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ALUMINUM SILICON CARBIDE AND ALUMINUM GRAPHITE PARTICULATE COMPOSITES

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ABSTRACT

Metal Matrix Composites (MMCs) have been used in several applications in aerospace and automotive industries. Although several technical challenges exist with casting technology. Achieving a uniform distribution of reinforcement within the matrix is one such challenge, which affects directly on the properties and quality of composite. In the present study a modest attempt has been made to develop aluminium based silicon carbide particulate MMCs, graphite particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. Experiments have been conducted by varying weight fraction of SiC, graphite and alumina (5%, 10%, 15%, 20%, 25%, and 30%), while graphite weight fraction 2%, 4%, 6%, 8% and 10% keep all other parameters constant. The results indicated that the 'developed method' is quite successful to obtain uniform dispersion of reinforcement in the matrix. An increasing of hardness and with increase in weight percentage of ceramic materials has been observed. The best results (maximum hardness) have been obtained at 25 % weight fraction of SiC and at 4% weight fraction of graphite.

Keywords: metal matrix composites, aluminum alloy, volume fraction, metal hardness.

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. Aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can all be varied to achieve required properties. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics.

One of the major challenges when processing MMCs is achieving a homogeneous distribution of reinforcement in the matrix as it has a strong impact on the properties and the quality of the material [1]. To obtain a specific mechanical/physical property, ideally, the MMC should consist of fine particles distributed uniformly in a ductile matrix and with clean interfaces between particle and matrix. MMCs are generally processed with liquid metal routes such as stir casting and infiltration. A powder metallurgy route is also used for specific applications. However, an infiltration route is the most commonly used method by industry and accounts for the largest volume in primary production [2]. One of the problems associated with the infiltration route is the high volume fraction of the reinforcement which requires additional processes to dilute the content to the required levels. Prolonged processing times and increased processing steps at elevated temperatures aid the chemical reactions between matrix and particle, which often result in brittle secondary phases [3].

Metal matrix composites (MMCs) are one of the important innovations in the development of advanced materials. Among the various matrix materials available, aluminum and its alloys are widely used in the 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 (SiC, Al_2O_3, zircon, graphite, and mica) because of the likely possibilities of these combinations in forming highly desirable composites [4]. Graphite, in the form of fibers or particulates, has long been recognized as a high-strength, low-density material. Aluminum graphite particulate MMCs produced by solidification techniques represent a class of inexpensive tailor-made materials for a variety of engineering applications such as automotive components [5], bushes, and bearings [6]. Their uses are being explored in view of their superior technological properties such as the low coefficient of friction [7], low wear rate [8], superior gall resistance [3].This has led to increases research interest on evaluating the effect of type and weight fraction of reinforcement in the matrix and procedure that used to produce of MMCs [9-13]. In this investigation varying volume fraction of SiC, graphite, alumina was studied to determine the best result of properties.

MATERIALS AND METHODS

Study materials

The matrix material used in the experimental investigation was an aluminum alloy (Si - 7.2%), whose chemical composition is listed in Table-1.

Table-1. Chemical composition (wt.%) of the Al-alloy used in the study.

Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Al
3.37	0.13	8.54	1.20	0.19	0.04	1.36	0.07	0.03	0.04	REM

This alloy conforms to BS1490, and LM25 is mainly used when good mechanical properties are required. It is, in practice, a general-purpose high strength casting alloy. In its heat-treated form, its tensile strength can be increased from around 130-150 $N{\cdot}mm^2$ to up to 230-280 $N{\cdot}mm^2$. Aluminum and silicon alloys have no solid solubility below the eutectic, and the microstructure solidifies in the form of silicon particles in an aluminum matrix. Aluminum-silicon castings have good corrosion resistance and are used in the cases where particularly high strength is required.

