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MECHANICAL BEHAVIOUR OF ALUMINIUM 6061 ALLOY REINFORCED WITH Al_2O_3 & GRAPHITE PARTICULATE HYBRID METAL MATRIX COMPOSITES

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ABSTRACT

Aluminium metal matrix composites (MMCs) have gained importance in various industries because of their good mechanical properties such as wear resistance, low density, high strength and good structural rigidity. Aluminium MMCs are preferred in the fields of aerospace, military, automotive, marine and in many other domestic applications. In this study, it is intended to develop and study the mechanical behaviour of Al6061/Al_2O_3/Graphite reinforced hybrid Aluminium metal matrix composites. The composite is prepared by using Liquid Metallurgy Route (Stir Casting Technique), although powder metallurgy produces better mechanical properties in MMCs, liquid state has some important advantages such as better matrix particle bonding, easier control of matrix structure, simplicity, low cost of processing, nearer to net shape and wide selection of material. Al6061 alloy is taken as the base matrix to which Al_2O_3 and graphite particulates are used as reinforcements.6 wt% of Al_2O_3 is added to the base matrix, whereas, the graphite is varied from 2,4 and 6 wt% into the base matrix. For each composite, re-inforcement particles are pre-heated to a temperature of 200ºC and then dispersed in steps of 3 into the vortex of molten Al6061 alloy to improve wettability and distribution. The hardness and tensile properties of prepared composites were examined. Mechanical properties like hardness and tensile strength of Al6061 alloy was increased by addition Al_2O_3 particles. The Micro-Vickers hardness of the Al6061-6wt% Al_2O_3 was found to decrease with addition of graphite content in the composite but the effect of graphite content on tensile strength of the composite was less.

KEYWORDS: 6061Al Alloy, Al_2O_3 and Graphite Particulates, Tensile Strength, Hardness, Hybrid Metal Matrix Composites, Stir-Casting

INTRODUCTION

A composite material is a 'material system' composed of a combination of two or more micro or macro constituents that differ in form, chemical composition and which are essentially insoluble in each other [1]. One constituent is called as Matrix Phase and the other is called reinforcing phase. Reinforcing phase is embedded in the matrix to give the desired characteristic [2]. Metal matrix composites (MMCs) are increasingly becoming attractive materials for advanced aerospace applications but their properties can be tailored through the addition of selected reinforcement [3-4]. In particular particulate reinforced MMCs have recently found special interest because of their specific strength and specific stiffness at room or elevated temperatures [5]. It is well known that the elastic properties of the metal matrix composite are strongly influenced by micro-structural parameters of the reinforcement such as shape, size, orientation, distribution and volume or weight fraction [6].

Among the various matrix materials available, aluminium and its alloys are widely used in fabrication of MMCs and have reached the industrial production stage. The emphasis has been given on developing affordable Al-based MMCs with various hard and soft reinforcements like SiC, Al_2O_3, Zircon, Graphite and Mica [7]. Graphite, in the form of fibers or particulates, has long been recognized as a high strength, low density material. Aluminium graphite particulate MMCs produced by solidification techniques represent a class of in expensive tailor-made materials for a variety of engineering applications such as automotive components, bushes and bearings [8].

As revealed in the so far performed research, the particulate graphite increases wear resistance and using a hybrid performance of Al_2O_3 contributes to improvement of mechanical properties, also at elevated temperatures [9]. The presence of Al_2O_3 could effectively prevent the matrix deformation, to carry the load and lock the micro cracks that often develop along the friction direction [10]. Aluminium matrix composites containing graphite particles have the potential for light weight tribo-components. Graphite as a solid lubricant material improves seizure resistance of composites [11]. The incorporation of hard reinforcing particles like Al_2O_3 into the matrix alloys improve their mechanical and tribological behavior, but may result in deteriorated machinability together with rapid counter face wear [12]. To overcome the above mentioned problems, hybrid composites containing both hard and solid lubricant materials with improved tribological properties have been developed [13]. Investigation of mechanical behaviour of aluminium alloys reinforced by micro hard particles such as Al_2O_3 and Graphite is an interesting area of research. Therefore, the aim of this study is to investigate the effect of graphite content on the hardness, tensile strength and tribological behaviour of Al6061-6wt. % Al_2O_3 composites, made by stir casting method, under dry wear conditions.

