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Experimental Investigations on Mechanical behavior of Al_2O_3 and Graphite Reinforced Aluminium Hybrid Metal Composites by Stir Casting Process

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Abstract— In the present work an attempt has been made to synthesize metal matrix composite using 6063 Al as matrix material reinforced with Al_2O_3 and Graphite particulates using liquid metallurgy route in particular stir casting technique. The addition of reinforcement graphite is maintained 3% as constant and the alumina is varied as 6%, 9% and 12%. For each composite, reinforcement particles were preheated to a temperature of 200° and then dispersed in steps of three into the vortex of molten 6063 Al alloy to improve wettability and distribution. Micro-structural characterization was carried out for the above prepared composites by taking specimens from central portion of the casting to ensure homogeneous distribution of particles. Hardness, tensile and microstructure of the prepared composite were determined before and after addition of Al_2O_3 and Graphite particulates. Micro-structural characterization of the composites has revealed fairly uniform distribution and some amount of grain refinement in the specimens. Further, the hardness, tensile strength properties are higher in case of composites when compared to unreinforce 6063 Al matrix. Tensile strength of 12 wt % of Al_2O_3 composite got maximum value is 79.335 mpa. The optical micrographs of 9 wt % of Al_2O_3 composite produced by stir casting method shows fairly uniform distribution of Al_2O_3 particulates in the 6063 Al metal matrix, when compared to the 6 wt % of Al_2O_3 and 12 wt % of Al_2O_3. The Vickers hardness of 12 wt % of Al_2O_3 is 49.5HV higher than that of the 6 wt % of Al_2O_3 is 40.6 HV and 9 wt % of Al_2O_3 is 46.1 HV
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Index Terms— Al 6063, Al_2O_3 Particulates, Hybrid metal composites, Stir-Casting, Mechanical properties.

1 INTRODUCTION

The application of Metal Matrix Composites (MMCs) as structural engineering materials has received increasing attention in recent years. Their high strength and toughness at elevated temperatures coupled with low-density makes them suitable for use in applications where conventional engineering materials, such as steel are used MMCs exhibit significantly higher stiffness and mechanical strength compared to matrix alloys, but often suffer from lower ductility and inferior fracture toughness MMCs gain the ability to withstand higher tensile and compressive stresses by the transfer and distribution of an applied load from the ductile matrix to the reinforcement material. There are different routes by which MMCs may be manufactured, and among all the liquid-state processes, stir casting technology is considered to have the most potential for engineering applications in terms o f production capacity and cost efficiency Casting techniques are economical, easier to apply and more convenient for mass production with regard to other manufacturing techniques. The selection o f high silicon content aluminium alloy was found to delay the chemical reaction whereas the use of inert atmosphere, and the controlled stirring parameters was found to minimize the porosity content.

Several authors have reported various on mechanical properties of hybrid metal matrix composites by stir casting route. V. N. Gaitonde *et al* (2012) [1] studied the wear and Corrosion Properties of Al5083/ Al_2O_3/Graphite Hybrid Composites. The metallographic studies clearly revealed the uniformity in the distribution of reinforcements and excellent bond between the matrix and the reinforce ment. The microhardness of hybrid composites is higher when compared to matrix alloy. An increased content of hard reinforcement in the hybrid composites leads to the enhancement in microhardness of hybrid composites. The slurry erosive wear of hybrid composites is less when compared to unreinforced matrix alloy. An increased content of reinforcement leads to improvement in the slurry erosive wear and improves the resistance of hybrid composites. B. M. VISWANATHA *et al* (2009) [2] studied the mechanical property evaluation of A356/SiCp/Gr metal matrix composites. A356 hybrid composites have been successfully fabricated by liquid metallurgy route with uniform dispersion of SiCp and Gr particles. The hardness of composites increased significantly with addition of SiCp, while maximum hardness was obtained for 9% of SiCp. The addition of low weight percentage of SiCp to A356 leads to increase in tensile

