Study of tensile and compressive behaviour of the in-house synthesized al-alloy nano composite

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Abstract. The present study is focused on the in-house synthesis of graphene reinforced Al-alloy nanocomposites using stir casting process. The concentration of graphene nanopowder (size range: 3-8 nm) is taken as 2 wt. % and 6 wt. %. Tensile and compressive characterization study has carried out on the prepared synthesized specimens as per the ASTM standard, and further examined the microstructure of the specimens to study the behaviour of nanopowder dispersed in Al-alloy matrix. The results reveal that the tensile and compressive strength of the graphene reinforced (increasing concentration to 6 wt. %) Al-alloy nanocomposite has increased by 49% and 44% respectively as compared to un-reinforced material. Moreover, it has been observed that with increasing concentration of reinforcement, the specimen exhibits brittle character and accordingly the percentage of elongation found to be reduced. The effect of graphene nanoparticles on the tensile and compressive behaviour of the composites has also documented in this article.

Keywords. Graphene, Al-alloy, Nanocomposites, Stir casting, Tensile strength, Compressive strength

1. Introduction

In the present century nanotechnology has gained a considerable importance with its application in multidisciplinary scientific field for the aim of producing nanomaterials at nano level scale known as nanostructured materials. Nanostructured materials are those materials which are having at least one dimension in the range of 1 to 100 nm. These nanostructured material materials include nanoparticles, nanocomposites, nanotubes, nanorods, thin films, etc. However, in recent times nanocomposites in the field of nanotechnology has drawn a lot of attention among the researchers and has become a fast-growing field. Nanocomposites are those materials in which the dispersed phase is in the nanometer range. The nanocomposites have played a significant role in scientific, industrial and medical fields because of their extraordinary properties as compared to the conventional composites. Their uniqueness arises due to the large surface area to volume ratio of the dispersed material.
indicating that a large fraction of atoms present on the material surface which are chemically unsaturated. Among various nanocomposites, metal matrix nano-composites (MMNC) have gained a remarkable research and market attention because of their novel physical, mechanical, electrical, optical, bio-medical properties etc. as compared to the metal matrix composite (MMC) and interdisciplinary emerging applications [1]. In one of the literature, aluminium matrix composites with different concentration of SiC, (0, 5, 10 and 20 wt. %) were fabricated using stir casting technique. The tensile strength and hardness of the reinforced aluminium composites was found to be increased with respect to un-reinforced one and observed to be maximum at 20 wt.% SiC. Also, found that there is a maximum reduction in wear of the reinforced composites at 20 wt. % SiC. Microstructural examination revealed the non-homogeneity nature of the reinforced composites with formation of porosities. Sivananth et al. [2] studied the characterization of TiC reinforced Al metal matrix composite prepared by stir casting process at three different concentration of TiC particulates (10,12 and 15 wt. %) and are in the size of 325 meshes. They have conducted the tensile and impact test and also studied the microstructure of the composites. They found that the tensile strength was increased as compared to the unreinforced Al and observed to be maximum at 15 wt.% TiC. The brittle nature of the test samples found to be increased with the increase in wt% of TiC particles in Al matrix. Yoshina et al. [3] investigated the synthesis and properties of graphene and graphite based aluminium metallic material. The density and tensile strength of the unreinforced aluminium was found to be 2.7g/cm³ and 41.46MPa. But, after incorporating 2 wt .% of graphene sheets and graphite, tensile strength has found to be increased to 48.1MPa and 43.92MPa respectively while the density decreased to 2.4g/cm³ common in both cases. Yc et al. [4] studied the mechanical characteristics of glass reinforced aluminium matrix composite prepared by stir casting. They used matrix material Al6061 alloy and reinforced with 3 to 12 wt. % glass particulates. They used glass particulates of different sizes - 75, 88, 105 and 250 µm. They found that by addition of reinforcement up to 9wt% the tensile strength and hardness found to be increased and thereafter decreased.

Based on the literature survey it has been found that the study of tensile and compressive behaviour of a developed graphene reinforced aluminium nano-composite for a suitable application has not been explored. Therefore, the present work has focused on the development and experimental characterization of graphene reinforced aluminium matrix nanocomposites by stir casting process. Further, to study the effect of GRNP on tensile and compression behaviour of the composites.

2. Experimental details

2.1. Materials

In the present study, aluminium alloy is taken as matrix material because of its properties like high strength to weight ratio, good corrosion resistance, ease of extrudable, etc. as compared to the metallic aluminium [5]. Aluminium alloy purchased from Zunaid Steel, Chennai, and was tested in an Analytical Laboratory to ensure the purity of the material and conform to the ASTM B221M-05a Alloy “6005A” with respect to the tested parameter concerned. The elemental composition of the tested alloy is given in table 1.

| ELEMENTS | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|----------|----|----|----|----|----|----|----|----|----|
| %        | 0.837 | 0.161 | 0.011 | 0.498 | 0.695 | 0.022 | 0.010 | 0.024 | 97.629 |

Graphene is a single layer of carbon atom which is arranged in a hexagonal lattice by means of sp2 hybrid bonds. All graphitic forms of carbon are derived from the carbon allotrope which is known as Graphene. Graphene also exhibits extraordinary properties like highly stiff, has zero effective mass, exhibits very high thermal conductivity and optically transparent etc. [6]. Because of these above
novel properties we selected Graphene Nano-Powder as reinforcement. The Graphene nanoparticles (GRNP) studied in this paper was purchased from Adnano Technologies pvt. ltd. having average thickness 3-8 nm and average lateral dimension 5-10nm. The microstructure of GRNP is shown in figure 1.