EXPERIMENTAL DETAILS

Materials

Table 1: Chemical Composition of Al6061 Alloy by Weight Percentage

Si	Cu	Fe	Mn	Mg	Zn	Pb	Ti	Sn	Al
0.64	0.23	0.22	0.03	0.85	0.22	0.10	0.01	0.01	BAL

Hybrid metal matrix composites containing 6 weight percentages of Al_2O_3 particles and varying weight percentage of graphite were produced by liquid metallurgy route. For the production of hybrid MMCs, an Al6061 alloy was used as the matrix material while Al_2O_3 and graphite particles with an average size of 125μm were used as the reinforcements. The chemical composition of the Al6061 alloy is shown in Table 1 and properties of matrix and reinforcing materials are shown in Table 2.

Table 2: Properties of Al6061, Al_2O_3 and Graphite

Material/ Properties	Density gm/cc	Hardness (HB500)	Strength (Tensile/Compressive) (MPa)	Elastic Modulus (GPa)
Al6061	2.7	30	115 (T)	70-80
Al_2O_3	3.69	1175	2100 (C)	300
Graphite	2.09	1.7 mohs	---	8-15

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]. Al6061 has been chosen as matrix alloy. Preheated Al_2O_3 and graphite particles of laboratory grade purity of particle size 125 μm were introduced into the vortex of the molten alloy after effective degassing using solid hexachloroethane (C_2Cl_6). Before introducing reinforcement particles into the melt they were preheated to a temperature of 200^0C. The extent of incorporation of Al_2O_3 and graphite particles in the matrix alloy was achieved in steps of 3. i. e Total amount of reinforcement required was calculated and is being introduced into melt 3 times rather than introducing all at once. At every stage, before and after introduction of reinforcement particles, mechanical stirring of the molten alloy for a period of 10 min was achieved by using Zirconia-coated steel impeller. The stirrer was preheated before immersing into the melt, located approximately to a depth of 2/3 height of the molten metal from the bottom and run at a speed of 400 rpm. A pouring temperature of 750^0C was adopted and the molten composite was poured into permanent cast iron moulds. Thus composites containing 6 wt% of Al_2O_3 particles and 2, 4, and 6wt % of graphite were obtained in the form of cylinders of diameter 14mm and length 120mm.

Testing of Composites

To investigate the mechanical behavior of the composites the hardness and tensile tests were carried out using Zwick and computerized uni-axial tensile testing machine as per ASTM standards. The Micro-Vickers hardness values of the samples were measured on the polished samples using diamond cone indentor with a load of 100gms and 15 seconds as a holding time. Hardness value reported is the average value of 100 readings taken at different locations on the polished specimen. For tensile results, test was repeated three times to obtain a precise average value.

RESULTS AND DISCUSSIONS

Hardness Measurements

Table 3 and figure 1 shows the results of micro hardness tests conducted on matrix and the Al6061/ 6 wt% Al_2O_3 composite and also hybrid composites containing varying weight percentages of graphite particles i.e. 2, 4 and 6 wt% of graphite in Al6061/6 wt% Al_2O_3 composites. The Micro-Vickers hardness was measured on the polished samples using diamond cone indentor with a load of 100gms and the value reported is average of 50 readings taken at different locations. A significant increase in hardness of the alloy matrix can be seen with addition of Al_2O_3 particles.

The higher value of hardness of composites indicates that the existence particulates in the matrix have improved the overall hardness of the composites. This is true due to the fact that matrix is a soft material and the reinforcement 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. Further from the graph it can be observed that the hardness of Al6061/Al_2O_3/Graphite hybrid composites decreased by increasing the content of graphite particulates.

Table 3: Showing the Micro Hardness Measurement Results of as Cast Al6061, with Addition of 6 wt% of Al_2O_3 and 2, 4 &6 wt% of Graphite Particulates to Al6061

Sl. No.	Composition	Mean Micro Hardness No. (VHN)
1	Al6061 alloy	85.24
2	Al6061 alloy+6% of Al_2O_3	104.62
3	Al6061 alloy+6% of Al_2O_3+2% Graphite	98.45
4	Al6061 alloy+6% of Al_2O_3+4% Graphite	94.58
5	Al6061 alloy+6% of Al_2O_3+6% Graphite	93.21