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strength and decrease in percentage elongation. SUDINDRA S and C ANIL KUMAR [3] had done studies on Al6061/Al2O3 and graphite hybrid metal matrix composites. From optical microscopy results it is found that addition of magnesium at 0.1 ratio to the reinforcement increases the wettability and dispersion of the reinforcement particles. Tensile strength of prepared composites is higher in case of composites, when compared to cast 6061Al. Addition of 10wt% Al_2O_3 increases the tensile strength considerably with respect to base matrix Al6061. Whereas the addition of Graphite particulates doesn't vary the tensile strength much with respect to Al_2O_3 added composition. Hardness number of the prepared composites is higher than the base 6061Al-alloy. Addition of 10wt% Al2O3 increases hardness considerably, whereas the addition of Graphite particulates decreases the hardness and increasing in ductility, the cumulative effect results higher than the Al6061 alloy. Addition of 10wt% Al_2O_3 decreases the wear rate compared to base Al6061 alloy. The Cumulative effect of 10wt% Al_2O_3 and Graphite particulates with varying percentage further decreases the wear rate. As the addition of Al_2O_3/Graphite particulates increases tensile strength and is decreasing the wear rate, these composites can be used for journal bearings and antennas in aircrafts. B. Vijaya Ramnath *et al.* [4] studied the evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites. It has been inferred that the tensile strength of sample 3 is marginally higher than other two samples because of its aluminium content. But, the sample 1 has higher tensile strength (54.60 MPa) than sample 2 (51.75 MPa). It has been noted that the flexural strength of sample 3 is higher than other two samples. Considering the results of the impact test, the impact value of sample 1 (2.18 J) is lower than the impact value of sample 2 (2.42 J), but higher than that of sample 3 (2 J). Also, the Brinell hardness of sample 1 (48.53) is marginally lower than that of sample 2 (52.80) but higher than that of sample 3 (37.83). Bharath V *et al.* [5] studied on the preparation of 6061 Al-Al_2O_3 MMC's by stir casting and evaluation of mechanical and wear properties. Rajeshkumar Gangaram Bhandare and Parshuram M. Sonawane [6] studied on the Preparation of Aluminium Matrix Composite by Using Stir Casting Method. Ajay Singh Verma *et al.* [7] studied on the effect of process parameter of AL-6063 based fly ash composites using Taguchi. A.Baradeswaran et al. (2014) [8] studied on the experimental investigation on mechanical behavior, modeling and optimization of wear parameters of B_4C and graphite reinforced aluminium hybrid composites. The high hardness and good % elongation obtained in the AA 7075 hybrid composite compared to the AA 6061 alloy and its hybrid composite. The wear resistance of the composites was increased with the addition of 10 wt % B_4C and 5 % graphite particles. The wear rate is significantly less for the composites compared to base metal. Despite the fact there are many studies reported in literatures on mechanical behavior of aluminum metal composites, very less work has been published on effect of graphite on Al 6063. Henceforth, the present research work has been ventured with an object to evaluate the use of aluminium oxide (Al_2O_3) with graphite (Gr) as reinforcing material in Al 6063 alloy.

2 Experimental Details

Stir casting machine is mainly used for the manufacturing of hybrid metal matrix composite is shown in figure 1. Al 6063 alloy is used as the base matrix in the present investigation.

Fig. 1. Stir Casting setup

Table 1. gives the chemical composiotion of the Al 6063 alloy Base alloy was melted in electric furnace and different casting were produced. Aluminium oxide (Al_2O_3) with graphite (Gr) are used as reinforcing materials in Al 6063 alloy.

Table 1. Chemical composition of Al-6063 (wt pct)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
0.6	0.35	0.1	0.1	0.9	0.1	0.1	0.1	Bal

Aluminum oxide is selected as reinforcement because of its high hardness and low co-efficient of thermal expansion, high wear resistance, good mechanical properties, high temperature strength and thermal shock resistance. Graphite is a solid lubricant, which allows high corrosion resistance and relatively reduces the coefficient of friction, palverise the wear products, advances heat abstraction and increases seizure resistance. The properties of Aluminium oxide (Al_2O_3) and graphite (Gr) are complied in Tables 2 and 3 respectively. Al 6063 alloy in form of bars were used for the preparation of the specimens. Aluminium alloy is cleaned to remove dust particles, weighed and then poured in the crucible for melting. During melting nitrogen gas is used as inert gas to create the inert atmosphere around the molten matrix. Powder of alumina (Al_2O_3) and graphite are used as reinforcement. 1% by weight of pure magnesium powder is used as wetting agent. At a time total 700 gram of molten composite was processed in

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the crucible. Reinforcements are heated for half hour and at temperature of 500°C. When matrix was in the fully molten condition, Stirring is started after 2 minutes. Stirrer rotations per minute is gradually increased from 0 to 300 rotations per minute (RPM) with the help of speed controller. Temperature of the heater is set to 630°C which is below the melting temperature of the matrix. A uniform semisolid stage of the molten matrix was achieved by stirring it at 630°C.Pouring of preheated reinforcements at the semisolid stage of the matrix enhance the wetability of the reinforcement, reduces the particle settling at the bottom of the crucible. Reinforcements are poured manually with the help of conical hopper. The table 4 shows the varying composition of hybrid composite specimens.

