AL22 - Effect of Graphene on the Mechanical and Conducting Properties of Aluminium

Priyambada Nayak[1], Balaram Polai[2], Arijit Mitra[3] and Saroj. K. Nayak[4]
1. Post-Doctoral Fellow
2. Junior Research Fellow
3. Post-Doctoral Fellow
4. Professor
School of Basic Science, Indian Institute of Technology, Bhubaneswar, Odisha, 752050, India
Corresponding author: priyambada.pce@gmail.com,

Abstract:

Aluminum, its composites and alloys have already been widely applied in the fields of aircraft, space, automobile, transportation and building industries due to their dynamic properties such as high strength, excellent stiffness, low density with good thermal and electrical properties. In view of the above, certain alloys and composites of aluminium are being produced in the smelters by adding unit operations. In the current paper, the authors have tried to incorporate graphene (a relatively new material) in to aluminium to find its effect on the mechanical and conducting properties. The high fracture strength of graphene (125 GPa) offers better platform as a reinforcing material in aluminium matrix composites when introduced in a given set of conditions. In the present work graphene reinforced aluminum (Al-Gr) with different compositions were fabricated under a set of experimental conditions. The crystal structure, surface morphology and grain size of the fabricated Al-Gr materials were analyzed with the help of X-Ray diffractometer (XRD), scanning electron microscopy (SEM) and Raman spectroscopy. Microstructure analysis shows uniform distribution of graphene throughout the matrix. Micro-hardness test reveals a significant increase in hardness up to 0.5wt.% of graphene reinforcement and later on decreases with more percentage of graphene. The improvement of mechanical properties observed are attributed to the uniform dispersion of graphene in the aluminium matrix and an excellent interfacial bonding between graphene and aluminium. Further, both electrical and thermal conductivity of all the prepared samples have been performed to find the effects. Incorporation of graphene in aluminium metal shows excellent mechanical and conducting properties compared to virgin metal.

Key words: Graphene (G), graphene reinforced aluminium (Al-Gr), mechanical properties, electrical and thermal conductivity.

1. Introduction

Aluminium is one of the potential engineering materials because it has excellent properties such as high specific strength, high thermal and electrical conductivities, superior corrosion resistance and low density with cost-effectiveness [1-5]. Due to these properties, aluminium and its alloys are used in the field of electronics, thermal management, automotive, aerospace and aeronautical industries. However, in last two decades, there has been high demand for the improvement of strength of aluminum and its alloys due to its low strength to weight. Therefore aluminum-based metal matrix composites have great attention by the research community.

In general, the matrix will be the low-density metal (herein aluminium) and the reinforcing material will be a different material such as fibre, ceramic, polymer etc. Matrix in as monolithic material is continuous in nature and the diverse materials are embedded in it. Reinforcements are added to the matrix in order to improve its properties like hardness, strength, elongation, conductivity, corrosion resistance, etc. But due to the lightweight requirements traditional reinforcements corresponding to ceramics and fibers cannot fulfill the need.

Carbon-based materials such as carbon nanotubes (CNTs), graphite and graphene are getting special attention in modern society due to their superior mechanical [6], electrical [7], thermal properties [8] and tribological behavior [9, 10]. Among them the two-dimensional (2-D) Graphene with sp^2-hybridization has much attracted because of its excellent properties, such as high Young's modulus (1 TPa) [11], high fracture strength (125 GPa) [12], extremely high thermal conductivity (5000 W/mK) [13] and super charge-carrier mobility (200 000 cm^2/Vs) [14]. At present, reports are available on graphene-reinforced polymer [15] and ceramics [16] matrix composites. However, aluminium reinforced with is still in its infancy because of the preparation technology. On the other hand, powder metallurgy method is widely used for the preparation of AMCs (Aluminium metal matrix composites) due to its low processing temperature, which is beneficial for interface reactions and uniform dispersion. Wang et al. fabricated Al-metal matrix composites with the reinforcement of grapheme by powder metallurgy technique and obtained a tensile strength of 249 MPa in the 0.3 wt% graphene nanosheet addition which was 62 % greater than pristine Al [17]. Also the mechanical properties are investigated by Bartolucci et al in 0.1 wt % GNSs/Al composite samples by hot isostatic pressing and hot extrusion and found a remarkable decrease in tensile strength and elongation [18]. Similarly, Li et al. reported an increase of the elastic modulus and hardness (17-18 %) with the addition of 0.3 wt% graphene oxide in Al [19].

All the above studies showed that the mechanical properties of aluminum metal matrix composite can be improved by addition of grapheme platelets and graphene nanosheets. Therefore, still it is a great challenge to produce well-dispersed graphene in aluminium via a conventional metallurgical process due to the environment issue and density mismatch between graphene and aluminum matrix. In the present work we are trying to prepare Al metal matrix composites with the reinforcement of graphene by ball milling and vacuum sintering process. The effect of graphene contents on the mechanical and conducting properties of the prepared Gr/Al composites were investigated in detail.

2. Experimental

Pure aluminum powder (99.7 % purity; Loba Chemie Pvt. Ltd.) with particle size 20–45 µm and density 2.71 g/cm^3) and Graphene (purity 99 %) density 0.24 g/cm^3 and mean diameter in the range of 0.5–20 mm was used as the starting material. Figure 1(a, b) shows the SEM images of the received aluminium powder and graphene, respectively. Graphene reinforced (0.25 wt %, 0.5 wt %, 1 wt % and 2 wt %) aluminium composites were fabricated by powder metallurgy method. Therefore, respective weight of powder ratios was taken into a stainless steel (SS) jar along with stainless steel (SS) balls in the presence of toluene as a process control agent. The balls to powder ratio was maintained 10:1. The milling was carried out for 10 hours at 300 rpm in high energy ball mill. After the milling, the Al based composite powder was dried and green pellets of different size were prepared using hydraulic press machine. The applied pressure was of 163 MPa with holding time of 3 minutes. The green pellets were then subjected to vacuum sintering at 550 °C for 2 hours, with heating rate of 5 °C /min, and then cooled down and finally taken for various characterizations.

4. Conclusions

From the current research work the following conclusions are drawn

1. Aluminium-graphene metal matrix samples of different composition have been prepared successfully by powder metallurgy techniques.
2. SEM result reveals the composite materials as spherical grains along with some minute amount of channel pores for higher graphene reinforced composition, which are uniformly distributed throughout the material.
3. Measured density of the composite samples was found to decrease with an increase in graphene content.
4. Vicker's hardness increases with graphene content and it was maximum when the graphene content was 0.5 wt%, which is related to the microstructural properties.
5. Similarly, ultimate tensile strength and electrical conductivity are maximum for 0.5 wt.% graphene content sample and this is related to effective load transfer. On the other hand, thermal conductivity increases linearly with the graphene content.
6. In summary, the increase in hardness, tensile strength and conductivities indicates that graphene is an appropriate reinforcing material in aluminium for different applications.

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6. References

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