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Effect of Silicon Carbide Particulates on Mechanical Properties of Graphite Aluminium

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Abstract: In this work, using stir casting technique aluminium matrix was reinforced with graphite particles and silicon carbide particles to study the effect of graphite and silicon carbide reinforcement using mechanical testing and to study the mechanical behaviour. Different volume fractions of silicon carbide 10%, 15% and 20% are incorporated into the alloy, maintaining the volume fraction of graphite as 5% for all proportions. The distributions of reinforcement are made uniform by using a mechanical stirrer attachment and the various compositions of metal matrix composite are casted for testing. Mechanical properties such as Brinell hardness test, tensile test, compressive stress test are conducted mechanical behaviour of the composite is studied. With 80% of Aluminium15% reinforcement of SiC & 5% of Gr particles, the hardness and compression strength are higher.

Keywords: MMC (Metal Matrix Composite), AMC (Aluminium Matrix Composite), Silicon carbide, Graphite, hardness, tensile, compression

I. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are a reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part.

The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fibre or a particulate. Particulate composites have dimensions that are approximately equal in all directions. They may be spherical platelets or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiff than continuous fibre composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness.

The continuous phase is the matrix, which is a polymer metal or ceramic. Polymers have low strength and stiffness, metals have intermediate strength and stiffness but high ductility and ceramics have high strength and stiffness but are brittle. The matrix (continuous phase) performs several critical functions, including maintaining the fibres in the proper orientation and spacing and protecting them from abrasion and the environment. In polymer and metal matrix composites that form a strong bond between the fibre and the matrix, the matrix transmits loads from the matrix to the fibres through shear loading at the interface. In ceramic matrix composites, the objective is often to increase the toughness rather than the strength and stiffness; therefore, a low interfacial strength bond is desirable. The type and quantity of the reinforcement determine the final properties.

Metal-matrix composites, especially those reinforced with nano-micron particles, enjoy the revival of research and industrial interest caused by the new developments in materials processing and the increased demand for light-weight structural and functional materials.

1.1 Metal matrix composite (MMC)

A material in which a continuous metallic phase (the matrix) is combined with another phase (the reinforcement) that constitutes a few percent to around 50% of the material's total volume. In the strictest sense, metal matrix composite materials are not produced by conventional alloying. This feature differentiates most metal matrix composites from many other multiphase metallic materials, such as pearlite steels or hypereutectic aluminium-silicon alloys.

The particular benefits exhibited by metal matrix composites, such as lower density, increased specific strength and stiffness, increased high-temperature performance limits, and improved wear-abrasion resistance, are dependent on the properties of the matrix alloy and of the reinforcing phase. The selection of the matrix is empirically based, using readily available alloys; and the major consideration is the nature of the reinforcing phase.

A large variety of metal matrix composite materials exist. The reinforcing phase can be particulate, fibrous, plate like, or equiaxed (having equal dimensions in all directions); and its size can also vary widely, from about 0.1 to more than 100 micrometers. Matrices based on most engineering metals have been explored, including aluminium, magnesium, zinc, copper, titanium, nickel, cobalt, iron, and various aluminides.

This wide variety of systems has led to an equally wide spectrum of properties for these materials and of processing methods used for their fabrication. Reinforcements used in metal matrix composites fall in five categories: continuous fibres, short fibres, whiskers, equiaxed particles, and interconnected networks.

Composite properties depend first and foremost on the nature of the composite; however, certain detailed micro structural features of the composite can exert a significant influence on its behaviour. Physical properties of the metal, which can be significantly altered by addition of a reinforcement, are chiefly dependent on the reinforcement distribution.

1.2 Aluminium Matrix Composites (AMC)

Matrices of Aluminium Matrix Composites are usually based on aluminium-silicon (Al-SiC) alloys and on the alloys of 2xxx and 6xxx series. The reinforcement in AMCs could be in the form of continuous/discontinuous fibres, whisker or particulates, in volume fractions ranging from a few percent to 70%.

1.2.1Properties of Aluminium Matrix Composites

- High strength even at elevated temperatures.
- High stiffness (modulus of elasticity).
- Low density.
- High thermal conductivity.
- Excellent abrasion resistance.

1.3 Reinforce materials for AMC

- Alumina (Al_2O_3) or silicon carbide (SiC) particles (particulate Composites) in amounts 15-70 volume%
- Continuous fibres of alumina, silicon carbide, Graphite (long-fibre reinforced composites).
- Discontinuous fibres of alumina (short-fibre reinforced composites).

1.4Fabrication methods of AMC

Aluminium Matrix Composites are manufactured by the following fabrication methods:

- Powder metallurgy (sintering).
- Stir casting.
- Infiltration.

