Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 26(2016) 2336−2346
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Thermostability, mechanical and tribological behaviors of polyimide matrix composites interpenetrated with foamed copper

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Received 23 September 2015; accepted 18 April 2016

Abstract: Polyimide matrix composites interpenetrated with foamed copper were prepared via pressure impregnation and vacuum immersion to focus on their thermostability, mechanical and tribological behaviors as sliding electrical contact materials. The results show that the interpenetrating phase composites (IPC) are very heat-resistant and exhibit higher hardness as well as bending strength, when compared with homologous polyimide matrix composites without foamed copper. Sliding electrical contact property of the materials is also remarkably improved, from the point of contact voltage drops. Moreover, it is believed that fatigue wear is the main mechanism involved, along with slight abrasive wear and oxidation wear. The better abrasive resistance of the IPC under different testing conditions was detected, which was mainly attributed to the successful hybrid of foamed copper and polyimide.
Key words: foamed copper; pressure impregnation; thermostability; mechanical properties; tribological behaviors

1 Introduction

With the rapid development of polymer materials, they have been widely applied in the field of tribology, such as polytetrafluoroethylene (PTFE), polyetheretherkrtone (PEEK), epoxy resin (EP), polyimide resin (PI) [1−3]. It is noticed for a long time that polymer materials show favorable mechanical properties, corrosion resistance and excellent chemical stability [4,5]. However, their electrical conductivity and thermal conductivity can be very poor, which limit their applications greatly because some products (such as pantograph slide plates, and motor brushes [6]) require specific conductivity. Once the friction heat accumulates at the interface which is hard to dissipate, the materials would deteriorate even fail with the rising temperature caused by the heat buildup [7]. Therefore, it is extremely urgent to improve the properties of polymers. Then, the compound of materials, especially the idea of interpenetrating phase composites (IPC), is an available way.

Nowadays, polymer materials are closely linked to IPC. IPC are multi-phase materials in which the constituent phases are interconnected three-dimensionally and topologically throughout the microstructure [8]. In this study, we introduce foamed copper skeletons into the PI to acquire an IPC. The foamed copper possesses numerous special properties, such as low density, specific mechanical performance, high specific surface area, and high conductivity [2]. Such continuous skeletons are able to play roles both in the improvement of polymer strength and enhancement of heat dissipation and electrical conductivity. Many researchers pay attention to the study of IPC. LI et al [9] studied on the copper foam-supported Sn thin film as a high-capacity anode for lithium-ion batteries and the film electrode showed good cycle performance. HONG and HERKING [10] researched open-cell aluminum foams filled with phase change materials as compact heat sinks, and found out that as the surface area density of foams raised, both the heating and cooling times of the testing sample increased. CREE and PUGH [11] discussed the dry wear and friction properties of A356/SiC foam IPC and obtained that the low friction coefficient and wear rate of the novel material provided the possible applications in light-weight fields.

At present, some relatively mature manufacturing processes of IPC have come into being. WANG et al [12] first prepared the porous preform via cold molding and sintering of the mixed dry PPS polymer powder and NaCl particles. Then, the porous preform was filled with

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DOI: 10.1016/S1003-6326(16)64355-8

lithium-base grease at 120 °C for 2 h under vacuum condition. Carbon/epoxy resin composites with an interpenetrating network structure were prepared with natural sponge and thermoset epoxy resin by injecting resin into the sponge, curing at 160 °C for 2 h [13]. WANG et al [14] introduced a new technology on preparation of IPC successfully. They infiltrated methyl methacrylate (MMA) adequately into the metal skeleton, and then exposed the materials with ^{60}Co γ-ray at 25 °C to induce in-situ bulk polymerization. Although lots of works on resin matrix composites interpenetrated with metal skeleton have been done, there are still many respects requiring further research.

In this study, the novel polyimide matrix composites interpenetrated with foamed copper were prepared by pressure impregnation and vacuum immersion. Here, polyimide resin, foamed copper, copper powder, MoS_2 and graphite were introduced as raw materials. MoS_2 and graphite are the most common but effective lubricants in the field of tribology material [15,16], while the copper powder is applied as an additive. The thermostability, mechanical properties, as well as friction and wear behaviors of composites were investigated in detail to better evaluate this novel material. Finally, this study is expected to provide a possibility of preparing advanced and practical sliding electrical contact materials.

