Figure 2: Showing details of tensile test specimen.

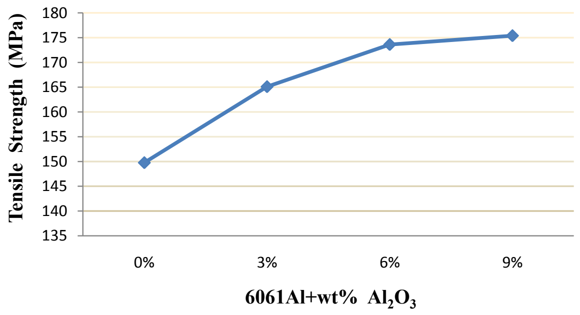

Figure 3: Showing the tensile test results as-cast 6061Al, 6061Al with 3, 6 and 9 wt% of Al_2O_3.

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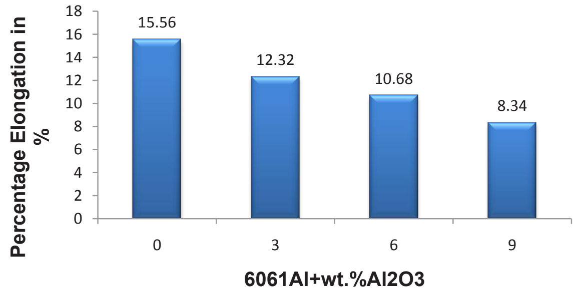

Figure 4: Percentage Elongation vs. 6061Al-Al_2O_3 Composite.

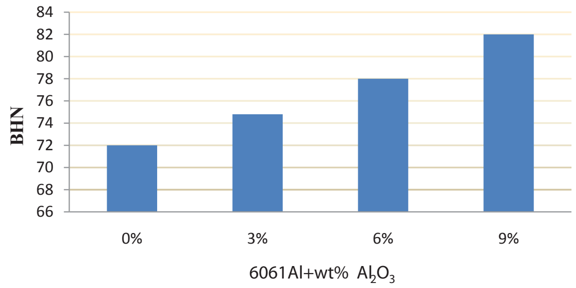

Figure 5: Showing the variations in hardness of 6061Al before and after addition of different wt % of Al_2O_3 Particulates.

that aluminum is a soft material and the reinforced particle especially ceramics material being hard, contributes positively to the hardness of the composites. The presence of stiffer and harder Al_2O_3 reinforcement leads to the increase in constraint to plastic deformation of the matrix during the hardness test. Thus increase of hardness of composites could be attributed to the relatively high hardness of Al_2O_3 itself.

Microstrucural studies

Fabrication of metal –matrix composites with alumina particles by casting processes is usually difficult because of the very low wettability of alumina particles and agglomeration phenomena which results in non-uniform distribution and poor mechanical properties. In the present work, an attempt has been made to prepare 6061Al aluminium alloy matrix composites with micro size alumina particles by stir casting method with a novel three stages mixing combined with preheating of the reinforcing particles.

Figure 6 a-f shows microstructure of as cast 6061Al and 6061Al with 6wt% (Figure 6c and 6d) and 9 wt% (Figure 6e and 6f) Al_2O_3 particulates. The microstructure of the prepared composites contains primary α-Al dendrites and eutectic silicon, while Al_2O_3 particles are separated at inter-dendritic regions and in eutectic silicon. Figure 6c-6h reveals the distribution of alumina particles in different specimens and it can be observed that there is fairly uniform distribution of particles and also agglomeration of particles at few places were observed in both the composites reinforced with 6wt% and 9wt% Al_2O_3. The microphotographs also indicate that the Al_2O_3 particles have tendency to segregate and cluster at inter-dendritic regions which are surrounded by eutectic silicon (Figure 6c-6h). Further, the micrographs show that grain size of the reinforced composite (Figure 6c-6f) is smaller than the alloy without alumina particles (Figure 6a and 6b) because, Al_2O_3 particles added to melt also act as heterogeneous nucleating sites during solidification.

