Tribology International 103 (2016) 406–411

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Short communication

Fabrication and tribological properties of copper matrix composite with short carbon fiber/reduced graphene oxide filler

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ARTICLE INFO

Article history:
Received 12 April 2016
Received in revised form
14 July 2016
Accepted 29 July 2016
Available online 30 July 2016

Keywords:
Metal matrix composites
Friction
Wear
Lubrication

ABSTRACT

Copper matrix composite with short carbon fiber(CF)/reduced graphene oxide(rGO) hybrid filler have been fabricated by freeze-drying and spark plasma sintering. Microstructure and tribological properties of as-prepared composites were characterized. The microstructural observation shows that the rGO exhibits both agglomerated and dispersed states, and the uniform CF presents the various space orientations in the Cu matrix. The composite with CF/rGO hybrid filler exhibited the lower friction coefficient (0.32), and whose wear rates decreased respectively by 45.3% and 86.0% in comparison with pure Cu and the composite with rGO filler. The CF/rGO hybrids act as solid lubricant and play the major role in the improved tribological performance. The formation, friction-reducing and anti-wear mechanisms of the composite were discussed.

1. Introduction

Copper matrix composites (CMCs) have attracted much attention during recent years in applications as bearing, electrical sliding contacts, resistance welding electrodes, and so on [1]. As attractive reinforcements, carbon materials like graphite, carbon nanotube and carbon fiber were popularly employed due to high thermal conductivity, low coefficient of thermal expansion and good self-lubricant property [2,3]. And most important, they attain the enhanced mechanical, thermal, electrical and tribological properties of CMCs [3,4]. Still, the performance enhancement of CMCs is increasingly required to explore new reinforcing methods in order to extend their application.

Besides properties such as thermal conductivity [5], high modulus (1 TPa) [6] and fracture strength (125 GPa) [6], the unusual friction and wear properties at nano to micro scales were possessed by the graphene [7,8]. Interestingly, the few-layer graphene also exhibited the extraordinary macrotribological properties, which can last for 47,000 cycles despite rather high contact pressure of 0.5 GPa [8]. Most previous investigations focused on the improved tribological properties of graphene/metal nanocomposites (<0.3 wt% graphene) [9–11]. More graphene addition further reduced the friction coefficient of metal matrix, but resulted with the increased wear rate [10].

Recently, attempts of hybrid CMCs have been made to further enhance the mechanical and/or tribological properties by the incorporation of both type and dimensions of the reinforcing medium [12,13]. Carbon fiber, a conventional microscale fiber, is a excellent potential reinforcement in the composites. Some reports [14,15] shown that the addition of carbon fiber significantly improved the metallic and polymeric properties. Herein, to combine the merits of two-dimensional lamellar graphene and conventional microscale carbon fiber, the objectives of the current work are to synthesize copper matrix composite with hybrid CF/rGO filler and investigate microstructure and tribological properties of the resultant composites.

2. Experimental procedure

For this investigation, GO was firstly prepared from purified natural graphite by a modified Hummer's method [16]. Expandable graphite powder (8 g) was mixed with a mixture of concentrated 1.5 L H_2SO_4 and 70 g $KMnO_4$. After reaction at 55 °C for 6 h, the mixture was cooled to room temperature, poured into an ice bath (1.5 L) and further treated with H_2O_2 (30%, 10 mL). The mixture gradually became the bright-yellow suspension. For purification, the mixture was washed by repeated rinsing and

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http://dx.doi.org/10.1016/j.triboint.2016.07.027
0301-679X/