Experimental procedure

The metal matrix composite used in the present work was carried out by the stir casting method. Al–Si alloys in the form of ingots were used. The cleaned metal ingots were melted to the desired super heating temperature of 750°C in graphite crucibles under a cover of flux in order to minimize the oxidation of the molten metal. A three-phase electrical resistance furnace with temperature controlling device was used for melting. For each melting 300 - 400 g of alloy was used. The super heated molten metal was degassed at a temperature of 780 °C. SiC particulates, preheated to around 500°C, were then added to the molten metal and stirred continuously by a mechanical stirrer at 720°C. The stirring time was between 5 and 8 minutes. During stirring, magnesium was added in small quantities to increase the wettability of SiC particles. The melt, with the reinforced particulates, was poured into the dried, coated, cylindrical permanent metallic moulds 80 mm in diameter and 175 mm high. The pouring temperature was maintained at 680 °C. The same molten metal SiC particle mixture was poured into strip. The melt was allowed to solidify in the moulds. For the purpose of comparison, the base alloy was cast under similar processing conditions.

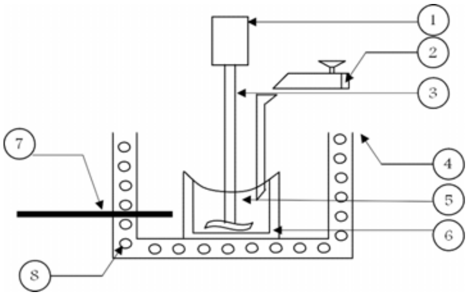

Figure-1. A schematic view of the furnace.

1. Motor
2. Shaft
3. Molten aluminum
4. Thermocouple
5. Particle injection chamber
6. Insulation hard board
7. Furnace
8. Graphite crucible

The melting was carried in a tilting electric furnace in a range of 760 ± 10^0C. A schematic view of the furnace has been shown in Figure-1.

Macro-and micro structural characterization

Macro structural studies were conducted in order to investigate the distribution of SiC particles retained in the metal matrix. Samples were taken to reveal the particle distribution on a macroscopic scale. Micro structural characterization studies were conducted on unreinforced as well as on reinforced samples. This was accomplished by using a microscope. The composite samples were metallographically polished prior to examination. Characterization was done in etched conditions. Etching was accomplished using Keller's reagent.

Bulk hardness and micro hardness

Bulk hardness measurements were carried out on the base metal and composite samples by using the standard the Brunel hardness test. The Brunel hardness measurements were carried out in order to investigate the influence of sic particulate weight fractions on the matrix hardness. The applied load was 500 kg, and the indenter was a steel ball 10 mm in diameter. Micro hardness measurements were carried out in order to investigate the influence of Sic particles on matrix hardness. The load applied was 50 g, and. Micro hardness measurements were made on the particle and in its vicinity. Round specimens 20 mm in diameter were prepared and polished on different grits of emery paper. Averages of 5 readings were taken for both bulk hardness and micro hardness measurement.

RESULTS AND DISCUSSIONS

Aluminum silicon carbide composite

The aluminum silicon carbide couple

The thermodynamic principles governing the chemical interaction between aluminum and silicon carbide can now be considered as well understood. High temperature isothermal sections of the Al- C -Si ternary phase diagram have been determined [7] and a model based on stable and metastable phase equilibrium has been developed for describing the Al- Si - C interaction at the medium and low temperatures of interest for composite manufacture. According to this model, Sic is in thermodynamic equilibrium with solid aluminum at every temperature lower than 650°C (Figure-2). At 650 ± 3°C, the following invariant transformation occurs in the Al- C -Si system. Sic + Al ==™ $Al_4C_3 + L_0$

Where L_0 is a ternary liquid phase containing aluminum (major constituent), silicon (1.5 at %) and carbon (less than 1 ppm). At temperatures higher than 650 °C, solid or liquid aluminum reacts with Sic, producing Al_4C_3 and silicon. If SiC is in excess, a three-phased monovariant equilibrium involving unreacted SiC, Al_4C_3 and a ternary liquid phase L_1 can be attained (Figure-2). The carbon content of this liquid phase L_1 simultaneously in equilibrium with Sic and Al_4C_3 remains very low whereas its silicon content increases with the temperature from 1.5 at.% at 650°C to 4.5 at.% at 727°C and 12.5 at.% at 1000°C (Figure-2).