Table 2. Properties of aluminum oxide(Al_2O_3)

Density (g/cm3)	Modulus of elasticity (GPa)	Poisson's ratio	Tensile strength (MPa)	Fracture toughness (MPa)	Coefficient of thermal expansion	Thermal conductivity (W/m-k)
3.9	380	0.22	282 - 551	4.2 - 5.9	7.4	39

Table 3. Properties of Graphite

Bulk density	1.3 - 1.95 g/cc
Porosity	0.7% - 53%
Modulus of elasticity	8 - 15 GPa
Compressive strength	20 - 200 MPa
Coefficient of thermal expansion	1.2 - 8.2 × 10−6 C
Thermal conductivity	25 - 470 W/m°K
Specific heat capacity	710 - 8130 J/m°K
Electrical resistivity	5 × 10−6 - 30 × 10−6 □m

Table 4. Designation of hybrid composites.

Composites	Composition
C1	Al6063 + 6wt%Al2O3 + 3wt%Gr
C2	Al6063 + 9wt%Al2O3 + 3wt%Gr
C3	Al6063 + 12wt%Al2O3 + 3wt%Gr

The flow rate of reinforcements measured was 0.5 gram per second. Dispersion time was taken as 5 minutes. After stirring 5 minutes at semisolid stage slurry was reheated and hold at a temperature 900°C to make sure slurry was fully liquid. Stirrer RPM was then gradually lowered to the zero. The stir casting apparatus is manually kept side and then molten composite slurry is poured in the metallic mould. Mould is preheated at temperature 400°C before pouring of the molten slurry in the mould. This makes sure that slurry is in molten condition throughout the pouring. While pouring the slurry in the mould the flow of the slurry is kept uniform to avoid trapping of gas. Then it is quick quenched with the help of air to reduce the settling time of the particles in the matrix. The mould having diameter 12.5mm and length of 125mm is shown figure 2 and prepared specimen is shown in figure 3.


Fig. 2. Permanent mould for producing composites


Fig. 3. Prepared composite specimen

3 Results And Discussion

3.1 Examination of tensile strength

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 test specimens were used for each run. The tensile properties, such as, tensile strength, yield strength and %elongation were extracted from the stress-strain curves and are represented in table 5. Figure 4 shows the tensile specimen after the test.

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Table 5. tensile test results

Sample	Composition of composite Specimen	Break load (kN)	Tensile strength (Mpa)	Yield strength (Mpa)	Elongation(%)
Sample 1	Aluminium alloy(raw)	3.230	57.21	45.67	2.07
Sample 2	Al6063+6wt% Al2O3+3%Gr	3.420	61.30	49.03	2.87
Sample 3	Al6063+9wt% Al2O3+3%Gr	3.840	77.15	61.72	2.47
Sample 4	Al6063+12wt% Al2O3+3%Gr	3.540	79.33	62.60	5.09


Fig. 4. Tensile test specimen

From the Table 5 it is clear that the fracture strength of composites (6%, 9% and 12%) is higher than when compared to as cast 6063 Al. Figure 5 shows the tensile results of the three samples

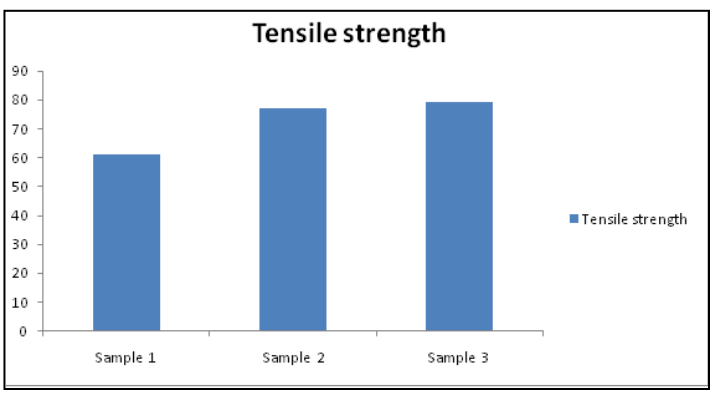

Fig. 5. Tensile test results

From the figure 5 Tensile strength of 12 wt % of Al_2O_3 composite got maximum value is 79.335 Mpa when compared to the other samples

3.2 Microstructural Examination

Figure 5(a) shows the microstructure of the fractured surface of tensile test of sample 1 at 100xmagnification. Microstructure consists of uniformly distributed fine intermetallic particles in a matrix of aluminium solid solution. Grain flow pattern are seen. No cracks, porosity and other defects. The general arrangement of aluminium molecules and reinforcements of the aluminium alloy are faintly visible in the image. The darker particles are boron carbide and the lighter ones are aluminium. The elliptically shaped aluminium particles in the matrix are more clearly visible at a magnification of 200x. Figure 5(b) reveals the fractured surface of the sample 2 after tensile test at 100x magnification. Microstructure consists of uniformly distributed fine intermetallic particles in a matrix of aluminium solid solution. Discontinuous grain flow pattern are seen. No cracks, porosity and other defects. The general arrangement of the composite is clearly visible in the image. Many micro cracks and porous sites are observed in the sample which is attributed to poor manufacturing and improper stirring of the composite. Figure 5(c) shows the microstructure of sample 3 which consist of aluminium alloy. Microstructure consists of uniformly distributed fine intermetallic particles in a matrix of aluminium solid solution. Grain flow pattern are seen. No cracks, porosity and other defects. The picture shows the inner surface of sample 3 which consist of aluminium and other components like Al_2O_3 and graphite particulates. It consists of tighter packing than the other composites which explains the better tensile properties of the sample 3 compared to samples 2 and 3.

