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Microstructure, mechanical properties and wear behaviour of Zn−Al−Cu−TiB_2 in situ composites

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Abstract: Zn−Al−Cu−TiB_2 (ZA27−TiB_2) in situ composites were fabricated via reactions between molten aluminum and mixed halide salts (K_2TiF_6 and KBF_4) at temperature of 875 °C. The microstructure, mechanical properties and wear behavior of the composites were investigated. Microstructure analysis shows that fine and clean TiB_2 particles distribute uniformly through the matrix. The mechanical properties of the composites increase with the increase in TiB_2 content. As TiB_2 content increases to 5% (mass fraction), an improvement of HB 18 in hardness and 49 MPa in ultimate tensile strength (UTS) is achieved. The overall results reveal that the composites possess low friction coefficients and the wear rate is reduced from 5.9×10^{-3} to 1.3×10^{-3} mm^3/m after incorporating 5% TiB_2. Friction coefficient and worn surface analysis indicate that there is a change in the wear mechanism in the initial stage of wear test after introducing in situ TiB_2 particles into the matrix.

Key words: in situ composites; TiB_2 particles; friction coefficient; wear rate; mechanical properties

1 Introduction

The zinc-based alloys containing aluminum, copper and magnesium are characterized by high strength, excellent tribological properties and low melting temperatures, thus having potential for replacing the traditional bronze and iron base foundry alloys to produce wear resistant components [1,2]. In recent years, reinforcing with second phase particles has been noted to substantially improve the mechanical properties and wear response of zinc-based bearing materials. Conventional preparation of zinc-based composites involves the addition of externally synthesized particles, for instance, SiC [3], Al_2O_3 [4], ZrO_2, graphite [5] and TiO_2 [6] into molten matrix. Various problems, such as particles segregation and poor adhesion at the interface and inferior thermodynamically instability of the reinforcement frequently arise owing to surface contamination of the reinforcements and poor particle−matrix wettability.

Recently, in situ fabrication techniques have been developed to produce metal matrix composites (MMC). Since the formation and growth of reinforcement take place within the matrix, in situ preparation of composites provides advantages including uniform distribution of finer particles, excellent bond at the interface, thermodynamically stable reinforcements that overwhelm the conventional ex situ processes, yielding better mechanical and tribological properties. Although various in situ techniques have been used to fabricate aluminum [7−9], magnesium [10], copper [11], iron [12] base MMC, fewer studies have been reported regarding the fabrication and properties of zinc-based in situ composites.

The present work focuses on the fabrication, microstructure, mechanical properties and wear behaviour of TiB_2 particulate reinforced ZA27 in situ composites synthesized by mixed salt route. TiB_2 is an advanced reinforcement for zinc-based composites as it possesses a useful combination of physical and mechanical properties, including high melting point (3225 °C), high elastic modulus (534 GPa), high hardness (HV 960) and outstanding wear resistance. More importantly, it does not react with zinc or aluminum to form reaction product at the interface between reinforcement and matrix [13,14]. ZA27 alloy, the nominal composition listed in Table 1, was selected

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Table 1 Chemical composition of ZA27 alloy (ASTM B 240−2004) (mass fraction, %)

Al	Cu	Mg	Zn
25.5−28.0	2.0−2.5	0.012−0.020	Bal.

as the matrix alloy because. On one hand, it has been considered for a number of commercial applications due to good mechanical properties, machinability and wear properties [15,16]; on the other hand, aluminum in ZA27 helps to facilitate the salt reaction via aluminothermy reduction in the synthesis process.

2 Experimental

ZA27−TiB_2 in situ composites were produced in the laboratory by mixed halide salt reaction. Commercial pure aluminum (99.7%) was melted and heated to 875 °C in a graphite-clay crucible with a resistance furnace. Pre-dried K_2TiF_6 and KBF_4 salts, weighed at a stoichiometric ratio Ti to B of 1:2, were fully blended and wrapped with aluminum foil. A small amount of KCl, $CaCl_2$ and Na_3AlF_6 salts were added as the reactive assistant and covering agent. The mixed salts were then pressed into the melt and stirred thoroughly for 30 s. The melt was held at 875 °C for 45 min to allow the reaction to reach completion. Cu and Mg were added in the form of Al−Cu and Al−Mg master alloys, whilst Zn was added in the form of molten zinc. After removing the slag and degassing by refining flux and high-purity argon, the melt was poured into a preheated thin-wall permanent mold. A total of three composites (see Fig. 1(a)) were produced with different mass fractions of TiB_2 (1%, 3% and 5%). The chemical composition of the composites was determined by atomic absorption analysis.

