Characterization of As Cast and Heat Treated Aluminium Based Hybrid Metal Matrix Composites

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Abstract— Aluminium alloys are widely used in automobile industries and aerospace applications due to their good mechanical properties as compared with conventional metals and alloys. The low production price and better mechanical properties of the composites make them very useful for various applications in many fields. Even though the mechanical properties are better in Al 6061, due to its high wear behavior constrains its application. The present investigation has been focused on the development of hybrid composite involving Aluminium metal matrix reinforced with particulates of Silicon carbide and graphite. The composites are fabricated using liquid metallurgy routing. The Al 6061 composites were cast by stir casting liquid metallurgy route with a percentage of graphite varying from 2%wt to 6%wt in steps of 2%wt whereas the percentage of silicon carbide is kept constant at 10 %wt. The cast composites were tested for hardness, wear characteristics with, without heat treatment (T-6) and obtained results were correlated with microstructure. The result indicates that there is a nominal improvement in the hardness values and wear properties of both with and without Heat treated specimens.

Index Terms— Abrasion, Brinell Hardness number, Hybrid metal matrix composite, Pin on disk apparatus, quenched, Stir casting, Tribology, wetability

1 Introduction

WITH the increasing demand for high performance materials with versatile properties new composite materials are being formulated and tested to satisfy the product needs. Composites are a mixture of materials consisting of a matrix with micron-level and Sub-micron level dispersion of similar kinds of materials. Usually the reinforcing component (primary material) is distributed in the continuous or matrix component (Secondary material). In hybrid materials the constituents combine at a nanometer or molecular level, therefore there is a situation of orbital interaction which creates new properties by new electron orbits formed between each material, this leads to new material that can exhibit new properties not necessarily found in the individual components. In this paper the Tribology and hardness properties of the composites are investigated.

Aluminium 6061 is a ductile and corrosion resistant to atmospheric conditions. Silicon carbide is added to the formulation to investigate the hardness properties and graphite to investigate the tribological properties.

2 Literature Review

Rama rao et al[1] . Examined that aluminium alloy-boron carbide composites were fabricated by liquid metallurgy techniques with different particulate weight fraction (2.5, 5 and 7.5%). Phase identification was carried out on boron carbide by x-ray diffraction studies microstructure analysis was done with SEM a composites were characterized by hardness and compression tests. The results shows increase the amount of the boron carbide. The density of the composites decreased where as the hardness is increased. Whereas The compressive strength of the composites was increased with increase in the weight percentage of the boron carbide in the composites.

Karunamoorthy et al [2]. Analysed that A 2D microstructure-based FEA models were developed to study the mechanical behaviour of MMC. The model has taken into account the randomness and clustering effects. The particle clustering effects on stress-strain response and the failure behavior were studied from the model. The optimization of properties was carried out from analysis of microstructure of MMC since the properties depend on particles arrangement in microstructure. In order to model the microstructure for finite element analysis (FEA), the micro-structures image converted into vector form from the raster than it conversion push to IGES step and mesh in FEA model in ANSYS 7. The failure, such as particle interface decohesion and fracture the predicted for particle clustered and non-clustered micro structures. They analyzed that failure mechanisms and effects of particle arrangement.

Sozhamanna et al [3]. Analysed that the methodology of microstructure based elastic-plastic finite element analysis of PRMMC. This model is used to predict the failure of two dimensional microstructure models under tensile loading conditions. Hence analyses were carried out on the microstructure of random and clustered particles to determine its effect on strength and failure mechanisms. The FEA models were generated in ANSYS using SEM images. The percentage of major failures and stress-strain responses were predicted numerically for each microstructure. Here the mixture material Al alloy, SiC.

