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INFLUENCE OF NANO REINFORCED PARTICLES ON THE MECHANICAL PROPERTIES OF ALUMINIUM HYBRID METAL MATRIX COMPOSITE FABRICATED BY ULTRASONIC ASSISTED STIR CASTING

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ABSTRACT

During the past few decades, materials design has shifted emphasis to pursue low cost, quality, light weight, environment friendliness, and performance. Aluminium matrix composites are important class of engineering materials used in aerospace, automotive, engineering, defence and other industries because of their lower density, higher specific strength, and better physical and mechanical properties. Aluminium Matrix composites are projected to significantly reduce the overall weight of the vehicles while maintaining satisfactory structural strength. Reinforcement of micro or nano-sized range particles with aluminium matrix yields improved physical and mechanical properties in composite materials. In this paper, we have investigated the effect of ultrasonic stirring in aluminium matrix composite with micro silicon carbide particles (fixed 5% wt.) and Nano Graphene (1, 3 and 5% wt.). Al356 was used as a matrix material. Micro SiC and Nano graphene produced by reduction of Graphite oxide Method were added as the hybrid reinforcements in varying proportions. Al 356 alloy/ (Graphene + SiC) hybrid composites with different hybrid ratios were synthesized using semisolid stirring assisted ultrasonic cavitation method. For comparison, an Al356 alloy + 5% SiC sample was also casted under the same conditions. Various properties of composites like tensile strength, ductility, Flexural strength, hardness, impact strength were measured and compared with Al356 + 5% SiC sample. The application of ultrasonic vibration on the composite during melting refined the grain structure of the matrix, and improved the distribution of nano-sized reinforcement. From the results of tensile test, it is found that the value of tensile strength increases with increase in Wt. % of graphene. The hardness of composites with 3% Nano graphene is higher than 1 and 5 % Nano graphene. The presence of Nano graphene in Al 356 alloy SiC composites validates the fact that, there is an improvement in mechanical properties.

Keywords: stir casting, aluminium matrix composites, ultrasonic stirring, graphene, hybrid composites, nano reinforcement.

INTRODUCTION

To overcome the limitations of Conventional monolithic materials in achieving good combination of strength, stiffness, toughness and density etc. and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent interest [1]. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. Aluminium is the most popular matrix for the metal matrix composites and they are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity [2].

In recent years, the particulate reinforced aluminium matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components [3]. Cast aluminium matrix particle reinforced composites have higher specific strength, specific modulus and good wear resistance as compared to unreinforced alloys. Casting route is preferred as it is less expensive and amenable to mass production. Among the entire liquid state production routes, stir casting is the simplest and cheapest one [4]. The only problem associated with this process is the non-uniform distribution of the particulate due to poor wet ability and gravity regulated segregation. Clusters of small particles are easily formed in the particulate reinforced metal matrix composites. Small particles in the melt always have the tendency to aggregate together to decrease the free energy of the whole system. Mechanical stirring is capable only for breaking up large clusters but cannot provide shear stress larger enough to break up smaller clusters of particles [5].

In order to achieve a uniform dispersion and distribution of nanoparticles in aluminium matrix nanocomposites, G.I.Eskin *et al*. [6], Yong Yang *et al*. [7],Yong Yang, Xiaochun Li *et al* [8] developed an innovative technique that combined solidification processes with ultrasonic cavitation based dispersion of nanoparticles in metal melts. It was reported that ultrasonic cavitation can produce transient (in the order of nanoseconds) micro “hot spots” that can have temperatures of about 5000◦C, pressures above 1000 atm, and heating and cooling rates above 1010 K/s [9].

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Furthermore, ultrasonic vibration can improve the wettability between the reinforced nanoparticles and the metal matrix, and distribute particles uniformly into the metal matrix.

EXPERIMENTAL PROCEDURE

Materials for Experiments

Aluminium alloy Al 356 was selected as matrix material. Because it is readily castable, widely studied and used. The alloy was tested for mechanical property and its constituents of Al 356 are given in Table-1. These values are obtained by using optical emission spectrometer (SHIMADZU-JAPAN, Model: TDA-7000) at Mettex Laboratories, Chennai. To select a suitable reinforcement and matrix for the aluminium nanocomposite, important factors such as density, wettability and chemical reactivity at high temperatures should be considered.

