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Mechanical behaviour of Aluminium metal matrix composite reinforced with graphene particulate by stir casting method

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ABSTRACT

Aluminum metal matrix composite have the potential to replace the conventional materials because of obtaining superior properties such as high specific strength, high stiffness, high hardness, high wear resistance and low density. In the past three decades composite materials were playing a vital role in various sectors especially in aeronautical, avionics and automotive sectors. The present works dealt with the mechanical behaviour of aluminum metal matrix reinforced with graphene particles in different weight fractions such as 0.33%, 0.55% and 0.77% were prepared by stir casting method. The result revealed that 0.33% weight fraction of graphene is recommended for obtaining optimum results by stir casting process.

KEY WORDS: Aluminum metal matrix composite, Stir casting, Reinforcement, Graphene.

1. INTRODUCTION

Composite materials are playing vital and major role in research and development of various engineering and aeronautical sectors. In the past three decades composite materials are replaced most of the traditional materials because of obtaining superior properties such as higher specific strength, high hardness, high wear resistance, high thermal resistance and low density. Specifically aluminum metal matrix composites have preferred in aeronautics, marine and automotive industries for obtaining best result of mechanical properties. Composite materials are manufactured through solid and liquid method. In the liquid metallurgy route following methods are preferred such as stir casting method, electromagnetic stir casting method, centrifugal cast and in-situ method. The particle that is the particulate were reinforced with injection process into liquid matrix through liquid metallurgy route by die casting process. Die casting process is preferred because of less expensive and fit for mass production process. Among the entire liquid state production processes, stir casting is the simple and economical one (Hashim, 1999). Aluminum is one of the elements in boron group with atomic number 13. Pure aluminum has relatively soft material when comparing to the other non-ferrous materials. To overcome this issue of metal can be alloyed with other metals to obtaining superior mechanical and thermal properties. Most of the aluminum available in the market, manufacturers has been alloyed with at least one other element. The typical alloying elements are copper manganese, magnesium, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further sub divided into the categories heat treatable and non-heat-treatable. Composite materials are classified into based on matrix material such as if matrix material is polymer it is called as polymer matrix composite (PMC), if matrix material is metal it is called as metal matrix composite (MMC) and if the matrix material is ceramic it is called as ceramic matrix composite (CMC) (Surappa, 2003). 7000 series alloys such as 7050 are used in transport applications, like marine, automotive and aviation, due to their high strength and low density. Also used in Rock climbing equipment, bicycle components, inline skating-frames and hang glider airframes are commonly made from 7075 aluminum alloy. The problem exist in the stir casting process is the non-uniform distribution of the reinforcements. Present work is based on the mechanical behaviour of Aluminium7050 with graphene as reinforcement produced by stir casting method with different weight % of graphene were used and various tests were conducted on the composite material such as hardness test, tensile test, impact test, optical microscope and scanning electron microscope (SEM) tests were performed on the samples produced by stir casting method.

Various reinforcements are used in aluminum composite materials such as silicon carbide, aluminum oxide, boron carbide, titanium carbide, graphite etc., Graphene is a two-dimensional carbon material showing unique combination of mechanical and thermal properties. In particular, graphene have both superior tensile strength of 130 GPa and Young modulus of 1 TPa (Lee, 2008). These excellent mechanical characteristics cause a great potential in using graphene particles as strengthening elements in polymer, ceramic and metal-matrix composites for functional and structural applications. Aluminum is belonging to the metal family having the combination of less weight and high strength. Aluminum used in mainly in automotive and aerospace industries so they need less weight more strength. To alter mechanical properties of aluminum such as tensile, wear resistance, hardness etc. by adding a reinforcement such that due to that added material we get a final product of desired properties. Author investigated that adding of 0.8 vol % of graphene results obtained as fracture toughness of material increased to 40% (Harshit Porwal, 2013). Graphene found that the addition of 0.22% of graphene to aluminum increases it crack resistance to 50% and hundred million increases in electrical conductivity is observed (Centeno, 2013). This variation of properties in aluminum due to reinforcement brings us a new concept known as AMMC (aluminum metal matrix composites). In the present work dealt with aluminum 7050 matrix material reinforced with graphene in different weight percentages such as 0.33%, 0.55% and 0.77% to optimizing process parameters of stir casting process and various tests were performed for recommending homogeneous distribution of reinforcement.

