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Preparation and characterization of reduced graphene oxide/copper composites incorporated with nano-SiO_2 particles

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ABSTRACT

Reduced graphene oxide/copper (rGO/Cu) composites incorporated with nano-SiO_2 particles were successfully fabricated using the raw materials of GO dispersion, hydrophilic nano-SiO_2 and electrolytic Cu powder. The as-prepared composites were characterized by X-ray diffraction, field-emission scanning electron microscope and energy dispersive spectroscopy. Microstructural observation of the composite powders indicated that the graphene oxide (GO) was effectively reduced by $N_2H_4 \cdot H_2O$ addition in the composite slurry, and the nano-SiO_2 particles and rGO sheets were randomly and completely mixed with Cu particles. The as-sintered composites exhibited the small rGO agglomerations in the Cu matrix, and the more nano-SiO_2 additions led to the agglomerations increase. The mechanical property testing revealed that rGO/Cu composites with nano-SiO_2 incorporation exhibited the higher hardness and strength, compared with the rGO/Cu composite and as-cast pure Cu. However, the strengthening in the composites with higher SiO_2 content accompanied with the expense of compressive ductility. Microstructural formation and strengthening mechanism of the composites are also discussed in details.

1. Introduction

Copper and its alloys have been widely applied as the structural materials for engineering applications due to their excellent electrical conductivity, thermal conductivity and chemical stability [1–3]. However, these materials suffer some problems like corrosion and inferior high-temperature properties, thereby greatly limiting their uses [1,4]. Hence there lies a challenge to improve the room- and high-temperature strength and wear resistance of Cu and its alloys at operating temperature [1]. Their performance enhancement is increasingly required to develop new structural materials in order to extend their application.

Recently, the introduction of secondary-phases in Cu and its alloys matrix to fabricate Cu-based composites, has developed as one of the efficient strategies to achieve superior properties. These composites possess the excellent thermal and electrical conductibility, high corrosion resistance, anti-friction and anti-wear ability over Cu and its alloys [5–8]. In such composites, some secondary-phases, such as TiC [1,8], SiC [9], Al_2O_3 [10], graphite [11], diamond [11,12], etc, were widely incorporated into Cu matrix, and several processing techniques have been explored and employed to synthesize such composites [5–12]. Interestingly, as the attractive reinforcement medium of Cu-based composites, various carbon materials like graphite and carbon nanotubes have been extensively investigated due to their excellent mechanical, thermal, electrical and wear-resistant properties [5,11]. And, above all, the addition of various carbon materials exhibited many significant property enhancements (especially strength, electrical conductivity and wear resistance) to Cu matrix [5,11,13]. As a two-dimensional carbon atoms layer, the graphene possesses the high Young's modulus (1 TPa) [14], high fracture strength (125 GPa) [14] and extreme thermal conductivity (5000 Wm^{-1} K^{-1}) [15]. It has recently attracted tremendous attention as a reinforcing agent for developing metal matrix composites [16,17]. Thereinto, some methods have been employed to synthesize graphene/Cu composites, such as high-ratio differential speed rolling technique,

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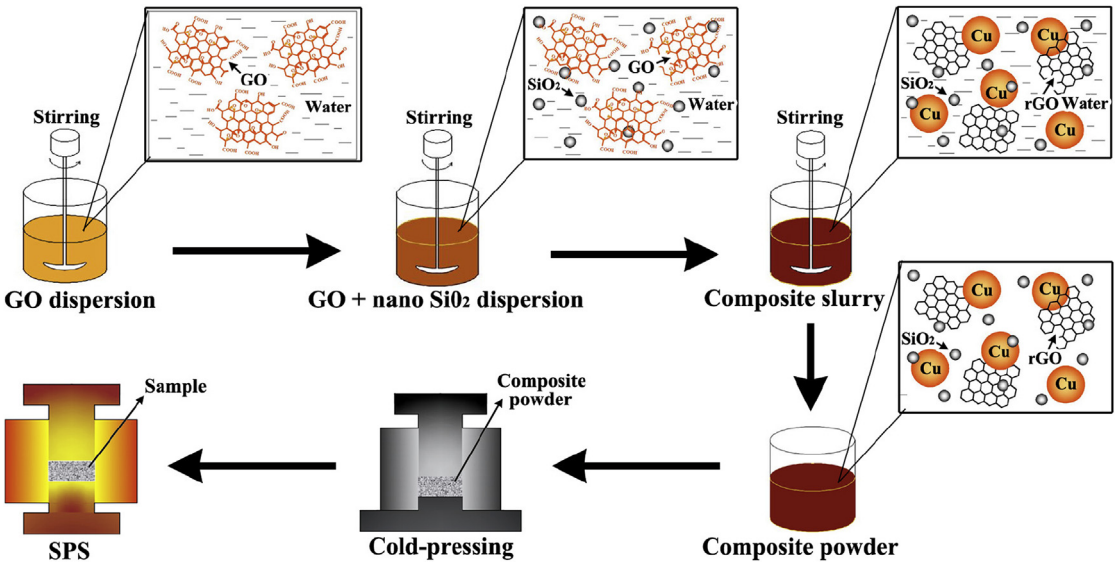

Fig. 1. Schematic illustration of fabrication process of rGO/Cu composites incorporated with nano-SiO_2 particles.