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Venkat prasat et al [4]. Investigated that tribological behavior of aluminium alloy reinforced with alumina and graphite this is fabricated by stir casting process. The wear and frictional properties of the hybrid metal matrix composites was studied by performing dry sliding wear test using a pin – on- test wear test. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. AL27 orthogonal array was selected for analysis of the data. Investigation to find the influence of wear rate sliding speed applied load sliding distance, as well as the coefficient of friction. The results show that sliding distance has the highest influence followed by load and sliding speed. Finally, confirmation test were carried out to verify the experimental results and scanning electrons microscopic studies were done on the wear surfaces. The incorporation of graphite as primary reinforcement increases the wear resistance of composites by forming a protective layer between pin counter face and the inclusion of alumina as a secondary reinforcement also has a significant effect on the wear behavior. The regression equation generated from the present model was used to predict the wear rate and coefficient of friction of HMMC for intermediate conditions with reasonable accuracy.

Keshavamurthy et al [5]. Experimented that Al6061 matrix composite reinforced with nickel coated silicon nitride particles were fabricated by liquid metallurgy. Microstructure and tribological properties of both matrix alloy and developed composites have been evaluated. Wear tests and dry sliding friction were carried out using pin on disk type machine over a load range of 20-100N and sliding velocities is 0.31-1.57m/s. Results revealed that, coated of nickel in silicon nitride particle are uniformly distributed throughout the matrix alloy. Al6061-Ni-p-si3N4 composite exhibited lower wear rate and coefficient of friction compared to matrix alloy. The coefficient of friction decreased with increased in load up to 80N. A Further increase in the load, also increasing coefficient of friction and sliding velocity.

3 Experimental procedure

3.1 Material properties

3.1.1 Al 6061

Aluminium 6061 is one of the most extensively used of the 6000 series aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilities. It has good toughness and surface finish in, turn it is corrosion resistant to atmospheric weather. Aluminium is ductile in nature, hence it is not suitable for many applications.

Table 1:Composition of Al 6061 (% weight)

Material	Amount (%weightt)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4 – 0.8
Iron	Max. 0.7
Copper	0.15-0.40
Zinc	Max. 0.25
Titanium	Max. 0.15
Manganese	Max. 0.15
Chromium	0.04-0.35
Others	0.05

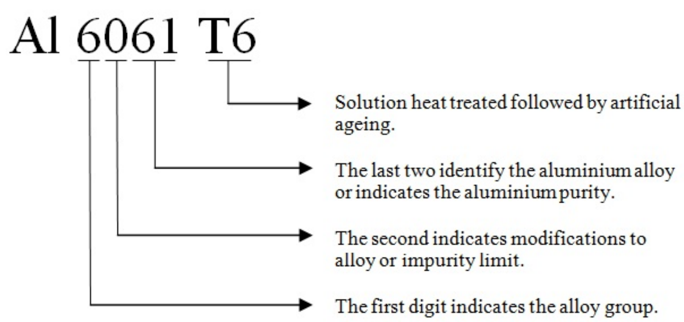

Fig 1 Aluminium alloy designation

Physical properties

- Density : 2.7 g/cm3
- Melting Point : Approx 580°C
- Modulus of Elasticity : 70-80 GPa
- Poison's Ratio : 0.33

3.1.2 Silicon Carbide

Silicon carbide is composed of tetrahedral carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide is not assailed by any acids or alkalis or molten salts up to 800°C. In air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. Silicon Carbide is one of the highly hard material it has the hardness of 2800 Kg/mm^2.

3.1.3 Graphite

Graphite is one of two naturally occurring crystalline forms of the sixth element, carbon, the other being diamond. It is a soft greyish black mineral with a metallic luster. A graphite crystal is made up of loosely stacked one atom thick graphene layers much like a deck of cards. These layers can slide around giving graphite its lubricity. Graphite is an excellent conductor of heat and electricity and is relatively inert being unaffected by most chemicals. It maintains its properties even at extreme temperatures in excess of 3500°C, which makes it invaluable to the industry. It is a good dry lubricant and hence reduces wear and abrasion.

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Addition of Magnesium enhances the wetability. However increase the content above 1wt. % increases viscosity of slurry and hence uniform particle distribution will be difficult [6].