Table-1. Chemical composition of Al 356 alloy.

Elements	Weight. %
Silicon, Si	6.515
Iron, Fe	0.20
Copper, Cu	0.20
Manganese, Mn	0.10
Magnesium, Mg	0.275
Zinc, Zn	0.10
Titanium, Ti	0.20
Aluminium, Al	Balance

Silicon carbide is selected as one of the reinforcement materials because of its good wettability, nearly identical density and the big difference of the thermal expansion coefficients with aluminium alloys [10, 11, and 12]. The parameter of silicon carbide particles as given by supplier is shown in Table 2. Nano Graphene, the other reinforcement is selected because of its unique property i.e., this is the only form of carbon (or solid material) where every atom is available for chemical reaction from two sides thus resulting in ease of combining with it matrix and also in general improvement of mechanical tensile strength[13,14]. To increase the wettability of reinforcement particles in the molten Al, 1 wt. % of magnesium (Mg) was added to molten aluminium during casting [15].

Table-2. SiC micro particle parameters.

Commercial name	Silicon carbide
Purity	97.5%
Average Particle Size	120 nm
Colour	Greyish White
Density	3.22 g/cc
Morphology	Spherical

Synthesis of Nano-Graphene

Graphene oxide was synthesized from natural graphite by a modified Hummers method. The step by step procedure is followed as shown in Figure. 1. Graphite (1 g) and $NaNO_3$ (2.5 g) were mixed with 50 mL of H_2SO_4 (95% conc.) in a 500 mL flask. The mixture was stirred for 30 min within an ice bath as shown below in figure 1a. Under vigorous stirring, potassium permanganate (6g) was added to the suspension. The rate of addition was carefully controlled to keep the reaction temperature below 20 °C. The mixture was stirred and then, 100 mL of H_2O was slowly added still under vigorous stirring as shown below in figure 1b.

The reaction temperature was rapidly increased to 98 °C with effervescence, and the colour changed into yellow. For purification, the mixture was washed by rinsing and then deionized (DI) water for several times. After filtration and drying solid graphene oxide (GO) was obtained. Reduced graphene oxide (GOR) was prepared by chemical reduction of graphene oxide with hydrazine hydrate. 0.3 g of GO was dispersed in 50 mL of deionized water. Then, 1 ml of hydrazine hydrate was added and the mixture was heated at 100 °C for 24 hrs. After the reaction was completed, the solid GOR was centrifuged, repeatedly washed with DI water, and the final product was dried at 80 °C overnight.

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a) Suspension in icebath b) Magnetic stirring


c) Greenish brown suspension d) Heating in hot plate apparatus

e) Graphene powder

Figure-1. Preparation of graphene.

The structural and chemical properties of the GOR samples were characterized using X-ray diffraction (XRD) [16]. The XRD pattern of sample GO exhibited a strong peak at $2\theta = 11.6^{o}$, which corresponded to an interlayer spacing of about 0.76 nm, indicating the presence of oxygen functionalities, which facilitated the hydration and exfoliation of GO sheets in aqueous media. After chemical reduction, the hydrophilicity of the water-dispersed. GO sheets gradually decreased, leading to an irreversible agglomeration of GOR sheets. The Broad peak centered at $2\theta = 25.8°$in the XRD pattern of the GOR sample confirmed a random packing of graphene sheets in the GOR.

Fabrication of Composites

Ultrasonic cavitation assisted Stir casting process as shown in Figure-2 starts with placing empty crucible in the muffle. At first heater temperature is set to 500 ^{o}C and then it is gradually increased up to 900 ^{o}C. Aluminium alloy Al 356 is used as Matrix material. Required quantity of aluminium alloy is cut from the raw material, cleaned, weighed and then poured in the crucible for melting. During melting Nitrogen gas is used as inert gas to create the inert atmosphere around molten matrix.

Figure-2. Experimental setup used for stir casting.

The layout of the ultra-sonic cavitation assisted stir casting apparatus is shown in above figure-2. It consists of conical shaped graphite crucible which is used for fabrication of AMC, as it withstands high temperature which is much more than required temperature [680 ^{o}C].

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Required quantities of reinforcement powder and magnesium powder are weighed, mixed and added. Reinforcements are heated for half hour and at temperature of 600 °C. When matrix was in the fully molten condition, stirring is started after 2 minutes. Temperature of the heater is set to 630 °C which is below the melting temperature of the matrix [17, 18].

a) Melting Al 356 in furnace b) Stirring of molten mixture

c) Ultrasonic cavitation d) Cast specimens

Figure-3. Fabrication of casted specimens.

