Characterization of Graphene Reinforced Aluminum Nanocomposites by Squeeze Cast Technique

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Abstract- **Aluminium matrix composites are among the most promising candidate materials for light weight and high strength applications such as transportation and armour. The present study includes 6061 aluminum matrix composites reinforced with Graphene (GR) preform were successfully fabricated by squeeze casting using the laminate fabrication technique. This research work aims at optimizing the fabrication process in order to achieve improved strength and mechanical properties. It focuses on the liquid infiltration squeeze casting method. Good mechanical bonding between fiber and aluminium is achieved by liquid aluminium. Oxidation products at fiber/aluminium interface and porosity are reduced. As a result, composites are produced with overall improved mechanical properties. The flexural strength is increased by 17.61% and 5.23% with 4 wt.% and 2 wt.% of reinforcement respectively. Whereas the hardness of material for 4 wt.% decreases and for 2 wt.% shows increment.**

Keywords: Composite, SEM, XRD, Graphene, Squeeze metal casting

I. INTRODUCTION

The applications of metal matrix composites (MMCs) range from military and commercial aircraft to helicopters and spacecraft, automotive and marine, electronics, sports industries, and electrodes for metal plating processes. Particularly, for high temperature applications, polymer matrix composites are inappropriate due to their low melting point. Therefore, either metals, MMCs or in the case of extreme temperatures, ceramic matrix composites must be considered [1]. Currently, both Airbus (A350) and Boeing (787) are developing next-generation aircrafts with over 50% composites.

Aluminum matrix composites possess excellent mechanical properties, low density, high corrosion resistance and good processing performance, which have become one of the most widely used metal matrix composites (MMCs) . Due to the lightweight requirements in auto and aerospace industry, traditional reinforcements like ceramics and fibers cannot satisfy the need . Graphene is a one-atom-thick planar sheet of sp2-bonded carbon atoms that are densely packed in a honeycomb crystal latice. Due to large surface areas, light weight, unique electronic, extraordinary mechanical and thermal properties, graphene has attracted tremendous attention in recent years. Compared to the one-dimensional carbon nanotube, the two-dimensional graphene is much easier to be controlled and dispersed in metal matrix. Moreover, graphene can be prepared in large quantities by chemical exfoliation of graphite, which makes it an ideal reinforcement in MMCs [2].

Squeeze cast aluminium matrix composite pistons are widely used in heavy-duty diesel engines. The low coefficient of thermal expansion of composites enables near “zero” clearance pistons by reducing piston clearance from 0.051 mm to 0.005 mm which minimizes ring seal leakage. The dimensional stability of MMCs makes them appropriate for tools and dies for shape metal parts. The extremely high stiffness of graphite fibers enables composites to meet space structure application requirements such as in antennae and telescopes where precise pointing and tracking are required[3].The present work aims at fabricating the graphene reinforced aluminum matrix nanocomposites by using squeeze cast technique and to characterize the mechanical properties of the samples.

II. EXPERIMENTAL PROCEDURE

Commercially available aluminium alloy 6061 is used as composite matrix. Aluminium is one of the most abundant metals and valuable because of many properties such as its lightweight, high strength, long life, high ductility, machinability, excellent thermal and electrical conductivity, recyclability and corrosion resistance [4, 5]. Some important properties and the chemical composition of 6061 are tabulated in Table 1.

The GR powders were used as reinforcements due its enhanced mechanical behavior and its compatibility with metal matrix composites [6-8]. Scanning electron microscope (SEM) and by X-ray diffraction (XRD) were used to first investigate and examine the graphene powders. Figure 1 shows The SEM images of GR and it noticeably indicates that the particles are of carbon. XRD patterns of GR are shown in figure 2 and it reveal that the peak points are of carbon.

Table 1: properties of Aluminium 6061

Physical Properties	Values
Density	2.7 g/cc
Brinell hardness	95
Ultimate tensile strength	310 MPa
Yield tensile strength	276 MPa
Modulus of elasticity	69.0 GPa
Linear coefficient of thermal expansion	23.6 µm/m-°C
Thermal conductivity	167 W/m-K
Melting point	582 - 652 °C
Solidus	582 °C
Liquidus	652 °C