X-Ray diffraction analysis

Figure 7a and 7b shows the XRD analyses were conducted on 6061Al based composites reinforced with 9 and 12 wt% of Al_2O_3 particles in order to confirm the presence of Al_2O_3 as to identify other phases formed.

Figure 7a shows the X-ray diffraction pattern and results of 6061Al alloy with 9 wt% Al_2O_3 MMC's. In X-ray diffraction pattern (Figure 7a), nine peaks have been obtained in the 2 span ranging from 20 to 100 and the peaks at 2ϴ of 38.44°, 44.7°, 65.32° and 77.2° belongs to Pure Al and the peaks at 2ϴ of 42.23°, 51.46°, 57.56° and 75.42° belongs to Al_2O_3 and other remaining minor peaks attributed to impurity.

Figure 7b shows the X-ray diffraction pattern and results of 6061Al alloy with 12 wt% Al_2O_3 MMC's. In X-ray diffraction (Figure 7b), Ten peaks have been obtained in the 2 span ranging from 20 to 100 and the peaks at 2ϴ of 38.44 °,44.7°, 65.32° belongs to Pure Al and the peaks at 2ϴ 26.23°, 37.46°, 44.67°, 58.2° and 66.2° belongs to Al_2O_3 and other remaining minor peaks attributed to impurity.

Wear properties

Wear is a process of material removal phenomenon. The prepared 6061Al with varying weight percentage of Al_2O_3 composites were subjected to wear test under dry sliding condition. The test was conducted on 8mm diameter and 30mm long cylindrical specimens against a rotating En-32 steel disc. The tangential friction force and wear were monitored with the help of electronic sensors. These two parameters were measured as a function of load and sliding distance. For each type of material, tests were conducted at 50N nominal load and keeping the sliding speed fixed at 400rpm, wear tests were carried out at room temperature without lubrication.

Figure 8 wear rate of composites decreases after addition of Al_2O_3

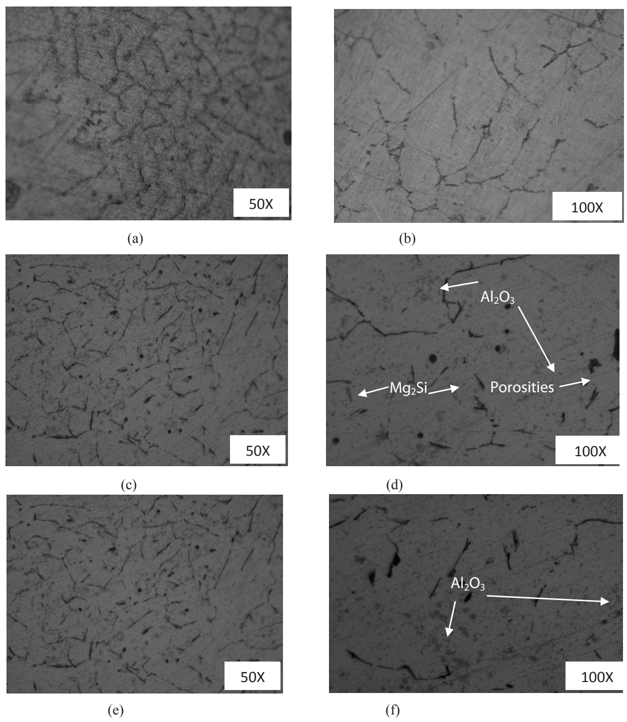

Figure 6: a-f Showing the optical microphotographs of 6061Al with and without Al_2O_3 particulates at 50X and 100X (a-b) as-cast, (c-d) with 6wt% of Al_2O_3p, (e-f) with 9wt% of Al_2O_3p.

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particles compared to base alloy (6061Al alloy). This is due to the incorporation of hard Al_2O_3 particles in the 6061Al alloy restricts such ploughing action of hard steel counterpart and improves the wear resistance.

Conclusions

1. Aluminium based metal matrix composites have been successfully fabricated by melt stir method by three step addition of reinforcement combined with preheating of particulates.