A uniform semisolid stage of the molten matrix was achieved by stirring it at 630 °C. 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 2/3 rd of the transducer of the ultrasonic cavitation assembly is immersed molten composite and ultrasonically processed for 10 min .Then slurry is poured in the metallic mould. Mould is preheated at temperature 500 °C before pouring of the molten slurry in the mould. This makes sure that slurry is in molten condition throughout the pouring. Then it is quick quenched with the help of air to reduce the settling time of the particles in the matrix. The following samples given in Table-3 are fabricated using ultrasonic assisted stir casting technique.

Table-3. Composition of fabricated samples.

S. No	Composition
1	Al 356 (94% wt.) + SiC (5% wt.)
2	Al 356 (93% wt.) + SiC (5% wt.) + Mg (1% wt.) + Graphene (1% wt.)
3	Al 356 (91% wt.) + SiC (5% wt.) + Mg (1% wt.) + Graphene (3% wt.)
4	Al 356 (89% wt.) + SiC (5% wt.) + Mg (1% wt.) + Graphene (5% wt.)

RESULTS AND DISCUSSIONS

Tensile Test

The tensile strength was determined with the help of Universal Testing Machine. The specimens were clamped between the fixed crosshead and the moving crosshead of the machine. The load was attached and the pressure valve was released so that the moving crosshead move down and the sample came under tension. After yielding the sample broke and at this point tensile strength was measured. For this purpose Al-SiC-Nano graphene hybrid composite samples will be fabricated as per the ASTM E8 standard [19]. Tensile strength or the ultimate stress of the cast different weight % of Nano graphene samples was measured and the trend was compared with Al-SiC composites.

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Figure-4. Prepared tension test samples.

It can be observed that with addition of 5 % Nano graphene, the ultimate tensile strength and yield strength of the nanocomposites improved by 47% and 34% respectively. But ductility has been decreased. This can be understood from the decrease in elongation percentage to 1.64%. From the following graph shown in Figure-5, it is observed that the value of tensile strength increases with increase in Wt. % of graphene. This validates the fact that presence of Nano graphene increases the tensile strength of Al 356 alloy SiC composites.

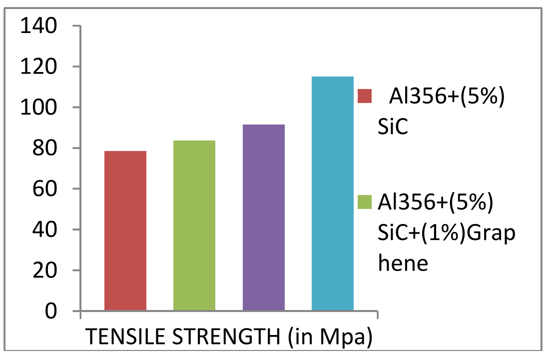

Figure-5. Tension test.

Hardness Test

In this test, resistance to indentation is measured. Rockwell hardness test is carried out to find the hardness of the samples. As the indenter moves downward during the test, the pressure has been accompanied by non-uniform matrix flow along with localized increase in particle concentration, which tends to increase the resistance to deformation. Consequently, the hardness value increases due to local increase in particle concentration associated with indentation up to 3% weight fraction of Nano graphene. Beyond this weight fraction, the hardness trend started decreasing. The samples were prepared for hardness test as per ASTM standards shown in Figure-8.

Figure-6. Hardness test samples.

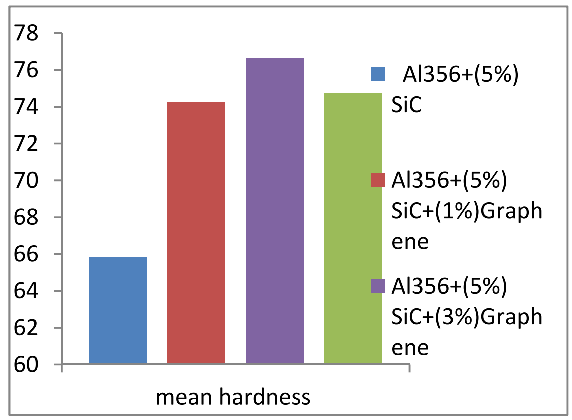

Figure-7. Hardness test.