Table 1
The nominal composition of rGO/Cu composites incorporated with nano-SiO_2 particles.

Composites	Cu (wt.%)	rGO (wt.%)	Nano-SiO_2 (wt.%)	Mass ratio (rGO: Nano-SiO_2)
#1	97.5	2.5	0	0
#2	97.0	2.5	0.5	5:1
#3	96.0	2.5	1.5	5:3
#4	95.0	2.5	2.5	1:1

mechanical properties and being a excellent potential reinforcement in the composites. Some reports shown that the addition of nano-SiO_2 particles significantly improved the concrete and ceramic properties [21,22]. Especially, the import of nano-SiO_2 particles also led to some novel properties in nano-SiO_2/metal composites. For instance, the nano-SiO_2 added Ni–W composites exhibited the improved hardness and corrosion resistance, and the nano-SiO_2/Ni composites shown the improved wear resistance with increasing

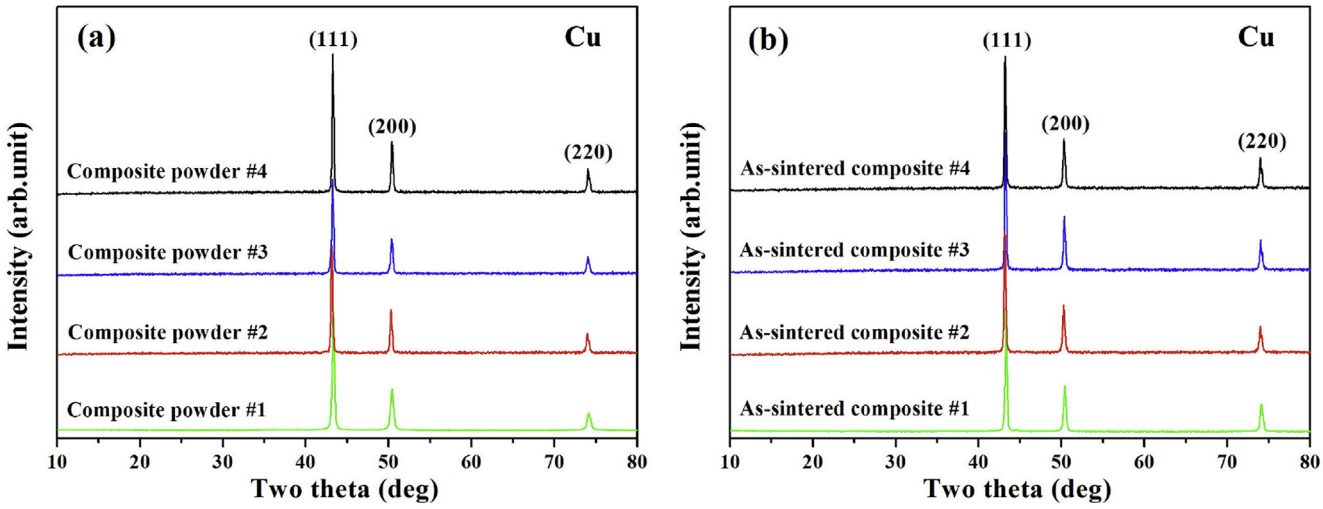

Fig. 2. X-ray diffraction patterns of the freeze-dried composite powders (a) and as-sintered composite samples by SPS (b).

CVD-grown and chemical reduction [17–19]. Kim et al. [18] prepared multi-layer graphene/Cu conposites using high-ratio differential speed rolling, and found that the addition of graphene improved the strength of Cu matrix. However, some reports focused on the reduced graphene oxide (rGO)/Cu nonacomposites using the chemical reduction of copper ions and GO. Interestingly, the excellent interfacial bonding and enhancing strength and wear resistance of rGO to Cu matrix were confirmed [17,20].

Nano SiO_2, a common nanoparticle, possesses some outstanding nano-SiO_2 particle content [23–25]. In addition, after incorporating with nano-SiO_2, the graphene/SiO_2 composites showed the better thermal conductivity, as well as enhanced electro-chemical performance [26,27]. Herein, to combine the merits of nano-SiO_2 and rGO, we synthesized the reduced graphene oxide/copper (rGO/Cu) composites incorporated with nano-SiO_2 particles through a combined methodology based on freeze-drying and spark plasma sintering, using the raw materials of GO dispersion, hydrophilic nano-SiO_2 and electrolytic Cu powder. Microstructural characteristic and