Evaluation of Mechanical Properties of Al6061 Reinforced with Hematite

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***Abstract*—The Metal Matrix Composites (MMCs) are being used in many engineering and structural applications in the recent years due to their high strength to weight ratios (1, 2). In the present work an attempt has been made to fabricate a new composite with Al6061 as matrix material and Hematite also known as ferrous oxide (Fe2O3) as reinforcement. The need for higher strength and higher hardness of the composite has initiated the present investigation. The Hematite reinforcement was added to Al6061in different proportions (2, 4, 6 & 8 %) by weight and composites were prepared by Liquid Metallurgy (stir casting) technique through the vortex method. The casted composite specimens were machined as per ASTM standards. The Mechanical properties were evaluated and compared with base alloy. Significant improvement in hardness and tensile strength were observed with the increase in the wt % Fe2O3. The microstructural studies of the composite showed a better dispersion of the Fe2O3 in the matrix.**

Keywords— Al6061, Hematite (Fe2O3), Composites, MMCs, Stir Casting, Hardness, Tensile Strength

I. INTRODUCTION

Composite materials have numerous advantages over conventional monolithic materials; the tensile strength, hardness, strength to weight ratio and various other mechanical properties are enhanced by the addition of reinforcements in forms of fibre (oriented or disoriented), whiskers, particles (large of small).The development of metal matrix composite (MMC) is reported as one of the major innovations in materials science in the last three decades [1, 2]. In MMCs, a metal as matrix will contain reinforcements or dispersoids. These may be of different sizes and shapes with varying aspect ratios [3, 4]. These MMCs can be produced by (i) solid state, (ii) liquid state or (iii) vapor state processes [4-7]. An analysis of these processing techniques involving various types of dispersoids particularly for the automotive applications revealed [4] that liquid metal processing (foundry technique) with particulate type of dispersoid is more attractive than others. Further, it is possible to produce large volume of complex shaped components at high production rates [1, 8] along with producing near net shapes by the foundry techniques, thus making MMCs to be more cost effective [4-7]. By the judicious selection of matrix-dispersoid combination and processing method, it is reported that these MMCs exhibit some attractive specific properties compared to those of ferrous and some non-ferrous monolithic materials. They include 20-50% increase in stiffness, 20-30% in ultimate strength (UTS), about 30% lower coefficient of thermal expansion, high thermal and electrical conductivities, improved damping properties, friction wear (2-5 times) and seizure resistance, over the matrix material [4-12]. Nevertheless, the enhancement of one property is obtained at the expense of the other. Therefore, the reinforcement that is to be added to a material is decided on the basis of the application of the material and the environment of operation.

Besides, in recent times, MMCs are commercially produced by both liquid metallurgy and powder metallurgy techniques followed by secondary processing with their cost depending on the order placed for the size of billet or the secondary processes [1,2, 5-8, 14]. Of course, several products for aerospace, automotive, general engineering applications, military, railways and even in entertainment (sports) sectors have been fabricated and successfully tested and are also being in use abroad. Aluminum composites sought over other conventional materials in the field of aerospace, automotive and marine applications owing to their excellent improved properties [7-8, 16-17]. These materials are of much interest to researchers from few decades.

Through extensive literature research it was found that Aluminium is the most sorted out material, as it is light, moderately strong, easy to machine and is both ductile and malleable. Aluminium 6061 and Hematite (Fe_2O_3) 45 microns of LR grade are used for this experimental study. Aluminium 6061 was chosen based on the fact that it is one of the most widely used commercial form of aluminium in the market [1-8]. Al6061 signifies that, materials such as Magnesium and Silicon are added in order to increase fluidity and flowability of the metal in casting and extraction processes [13]. The reinforcement Hematite is iron oxide (Fe_2O_3) and is naturally available in powder form. It is harder than pure iron, but more brittle [13, 20].

A special mention about hematite is that it is used as an antirust coating on iron structures [25].