1.5 Stir casting

The foundry casting processes have been a favoured processing method as they lend themselves to the manufacture of large number of complex shaped components. Especially, the stir casting mostly used to produce the MMCs because it shown to be a very promising for the manufacture of near net shape composites in a simple and cost effective manner. The major problem in this technology is to obtain sufficient wetting of particle by the liquid metal and to get a homogeneous dispersion of the ceramic particles. Several structural defects such as porosity, particle clustering, oxide inclusions and interfacial reactions were found to arise from the unsatisfactory casting technology studied the thyrotrophic behaviour, development of the particle shape, and particle distribution in the metal matrix composites by using stir casting.

1.6 Applications

- Carbide drills are often made from a tough cobalt matrix with hard tungsten carbide particles inside.
- Some tank armours may be made from metal matrix composites, probably steel reinforced with boron nitride. Boron nitride is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel.
- Ford offers a Metal Matrix Composite (MMC) driveshaft upgrade. The MMC driveshaft is made of an aluminium matrix reinforced with boron carbide, allowing the critical speed of the driveshaft to be raised by reducing inertia. The MMC driveshaft has become a common modification for racers, allowing the top speed to be increased far beyond the safe operating speeds of a standard aluminium driveshaft.

II. References

S. Suresha , B.K. Sridhara: International Journal of Machine and Design, vol. 31 (2010) . pp. 4470–4477 [1], Suresha noticed that use of graphite (Gr) reinforcement in aluminium matrix composites has been reported to be beneficial in reducing wear due to its solid lubricant property, but it results in reduction of mechanical strength. Addition of silicon carbide (SiC), on the other hand, improves both strength and wear resistance of composites, but high amount of SiC makes machining difficult and composites become brittle. Thus, SiC can be advantageously used as a second reinforcement to overcome the problem of strength reduction of Gr reinforced composites, resulting in what is known as hybrid composites. Aluminium matrix composites reinforced with equal weight fraction of SiC and Gr particulates up to 10% are studied with regard to hardness improvement and modified dry sliding wear behaviour

G.Elango, B.K. Raghunath: International Conference on Design and Manufacturing, vol. 64 (2013) .pp. 671 – 680 [3],It is noticed that the wear behaviour of aluminium alloy LM25 reinforced with SiC particulate and further addition of TiO2 particulate fabricated by stir casting process is investigated. The results show that, the reinforcement of the metal matrix with SiC and TiO2 reduces the wear rate at room temperature. An attempt has also been made by keeping SiC percentage constant and increasing the TiO2 percentage it also proves wear rate decreases as the TiO2 content increases. The results also indicate that the wear of the test specimen increases with the increasing load and sliding distance. The coefficient of friction decreases with load and increasing volume content of reinforcement.

B.M.Viswanatha, M.P.Kumar, S.Basavarajappa, T.S.Kiran: International Journal of Tribology in Industry, vol. 36(2014) .pp. 40-48 [4], It shows that investigation shows the wear behaviour of cast and heat treated, A356 aluminium alloy reinforced with SiC and Graphite particles subjected to different ageing durations. The liquid metallurgy technique was used to fabricate the composites. The reinforcement content was varied from 0 to 9 % by weight in steps of 3 % of SiC p and fixed quantity of 3 % by weight of graphite particles. All the specimens were artificially aged at different durations of 3, 6, 9 and 12 hrs at a temperature of 155 ^{0}C ± 5. The wear tests were performed for alloy and composites by varying load, speed and sliding distance for both aged and as-cast conditions by using a pin on disc wear testing machine. The results reveal that the wear rate of composites was less than that of non-reinforced alloy.

IhomA.Paul, Nyior G. Bem, Ibrahim G. Zamanni: International Journal of Research and Reviews in Applied Sciences, vol. 12(3) (2012) [7], It is observed that the effect of thermal ageing on microstructure and some mechanical properties of Al/2.0% glass reinforced composite. The results have shown that thermal ageing of the as-cast composite has effect on the microstructure. it was found that the microstructure of the thermal aged composite was related to the hardness and the tensile strength of the composite

Syed Ahamed, D. Abdul Budan, Joel Hemanth: International Journal of Emerging Technology and Advanced Engineering, vol, 4 (2014) [9], Ahamed shows that the wear resistance of cryogenically chill cast Al-alloy/kaolinite/C hybrid MMCs is significantly dependent on the kaolinite and graphitic carbon content, the rate of cooling (which in turn depends on the thickness of the chill employed), different loading conditions as well as ageing time. The strength, hardness, and wear resistance of the chilled MMCs are superior to those of the unreinforced matrix alloy. It was found that these properties improve with increase in dispersoid content up to 9 wt%. Further increase in dispersoid content results in deterioration in mechanical properties. Through micro structural analysis it is proved that the microstructure of base metal matrix can be refined effectively by cryogenically cooling the material which is cast using copper chills. At low load, wear mechanism is abrasive wear whereas at higher load conditions it is adhesive wear.