Figure shows the comparison of hardness of aluminium alloy with fixed 5% SiC composites with varying proportions of Nano graphene added composites. From the graph it is observed that (1) the aluminium alloy with 5% SiC composite without Nano graphene have lower hardness. (2) The hardness of composites with 3% Nano graphene is higher than 1 and 5 % Nano graphene (3) the highest hardness was observed in 3% Nano graphene composites.

Flexural Test

The flexural test method measures behaviour of materials subjected to simple beam loading. It is also called a transverse beam test. Flexural strength is defined as the maximum stress in outermost. The Flexural test measures the force required to bend the specimen under three point loading conditions. The data is used to select those materials that will support loads without flexing. The specimen deflection is measured by crosshead position and results can also be plotted on stress-strain curve. The figure shows that the 5% Nano graphene composite has higher bending load than the other composites. Therefore on increasing Nano graphene, the bending load gets increased at minimal differences.

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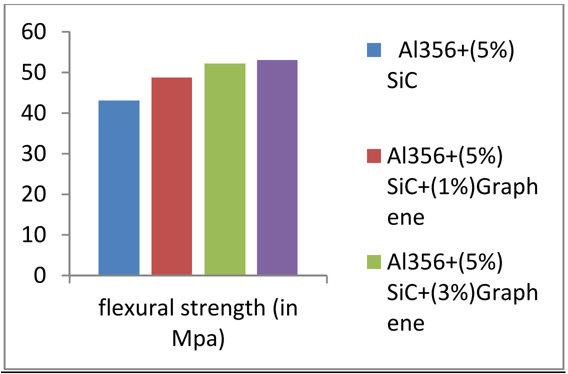

Figure-8. Flexural Test.

Impact Test

The Charpy impact test is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. The charpy impact test is performed to determine the amount of energy absorbed by material during fracture. The test samples are prepared based on ASTM E23-12c standard [19]. By adding reinforcements with the matrix can change the impact strength of the matrix. Addition of Nano graphene in the aluminium Al 356 improves its impact strength.

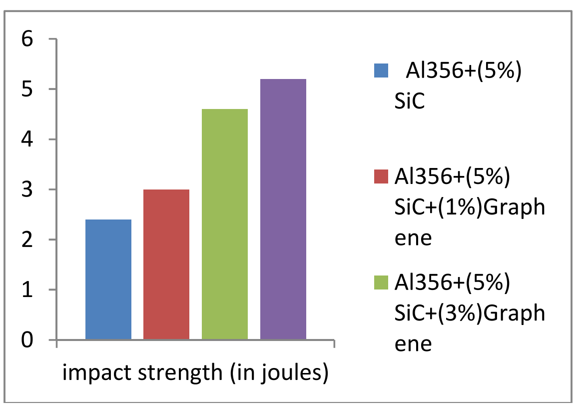

Figure-9. Impact Test.

CONCLUSIONS

The significant conclusions are obtained by analysing all the results through various tests and experiments and it is inferred that Al 356 matrix reinforced with fixed ratios of SiC and varying proportions of graphene will possess improved properties than its original alloy. The change in properties of the metal matrix occurs only when the mixture of reinforcements is uniformly distributed in the matrix. Hence Ultrasonic cavitation assisted stirring procedure is followed for the fabrication of the cast specimens which produce better results and avoids agglomeration up to certain extent. Various mechanical properties of the cast specimens are tested and concluded that the addition of graphene to the Aluminium Al 356 matrix had improve its mechanical properties effectively. Since the cost of Nano graphene was high due to its Complex production processes, Chemical method which involves the reduction of graphite oxide was used to produce Nano graphene at cheaper costs. Though ultrasonic cavitation was used, agglomeration still exists and it leads to further research in future. The tensile strength and yield strength of the cast specimens increase with increase in percentage of graphene in the aluminium matrix. The hardness of composites with 3% Nano graphene is higher than 1 and 5 % Nano graphene composites. The flexural strength and impact strength also improved in addition of Nano graphene. From the studies in overall, it can be concluded that Al 356 alloy/ (Graphene + SiC) hybrid composites exhibits superior mechanical properties and has tremendous potential for application (such as the fuselage skin) in the aerospace industry.

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