2 Experimental

2.1 Materials

The foamed coppers, as indispensable components in the composites, were self-prepared by chemical plating on polyurethane (PU) sponge. Characteristics and mechanical parameters of foamed copper are given in Table 1. The apparent density of foamed copper is 0.22 g/cm^3, with 2.5 mm average aperture and 97.7% porosity.

Table 1 Characteristic parameters of foamed copper

Parameter	Foamed copper
Average aperture/mm	2.5
Porosity/%	97.7
Apparent density/(g·cm^{-3})	0.22
Compressive strength/MPa	0.37

Figure 1 shows the SEM images of raw material powders. It is noticed that the electrolytic copper powders have an average particle size of 15 μm with dendritic structures and PI powders show quite different particle sizes, while MoS_2 and colloidal graphite powders with similar irregular lamellar shapes are 7 μm

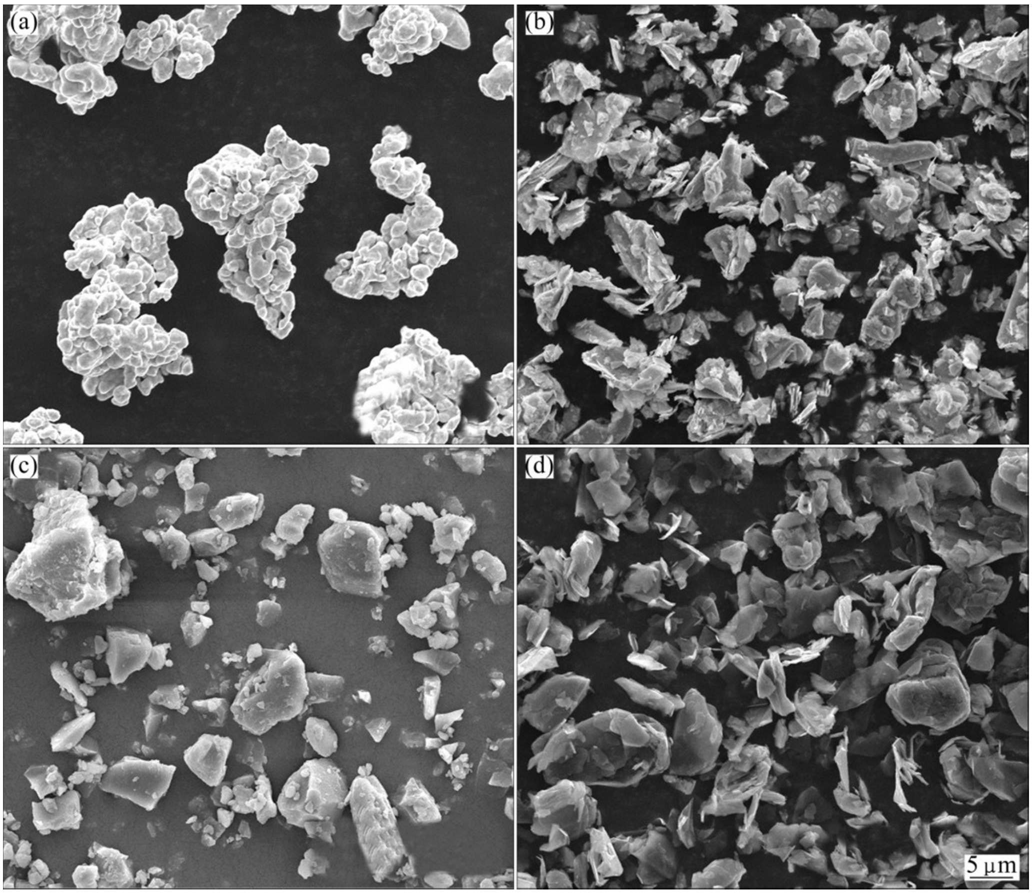

Fig. 1 SEM images of raw material powders: (a) Electrolytic copper; (b) MoS_2; (c) PI resin; (d) Colloidal graphite