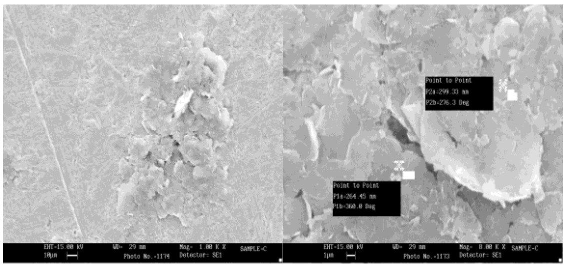

Fig. 1: SEM images of GR

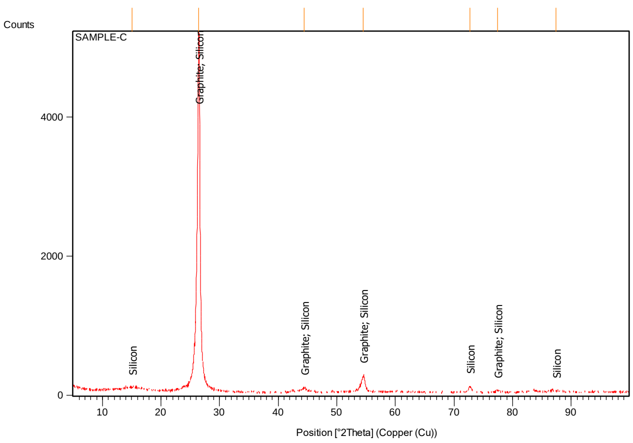

Fig. 2: XRD images of GR

The casting and squeeze castings are the important methods to produce MMC through liquid metallurgy route.The squeeze casting includes combination of casting and forging technique.[9,10].The squeeze casting equipment, stainless steel 316 is selected as it can withstand high temperature and accelerated oxidation environment experienced during squeeze casting. The squeeze casting setup consists of two stainless steel spacers, stainless steel plunger, die, and base as shown in Figure 3. The cylindrical die is designed in order to minimize leakage, provide uniform pressure , and ensure smooth ejection of the cast . The die cavity has an internal diameter of 78 mm with 5.5 mm wall thickness. It is connected to a 12 mm thick perfectly flat welded flange of 122 mm diameter using head cap screws and nuts. The plunger is a close fit to the die cavity in order to minimize leakage. The plunger is designed to be 50 mm longer than the die depth in order to be also used as ejector of the squeeze cast sample.

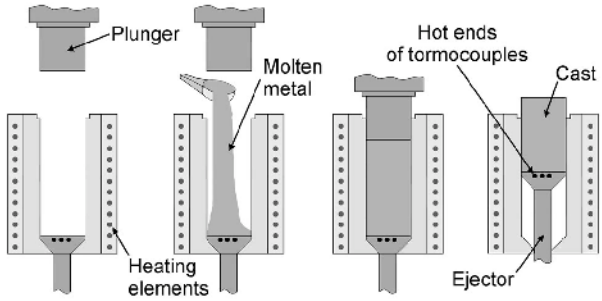

Fig. 3: Schematic representation of squeeze cast

Extruded aluminium A6061 rods with 50 mm diameter are used. A band saw is used to cut the rods into appropriate sizes. The aluminium charge is molten in a graphite crucible cup placed inside a Lindberg Blue M vertical type furnace. Simultaneously the preform is heated in a horizontal type convectional furnace. A graphite crucible is selected due to its high thermal shock resistance. It has a molded-in pouring lip to facilitate pouring of molten aluminium into the die cavity.The samples were fabricated with 1wt%, 2wt%, 3wt% and 4wt% of the graphene powders in aluminum matrix. Impact, hardness, and bend tests are conducted. The behaviour of the composite obtained by squeeze casting is compared to that of the reference aluminium alloy casted under identical conditions. Vickers hardness tests are used to investigate the local hardness, the adhesion between the fiber and matrix and the formation of different phases at the fiber/matrix interface. These tests are performed using a STRUERS DURAMIN A/S DK-2750 micro-hardness testing machine. An indentation load of 500g (Hv0.5) is used and hardness values are obtained from the digital output of the machine.

Three point bend tests are used to measure the force required to bend a beam under 3 point loading conditions. Specimens for the three point bend tests are rectangular bars cut in dimensions of 55 mm length (L), 12 mm width (b), and 3.64 mm to 6.0 mm thickness (d). A test specimen is held as a simply supported beam and is subjected to three-point bending. A computer controlled Instron universal test frame is used as shown in Figure 3-17. The cross-head displacement speed is 10 mm/min and the deflection is measured up to 2 to 5 mm after the start of fracture.

Optical and scanning electron microscopy investigations are used for microstructure, chemical composition, phase formation at the interface, and porosity characterization.

III. RESULTS AND DISCUSSION

Microstructural analysis of all the samples was conducted using Scanning Electron Microscopy (SEM). A SEM micrograph of sample 2wt% is illustrated in Figure 4 and shows the reinforcements are distributed uniformly.

The matrix region of the samples containing the original fiber fabric differs from that of the low density fiber fabric, and the variation in the interspacing between plain weave tows affects the composites' overall properties.

SEM EDX (Energy-Dispersive X-Ray Spectroscopy) is carried out for chemical analysis. Precipitation of elements is observed at some regions near the interface as shown in Figure 5 and 6.

