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Original Research

Effect of Graphene Nanoplatelets addition on mechanical properties of pure aluminum using a semi-powder method

Muhammad Rashad[a,b,*], Fusheng Pan[a,b,c,*], Aitao Tang[a,b], Muhammad Asif[d]

[a]College of Materials Science and Engineering, Chongqing University, Chongqing 400044, China
[b]National Engineering Research Center for Magnesium Alloys, Chongqing University, Chongqing 400044, China
[c]Chongqing Academy of Science and Technology, Chongqing 401123, China
[d]School of Materials Science and Engineering, Dalian University of Technology, Dalian 116024, China

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Abstract

In recent years, graphene has attracted considerable research interest in all fields of science due to its unique properties. Its excellent mechanical properties lead it to be used in nano-composites for strength enhancement. This paper reports an Aluminum–Graphene Nanoplatelets (Al/GNPs) composite using a semi-powder method followed by hot extrusion. The effect of GNP nano-particle integration on tensile, compressive and hardness response of Al is investigated in this paper. It is demonstrated that 0.3 wt% Graphene Nanoplatelets distributed homogeneously in the matrix aluminum act as an effective reinforcing filler to prevent deformation. Compared to monolithic aluminum (in tension), Al–0.3 wt% GNPs composite exhibited higher 0.2% yield strength (+14.7%), ultimate tensile strength (+11.1%) and lower failure strain (−40.6%). Surprisingly, compared to monolithic Al (in compression), Al–0.3 wt% GNPs composite exhibited same 0.2% compressive yield strength and lower ultimate compression strength (−7.8%), and lower failure strain (−20.2%). The Al–0.3 wt% GNPs composite exhibited higher Vickers hardness compared to monolithic aluminum (+11.8%). Scanning electron microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDS) and X-ray diffraction (XRD) were used to investigate the surface morphology, elemental percentage composition, and phase analysis, respectively.

Keywords: Powder metallurgy method; Mechanical properties; Aluminum matrix; Graphene nanoplatelets

1. Introduction

Since the ground-breaking experiment by Andre Geim and Kostya Novoselov [1], graphene has awakened considerable research interest in the field of material science and engineering community. This two-dimensional material, consisting of sp^2-hybridized carbon atoms, has unique mechanical [2], thermal [3] and electrical properties [4]. It has 1 TPa modulus of elasticity and fracture strength of 125 GPa. One possible way to harnessing the graphene's extraordinary properties for application is to incorporate and disperse graphene in different material matrices i.e. polymers, metals and ceramics. Graphene has widespread applications in the field of electronics and polymer reinforcement. However there are only few reports on metal–graphene composites. In the field of Thermal interface materials (TIMs) graphene (thermally conductive nano-material) has been used as excellent fillers. The strong graphene coupling to metal matrix particles caused an increase in thermal conductivity of resulting composite up to 2300% [5–7].

Aluminum, a low density metal and its alloys have attracted considerable interest in the field of aerospace and automobile industry in order to reduce fuel consumption and emission of

*Corresponding authors at: Chongqing University, College of Materials Science and Engineering, Chongqing 400044, China. Tel.: +86 23 65112635; fax: +86 23 67300077.
E-mail addresses: rashadphy87@gmail.com (M. Rashad), fspan@cqu.edu.cn (F. Pan).

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carbon dioxide gas. Metal aluminum has good electrical, thermal and corrosion resistive properties [8,9]. Owing to high ductility, workability and strength to weight ratio, it has widespread applications in vehicles, household appliances containers, etc. [10].

Aluminum based metal matrix composites (MMCs) can be obtained by diffusing reinforcement particles in metal Al using solid or liquid phase methods. Over the past decade, carbon nanotubes (CNTs) have been extensively used as reinforcement of aluminum, to meet high and ever increasing demand of structural strength [11]. Though CNT/Al composites are widely investigated but still uniform dispersion of CNTs is a big challenge for the researchers, which prohibit its use in practical applications. Graphene Nanoplatelets (GNPs) which are two dimensional structures can be dispersed in all kinds of solvents and matrices easily as compared to CNTs. Therefore we are confident to replace the CNT/Al composite by GNP/Al composite in future using different techniques. Powder metallurgy techniques (PM) which consist of basic three steps (mixing, compacting, and sintering) offers homogeneous and uniform distribution of reinforcement particles in the matrix. Our novel nano-processing route is free of ball milling. As ball milling is considered a big problem because it produces heat which can burn powder easily. Therefore our method can be an alternative of ball milling and it has a great potential for synthesis of Al based matrix nano-composite which is considered good for engineering applications.