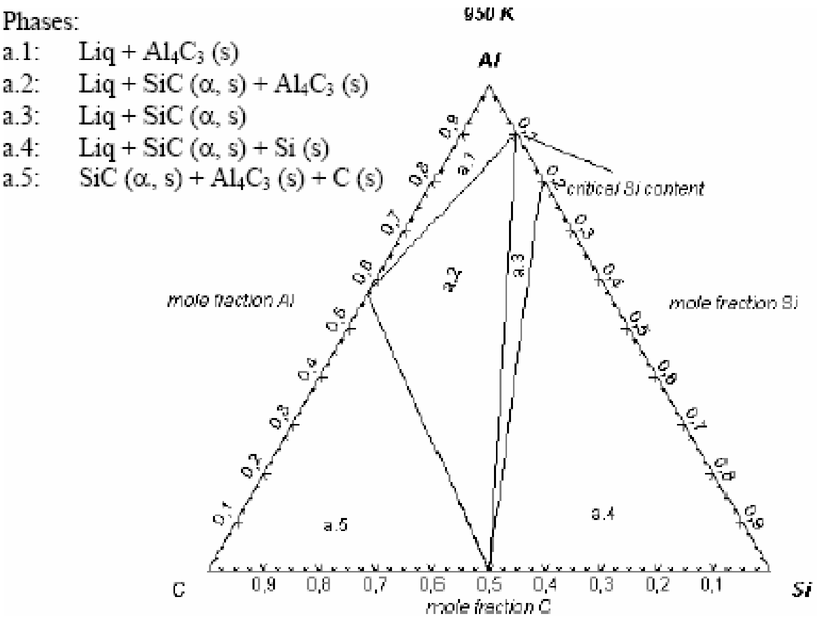

Figure-2. Phase diagram of Al- C -Si system [7].

The Al-SiC couple is non-reactive at temperatures lower than 650°C and reactive above. In the latter case, the couple can however be rendered non-reactive by the addition to aluminum of sufficient amounts of silicon. From these thermodynamic principles flow two different manners to avoid formation of Al_4C_3 at the matrix/reinforcement interface during the elaboration of Al-SiC composites: either these composites are processed in the solid state at temperatures lower than 650°C or they are elaborated at temperatures higher than 650 °C by melt infiltration with a Al-Si alloy containing the appropriate amount of silicon. In the latter case, precautions have however to be taken to avoid bridging of SiC by Si crystals on cooling (addition to the alloy of a Si modifier, control of the solidification, appropriate heat-treatment).

Microstructure examination

Metallographic samples were sectioned from the cylindrical cast bars. A 0.5 % HF solution was used to etch the samples wherever required. To see the difference in distribution of SiC particles in the aluminum matrix, microstructure of samples; First sample was prepared without applying any stirring process and the second sample has been fabricated with the help of manual stirring. All other samples were developed by using two step mixing method of stir casting technique by taking varying weight fractions of Sic particles. The various weight fractions were 5%, 10%, 15%, 20%, 25% and 30% of SiC particles. As observed from Figure-3, when the composite has been developed without applying stirring process, particle clustering occurred in some places, and some places were identified without Sic inclusion. This was due to the fact that when the SiC.