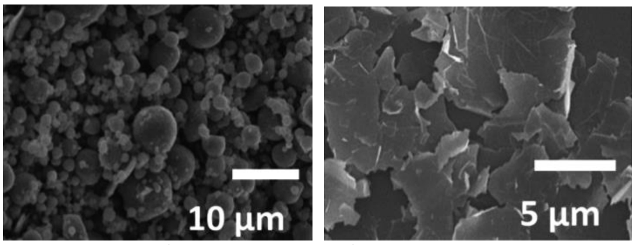

Fig. 4: SEM of 2wt% graphene reinforced aluminum composites

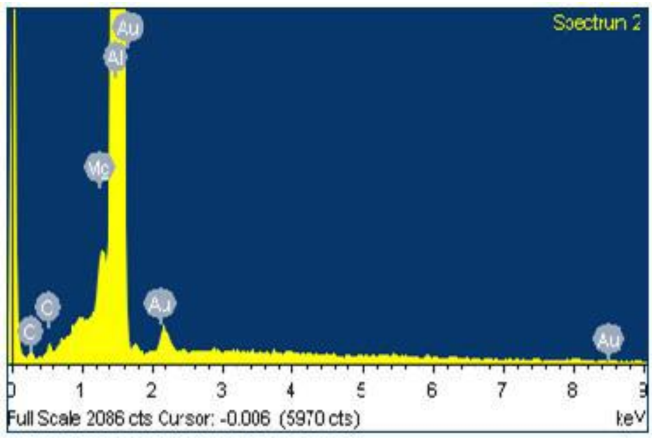

Fig 5: SEM EDX area mapping of 2wt% sample

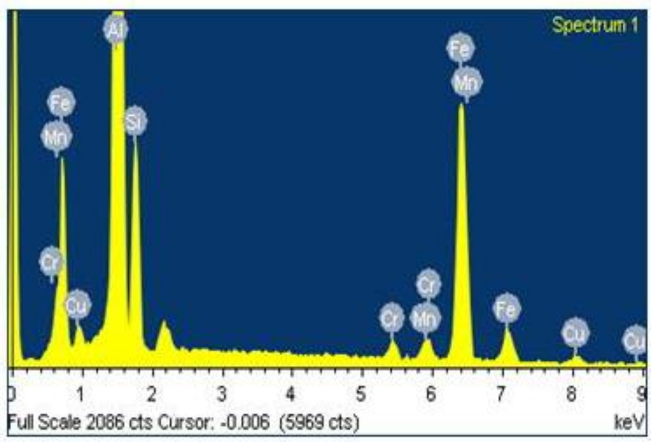

Fig 6: SEM EDX area mapping of 3wt% sample

It is evident from the element contents summarized that other than aluminium and carbon, oxygen, magnesium, and silicon are present. Between the different samples, the weight percentages of aluminium and carbon are almost identical. Precipitates are also observed clustered together at grain boundaries within the matrix and at the fiber/matrix interface as can be seen in Figure 5 and 6.

Vickers hardness measurements at carbon fiber/aluminium matrix interface are summarized in table 2 and Figure 7. It is observed that the reinforced materials showed improved hardness compared to base material.

The flexural strength values are tabulated in Table 3. The overall results of the current study show better values in terms of bend strength compared to the best results of the base matrix.

Table 2: Vickers hardness

Composition	Vickers Hardness
Aluminum	47
Aluminum +1wt% GR	65
Aluminum +2wt% GR	69
Aluminum+3wt% GR	72
Aluminum+4wt% GR	66

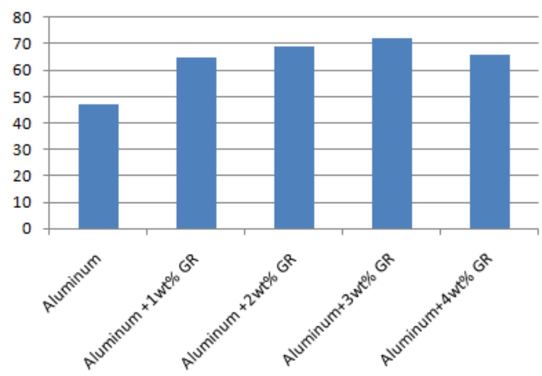

Figure. 7: Graph of Vickers hardness

Table 3: Bend moduli for the different composites and Flexural strength

Samples	Al	Al+ 1wt% GR	Al + 2wt% GR	Al +3wt% GR	Al + 4wt% GR
Thickness 'd' (mm)	3.79	4.08	6.4	6.5	6
Length 'L' (mm)	55	55	55	55	55
Width 'b' (mm)	12	12	12	12	12
m (P/D)	490.03	585.29	724.56	4826.31	5012.2
Flexural modulus 'E' (GP)	36.25	43.28	39.2	79.95	79.65
Flexural strength (MPa)	222.35	225.39	234	250.58	261.49

IV. CONCLUSION

Carbon fiber reinforced aluminium matrix composites are successfully manufactured by the squeeze casting infiltration process. The resulted composites show improved properties as follows:

- The fiber/matrix bond is primarily of adhesion type and the interface is free from reaction products. In this process, liquid pressure during cooling and low liquid viscosity promotes strong fiber/matrix bonding.
- Liquid infiltration produces overall higher hardness at fiber/matrix interfaces than base matrix.
- The flexural strength of the composites is increased by 17.61% compared to the base matrix probably due to higher fiber contents. The flexural strength of the composites is also increased by about 5.23% compared to that of the reference 6061 aluminium alloy squeeze casted under identical conditions.

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