2. EXPERIMENTAL WORK

Raw materials preparation: Aluminum 7050 and graphene were prepared by liquid metallurgy route such that stir casting method. Electric induction furnace has been used for getting liquid metal, reaching of 500°C raw materials were put into the furnace to getting liquid metal. Reaching of liquid state of molten aluminum add with the preheated graphene reinforcements in the separate chamber. Maintain the constant process parameters during stirring such as melting temperature 820°C, stirring time 5 to 10 seconds and stirring speed 400 rpm. After that poured into the preheated die to obtaining casting. Chemical composition of Aluminum 7050 is listed out in table.1.

Table.1. Chemical composition of Aluminum 7050

Component	WT.%	Component	WT.%
Si	Maximum 0.12	Cr	Maximum 0.04
Ti	Maximum 0.06	Cu	2-2.6
Zn	5.7-6.7	Fe	Maximum 0.15
Al	87.3-90.3	Mg	1.9-2.6
Zr	0.08-0.15	Mn	Maximum 0.1
Other each	Maximum 0.05	Other each total	Maximum 0.15

Tensile test: The tensile tests were carried out according to the ASTM E8 standard by universal testing machine to determine the amount of tensile strength to withstand during fracture.

Compression test: The compression tests were carried out in according to ASTM standard by universal testing machine to determine the amount of compressive strength to withstand during fracture. Compression test conducted with the three different samples which is prepared by wire cut machine.

Hardness test: The hardness tests were conducted by Brinell hardness tester in accordance to the ASTM E10 standard with the ball indenter diameter 10mm, load applied 500 kg and 20 seconds. The test were carried out in the room temperature atmosphere in the range of 30 to 32°C and measurements of hardness were obtained from five different places on each sample then considered as average hardness value.

Three point bending test (Flexural test): Flexural test were carried out in accordance to the ASTM:A-370 standard to measure the behaviour of materials subjected to simple bending tests. Three point bending test the maximum bending load were calculated based on the flexural formula as:

$$\sigma_b = BM \times y / I;$$

Where, σ_b is flexural stress; BM is bending moment =WL/4; W is load applied; L is span length of beam; y is the distance between the neutral axis to the top layer of specimen; y=t/2; t is thickness of specimen; I is moment of inertia.

$$I = bt^3/12$$

$$\sigma_{b\ max} = (WL/4) \times t/2 / bt^3/12$$

Maximum flexural stress initiated at mid span of the specimen.

Impact test: The impact test were carried out in accordance with the standard ASTM E23-12C by Izod machine to determine the amount of energy absorbed by the specimen during fracture. Impact test conducted with three different samples, as shown in the fig.1. Required impact strength is equal to energy required to break the specimen/area of cross section of specimen.