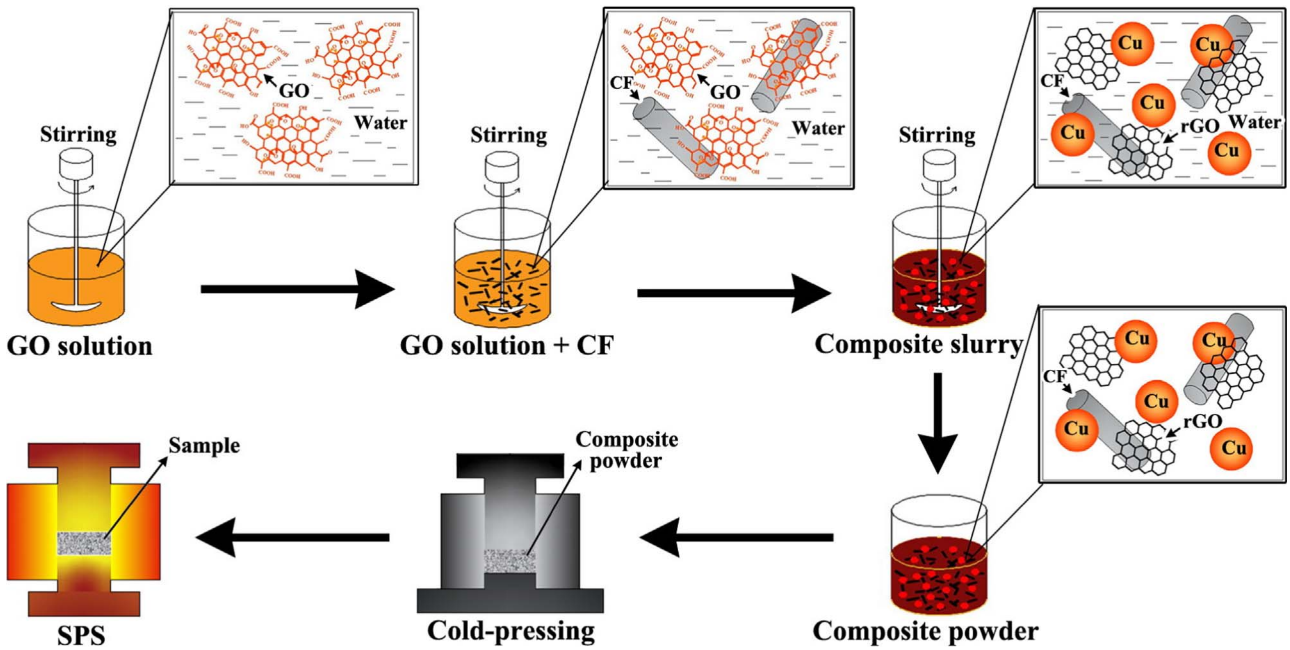

Fig. 1. Schematic illustration of fabrication process of copper matrix composites with CF/rGO hybrid filler.

centrifugation with 10% HCl and DI water several times. As-synthesized GO was suspended in water to give a brown dispersion, which was subjected to dialysis to completely remove residual salts and acids.

Fig. 1 shows the schematic illustration of fabrication process of copper matrix composites with CF/rGO hybrid filler. Firstly, the short carbon fiber (T700, 1–2 mm) was added into as-prepared GO dispersion, and their mixtures were mechanically stirred for 3 h. After that, the hydrazine hydrate (80%) was added drop by drop, and then the electrolytic Cu powder (99.9% pure) was added and formed a powder slurry under the mechanical stirring. The composite slurry was frozen until totally solid. The frozen composite slurry was maintained under vacuum (1 Pa) and removed the water by sublimation to obtain the freeze-dried composite powder. Finally, the composite as a powder was compacted at a pressure of 450 MPa, and then sintered under vacuum at 750 °C for 8 min under a pressure of 45 MPa to synthesize Cu–2.5rGO–1.0CF (wt%) composite, with a heating rate of 50 °C/min, using a spark plasma sintering (SPS-211Lx, Japan). For comparison, pure copper and Cu–2.5rGO (wt%) specimens were fabricated using the same processing parameters as those for the composite.

X-ray diffraction (XRD) was carried out to determine phase constitutions of the specimens via Rigaku D/max-2200 diffractometer. Microstructural observation was studied by transmission electron microscope (TEM, Tecnai G2 F30) and scanning electron microscopy (SEM, FEI Quanta 200FEG) equipped with backscattered electron detector (BSE). The tribology test of this study were carried out using a pin-on-disc tribometer (Fig. 2) operating in dry sliding condition. In the tests, cylindrical pins with dimension of 6 mm in diameter and 10 mm in height were used from the as-prepared samples. As a counterpart, the bearing steel GCr15 disc hardened to 62 HRC was used. Prior to test, all contact surfaces were metallographically polished with 800 grit size SiC paper and cleaned with acetone. The applied load and sliding speed were maintained respectively at 20 N and 1.6 m/s at a constant sliding distance of 2000 m. The coefficient of friction was continually recorded during the tests, and the average value was calculated for each test within the distance of 2000 m. Wear rate was calculated by the formula of $w = v/pl$, where w is the wear rate, v is the worn volume of the specimen, p is the normal load applied and l is the sliding distance of specimen. Microhardness tests were conducted on a HVS-1000 Vickers sclerometer with the load of 29.4 N and a load-dwell time of 10 s, and eight indentations were taken for each sample to obtain an average value. The worn surfaces at the end of tests were examined and analyzed using SEM with energy dispersive X-ray spectroscopy (EDX).

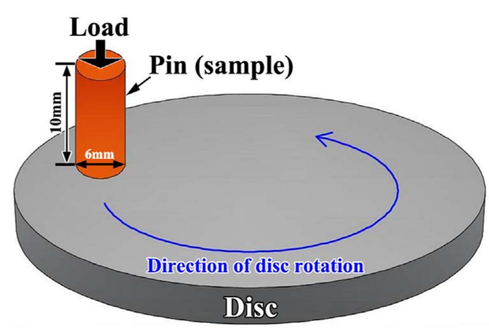

Fig. 2. Schematic illustration of pin-on-disc tribometer.

3. Results and discussion

3.1. Microstructural characterization

For the freeze-dried composite powders and sintered composite, their XRD peaks (Fig. 3a) at 2θ=43.3°, 50.4° and 74.2° were assigned to the (111), (200) and (220) planes of face-centered cubic (fcc) structured Cu phase. No characteristic peaks of CF and rGO were detected, possibly due to the strong peaks of Cu. The CF/rGO mixture and rGO were separated and collected from freeze-dried composite powder, and investigated by XRD together with GO and starting CF, as shown in Fig. 3b. A strong peak of GO appeared at 2θ=9.8°corresponding to (001) reflection peak, which is due to the formation of intercalated water moieties and oxygen functionalities groups between the layers of GO [17]. However, the peak at 2θ=9.8°disappeared completely in rGO or CF/rGO mixture, a broad (002) reflection peak presented at 2θ=27.1°, which