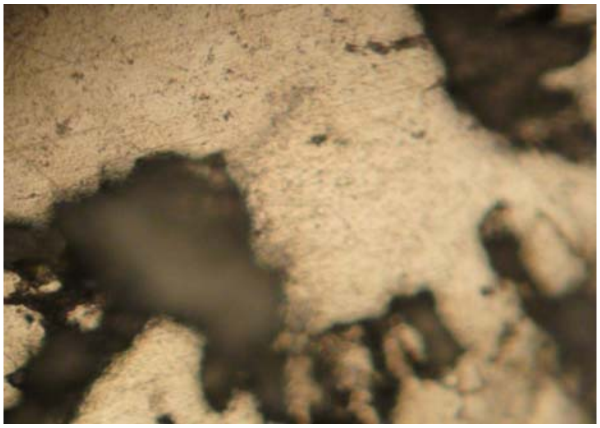

Figure-3. Optical microscopy of aluminum silicon carbide composite shows particle clustering.

Particles were added into the molten alloys, they were observed to be floating on the surface, though they have a large specific density than the molten metals. This was due to high surface tension and poor wetting between the particles and the melt. In fact, wettability between most ceramic particles and liquid metals has been poor. A mechanical force can usually be applied to overcome surface tension to improve wettability. Stirring has been carried out in a semi-solid state. In this state, primary α-Al phase exists, so agitation can apply large forces on the Sic particles through abrasion and collision between the primary α-Al nuclei and particles. This process can help to break the gas layers and perhaps oxide layers as well and to spread the liquid metal onto surfaces of the Particles, thus helping to achieve good wettability. It was found that cast composites with up to 25% by weight particles could be obtained using this method. The advantages of using semisolid slurries have been usually considered to be the increase in the apparent viscosity and the prevention of the buoyant migration of particles as shown in Figure-4.

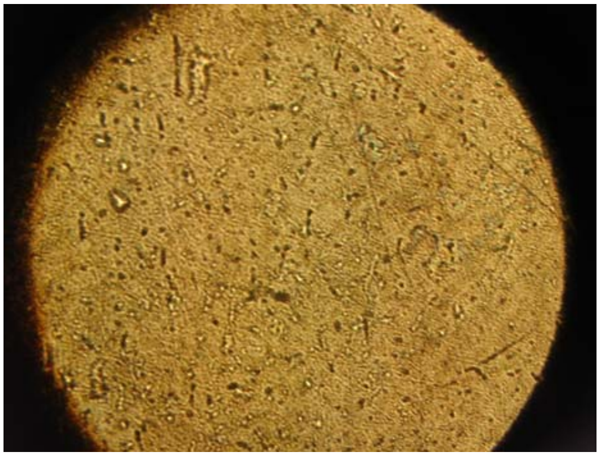

Figure-4. Shows the distribution of silicon carbide in metal matrix after stirring process.

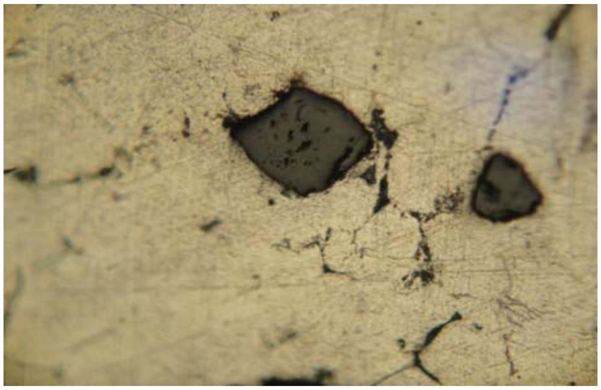

Figure-5. Optical microscopy shows silicon carbide particles in aluminum matrix.

Hardness measurements

Experiments have been conducted by varying weight fraction of Sic (5%, 10%, 15%, 20%, 25%, and 30%). Hardness test has been conducted on each specimen using a load of 250 N and a steel ball of diameter 5 mm as indenter. Diameter of impression made by indenter has been predicted by Brunnel microscope.