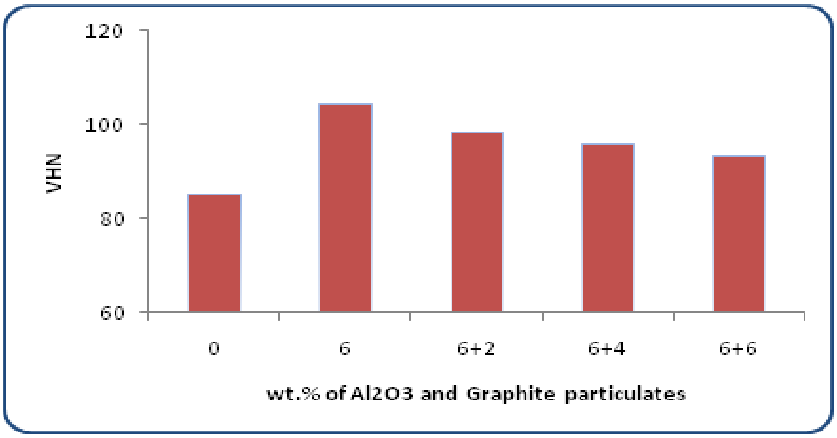

Figure 1: Graph Showing the Variations in Hardness of Al6061 before and after Addition of Different wt% of Al_2O_3 Particulate

Tensile Properties

To investigate the mechanical behavior of the composites the tensile tests were carried out using computerized uni-axial tensile testing machine as per ASTM standards. Three specimens were used for each test and average value is reported. The tensile properties, such as, tensile strength, yield strength and % elongation were extracted from the stress-strain curves and are represented in Table 4 and Figure 2 a-b-c. It is clear that tensile strength of composites containing 6 wt% of Al_2O_3 particulates is higher when compared to as cast Al6061, while ductility of composite is lesser that unreinforced alloy.

Increase in strength is possibly due to the thermal mismatch between the metallic matrix and the reinforcement, which is a major mechanism for increasing the dislocation density of the matrix and therefore, increasing the composite strength. However, the 6 wt% of Al_2O_3 reinforced composite materials exhibited lower elongation than that of unreinforced specimens. It is obvious that plastic deformation of the mixed soft metal matrix and the non-deformable reinforcement is more difficult than the base metal itself.

As a result, the ductility of the composite drops down when compared to that of unreinforced material. Further, by adding graphite particulates in steps of 2, 4 and 6 into Al6061 alloy along with 6 wt% of $Al_2O_{3,}$ it was observed that there is not much effect of graphite content on tensile properties of hybrid composites. But, as percentage of graphite increases the percentage elongation was more in Al6061-Al_2O_3-Graphite hybrid metal matrix composites. This percentage increase in elongation is due to addition of graphite particulates mainly due soft behaviour of graphite which decreases the hardness of hybrid composites.

Table 4: Showing the Tensile Test Results of as Cast Al6061, with Addition of 6 wt% of Al_2O_3 and 2, 4 &6 wt% of Graphite Particulates to Al6061

Sl No	Composition	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Percentage Elongation
1	Al6061 alloy	136	146.13	21.23
2	Al6061 alloy+6% of Al_2O_3	147.24	165.97	15.28
3	Al6061 alloy+6% of Al_2O_3+2% Graphite	135.89	159.58	17.15
4	Al6061 alloy+6% of Al_2O_3+4% Graphite	136.32	161.83	18.98
5	Al6061 alloy+6% of Al_2O_3+6% Graphite	151.56	169.78	19.69

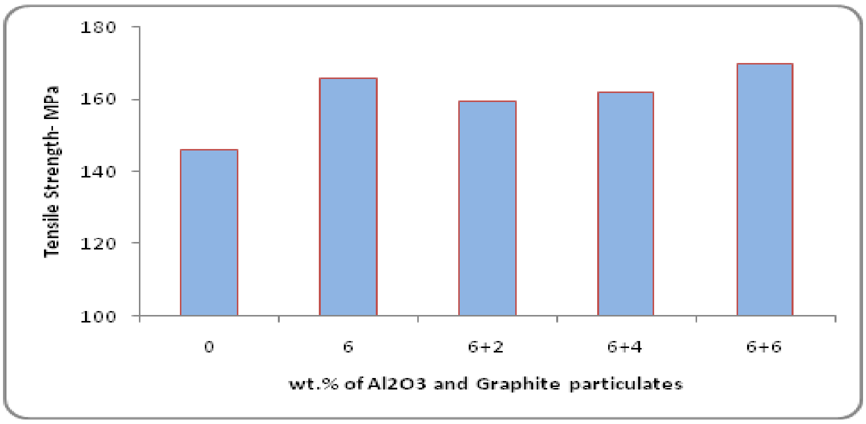

Figure 2(a): Graph Showing the Variation in Ultimate Tensile Strength of 6061Al-Alloy before and after Addition of Al_2O_3 and Graphite Particulates

