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Mechanical enhancement of copper matrix composites with homogeneously dispersed graphene modified by silver nanoparticles

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Reduced graphene oxide modified by silver nanoparticles (Ag-RGO) has been employed as a reinforcing component to prepare the copper matrix composites. The Cu composites with 0.6 vol% Ag-RGO exhibit a significant improvement in the yield strength and ultimate tensile strength, being approximately 98% and 93% higher than that of pure Cu, respectively, much better than the RGO/Cu composites. Simultaneously, the electrical conductivity of Ag-RGO/Cu composites could reach 92.69% IACS. The significant strength enhancement is attributed to the addition of Ag nanoparticles which prevent the agglomeration of the RGO and enhance adhesion between the RGO and the Cu matrix. The results indicated that Ag-RGO is an effective reinforcing component to improve the mechanical properties of the graphene/metal composites.

1. Introduction

Graphene, a single-layer carbon atom platelet discovered in 2004, has attracted remarkable attention due to its fascinating properties and nearly infinite applications [1–4]. Previous experimental and theoretical studies have indicated that the Young's modulus and breaking strength of graphene can reach as high as 1 TPa and 130GPa [5], respectively, making graphene an promising candidate reinforcement for nanocomposites. Surprisingly, though great success has been made for graphene enhanced polymer matrix [6], it is facing several challenges to maximize the reinforcement efficiency of graphene when added into metal matrix. One problem is the agglomeration tendency of graphene in composites [7]. The other problem is the poor bonding between the graphene and the metal matrix.

To solve these problems, several methods have been developed to synthesize graphene/metal composite. Kim et al. [8] have designed a new form of nanolayered composite consisting of alternating layers of metal (copper or nickel) and monolayer graphene that has ultra-high strengths of 1.5 and 4.0 GPa. Recently, Hwang et al. [9] have used a molecular-level mixing process to fabricate RGO/Cu nanocomposites and found that the yield strength of the 2.5 vol% RGO/Cu nanocomposite is 1.8 times higher than that of pure Cu. Moreover, high-ratio differential speed rolling has been applied to accelerate breaking up of multi-layer graphene into nanosizes and enhanced their dispersion in the matrix to fabricating high-performance graphene-reinforced metal matrix composites [10].

In this work, we have used RGO modified by silver nanoparticles (Ag-RGO) as a reinforcing component to enhance the mechanical properties of copper matrix composites. The Ag-nanoparticles anchored on the separated RGO surface can prevent the RGOs from aggregating during the processing and serve as adhesion contact points to improve interconnectivity of graphene-metal matrix.

2. Experimental details

Fig. 1 showed the diagrammatic sketch for the typical synthesis procedure of the Ag-RGO hybrids and the Ag-RGO/Cu composites. All reagents used in our experiment were analytical reagent grade and without further purification.

2.1. Fabrication of Ag-RGO

The GO was prepared using modified Hummer's method [11]. A silver-ammonia [$Ag(NH_3)_2OH$] solution was prepared by the dropwise addition of ammonia into $AgNO_3$ (50mM) until all the

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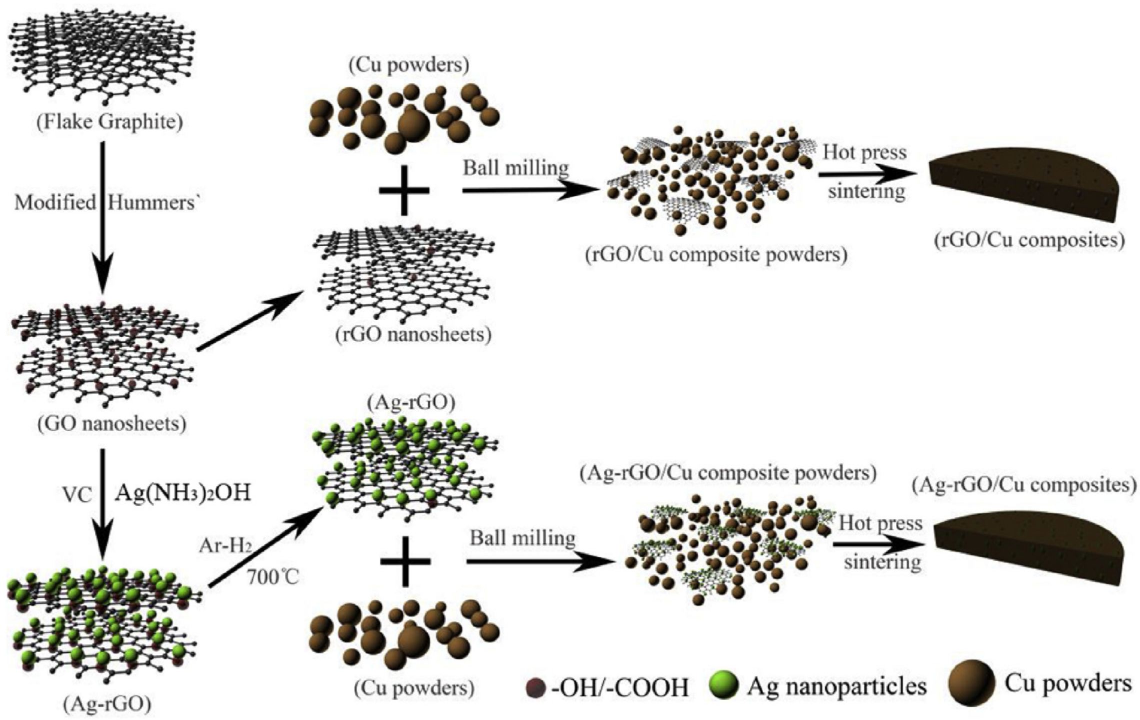

