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Properties and abrasive wear of TiB_2/Al-4%Cu composites produced by hot isostatic pressing

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Abstract

Al-4 wt%Cu alloy and composites reinforced with 5, 10, 15 and 20 vol% TiB_2 particles were prepared by hot isostatic pressing. The density, mechanical properties and abrasive wear behavior of these specimens were evaluated. Density measurement revealed that the hot isostatic pressing (HIP) process had resulted in fully densified unreinforced alloy, and composites containing TiB_2 particles up to 15%. Increasing the reinforcement particle content to 20% led to a slight reduction in the density of composites due to higher porosity. Tensile and hardness tests showed that the yield strength and hardness tend to increase with increasing TiB_2 volume content. Finally, two-body abrasive wear tests showed that the wear resistance of composites increases dramatically with increasing the reinforcement volume content. This was due to a strong particle-matrix bonding, and to the high hardness of the TiB_2 particles. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Aluminium-based alloys are widely used in the automotive and aerospace industries on account of their low densities. However, the relatively poor seizure resistance of aluminium alloys has restricted their uses in such engineering applications. The wear resistance of these alloys can be improved considerably by adding ceramic reinforcements into aluminium, leading to the formation of the metal-matrix composites (MMCs). Incorporation of ceramic reinforcements can result in a favorable combination of the high ductility of the aluminium matrix, and the high strength of the reinforcement phase. The ceramic reinforcements generally can be in the form of particles, whiskers and fibers. Particulate reinforced MMCs appear to be the most popular choice because they can offer relative ease in processing, lower fabrication cost, and nearly isotropic properties in comparison to fiber-reinforced materials. The particulate materials commonly added to the aluminium alloys include SiC, Al_2O_3, TiC and TiB_2. Among them, the mechanical properties of SiC-particle-reinforced Al-based MMCs have been extensively studied by several researchers [1–5]. However, particulate TiB_2 particle is particularly attractive because it is a hard material with a high wear resistance, high melting point, high elastic moldulus and high strength at elevated temperatures as well as good thermal conductivity [6]. Moreover, particulate TiB_2 can be produced in situ in the aluminum matrix by the reaction pressing process, which is expected to impart higher strength and better creep resistance because of the finer particle size and cleaner particle–matrix interface [7–9]. Roebuck and Forno reported that TiB_2 is a more effective reinforcement material for 2014-Al alloy than SiC as far as the strengthening effect is concerned [10]. Similarly, Smith and Chung reported that the TiB_2/Al composite exhibits higher tensile strength and stiffness than SiC/Al composite with a nearly similar reinforcement content at high temperatures [11]. At elevated temperatures, Otsula et al [12]. reported that the addition of 2 vol% TiB_2 to aluminium improves the compressive strength and ductility. TiB_2/Al composites therefore, show promise for use as materials in automotive and aerospace engines, and lightweight armour [11]. It is worth mentioning that abrasive wear caused by the impingement of particles onto the surface of a material is commonly encountered in many

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industrial applications and transportation sectors. Therefore, it is of practical importance to understand the abrasive wear of TiB_2/Al composite.

Compared to the vast number of studies on the wear behaviour of SiC-particle-reinforced MMCs [13–18], little information is available on the wear and particularly, the abrasive wear of TiB_2-particle-reinforced Al-based composites. Smith and Chung [11] have investigated the dry rolling wear of an Al-based composite reinforced with a very high volume fraction of TiB_2 particles, i.e. 0.61. Their results indicated that the TiB_2/Al composite is 12.8 times more resistant than aluminium owing to the absence of particle pull-out, and to the slow wear rate of TiB_2 particles. They further pointed out that the particle-matrix interface is free of brittle reaction products, thereby preventing decohesion of the particle or particle pull-out from the matrix. Particle pull-out has been reported to cause rapid wear of MMCs on account of the fact that the softer matrix is no longer protected by the reinforcement when the particles are removed from the composites [19]. Caracostas et al. have studied the lubricated sliding wear of a 2024-Al composite reinforced with in situ formed TiB_2 particles (1.3 μm) [20]. They reported that the in situ TiB_2 particles form a strong bond with the alloy matrix, so that fragmentation of the reinforcing particles is more likely to occur than particle/matrix decohesion is such composite. More recently, Tjong et al. have successfully fabricated in situ Al-based MMCs reinforced with both TiB_2 and Al_2O_3 particles, and studied their sliding wear behavior. The results showed that a strong particle-matrix bonding in $TiB_2.Al_2O_3$/Al and $TiB_2.Al_2O_3$/Al-Cu composites enabled the in-situ TiB_2 particles (~2 μm) to be retained in the surface during sliding, thereby resisting shear deformation during sliding [21].

