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The Effect of Mechanically Exfoliated Graphene Dispersion on the Mechanical Properties of Aluminum/Graphene Composites

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Abstract

Effect of few-layer graphene on mechanical properties is investigated for aluminum (Al) based composites with different volume fraction of graphene. Al/few-layer graphene composites are produced by hot-rolled of ball-milled powders. Few-layer graphene prepared by the mechanical exfoliation of graphite flakes are attached to Al powder using a low energy ball milling, and then graphene are embedded and dispersed in the Al matrix using a high energy ball milling. Few-layer graphene with 100 nm in long axis and 5 layers thick play a great role as reinforcing agent in the Al matrix by obstruction of dislocation movements and grain growth in the composites. Therefore, the yield strength increases with increasing content of the graphene which demonstrates efficient load transfer between the Al matrix and graphene. The result can be suggested being the wider applications of graphene with improvement in mechanical properties of the composites.

Introduction

Graphene, as the perfect two-dimensional (2-D) lattice of sp2-bonded carbon atoms [1, 2], has recently attracted increasing interest in materials science due to its excellent properties, such as high Young's modulus (1 TPa), fracture strength (125 GPa), thermal conductivity (5000 W m^{-1} K^{-1}) [3] and electrical conductivity (>200,000 cm^2 V^{-1} s^{-1}) [4].

In order to accomplish desired properties of graphene, graphite has been extensively chemically or mechanically exfoliated to give single-layer and few-layer graphene [5, 6]. However, there are challenges in exfoliation methods that chemical exfoliation process has many complex stages and mechanical exfoliation process has also chemically derived flakes before fabricating.

This work aims the mechanical exfoliation of graphene and mechanical properties of graphene-reinforced aluminum matrix composites varied according to volume fraction of graphene. Mechanically exfoliated few-layer graphene from graphite prepared by ball milling process, and the composites reinforced with few-layer graphene were fabricated by hot rolling. The morphologies of graphene and microstructures of the composites are examined. The Vickers hardness of the composites is evaluated by graphene contents.

Experimental procedure

Aluminum (Al) based composites containing few-layer graphene were fabricated by hot-rolling of the ball-milled powder. Firstly, wet mall milling was used to mechanically exfoliate graphite flakes (6−8 nm in thickness and typical surface area of 120−150 m^2/g) to graphene. The graphite flakes were solely milled with isopropyl alcohol ($(CH_3)_2CHOH$) using a planetary mill. A stainless steel bowl (250 mL) was charged with graphite (2 g) and stainless steel balls (~5 mm in diameter, 30 g) with the weight ratio of ball-to-powder of 15:1 and 50 ml of isopropyl alcohol. Planetary milling was performed with a rotation speed of 200 rpm for 1 h, where milling was paused for 75 min after every 15-min milling to maintain ambient processing temperature without any process control agent. Graphite flakes exfoliated by the shear forces during milling were dried at 150 ^oC for 3 h. Secondly, to aid additional exfoliation from graphite to few-layer graphene, mixing process was conducted. Exfoliated graphite flakes and aluminum powders (99.5 % in purity and <150 □μm in diameter) were mixed with a process control agent of 1 wt. % stearic acid ($CH_3(CH_2)_{16}CO_2H$) using a planetary mill with a rotation speed of 100 rpm for 3 h, where was paused 15 min after every 15 min milling to maintain processing temperature as the room temperature. Finally, to distribute few-layer graphene in aluminum powders, the mixed powder was high energy ball-milled in an attrition mill at 500 rpm for 6 h under a purified argon atmosphere. They were stirred by horizontal impellers attached to a vertical shaft at room temperature, and the outer surface of the vial was cooled using circulating water. During final milling stage, few-layer graphene attached on the aluminum powder is embedded and dispersed inside aluminum powder.

The ball-milled powders were fabricated by varying the volume fraction of graphene (i.e. 0.3, 0.5 and 0.7 vol%). The ball-milled powders was containerized in a copper tube (60 mm in diameter, 150 mm in height, and 1.5 mm in thickness), compacted, and then hot-rolled. The sample was heated to a pre-determined temperature of 500 ^oC with a heating rate of 15 ^oC /min, and rolling was conducted with a 12 % reduction per each pass; the final thickness of the samples was 1 mm. After rolling, the copper container was readily peeled off. Since graphene were deeply embedded in the powder, they did not significantly interrupt consolidation of the aluminum powders during hot rolling, providing a fully dense composite sheet.