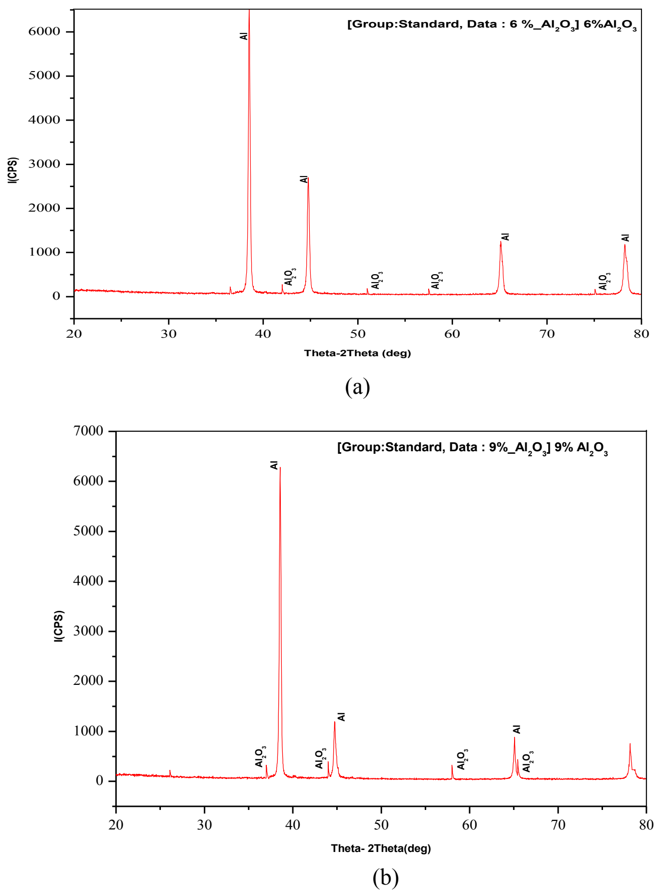

Figure 7: Showing the X-ray diffraction of the pattern of the 6061Al alloy with (a) 6 wt.% Al_2O_3 and (b) 9 wt. % Al_2O_3.

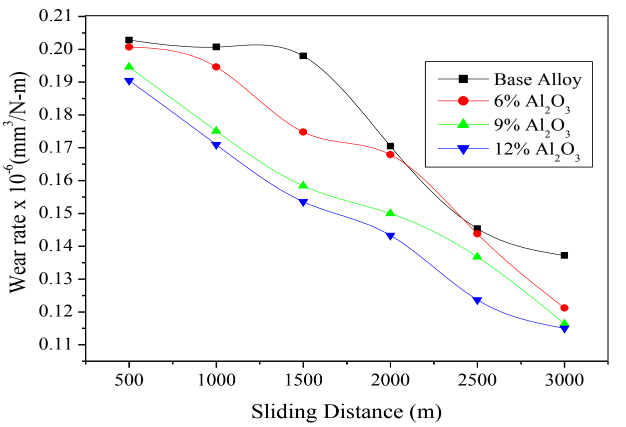

Figure 8: Showing the results of Wear rate and sliding distance of 6061 Al-Alloy before and after addition of Al_2O_3 particulates.

2. Strength of prepared composites both tensile and yield was higher in case of composites, while ductility of composites was less when compared to as cast 6061Al. Further, with increasing wt% of Al_2O_3 improvements in tensile strength were observed.

3. 6061Al–Al_2O_3 composites have shown higher hardness when compared to the hardness of 6061Al-alloy. Also hardness of composites increases with increasing wt% of reinforcement.

4. The optical microphotographs of composites produced by Melt stirring method shows fairly uniform distribution of Al_2O_3 particulates in the 6061Al metal matrix. The microstructure of the composites contained the primary α-Al dendrites and eutectic silicon with Al_2O_3 particles separated at interdendritic regions.

5. Higher wear rate was observed in as cast 6061Al alloy when compared to 6061Al-Al_2O_3 composites.

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