Table 1. Chemical composition of matrix material Al6061

Constituent	Si	Cu	Fe	Mn	Ni	Zn	Ti	Sn	Mg	Cr	Pb	Al
Percentages by weight	0.43	0.24	0.43	0.139	0.05	0.006	0.022	0.001	0.802	0.184	0.204	Balance

Table 2. Properties of Al &Al6061

Material	Ultimate Tensile Strength (MPa)	Yield Strength (Mpa)	Hardness (BHN)	Density (gm/cc)
Aluminum	40 – 50	15 – 20	15	2.6
Al 6061	110-115	45-55	30	2.7

Table 3. Properties of Hematite (Fe_2O_3)

Tensile Strength	Elastic Modulus	Poisson's ratio	Melting point	Density
350 MPa	211 GPa	0.35	1595 oC	5.26 gm/cc

Fig. 1. Ingots of Al 6061

Fig. 2. Hematite Powder

II. Fabrication

For the fabrication of the Aluminium Hematite composite material, stir casting technique was employed [14-15]. Stir Casting is a liquid state method of composite manufacturing, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirrer. This "Whirlpool" method provides the high strength homogeneous set of Aluminium composite material. The specific gravity of Hematite is 5.64 and that of Al6061 is 2.70, as a result of which the reinforcement would settle at the bottom of the crucible if not kept in continuous motion. To ensure uniform mixing of the reinforcement, the stir casting technique is employed. The other major reason for selecting stir casting is, its cost effectiveness.

Compositions of Aluminum and Reinforcement of different specimens are shown in the Table 4. The matrix material Al 6061alloy was heated up to 750^{o}C & melted in a graphite crucible using Induction heating furnace [14, 18-21]. Then the stirrer was immersed gently into the molten metal bath and rotated at a speed of 300 to 350 rpm to create a vortex in the liquid metal. After the metal was liquefied completely, Scum Powder (Alkaline Powder) was added to crucible to remove the slag and flux. Then preheated hematite powder was added to the melt slowly and stirring was continued to ensure uniform mixing of the reinforcement in the molten matrix. After complete addition of reinforcement the stirring was continued for 5-10 minutes and a degasing tablet (Hexa Cholro Ethane) was added to remove the gases entrapped in molten metal. Later the melt was poured into the preheated die. After complete solidification, the samples were removed from the die and used for various tests. The process of fabrication was repeated for various compositions of Al 6061 with Fe_2O_3. The figures 3 show the different stages of the fabrication of the composite.

Table 4. Compositions of Aluminum and Reinforcement of different specimens

	Sample A	Sample B	Sample C	Sample D
Weight of Al Added	1960 grams	1920 grams	1880 grams	1840 grams
Percentage of Hematite	2%	4 %	6 %	8 %
Weigh of Hematite added	40 grams	80 grams	120 grams	160 grams

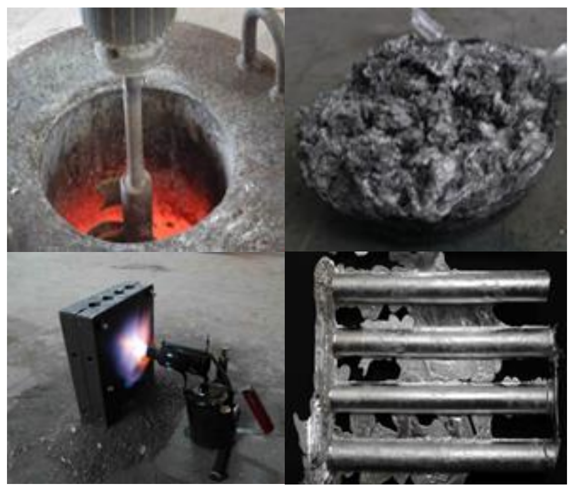

Fig. 3. Stirring of Molten metal in the furnace**,** Slag produced during casting process**,** Preheating of die and Castings of Al 6061 + Fe_2O_3

III. Experimentation

A. *Hardness Test*

The hardness values depend on the bonding between the matrix & reinforcements used in a MMC. Hardness of the specimen was determined using Brinnel Hardness Testing machine TKB 3000. A steel ball indenter of 5 mm diameter and a load of 250 kg was used for the test .The hardness was calculated using the formula given below.

$$BHN = \frac{F}{\frac{\pi}{2}D*(D-\sqrt{D^2-d^2})}$$

Where, F = Load applied in kgf., D = Diameter of the indenter in mm, d = Diameter of the indentation in mm

B. *Tension Test*

The specimen was prepared as per the ASTM standard which is shown in fig. 4. & machined to the dimensions shown in fig. 5. Tensile test was conducted using Tensile Test Machine KIPL –PC 2000. The Ultimate Tensile strength (UTS) and elongation were evaluated for all the combinations of reinforcements.