The objective of this study is to investigate the effects of Graphene Nanoplatelets (GNPs) additives on mechanical properties of Al using the powder metallurgy technique. In earlier work Wang et al. [12] have prepared Al/GNS composite by using 0.3 wt% of Graphene Nano sheets (GNS). They used a complicated experimental procedure and composite prepared had tensile strength of not more than 249 MPa with 0.3 wt% GNS. The objective of this study is to enhance the tensile strength of Al/GNP composite by using the same amount (0.3 wt%) of GNPs by adopting a simple, time saving and efficient method. Mechanical properties of prepared GNP/Al composite are investigated using tensile, compression and hardness tests. Scanning electron microscopy (SEM) and X-ray diffraction are used to examine the micro-structures of the prepared composite.

2. Experimental

2.1. Materials characteristics

Aluminum powder with 99% purity was bought from Shanghai Customs Golden Powder Material Co., Ltd., China. Graphene Nanoplatelets (GNPs) were supplied by Nanjing Xian Feng Nano Material Technology Co., Ltd., Jiangsu, China. Fig. 1 shows the SEM micrographs of as received aluminum powder (a) and Graphene Nanoplatelets (GNPs) (b). An average thickness of Graphene Nanoplatelets (GNPs) was 5–15 nm. Particle size of the as received aluminum was 1–3 μm, and the densities of aluminum powder and Graphene Nanoplatelets (GNPs) were 2.7 g/cm^3 and 2.25 g/cm^3 respectively.

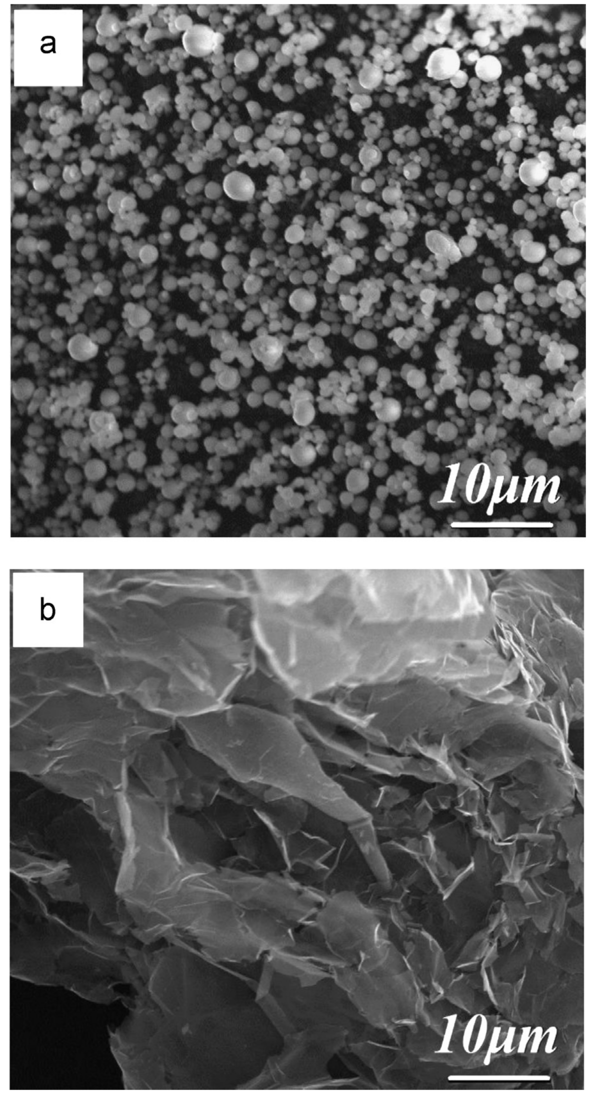

Fig. 1. FESEM image of (a) pure aluminum powder; (b) Graphene Nanoplatelets.

2.2. Synthesis of GNP/Al composite

At first Graphene Nanoplatelets (GNPs) were ultra sonicated in acetone for 1 h. At the same time, aluminum powder was immersed in acetone using mechanical agitator. After ultra-sonication, Graphene Nanoplatelets (GNPs) with particle contents of 0.3 wt% were slowly added to the aluminum powder slurry in acetone. Mixing process was continued for one hour using mechanical agitator to obtain the homogeneity in mixture. The mechanically agitated mixture was filtered and vacuum dried for 12 h at 70 °C to obtain the composite powder. The composite powder was compacted in a stainless steel mold at room temperature under the pressure of 170 MPa to obtain green billet with ∅30 × 30 mm dimensions. After compacting, the green billets were sintered in muffle furnace at 600 °C for 6 h followed by hot extrusion at 470 °C to obtain the rods of 16 mm diameter. The extrusion ram speed was 1 m/min. For comparison pure Al sample was also prepared using the same method excluding the graphene addition.