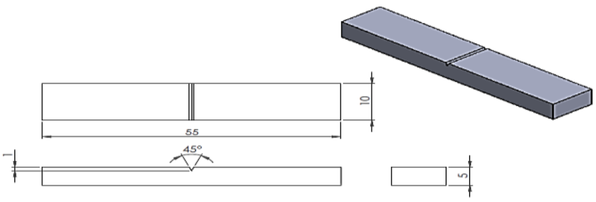

Figure.1. Specimen for impact test

Scanning electron microscope (SEM) test: Scanning Electron Microscope (SEM) also known as SEM analysis or SEM microscope is effectively used in microstructure analysis of composite materials. Scanning electron microscope carried out at high magnifications which generates high-pixel images and accurately measures very small features. Sample preparation plays an important and vital role in getting accurate results for the microscope analysis. For analyzing microstructure, the specimens were polished using emery papers with different grit sizes. Grit paper of 200 -1500 grit is used for finishing the specimen surface followed by polishing and etched with Keller's reagent. SEM is carried out using field emission scanning electron microscope brand name as ZEISS. The scanning electron microscope (SEM) is used to view at particular place and check the microstructure of the prepared sample. SEM produces the image when electrons in microscope contact with the surface of the sample it collides with the atoms and that contains the surface topography and composition. The electron beam is generally scanned in a raster scan pattern and the beam's position is combined with the detected signal to produce an image. SEM can achieve better resolution. SEM analysis will be carried out for three different samples Fig.2 to 5 shows the microstructures of fabricated Al7050 alloy matrix as well as Al7050 alloy matrix reinforced graphene with various weight fractions. Microstructure of cast Al7050 alloy matrix presented in different figures which reveals that the formation of a aluminum dendritic network structure which is formed due to the super cooling of composite during solidification. The surfaces of the composites specimens are examined directly by scanning electron microscope. The specimens sample are well cleaned thoroughly using acetone prior to observed under SEM. Samples are mounted on stubs are examined. The favorable sites for graphene particle incorporation were identified by SEM method.

3. RESULTS AND DISCUSSION

Tensile test reveals that increasing of graphene weight percentages decreasing tensile strength except 0.33 weight percentages of graphene. The results of tensile test on the samples revealed that addition of 0.33 wt% graphene leads to increase the tensile strength by 50 wt% which is illustrated in table.2. Compressive test result also reveals that same value of tensile test.

Table.2. Tensile strength of composite material

Description	Al 7050	Al + 0.33% Graphene	Al + 0.55% Graphene	Al + 0.77% Graphene
Ultimate tensile strength (UTS), MPa	90	145	55	47

The effects of reinforcement of graphene on the hardness of composite were obtained from the hardness test as shown in table.3. The values were obtained from the Brinell hardness testing machine. The result reveals that the hardness of Al 7050 with graphene reinforcements were observed adding 0.77 wt% leads to decreased hardness compare to base metal.

Table.3. Brinell hardness of Al7050+graphene composite

Trial	Plain Al7050	0.33% of Graphene+ Al7050	0.55% of Graphene + Al7050	0.77% of Graphene + Al7050
1	83.4	53.6	46.6	47.3
2	86.2	56.7	52.2	45.9
3	88.3	61.2	50.2	41.9
Average (BHN)	**85.9**	**57.1**	**49.6**	**45**

Authors (Surappa, 1978; Son, 2003; Lin, 1998; Pai, 1978) investigated that the various mechanical characteristics of specimen reinforced with various reinforcements and various weight fractions to obtaining different results. The flexural strength of specimen were obtained from three point bending test as shown in table.4 reveals that the flexural strength was decreased with the addition of graphene. Some of the researchers proved that the addition of graphite to aluminum alloys caused to decrease the strength, hardness, fracture energy and ductile property of material.

Table.4. Flexural strength of Al7050+graphene composite

Trial	Plain Al7050	0.33% of Graphene+ Al7050	0.55% of Graphene + Al7050	0.77% of Graphene + Al7050
Average (MPa)	**150**	**210**	**185**	**140**

Impact test result shows that the energy required breaking the specimen 2 N-m. Area of the cross section 50 mm^2. Required impact energy observed that all three specimens are same. No changes were observed in impact test.