A. Atrian, G.H. Majzoobi, M.H. Enayati, and H. Bakhtiari: International Journal of Minerals, Metallurgy and Materials, vol 21 (2014), page 295 [10], The synthesis of Al7075 metal matrix composites reinforced with SiC, and the characterization of their microstructure and mechanical behaviour. Further increasing the amount of SiC nano particles improves the strength, stiffness, and hardness of the compacted specimens. The increase in hardness and strength may be attributed to the inherent hardness of the nanoparticles, and other phenomena such as thermal mismatch and crack shielding.

N.Valibeygloo, R.AzariKhosroshahi, R.TaherzadehMousavian: International Journal of Minerals, Metallurgy and Materials vol.20 (2013), Page978 [11], The microstructure and mechanical properties of Al-4.5wt% Cu alloy reinforced with different volume fractions (1.5vol%, 3vol%, and 5vol%) of alumina nanoparticles, fabricated using stir casting method, were investigated. Calculated amounts of alumina nanoparticles (about φ50 nm in size) were ball-milled with aluminium powders in a planetary ball mill for 5 h, and then the packets of milled powders were incorporated into molten Al-4.5wt% Cu alloy. Micro structural studies of the nano composites reveal a uniform distribution of alumina nanoparticles in the Al-4.5wt% Cu matrix. The results indicate an outstanding improvement in compression strength and hardness due to the effect of nanoparticle addition. The aging behaviour of the composite is also evaluated, indicating that the addition

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of alumina nanoparticles can accelerate the aging process of the alloy, resulting in higher peak hardness values.

Mohammad Amin Baghchesara, Hossein Abdizadeh: International Journal of Mechanical Science and Technology, vol.26 (2) (2012). pp. 367-372 [17],

It is observed that aluminium alloy (A356.1) matrix composites reinforced with 1.5, 2.5 and 5 Vol.% nanoscale MgO particles were fabricated via powder metallurgy method. Optimum amount of reinforcement and sintering temperature were determined by evaluating the density, microstructure and mechanical properties of composites. Hardness and compression tests were carried out in order to identify mechanical properties. Reinforcing the Al matrix alloy with MgO particles improved the hardness and compressive strength of the alloy to a maximum value of 44 BHN and 288 MPa, respectively. The most improved compressive strength was obtained with the specimen including 2.5% of MgO sintered at 625°C. According to the experiments, a sintering temperature of 625°C showed better results than other temperatures. A good distribution of the dispersed MgO particulates in the matrix alloy was achieved.

C. Tabulation

Properties of SiC

Property	**Values**
Molar mass	40.1 g mol^{-1}
Density	3.21 g cm^{-3}
Melting point	2730 C , 3003k, 4946 F
Electron mobility	900 cm2/v-s
Refractive index	2.5

Properties of graphite

Property	**Values**	**Unit**
Bulk Density	1.3-1.95	g/cm^3
Modulus of Elasticity	8-15	GPa
Compressive strength	20-200	MPa
Flexural strength	6.9-100	MPa
Coefficient of Thermal Expansion	$(1.2\text{-}8.2) \times 10^{-6}$	^0C
Thermal conductivity	25-470	W/m.K
Specific heat capacity	710-830	J/kg.K
Electrical resistivity	5×10^{-6}-30×10^{-6}	Ω.m

. **Details of reinforcements**

Reinforcement	**Average grain size [µm]**	**Density [g/cm3]**
SiC	45	3.21
Gr	42	2.15

III. Specimen Preparation

The selected materials are then measured to specified proportion based on composition of Al-alloy of 90%Al+10%SiC, 75%Al+20%SiC+5%Gr, 85%Al+10%SiC+5%Gr, 80%Al+15%SiC+5%Gr percentage. Then these composition of materials are made to cylindrical bar by following stir casting method.

Stir casting process

The matrix material used for the current study was aluminium LM25 alloy, having composition average values provided by the supplier (Omega metals Ltd., India) in weight percentage as shown in Table 4.4. The Al-SiC alloy has an excellent combination of mechanical properties in the cast condition. Al-SiC-Gr composites at required composition by weight were prepared by sand casting technique.