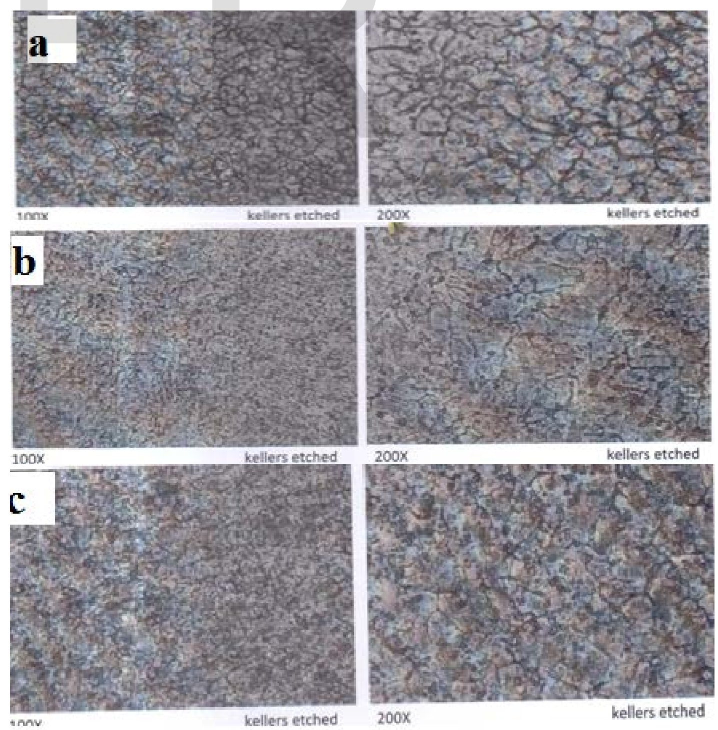

Fig. 5. a) the microstructure of the fractured surface of tensile test of sample 1 at 100xmagnification and 200X magnification, b) the microstructure of the fractured surface of tensile test of sample 2 at 100xmagnification and 200X magnification, c) the microstructure of the fractured surface of tensile test of sample 3 at 100xmagnification and 200X magnification

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3.3 Examination of Hardness

The micro vickers hardness tests conducted on Al 6063 composite containing 6%, 9% and 12% of varying Al2O3 and 3% of Graphite particles are prepared and the results are represented in Table 6. The Micro-Vickers hardness were measured on the polished samples using diamond cone indenter with a load and the value reported is average of 3 readings taken at different locations. A significant increase in hardness of the alloy matrix can be seen with addition of Al2O3 particles.

Table 6. Hardness values of composites [in VHN]

Sample	Composition of composite specimen	Trai 11	Trai 12	Trai 13	Avg Hard-ness
Sample 1	Al6063+6wt%Al2O3+3%Gr	41.5	38.5	42.0	40.6
Sample 2	Al6063+9wt%Al2O3+3%Gr	46.1	45.7	46.7	46.1
Sample 3	Al6063+12wt%Al2O3+3%Gr	50.4	47.9	49.1	49.5

4 Conclusion

In the present work Al 6063-x% Al_2O_3 -3% Gr (x=6, 9 &12) hybrid composite was successfully fabricated. The effect Al_2O_3 and graphite reinforcement in the matrix in terms of tensile strength, hardness and microsture was investigated and reported. The optimum percentange of reinforcement was also established. From the results of this study, the following conclusions were drawn

- It has been inferred that the tensile strength of sample 3 (12 wt % of Al_2O_3) is marginally higher than other two samples because of its aluminium content. Further, with the increasing wt% of Al_2O_3, the tensile strength shows an increasing trend.
- The optical micrographs of sample 2 (9 wt % of Al_2O_3) composite produced by stir casting method shows fairly uniform distribution of Al_2O_3 particulates in the 6063 Al metal matrix, when compared to the sample 1 (9 wt % of Al_2O_3) and sample 3 (12 wt % of Al_2O_3)
- The Vickers hardness of sample 3 (12 wt % of Al_2O_3) higher than that of the sample 2 (9 wt % of Al_2O_3) and sample 1 (6 wt % of Al_2O_3)

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