3.2 EXPERIMENTAL PROCEDURE

The details of the experiments carried out on Al 6061 alloy subjected to refinement and with heat treatment has been highlighted under the following headings.

- Preparation of reinforcement
- Melting and Stir casting
- Heat Treatment Process

Silicon carbide and graphite are sieved to a fine grain size of maximum 75μm. Al 6061 bars were machined according to the size of the crucible without adding any coolant (to avoid property changes).

Table 2 Composition of the composites

Sample No.	Al 6061 % by weight	Silicon carbide % by weight	Graphite % by weight
1	100	0	0
2	90	10	0
3	88	10	2
4	86	10	4
5	84	10	6

The same compositions were heat treated and tested.

Production of the hybrid metal matrix composite (MMC) through Stir casting Technique. The Al 6061 alloy melts at a temperature of 730 ± 20°C in a graphite crucible in a high temperature furnace. The stirring device was a graphite pole, which was equipped with 2 stirring blades, each 2 millimeter thick. The blades were mounted radially on a rotating rod being angled 5° to the radial horizontal rotational plane. Preheated Silicon carbide and Graphite particles at 500 °C for 1 hour was added into the vortex slowly and steadily while continuing stirring to ensure the complete dispersion of reinforced particles it also promotes wetability. The addition of Silicon carbide and Graphite will be added on the %wt of the Aluminium alloy 6061.The molten alloy was stirred at 400 rpm for up to 3 minutes. Die is preheated to avoid porosity and scale formation on the samples due to sudden cooling. The molten metal was poured into the preheated die after the removal of slag.

The Aluminium composites were heat treated and tempered to T-6 condition, i.e. the samples were heated at 530°C for 3 hours and then immediately quenched in water at room temperature and finally were artificially aged in furnace at 180°C for 5 hours and then air cooled at room temperature.

Fig 1 Stir Casting Apparatus

3 TESTING PROCEDURES

3.1 WEAR TEST

A pin- on- disc test apparatus is used to investigate the dry sliding wear characteristics of the Aluminium alloy and its composites as per ASTM G99 standards. As per ASTM standards, specimens were machined to 10mm diameter and 30mm height. The initial weight of the specimen was measured with an electronic weighing machine with at least count of 0.001 g. During the test machined samples were placed perpendicular to the steel disc. The parameters were set accordingly and pin was made to slide against the disc. The frictional traction experienced by the pin during sliding is measured continuously by PC-based data-logging system for post testing analysis. The test was carried out on a pin on disc apparatus at ambient.

Fig 2 Pin on Disc apparatus - Wear test

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3.2 Hardness Test

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. The specimen or the area or location must be selected and polished so as to give a reliable indication of the properties of the material. The specimen was placed on the anvil so that the surface is normal to the direction of applied load. Load (500 kgf) with a 5 mm diameter steel ball indenter and wait for 30 seconds duration, to ensure the complete acting of the load on the specimen by the indenter. Remove the load after 30 seconds, measure the indentation by using a travelling microscope and find out the BHN using formula.

The BHN is calculated according to the formula presented below

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

Where,

F (Load Applied)
D (Diameter of Ball Indenter)
d (Diameter of Indentation)

4 Calculations

Brinell Hardness Number (BHN)

$$BHN = \frac{2f}{\pi[D-(\sqrt{D^2}-d^2)]}$$

$$= \frac{2\times500}{\pi\times5[5-\sqrt{5^2-2.70^2}]}$$

$$BHN = 80.61$$

Where

F = load applied (500 kgf)

D = Diameter of indenter (5 mm)

d = Diameter of indentation (2.70mm)

BHN = Brinell hardness number

Disc running time:

$$T = \frac{d\times60\times1000}{\pi DN}$$

$$= \frac{10^3\times60\times10^3}{\pi\times120\times400}$$

$$T = 397.88 \text{ seconds}$$

Where

T = Disc running time (seconds)

d = Sliding distance (1000m)

D = Track diameter (120mm)

N = Revolution per minutes (400rpm)