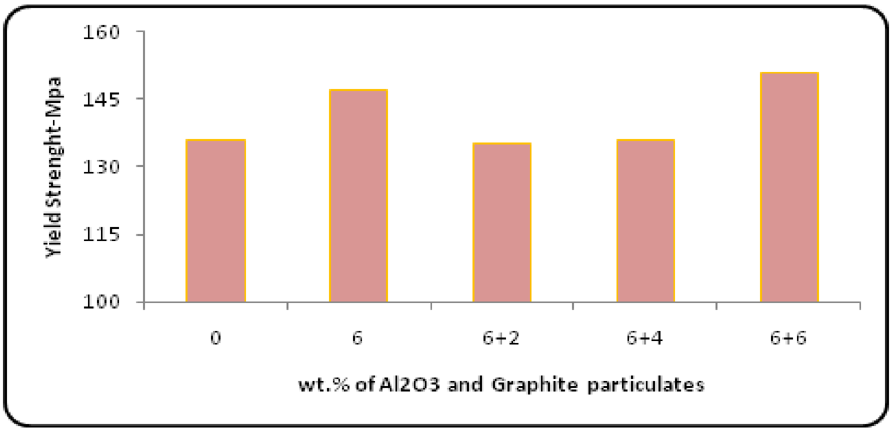

Figure 2(b): Graph Showing the Variation in Yield Strength of 6061Al-Alloy before and after Addition of Al_2O_3 and Graphite Particulates

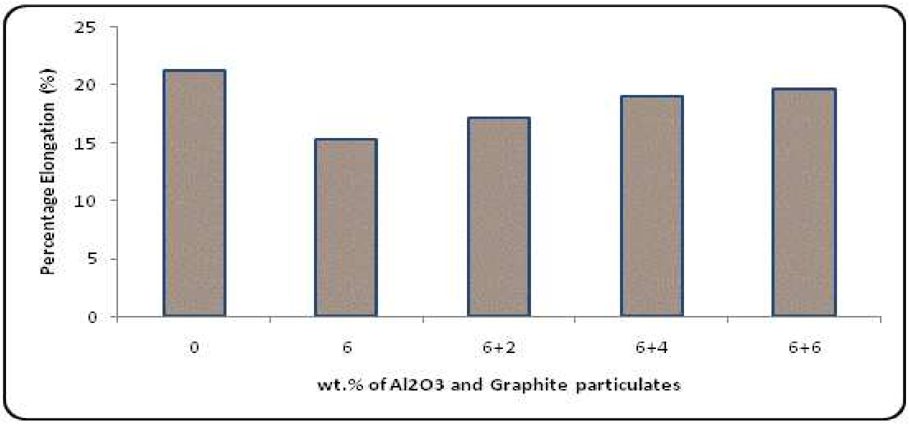

Figure 2(c): Graph Showing the Variation in Percentage Elongation of 6061Al-Alloy before and after Addition of Al_2O_3 and Graphite Particulates

CONCLUSIONS

- Aluminium based hybrid metal matrix composites have been successfully fabricated by melt stir method by three step addition of reinforcement combined with preheating of particulates.
- Tensile strength of prepared composites is higher in case of composites, when compared to cast Al6061.
- Addition of 6wt% Al_2O_3 increases the tensile strength considerably with respect to base matrix Al6061. Whereas the addition of Gr particulates doesn’t vary the tensile strength much with respect to Al_2O_3 added composition.

- Hardness of the prepared composites is higher than the base AL6061 alloy.
- Addition of 6wt% Al_2O_3 increases hardness considerably. Whereas the addition of Gr particulates decreases the hardness, but is higher than the Al6061 alloy.
- Ductility decreases with the addition of Al_2O_3 particles, which causes decrease in percentage elongation as compared to base alloy. Addition of graphite content increased the percentage of elongation compared to composites containing Al_2O_3 particles.

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