The following figure shows the measured quantity of matrix (Fig5.1) and reinforcement alloys (Fig5.2)

Measured matrix material

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Measured reinforcement material

A measured amount of silicon carbide particles and graphite was preheated at around 800ºC for 2 hrs to make their surfaces oxidized to achieve better weld ability and also to prevent decarburization of SiC and Gr at high temperature. Below shown fig 5.3 shows muffle furnace which used for pre-heating the reinforcement materials.

Muffle furnace used for preheating

Then a measured amount of Aluminium alloy (ingots) was melted in the furnace. The matrix material was loaded in a graphite crucible and it was placed inside a top loaded resistance furnace at different temperature level (700°C, 750°C, 800°C, 850°C, 900°C). The following Figure 5.4 shows the furnace with argon supply cylinder.

Furnace with Argon gas setup

Pre-heated silicon carbide particles and Gr were added to the aluminium melt. The four blade Stirrer was designed in order to produce the adequate homogenous particle distribution throughout the matrix material. After that, the melt was stirred for 20 min at an average mixing speed of 300-400 rpm to make a vortex in order to disperse the particles uniform in the melt. The axial and radial flows are provided to avoid different stagnant zones in the liquid melt by stirrer. Stirring of the mixture is carried out at different holding time (10 to 20 minutes) to achieve homogeneity of particulates. The SiC particles and Gr are uniformly distributed in the matrix when the processing temperature is around 700°C to 800°C as a hold of 10 minutes. The stainless steel stirrer blade was coated with zirconium to avoid the reaction between stainless steel and Al alloys at higher temperatures.

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Stirring process

The above shown Fig5.5 visualizes the process of stirring during fabrication. The Argon gas was supplied into the crucible during the stirring to avoid the formation of oxide layer on the surface of matrix melt. After thorough stirring, the melt was poured into sand moulds as shown in Figure5.6 below

Sand mould die

Now these moulds are allowed to cool and solidify, then the required cast composite rods are taken as shown in Figure 5.7.

Casted HMMC rods

Same method of preparation is followed for various compositions

Machining process

The obtained AMC rod from the moulds are then machined to the specified dimensions required for the further mechanical tests. These machining processes are carried out using CNC lathe machine and grinding machine. All the cast rods were machined to dimensional specification given in the Table 5.1.

Dimensions for machining specimens

Specimen	Dimensions	Number of specimens
Hardness test	Dia 15mm, Thickness 12mm	4
Tensile test	Dia 25mm, 100mm Long	4
Compressive test	Dia 20mm, 50mm Long	4

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Hardness specimen

Tensile specimen

Compression test specimen

The above shown Figure 5.8 shows machined micro hardness specimens, Figure 5.9 shows machined tensile specimens and Figure 5.10 shows machined compression test specimens.

IV. RESULTS AND DISCUSSIONS

Observation on hardness test:

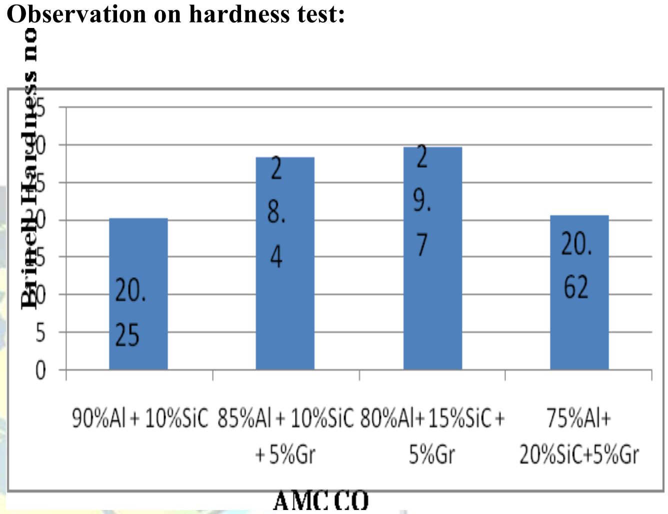

Figure .7.1. Brinell hardness evaluation for different amounts of reinforcing SiC and Gr

The observation of hardness values of various composition of aluminium matrix composites are shown in figure7.1. The SiC particles added to the aluminium alloy matrix have a satisfactory effect in improving the hardness of the composites. This is to be expected since aluminium is a soft material and the SiC particles being hard, contribute positively to the hardness of the composite. The results of the Brinell hardness measurements are shown in Figure 7.4. It increases with increasing wt% of the particulates used in this work. It also indicates that increase in SiC increases the hardness value of Al-alloy matrix but increase in SiC above 15% to 20% with Gr% not significantly varying in hardness value. From the Figure 7.1 increase in SiC up to 15% with combination of 5% Gr shows a high hardness value then increase in SiC up to 20%. Hardness on AMC compositions such as 90%Al+10%SiC, 75%Al+20%SiC+5%Gr, 85%Al+10%SiC+5%Gr, 80%Al+15%SiC+5%Gr are observed.

