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Original Article

Microstructural and sliding wear behavior of SiC-particle reinforced copper matrix composites fabricated by sintering and sinter-forging processes

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ABSTRACT

Cu and Cu/SiC_p composite compacts were prepared through sintering and sinter-forging processes. Influence of SiC particles and fabrication type on the tribological behavior of pure Cu and Cu/SiC_p composites was investigated. Dry sliding wear tests represented that the sinter-forged Cu composite compacts with 60 vol.% SiC exhibit the lowest wear loss compared to other compacts. Moreover, the results indicated that applying compressive force during sintering process of Cu and Cu/SiC_p compacts has a significant effect on reducing and eliminating porosities and achieving to higher bulk density. Therefore, wear loss of the Cu and Cu/SiC_p compacts produced through sinter-forging process was improved significantly compared to conventionally sintered Cu and Cu/SiC_p composite compacts.

1. Introduction

Owing to high electrical and thermal conductivity, low coefficient of thermal expansion (CTE), superior corrosion and oxidation resistance, good ductility and high melting point, metallic copper is one of the most commonly used structural and functional metals which can be utilized for engineering applications [1–3]. Nevertheless, due to its nature, there are some drawbacks, such as, low yield strength, weak creep resistance and low hardness, which can suppress applications of pure copper [1,3,4]. To overcome those limitations, ceramic particulate reinforcement dispersion, like SiC can improve high-temperature mechanical and tribological properties of copper because of high strength, superior wear resistance and high modulus of SiC reinforcement [3,5]. Cu/SiC composites

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combine both the superior ductility and toughness of copper and high strength and high modulus of SiC reinforcements [4,6]. SiC particulate-reinforced copper metal matrix composites (Cu/SiC_p MMCs) potentially can be employed for usages in high temperature structural applications, such as brakes and other severe frictional applications [7], electronic packaging [3,8], electrical contacts [3], resistance welding electrodes [3,9] and high performance switches [4]. The most common routes for particle-reinforced Cu matrix composites include casting and powder metallurgy methods [8–10]. Because of low agglomeration, low segregation and good wettability, powder metallurgy (PM) is preferred to casting [9]. Final processes to achieve a high densification rate of compacts in PM method involve hot isostatic pressing (HIP) or hot pressing (HP). Similar to conventional sintering, isotropic shrinkage can cause densification during isostatic pressing, whereas the shrinkage just in one direction can occur in hot pressing process, which generates shear strain inside compact. This created shear strain during hot pressing increases more effectively the densification than isostatic pressing, which does not generate shear strain. Sinter-forging process is different from hot pressing process in that powder compact is not forced via the walls of the die [11–13]. In sinter-forging, the initial powder is compacted under a uniaxial compressive load without any lateral restriction, i.e. there is no die wall to restrict shear deformation, which can cause densification of compact during sinter-forging, and moreover, shear and radial strain can eliminate flaws and improve densification of compact [11]. The sinter-forging process has been developed by Wakai et al. in 1986 for consolidation of fine-grained yttria-stabilized tetragonal zirconia (YSTZ) ceramic based-materials [14]. The sinter-forging process uses the super-plasticity property of ceramic materials to eliminate large pores, which can be created during sintering. Due to simultaneous deformation and densification of the ceramic compacts during sinter-forging, high density ceramic material can be obtained with a minimum value of grain growth [11–13]. This process has been used to fabricate the ceramic materials like Al_2O_3 [11,12] and their composites. Tjong and Lau [9] studied the tribological behavior of copper and its composites reinforced with SiC particles (5–20%), which were prepared by hot isostatic pressing (HIP) process. Their work represented that the addition of SiC particulates to copper matrix decreases the strain localization range in the subsurface region conducting to volume loss reduction. Kennedy et al. [7] investigated the tribological characteristics of several Cu/SiC_p composites, which were synthesized from copper-coated SiC particles. Their results indicated the interface bond strength worth between matrix and reinforcement particulates, using an intermediate coating on SiC particles resulted in wear rate reduction of Cu/SiC particulate composites. In this study, Cu and its composites reinforced with SiC particles were fabricated by conventional sintering and sinter-forging process, and compared the physical and mechanical properties of the samples like density, hardness and wear resistance.

2. Experimental materials and methods

2.1. *Materials*

The as-received powder material for the composite matrix was pure atomized and spherical copper powder with an average particle size of 45 μm. SiC reinforcement particulates with a diameter of <10 μm were irregular and angular in shape, both powders from Sigma–Aldrich, Germany with high purity of 99.9%. The morphology of both powder particles is shown in Fig. 1(a) and (b).

2.2. *Methods*

The metal matrix composites studied in this work, were based-on pure copper reinforced with 20, 40 and 60 vol.% SiC particles. Cu and Cu/SiC_p composites were fabricated through the sintering and sinter-forging processes. For this purpose, Cu and SiC powders were mixed using an attritor to produce composite powders including 20, 40 and 60 vol.% of SiC particulates. Then the composite powders were compacted under a uniaxial stress of 250 MPa at ambient temperature. Compacted powders were sintered at different conditions; all the samples were presintered in an inert atmosphere. Afterwards, on the presintered specimens were performed the sintering and sinter-forging processes to densify Cu and Cu with 20, 40 and 60 vol.% SiC, separately. The samples had disc-shaped with dimension of ϕ15 mm × 5 mm. Table 1 summarizes the various sintering and sinter-forging conditions which used to fabricate Cu and Cu/SiC_p compacts.

The density of Cu and Cu/SiC_p composite compacts was determined according Archimedes' method. In this technique, density is determined by measuring the difference between the specimen weight in air and when it is suspended in distilled water at room temperature. Hardness of both pure copper and composites were determined using a Vickers tester under an applied load of 0.245 N. Dry sliding wear

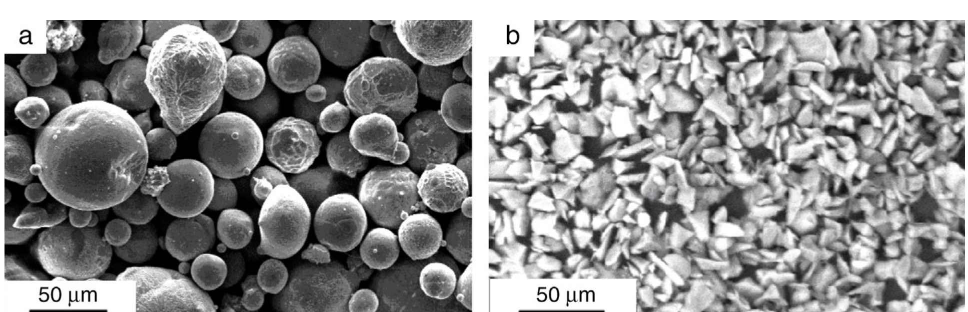

Fig. 1 – SEM micrographs of as-received powders of: (a) Cu, and (b) SiC.