![Figure 1. SEM image of GRNP](image)

2.2. Preparation of composites

The purchased bulk Al weighted and cut into small pieces and was placed in a graphite crucible. The crucible is placed in an electric furnace having maximum temperature of 1000°C. Degasser powder is used to remove the impurity from the molten metal and the coverall powder retains the temperature inside the crucible. After the dispersed phase properly mixed with continuous phase, the molten material was poured into the pre-heated die of 204 mm length and 22 mm diameter, solidifies and finally nano composite specimens were removed from the mould. The steps involve in the fabrication of nanocomposite are shown in figure 2.

3. Characterization

The GRNP distribution throughout the matrix has observed through the microstructures. For the microstructure, the test samples were polished using the emery papers and subsequently using cloth with diamond paste on revolving disc at 500 rpm. Microstructures were observed in etched condition using optical microscope at different magnification [7]. As per the ASTM E8M [2] (Figure 3), the fabricated specimens were prepared as shown in the figure 4 required for tensile testing of the specimens. Similarly, for compressive test of the specimens as per the ASTM E9 [8] (Figure 5), the specimens were prepared as presented in Figure 6. Three tensile test samples are prepared for each 2 wt. % and 6 wt. % concentration of reinforcement, and the same procedure was also followed for the compressive test.
Tensile test was performed using a computerized ultimate tensile machine at room temperature at on the Omega Inspection & Analytical Laboratory. From test results an average of three reading were taken. Further compression test also conducted on the Omega Inspection & Analytical Laboratory through UTM at room temperature, with gradually increased load until the specimen failed. An average of three readings was taken.

4. Results and discussion

4.1. Microstructures

The microstructure and the interfacial bonding between the dispersed medium and dispersed phase describe the properties of the composites. Figures 6 (a-d) reveals the optical microstructure of the unreinforced alloy, and 2, 6 wt. % GRNP reinforced AMCs and porosity respectively. Clustering and the non-homogeneous distribution of the GRNP in AMCs were observed from the microstructural analysis. This was attributed due to the poor wetting behaviours and variation of interaction time between GRNP and Al molten metal [7]. Moreover, air is entrapped between the particles during the addition of GRNP with Al molten metal in the mould cavity resulting in the formation of porosities. It was also observed that with increase in concentration of the GRNP, the amount of porosity increased due to more aspiration of air [9].
4.2. Tensile Strength

The relation between tensile strength and the weight % of GRNP showed in the figure 7. And from the test it is observed that with the addition of GRNP in Al melt, it shows greater strength than the unreinforced Al.

Figure 7. Tensile strength of GRNP reinforced AMC

It is because of the strongly interfacial bonding between the reinforcement and the matrix and grain strengthening effect [10]. It show that with the addition of wt.% of GRNP the percentage of elongation decreased, which means with the increased wt.% of GRNP the composite shows the brittle in nature. In the show the elongation as 5.16%, 2.75%, 2.17% in case of unreinforced alloy, 2wt.% and with 6wt.% addition of GRNP respectively. It also observed that with the increase of wt. % of reinforcement the amount of porosity also increased but because of the strong bonding the tensile strength also increased. Figure 8 showing the test specimen after failure and it has been observed that for 2 wt. % concentration the samples found to be broken near to head. This may be attributed to high concentration of porosity, which occurs due to less dense of reinforcement dispersed in the matrix near to head of the sample.
Figure 8. 2wt% and 6wt% Tensile test specimens after failure

4.3. Compression Strength

Figure 9 shows the relation between the compressive strength and the wt. % of GRNP. It reveals that due to the close spacing between the reinforcement and the matrix, the compressive strength of the composites increased monotonously as compared to the unreinforced Al alloy [11].

Figure 9. Compressive strength of GRNP reinforced AMC
With the increase of wt. % of GRNP from 0 to 2 and then 6 wt. % it shows that the compressive strength increased by 30.51% and 44.21% respectively. Figure 10 showing the deformed specimen after the compression load.

5. Conclusions
In this experimental study, a graphene nanoparticle based aluminium MMC has been developed with different weight percentages (2 and 6) weight % using stir casting. Tensile and compressive strength characteristics and the effect of GRNP on these characteristics were studied. The important conclusions are drawn as follows:

- Tensile and compressive strength of AMNCs as compared to unreinforced one was increased by 49% and 44% respectively with increased concentration of GRNP up to 6 wt. %.
- Graphene MMCs show brittle nature as compared to unreinforced Al alloy, along with addition of more wt. % GRNP.
- Large amount of porosity was observed in Al nanocomposites with increase in concentration of GRNP.

6. References

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