X-ray diffraction (XRD) test was carried out with a Shimadzu XRD−6000 to identify the various phases in the composites. The microstructures of the composites were examined with a Zeiss Supra 55 scanning electron microscope (SEM). Hardness tests of the composites were carried out by a Brinell hardness tester. The tensile specimens were prepared according to ASTM E8M−04 standard having a gauge length of 30 mm, a gauge diameter of 6 mm. The tensile strength was estimated with a computerized universal testing machine at room temperature and the strain rate for tensile test was 1.25×10^{-3} s^{-1}. The present values of the hardness and tensile properties are the average of three tests for each composite. The fracture surfaces of the failed tensile specimens were analyzed by SEM.

Wear tests were carried out at room temperature with a computer-controlled pin-on-disc wear testing machine, and the schematic diagram of the wear test is shown in Fig. 1(b). The pins with 4.8 mm in diameter and 12.7 mm in length were machined from ZA27 alloy

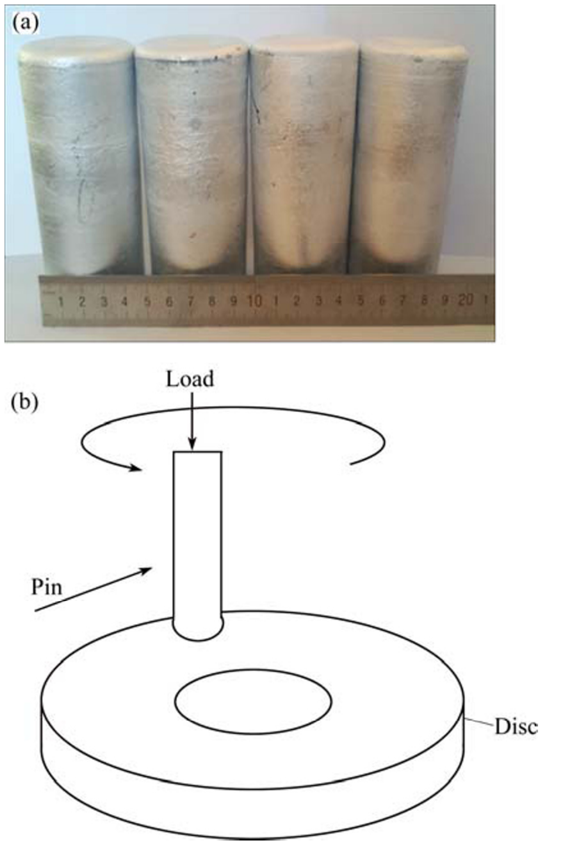

Fig. 1 Ingots of matrix alloy and composites (a) and schematic diagram of pin-on-disc wear test (b)

and the in situ MMC. The counterpart discs with an external diameter of 54 mm were made of SAE1045 steel (Fe−0.46%C−0.6%Mn−0.035%P−0.03%S) and had a hardness of HRC 50 after induction quenching. Wear tests were performed at a constant load of 90 N, which corresponded to a nominal contact stress of 5 MPa. For each sample, the wear test was carried out at a constant sliding speed of 0.75 m/s for 1 h (corresponding to a sliding distance of 2.7 km). SAE 40 oil was used as the lubricant. Each wear sample was ultrasonically cleaned in acetone and weighed before and after the test by an electronic balance with an accuracy of 0.1 mg to determine the mass loss. The wear rate was calculated by dividing the mass loss by sliding distance and measured density of the sample. The friction coefficients of the samples were recorded simultaneously by the computer. Three tests were carried out for each set of sample to get representative data. The worn surfaces were analyzed by SEM.

3 Results and discussion

3.1 Phase composition and microstructure of composites

The XRD patterns of the base alloy and the