Fig. 1. Diagrammatic sketch for the typical synthesis procedure of Ag-RGO hybrids and Ag-RGO/Cu composites.

precipitate was disappeared. The freshly prepared $Ag(NH_3)_2OH$ was then mixed with 50 ml GO dispersion liquid at 50 °C in ultrasound bath for 30 min. Then, 100 mmol of Vitamin C solution was slowly added as reducing agent [12] and left the reaction mixture stirring at 95 °C for 1 h. The products were collected by filtration and washed several times with deionized water. In order to improve the reduction degree of RGO, we also calcined the dried products under an Ar-7%H_2 atmosphere at 700 °C for 2 h as thermal reduction.

2.2. Fabrication of Ag-RGO/Cu composites

The Ag-RGO composites were dispersed into alcohol, and mixed with copper powders (~150nm, 99.99%). Subsequently, the mixture was treated by ball milling for 5 h at the rotate speed 400 rpm. The composite powders were then dried in vacuum drying oven and sintered by Vacuum Uniaxial Hot-Pressure Sintering Furnace at temperature 700 °C for 45 min under the press 50MPa. The pure Cu specimens, RGO/Cu composites with 0.6 vol% RGO and Ag-RGO/Cu composites with 0.6 vol% Ag-RGO were also fabricated under the same processing for comparison.

2.3. Characterization

The crystal phase of the samples were characterized by X-ray diffraction (XRD, Aolong DX-2700 diffractometer), Fourier transform infrared spectra (FT-IR, BRUKER TENSOR II Spectrometer), X-ray photoelectron spectroscopy (XPS, ESCALAB 250Xi) and Raman Spectroscopy (BrukerSenterra). The morphology and microstructure of the reinforcement and bulk Ag-RGO/Cu composite were observed by Scanning Electron Microscopy (SEM, Nova NanoSEM 430) and Transmission Electron Microscopy (TEM, FEI tecnai G2 F20). The density of composites was measured by Archimedes' principle and the theoretical densities of Cu (8.9 g/cm^3) and RGO (2.2 g/cm) were used to calculate the relative density of the samples. The electrical conductivity was measured using 4 point contact method (Low DC Resistance Tester, JK2516). Tensile test was performed using a TH500 universal testing machine under a crosshead speed of 0.5 mm/min at room temperature, and the test samples were designed to be cuboid with a gage length of 10mm and section of 2 mm × 1.5 mm.

3. Results and discussion

3.1. Characterization of Ag-RGO composites

The GO and Ag-RGO composites aqueous dispersion were initially measured by X-ray diffraction. Fig. 2 showed the XRD patterns of GO, RGO and Ag-RGO. GO showed a sharp diffraction

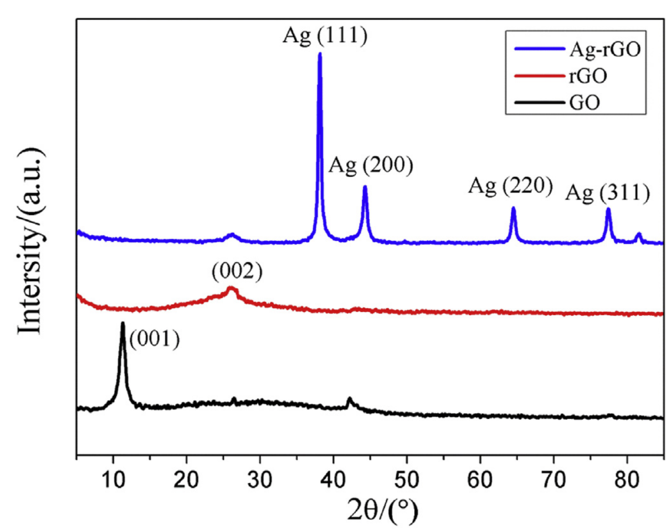

Fig. 2. XRD patterns of GO, RGO and Ag-RGO.