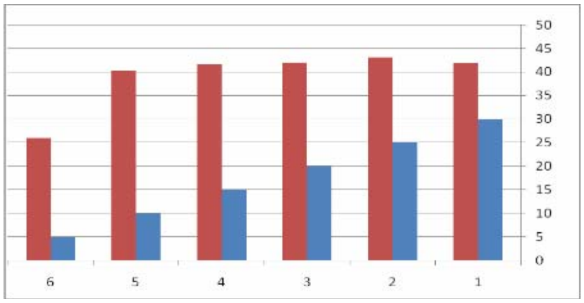

Figure-6. The relation between the weight percentage of silicon carbide and the hardness.

The results as indicated in Figure-6 the increasing the hardness of composite with increase in weight percentage of Sic up to 25% weight fraction. Beyond this weight fraction the hardness trend started decreasing as SiC particles interact with each other leading to clustering of particles and consequently settling down. Eventually the density of Sic particles in the melt started decreasing thereby lowering the hardness.

Aluminum reinforced with graphite particles

Microstructure examination

The specimens for microscopically observations were prepared by the standard technique of grinding with Sic abrasive papers and polishing with a diamond suspension solution. From microstructure quantitative analysis of the distribution of reinforcement particles in the MMCs obtained with AL-5%volume fraction of graphite.In the microstructure of the composite, agglomerates of the reinforcement particles are clearly visible as shown in Figures 7 and 8.

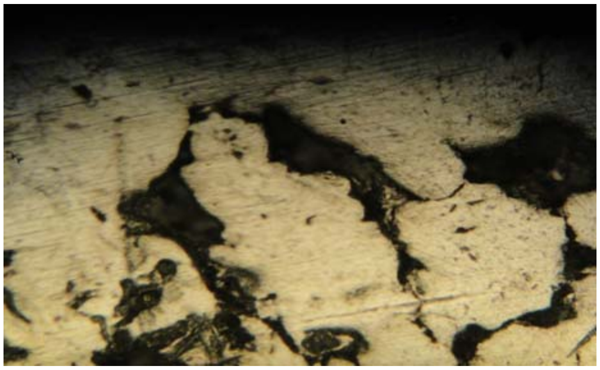

Figure-7. Optical microscopy of aluminum graphite particles.

Whereas the aluminum graphite composite sample shows a more uniform distribution of the reinforcement. During the distributive mixing, the rotation of the stirrer generates a vortex through which the graphite particles are drawn into the melt. The force provided by stirring the melt with a mechanical stirrer helps to overcome the surface energy barriers due to poor wettability of graphite by Al alloy. Once the particles are transferred into the liquid, the distribution is strongly affected by certain flow transitions. The axial flow causes lifting of particles due to momentum transfer and radial flow prevents particle settling. A high and local shear force is exerted on the agglomerates of the bulk cohesive graphite powder.

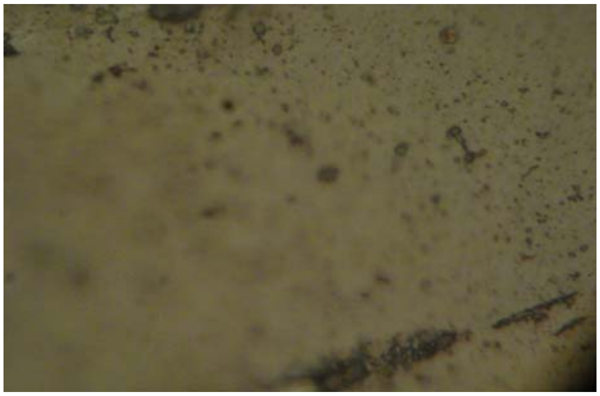

Figure-8. Optical microscopy of aluminum graphite composite.

Interfacial analysis

A strong bond between the reinforcement and matrix helps in the load transfer from the latter to the former. As a result, fracture takes place in the composite via the reinforcement and not along the interface [8]. Although the graphite is a non-load bearing constituent, a strong particle/matrix interface helps graphite particles embed themselves into the matrix properly, improving the fracture resistance. Good bonding between the graphite particle and the matrix is evident. There is no sign of void formation or extensive separation at the particle-matrix interface. The particles are well embedded in the matrix and the fracture shows microscopy (Figure-9) of Aluminum with graphite sample of the same composite also supports the fact that the interface is clean and sharp without any evidence for the formation of aluminum carbide at the interface, the result illustrated in Figure-9.