Particulate MMCs can generally be fabricated by ingot metallurgy (IM) and powder metallurgy (PM) processes. The IM route has the advantage of low production cost but it also exhibits some shortcomings such as ceramic-particle/metal interaction, microstructural inhomogeneities and poorer mechanical properties of the products. On the other hand, the advantages of the PM route include near-net-shape fabrication, lower processing temperatures, and higher mechanical properties, etc. In addition, extensive ceramic-particle/metal interfacial reactions can be avoided by using a solid-state process. It is well recognized that some cavities or porosity may exist in the sintered products, leading to these materials having poor corrosion and mechanical properties. Thus, additional mechanical treatment such as hot pressing or extrusion is needed in order to eliminate the internal voids of sintered materials. Recently, the hot isostatic pressing (HIP) technique is being increasingly used to consolidate the sintered materials. The HIP process consists of sintering the blended powders under the applications of high pressure and high temperature. The pressurizing medium is normally an inert gas such as pure argon. Several workers have successfully fabricated Fe-, Ni- and Ti-based MMCs by the HIP process [22–25].

The abrasive wear of materials generally can be classified into two-body and three-body abrasive wear [26,27]. Two-body abrasive wear denotes the wear of a metal surface sliding against a rough, harder body. Abrasion by bonded abrasive papers and cloths is regarded as two-body abrasion on the grounds that the abrasive particles are held fixed rather than being free to roll [10]. Three-body abrasive wear is associated with loose particles present between the surfaces of two components arranged in a sliding coupled system. The fixed abrasives cause about 10 times the wear as the loose abrasives for the same abrasives and the same average pressure in the case of metal. Abrasive wear gives a characteristic surface topography consisting of long parallel grooves running in the rubbing direction. The volume and sizes of the grooves varies considerably from light scratching to severe micro-cutting, ploughing and gouging. Generally, materials with a high hardness exhibit a higher abrasion resistance since they reduce the penetration of abrasive particles into the surface. In this work, Al-4 wt%Cu based composites containing 5, 10, 15 and 20 wt% TiB_2 particles were fabricated via the PM route followed by HIP. The mechanical and abrasive wear properties of these MMCs were investigated.

2. Material and experimental techniques

2.1. Materials

Aluminum powder (99% purity, 25 (μm in diameter), copper powder (99% Cu, Pb < 2000 ppm, O < 2000 ppm; 50 μm in diameter), and TiB_2 particles (99% purity, 45 μm in diameter) were purchased from Goodfellow Cambridge Ltd. The Al-4 wt%Cu alloy and MMCs contained 5, 10, 15 and 20 vol% TiB_2 were fabricated by the PM process. Sample preparation was done by mixing ultrasonically the powders, according to their composition, in alcohol. The powder mixtures were then cold compacted into tensile bars. They were subjected to the HIP treatment at 620°C and 100 MPa for 1 h using a ABB HIP equipment (model QIH-3). During HIP each specimen was subjected to a standard heating and cooling cycle and with the pressure being applied by means of argon gas. The specimen experienced incipient melting during HIP at 620°C. After HIP, the specimens were heat-treated at 535°C for 1 h followed by water quenching, and then aged at 150°C for 72 h (T6). The composites generally exhibited a peak hardness after aging for 72 h (Fig. 1).

Immersion density measurements were carried out according to Archimedes' principle. In the tests, density