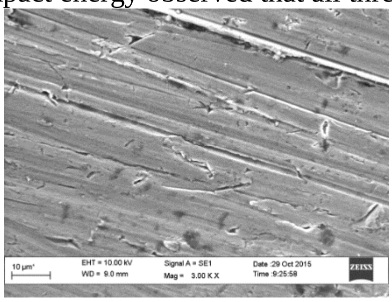

Figure.2.Plain Aluminum alloy Al7050

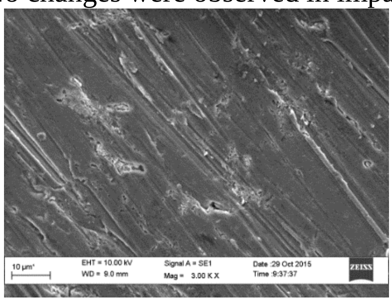

Figure.3. Al7050 with 0.33% of Graphene

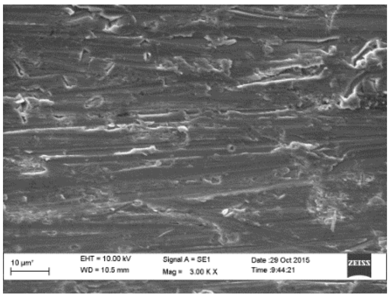

Figure.4. Al7050 with 0.55% of Graphene

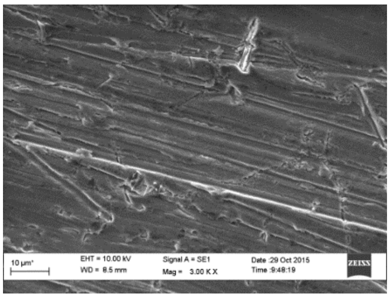

Figure.5. Al7050 with 0.77% graphene

As the microstructure plays an important role in analyzing the mechanical properties of the aluminum metal matrix composite. The favorable sites of the material were identified by SEM. The particle size, distribution of the reinforced material and the microstructure of the component are examined by using SEM. Figure 2 to 5 shows the scanning electron microstructure of the base matrix Al7050 and the alloys reinforced with 0.33 weight% graphene using stir casting respectively. The typical microstructure for this alloy consists of primary aluminum matrix shown as white phase and Al-Si eutectic shown as dark lamellar structure. The as-cast microstructures of the two castings show that the phases are uniformly distributed. The figure clearly shows a morphological change in the microstructure of the specimen. In the base matrix sample the microstructure is dendritic whereas in the other stir cast samples the primary dendrites are fragmented due to mechanical stirring and graphene weight fractions. However, with the continued stirring the plastic strains within the fragmented grains would be considerably less and the process of coarsening will generate. Since the coarsening is driven by interfacial energy, the process will lead to a reduction in the surface area and eventually spheroidal morphology was obtained. It was observed that not only the primary Al grains that was observed that white portions of the structure but also eutectic Si particles that is dark portions are globular in stir cast samples in comparison to the base matrix of the composite without stirring cast samples. As the structure contains good amount of eutectic phases it should give a range of mechanical properties with mechanical stirring during processing of stir casting process and graphene weight fractions. The microstructure observations well support the results of the mechanical properties of the alloys reinforced with nano particles using mechanical stirring. The observed refinement of the Si eutectic has been also observed and recorded before and has been attributed to the improved nucleation of Si particles and depletion of Si element near the Si particles. However the effect to heterogeneous nucleation initiated by the graphene particulates weight fractions.

Previous work reported that addition of graphene more than recommended fraction with the matrix aluminium 7050 obtained cluster formation. The result shows that the addition of 0.77 weight% nano particles did not produce a significant change in the mechanical property of composite material of the hypo-eutectic alloy Al7050. Microstructures of composites presented in fig.2 clearly reveals that the homogeneous distribution of graphene in the Al alloy matrix and there was no evidence of porosity and cracks in the casted samples due to the proper process parameters employed for the production of castings.

4. CONCLUSION

Aluminium 7050 alloy reinforced with graphene synthesized by stir casting process with different weight fraction of 0.33%, 0.55% and 0.77%. The mechanical properties such as tensile strength, compressive strength, hardness test, flexural strength, impact strength and scanning electron microscope test were obtained and analysed. From this research work following results were obtained quantitatively.

Defect free aluminium metal matrix reinforced with graphene was produced by stir casting method. No porosity noticed in the samples.

The SEM micrographs revealed that the presence of graphene 0.33 weight fraction obtained homogeneous dispersion.

The reinforcement of graphene particles made the tensile strength of aluminium matrix composites from 90 MPa to 145 MPa. It means that it increased 60% of base material.

Graphene 0.33% reinforced with Al7050 composites hardness value maintaining optimum value.

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