Wear rate:

$$\text{Wear rate} = \frac{v}{d}$$

$$= \frac{4.444\times10^{-12}}{10^3}$$

$$= 4.444\times10^{-12}\ m^3/m$$

Where

v = Volume of material removed (m3)

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$2700\times103 = \frac{0.012}{\text{volume}}$$

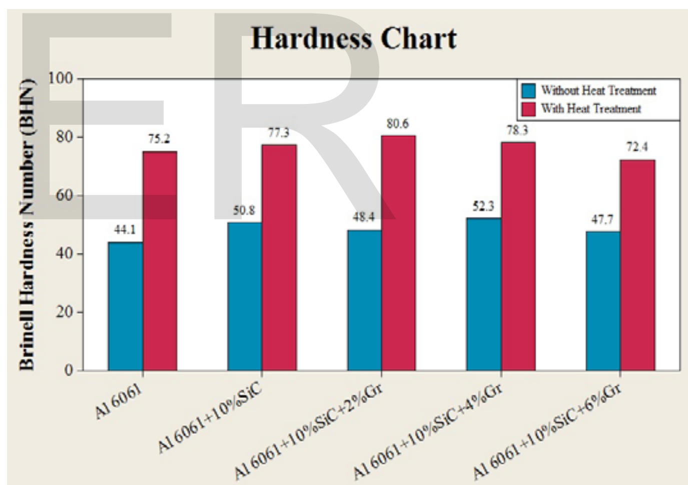
$$volume = 4.444\times10\text{-}9\ m3$$

d = Total sliding distance (1000m)

5 Results and Discussion

The Comparison was carried out on before heat treated and after heat treated (HT) Specimens with respect to As cast and varying percentage of graphite from 2 to 8% and with silicon carbide 10% constant.

5.1 Hardness



composites

Hardness property is influenced by silicon carbide (SiC) and its percentage is kept constant, so the hardness does not vary drastically. The negligible variation in the hardness is due to the varying graphite percentage.

Compared to without heat treatment, T6 heat treated specimen exhibits better hardness and the maximum hardness of 81BHN in Al6061+10%SiC+2%Gr. It's an increase of 45% compared to As cast Al6061.

5.2 Dry Sliding Wear Test

The trial was carried out on a pin on disk apparatus at ambient. For the following parameters the wear properties were examined.

Velocity of the disc = 400rpm
Track diameter of the disc = 120mm
Sliding distance = 1000m

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Running time of the disc = 397seconds

5.2.2 Weight reduction

The reduction in weight of the samples gives the wear behavior of the samples. The samples were weighed before and after wear test. The weight difference gives the wear of the samples.

Wear is influenced by graphite percentage because of it's lubrication property. The graphite percentage inversely proportional to weight reduction, which means wear is reduced. As compared to un-heat treated specimen, T6 heat treated specimen has better wear resistance.