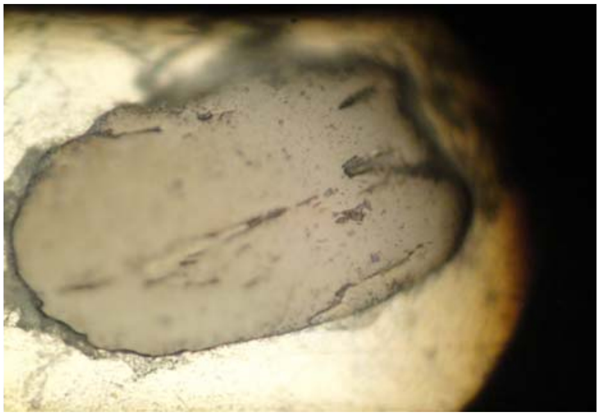

Figure-9. Microscopy photograph shows the interface between aluminum matrix and graphite particles.

Graphite can form aluminum carbide when it comes into contact with molten aluminum alloys at temperatures exceeding 627^{0}C and long contact time. One possible way to limit carbide formation is to alloy aluminum with elements very similar to carbon and change the interaction character on the interfacial boundary. Silicon is one such element. The addition of Si (from 7 to 10%) decreases carbon solubility in Al because a Sic layer or segregated Si may act as a diffusion barrier for carbon diffusion which reduces the reaction rate between C and Al which finally eliminates the formation of Al_4C_3. Further, in particular, high cooling rates are generally expected to limit the extent of a chemical reaction since the reaction times available for the melt/reinforcement interfaces are significantly reduced the presence of segregation of silicon.

Hardness measurements

Hardness test has been conducted on each specimen using a load of 250 N and a steel ball of diameter 5 mm as indenter. Diameter of impression made by indenter has been predicted by Brunel microscope.

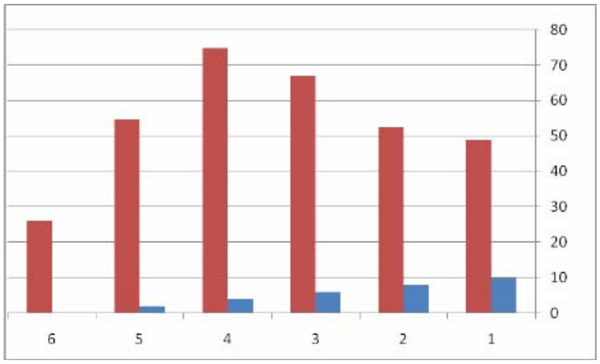

Figure-10. The relation between the weight percentage of graphite and the hardness.

As shown in Figure-10, the results indicates the increasing trend of hardness with increase in weight percentage of graphite up to 4 wt% weight fraction. Beyond this weight fraction the hardness trend started decreasing as graphite particles interact with each other leading to clustering of particles and eventually lowering the hardness.

CONCLUSIONS

The experimental study reveals the following conclusions:

- The results of study suggest that with the increase in composition of SiC, an increase in hardness is seen.
- The best result has been obtained at 25% weight fraction of SiC particles.
  Maximum Hardness = 45.5 BHN.
- Homogenous dispersion of SiC particles in the Al matrix shows an increase by applying stirring process.
- The distribution of particles and properties of composites significantly improved with graphite

particles of the reinforcement in the matrix with a strong interfacial bond between the two. The best result has been obtained at 4% weight fraction of graphite particles.
Maximum Hardness = 74 BHN

From the results above aluminum reinforce with graphite give high interfacial bound and high mechanical properties compare with silicon carbide reinforcement.

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