Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 25(2015) 3354−3362
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Sliding wear behavior of copper-based composites reinforced with graphene nanosheets and graphite

Jing-fu LI, Lei ZHANG, Jin-kun XIAO, Ke-chao ZHOU

State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, China

Received 27 November 2014; accepted 29 April 2015

Abstract: The mechanical and tribological properties of hot-pressed copper-based composites containing different amounts of graphene nanosheets (GNSs) are compared with those of copper−graphite (Gr) composites fabricated by the same method. The results show that the Cu−GNSs composites exhibit higher relative density, microhardness and bending strength compared with Cu−Gr composites with the same volume fraction of GNSs and Gr. Moreover, the friction coefficients and wear rates reduce significantly by the addition of GNSs, whereas the limited impact on reducing friction and wear is found on graphite. The abrasive and delamination wear are the dominant wear mechanisms of the composites. It is believed that the superior mechanical and tribological performances of Cu−GNSs composites are attributed to the unique strengthening effect as well as the higher lubricating efficiency of graphene nanosheets compared with those of graphite, which demonstrates that GNS is an ideal filler for copper matrix composites, acting as not only an impactful lubricant but also a favorable reinforcement.

Key words: graphene nanosheets; graphite; composite; friction coefficient; wear mechanism

1 Introduction

The inherent properties of copper, such as high thermal and electric conductivity, along with the self-lubricating property of graphite made copper−graphite composites to be a high-performance material, which has been widely used in many industrial applications, such as brushes, contact strips and bearing materials [1−3]. However, it is well known that the lubricating property of graphite is extrinsic [4], what's more, in order to obtain low friction and wear, numerous amount of graphite is needed to be incorporated into copper, which lowers the mechanical properties (i.e., hardness and fracture strength) of the composites [5−7]. In present time, with increasing the complexity, the power usage and serve life of the aforementioned applications, minimizing friction and wear-related mechanical failures in such moving mechanical assemblies remains to be an issue of global concern [8]. An intense effort is underway to find novel materials and lubricants that can potentially avoid friction's adverse impacts on efficiency and reliability [9,10] and the discovery of graphene may give the way to control friction and wear due to its impressive thermal, electrical, mechanical and tribological properties [11−14].

In recent years, more and more dedicated investigations have been realized and or have demonstrated the remarkable tribological performance of graphene. SHIN et al [15] have determined the ultralow friction coefficient (approximately 0.03) of exfoliated and epitaxial graphene in micro-scale scratch tests under ambient conditions. Moreover, unlike other solid lubricants such as MoS_2, WS_2 or graphite, a small amount of graphene is sufficient to reduce both friction and wear due to its high lubricating efficiency [16]. Solution-processed graphene, which is deposited from ethanol solution with low concentration (1 mg/L), has been detected to have anti-corrosion property in the case of steel against steel both in dry nitrogen and humid air environments due to the formation of a conformal protective coating on the sliding interface, which facilitates shear and slows down the tribo-corrosion [17,18]. More importantly, researches on graphene reinforced ceramic [19], glass [20] and polymer composites [21] are gaining high momentum. PORWAL et al [16] have investigated the tribological properties and wear mechanisms of silica−graphene nano platelet (GNP) composites, and the results clearly demonstrated that a percolating network of GNP above a critical concentration provided a lubricating effect to the silica matrix resulting in the decline of the friction coefficient

Corresponding author: Lei ZHANG; Tel: +86-731-88830464; E-mail: zhanglei@csu.edu.cn
DOI: 10.1016/S1003-6326(15)63970-X

by ~20% while increasing the wear resistance of the composite by ~5.5 times compared with pure silica, and micro-fracture along with wear debris was observed as the main wear mechanism for silica−graphene nano platelet composites. Graphene is also employed as an oil additive, providing elevated lubricating properties, which hinders friction and wear under a wide scope of test conditions [22]. All of these researches indicate the great competence and potential of graphene as a solid lubricant that can minimize friction and wear in various tribological applications.

It should be noted that the limited effort has been put forth in the study of tribological properties of metal matrix−graphene composites [14,23], and the superiority and applicability of graphene acting as a lubricant in metal matrix are not fully understood. This work emphasizes on the mechanical and tribological properties of copper-based composites with different volume fractions of graphene. In order to evaluate the anti-wear performance of graphene, the obtained results are compared with copper−graphite composites fabricated by the same method.