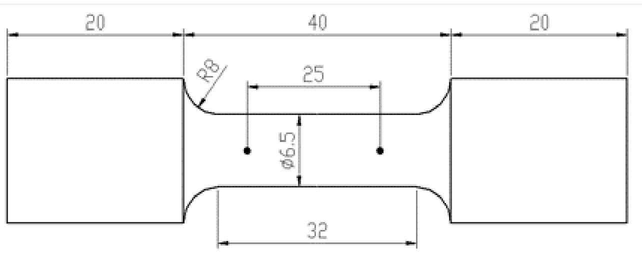

Fig. 4. ASTM Standard for Tensile Specimen

Fig. 5. Machined Tensile Specimen

C. *Microscopy Test*

The microstructure of a material reveals physical properties such as strength, toughness, ductility, hardness and so on (22-24). Optical microscopy is the cheapest and commonly used method to study the microstructure of a material. The specimens prepared by different proportions of the reinforcements for the microstructural study are shown in fig. 6.

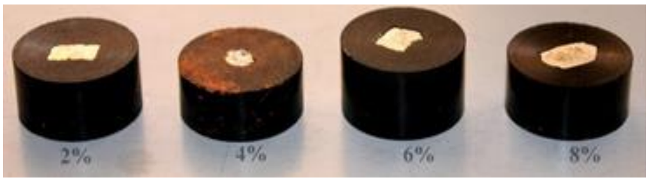

Fig. 6. Specimens for microstructural study

IV. Results and Discussion

A. *Density of Specimen*

The density of the specimen was calculated theoretically by rule of mixture and measured practically using the water submersion technique. The density of various samples is shown in the table below. The density increases with increase in the percentage of the reinforcement. Though the density of the reinforcement is higher than the matrix material, no much variation in the density of the composite was observed since the quantity of the reinforcements added was in smaller proportions. But there is a decrease in the value of density of the specimen of 4% reinforcement may be due to the casting defects such as blow holes or cold shuts.

Table 5. Density of different proportions of the composite

Weight % of Reinforcement	0%	2 %	4 %	6 %	8 %
Density in gm/cc (Theoretical)	2.70	2.75	2.81	2.87	2.93
Density in gm/cc (Experimental)	2.69	2.48	2.73	2.79	2.81

Fig. 7. Density of different proportions of composite

B. *Microscopy Tests*

The images of microstructure of composite of different reinforcement proportions studied under optical microscope are shown in fig. 8. The study reveals uniform dispersion of Fe_2O_3 particles in the matrix materials. As the percentage reinforcement increases, concentration of more particles in the grain boundaries is observed & it signifies the increase in the strength and hardness. No much clustering of reinforcements was observed in the matrix. The discontinuities in the grain boundaries decreases the elongation of the composite and hence the ductility is decreased.

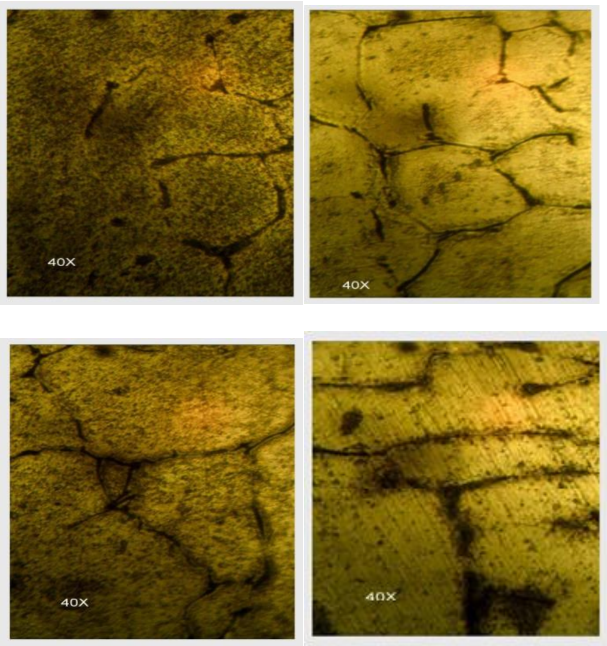

Fig. 8. Microstructure of 2%, 4%, 6% & 8% reinforcement composites under 40X

C. Hardness Test

Hardness of all the samples was tested and the results are shown in the table 6 and by graph in the fig. 9. It is evident from the graph that the hardness increases with the increase in weight percentage of the reinforcement. This may be because of addition of Fe_2O_3 particles, which are harder than the matrix material and render their inherent property of hardness to soft matrix material Al6061and makes the composite more brittle. A maximum increase of 30% is observed in the hardness.