Morphology of the ball-milled powder varied according to the milling condition was observed using a scanning electron microscopy (SEM). Vickers' hardness measurement was carried out on the specimens with an indenter load of 300 gf.

Results and Discussion

Figure 1 shows morphology of the ball-milled Al/graphene composite powders. The exfoliated graphene with the size below 10 μm are observed on the surface of the Al powder. As shown in Figure 1, transparent exfoliated graphene are located at the wrinkled Al powder surface.

The Vickers hardness of Al/graphene composites is shown in Figure 2 with different volume fraction of graphene. As shown in Figure 2, the hardness value increases with increasing volume fraction of graphene. Exfoliated graphene is well dispersed in the Al matrix which can play a role in hardness of the Al-based composites. Since agglomeration of reinforcement could be lead to the composites having poor mechanical properties. Therefore as shown in Fig. 2, hardness improvements are due to the dispersion strengthening effect by unagglomerated graphene.

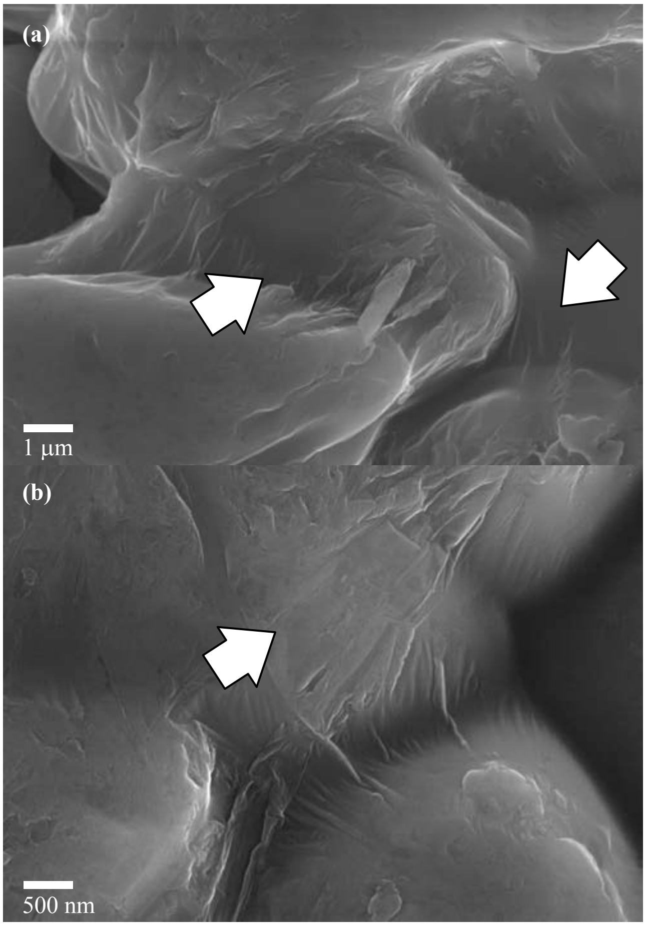

Figure 1. SEM images of (a) Al/graphene composite powders and (b) magnified image.

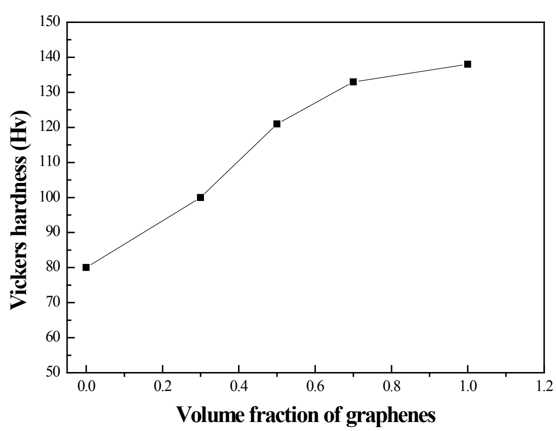

Figure 2. Vickers hardness of (a) Al/graphene composites.

Powder metallurgy process is more suitable than ingot metallurgy because the dispersion of reinforcements can be simply done. Although, more technical challenges to disperse graphene in Al matrix composites, the result can be applied to industrial applications with improvement in mechanical properties of the Al/grapheme composites.

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