2 Experimental

2.1 Material preparation

The commercially supplied graphene powder was suspended in acetone and sonicated using ultrasonic dispersing technology for more than 6 h until the suspension with homogeneous distribution of graphene particles was obtained. After sonication, the commercially available electrolytic copper powder (99.98% purity with average particle size of 25 μm) was added to the aforementioned suspension and mixed using magnetic stirring technology, meanwhile the slurry was dried at 30 °C in a vacuum drying oven for 4 h. The powder morphologies of graphite (Gr), graphene nanosheets (GNSs) and typical powder mixture of Cu−7.5%GNSs (volume fraction) are shown in Fig. 1. The graphite powder with an average particle size of 5 μm has a flake like morphology (Fig. 1(a)), whereas curled, wrinkled and overlapped stacks of graphene nanosheets are observed in Fig. 1(b). The well embedding of GNSs into the copper powder, as shown in Fig. 1(c), indicates the strong interface bonding between copper and GNSs in the sintered composites. The prepared composite powders were finally sintered into disks of 50 mm in diameter and 3 mm in thickness using hot pressing method at 900 °C with applying 25 MPa pressure for more than 40 min. The schematic diagram of preparation process is shown in Fig. 2. Accordingly, the copper matrix composites with graphene contents of 2.5%, 5%, 7.5% and 10% (volume fraction) were consolidated. Cu/Gr composites were also fabricated

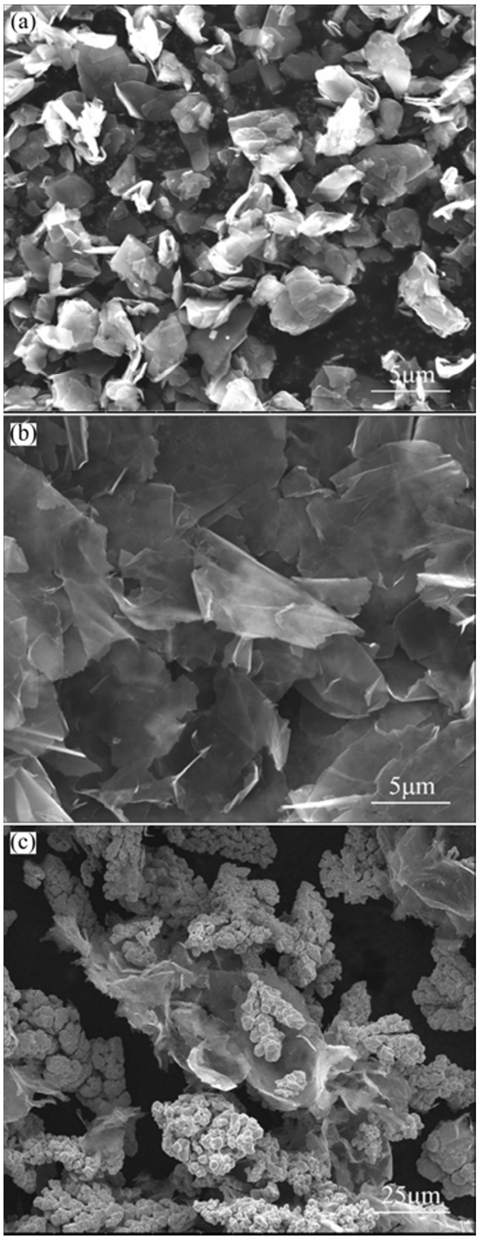

Fig. 1 SEM images of graphite (a), graphene nanosheets (b) and Cu/GNSs powder mixture (c)

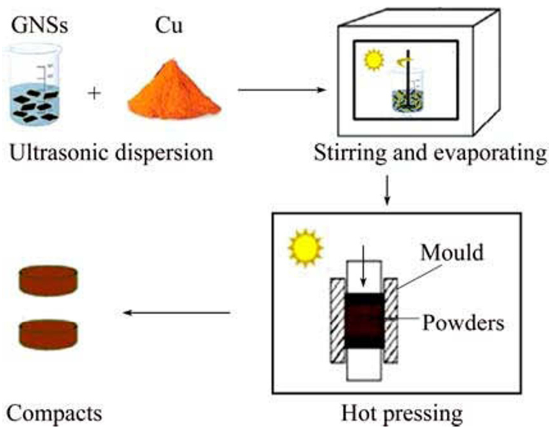

Fig. 2 Schematic diagram of preparation process of composites