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Observation on Tensile test:

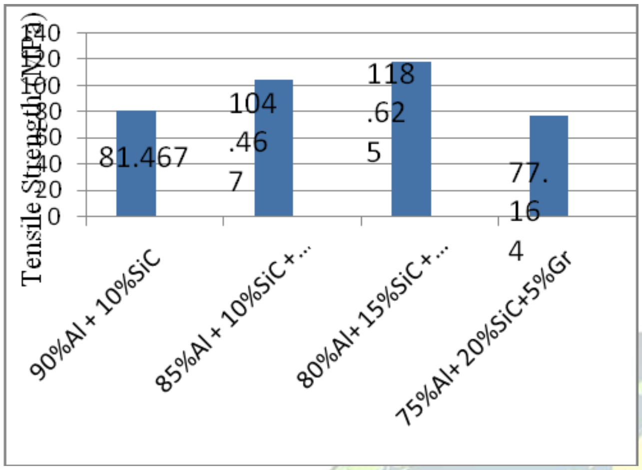

Figure .7.2. Tensile strength evaluation for different amounts of reinforcing SiC and Gr

The tensile strength evaluation for different amounts of reinforcing SiC and Gr. It indicate that the tensile strength increases with increase in volume fraction from 10 to 20% SiC and 5% Gr in Al-matrix in the composite. With increasing volume fraction, more load is transferred to the reinforcement which also results in a higher yield strength. The behaviour is in agreement with the work carried by Yung et al, (2004). However volume fraction of SiC increases above15% decreases intensile strength is observed. Due to increase in hard particles (SiC) in Al-matrix composite tends to increase the brittle nature of the material. Figure.7.3 indicates the various types of tensile fracture occur in different composition of Al matrix composites. In this case of Al-10% SiC there is slow propagation and an absorption of a large amount energy before fracture like many ductile materials (pure aluminium, steel etc). In this ductile fracture extensive plastic deformation (necking) takes place before fracture is observed clearly from Figure 7.3a. But in case of hybrid MMC, the addition of graphite particles (self lubrication) reduces stress concentration and crack propagation during ductile fracture which will improve the tensile strength of hybrid composite materials (Figure 7.2). It is clearly observed from the fracture of Al-10%SiC-5%Gr and Al-15%SiC-5%Gr tensile test specimens (Figure 7.3b and Figure 7.3c). From Figure 7.3d the brittle fracture of tensile specimen of Aluminium matrix composites 90%Al+10%SiC, 75%Al+20%SiC+5%Gr, 85%Al+10%SiC+5%Gr, 80%Al+15%SiC+5%Gr has observed.

V. CONCLUSION

From the study on mechanical characterization of Al-SiC-Gr reinforced metal matrix composite, the following conclusions are drawn.

1. With the stir casting technique setup attached with mechanical stirrer assembly, it is possible to develop MMC with uniform distribution of reinforced particulates on aluminium matrix.
2. Depending on the amount of SiC reinforcement, hardness values obtained by Brinell hardness values obtained by brinell hardness shows that the hardness of the composites improved, when SiC particles are added to Al-Alloy matrix whenever the particulates increases the hardness will have a satisfactory effect. An increase of SiC up to 15% with combination of 5% Gr has higher hardness value. A marginal reduction in hardness observed in AMC with 20% of SiC.
3. From tensile test, It indicates that the tensile strength increases with increase in volume fraction from 10 to 15% of SiC, beyond 15% SiC AMC experiences an appreciable loss in tensile strength. With increasing volume fraction, more load is transferred to the reinforcement which also results in higher yield strength. In hybrid MMC, the addition of graphite particles (self lubrication) reduces stress concentration and crack propagation during ductile fracture which will improve the tensile strength of hybrid composite materials.
4. From the compression test results, it is observed that the ultimate stress is high in the volume fraction of 15% of SiC with 5% reinforcement of Gr particulates in aluminium matrix and it reduces when the SiC decreases than 15% and when the SiC is 20% the ultimate stress is reduced slightly.
5. The mechanical properties of the following composites 90%Al+10%SiC, 75%Al+20%SiC+5%Gr, 85%Al+10%SiC+5%Gr, 80%Al+15%SiC+5%Gr are examined and observed. From the results obtained, It is observed that the 80%Al+15%SiC+5%Gr reinforced metal matrix composition is better applicable than the other metal matrix composition due to their superior characterization.

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