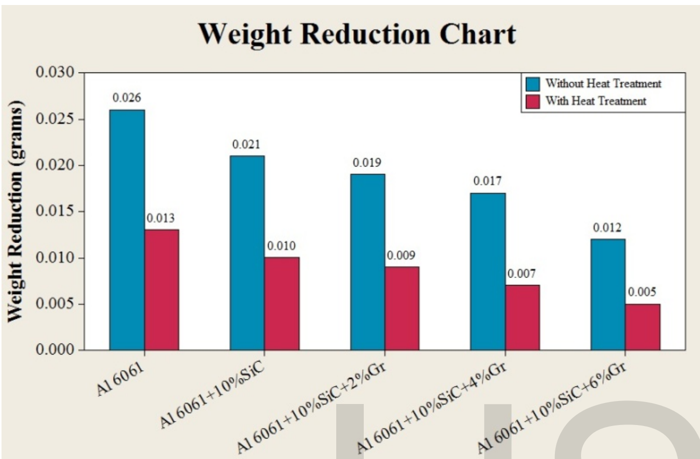

Fig 4 Weight reduction comparison of heat treated and un-heat treated composites

5.2.3 Friction coefficient

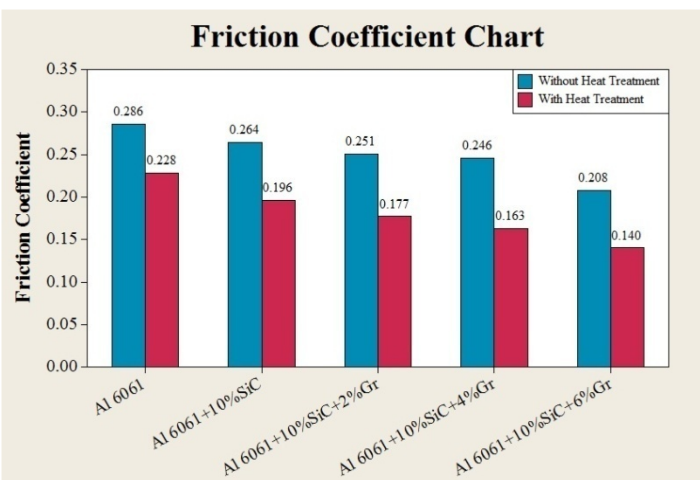

Fig 5 Coefficient of friction comparison of heat treated and un-heat treated composites

As graphite percentage increases the friction coefficient decreases. Minimum friction is obtained at Al 6061+10%SiC+6%Gr which is 51% lesser than As cast Al6061.

5.2.4 Wear rate

Wear rate is very high in aluminium 6061 (9.62 $m^3/m \times 10^{-12}$) and it was reduced to 80% by T-6 heat treated Al 6061+10%SiC+6%Gr (1.85 $m^3/m \times 10^{-12}$). Wear rate decreases with increase in graphite reinforcement. The rate of decrease in wear depends on the reduction in graphite percentage. A good improvement in the wear properties was achieved when heat treated(T-6). Investigation shows wear rate decreases with increase of graphite reinforcement.

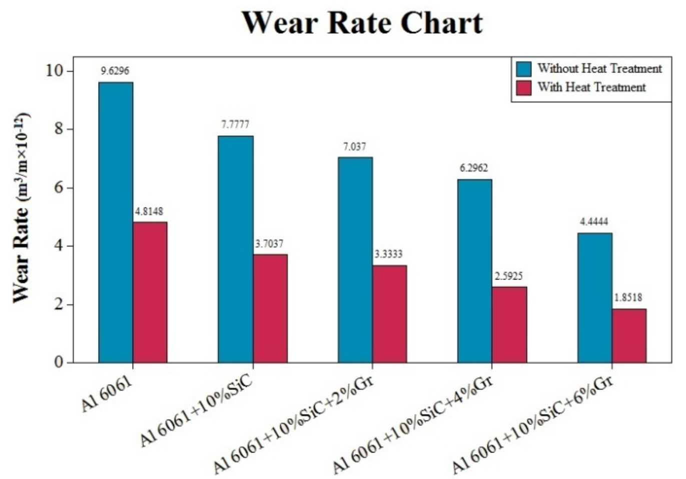

Fig 6 Coefficient of friction comparison of heat treated and un-heat treated composites

6 Conclusion

The aim of the study is to characterize the properties of heat treated and un-heat treated hybrid metal matrix composites

The above study on various heat treated and un-heat treated hybrid matrix composites of aluminium 6061 alloy and its reinforcements of silicon carbide and graphite powder reveal a good improvement in properties of wear and hardness.

- The die is preheated to avoid the scale formation and reduce the porosity of the samples.
- Wear loss of composites decreases with the increase in the content of graphite reinforcement under identical test conditions. Heat treatment has a profound effect on wear behavior of matrix alloy and its composites.
- Brinell hardness number (BHN) does not vary drastically because of the constant Silicon carbide reinforcement. Heat treatment has a significant effect on Brinell hardness of Al6061 matrix alloy and its composites.
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