Table 6. Hardness of composites of different percentage of reinforcements

Percentage of Reinforcement	Brinell's Hardness Number (BHN)
0%	28.5
2%	31.94
4%	31.95
6%	3057
8%	37.47

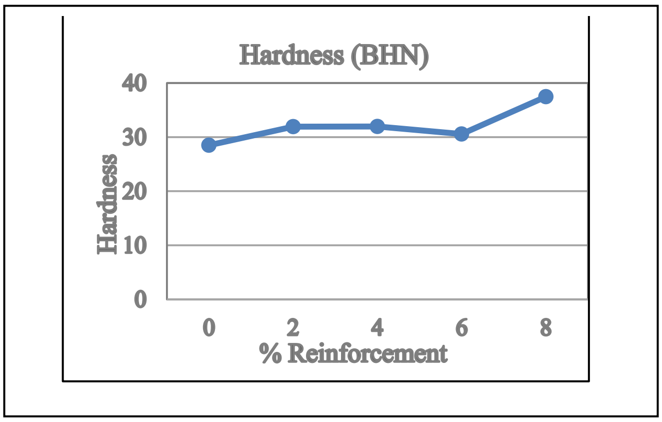

Fig. 9. *Hardness*

D. Tension Test

The Ultimate Tensile strength (UTS) and elongation of composites of different reinforcements were shown in the table 7. The UTS is shown by graph in fig. 10. It is evident from the graph that the ultimate tensile strength increases with increase in weight percentage of reinforcement (Fe2O3). The UTS gradually increases from 2% to 8% and a maximum of 25% is observed from the experimental work. The increase in UTS of the specimens is probably due to the presence of hard hematite particles that impart strength to the aluminum matrix by way of dispersion strengthening

Table 7. Ultimate Tensile strength (UTS) and elongation

Percentage of Reinforcement	Ultimate Tensile Strength (MPa)	Percentage Elongation
0%	112.46	7.28
2%	118.6	6.84
4%	128.2	5.72
6%	135.6	4.28
8%	141.2	5.64

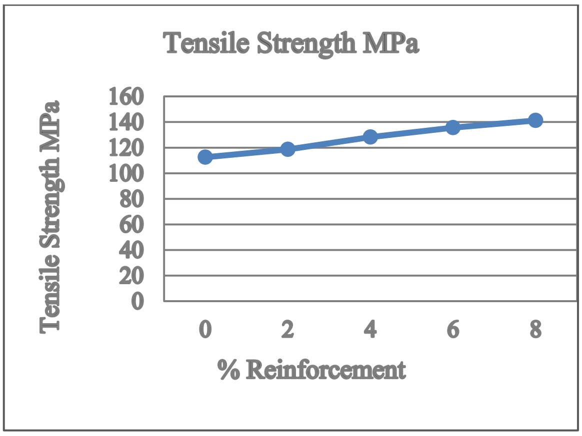

Fig. 10. Tensile Strength

V. Conclusions

- The density of the Aluminum-Hematite composite has increased with increase in weight percentage of reinforcement. It is evident from the results that the variation of density of the composite material is very small with maximum variation of 4% at 8% of reinforcement addition.

- The microstructure of the fabricated composite reveals fairly even distribution of the reinforcement particles. The grain boundaries are doubly layered as the percentage of reinforcement increases. This signifies the increase in the hardness.

- The hardness of the material increased as the percentage of reinforcement increased. This is due to the fact that hematite is harder & brittle in nature. A maximum of 30% increase in the hardness is observed at 8% reinforcement.

- Tensile strength of the fabricated composite increases with increase in weight percentage of reinforcement The good interface bonding between the matrix & the reinforcement material results in better transfer of load between the matrix and the reinforcement materials. And there is a decrease in the elongation of all the samples, which leads to poor ductility. It is due to the addition of hematite particles which are highly brittle in nature. A maximum of 25% increase in the UTS is observed at 8% reinforcement.

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