



A remarkable enhancement of mechanical and wear properties by creating a dual-scale structure in an Al–Sn–Si alloy

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ABSTRACT

Nanocomposite Al–Sn–based bearing alloys produced by mechanical alloying (MA) exhibit high hardness; however, their poor sintering density and ductility limit their wide spread application. Here, we present a strategy to produce a dual-scale structure in an Al–Sn–Si alloy consisting of coarse and ultrafine grains through a combination of conventional powder sintering and thermomechanical treatment. We found that severe deformation and the presence of an Al–Si eutectic mixture for sample induced abnormal grain growth of Al to create the dual-scale Al–Sn–Si alloy through annealing treatment. An optimum matching of ductility and strength, and optimum wear performance were achieved at annealing temperatures of 500 and 550 °C. Detailed investigation of the wear mechanism revealed that the combination of high strength and high ductility provided by the dual-scale structure is a key factor for the improvement of the wear properties.

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1. Introduction

Al–Sn alloys are widely used in engines as sliding bearing materials because of their good compatibility, thermal conductivity and wear performance [1–3]. These properties arise from the alloy's microstructure—a moderate-strength Al matrix with dispersed, isolated soft-phase Sn [2,3]. With the development high-speed and high-load engines, there is a higher demand for improved strength and wear performance of Al–Sn–based bearing alloys.

Segregation as a result of gravity inevitably occurs in the solidification process owing to the large difference in density between Al and Sn. These deteriorate the mechanical and wear properties of the immiscible Al–Sn system formed by conventional casting [4–6]. Grain refinement is an effective way to improve the hardness and strength of metals and alloys [7]. In recent years, various methods, such as mechanical alloying [2,3], physical vapor deposition [8], and severe plastic deformation [9], have been used to fabricate nanocrystalline or ultrafine-grain Al–Sn–based alloys. In particular, mechanical alloying is an effective way to produce controllably refined and homogenous microstructures in immiscible alloy systems [2,3,10]. Nanocomposite Al–Sn and Al–Pb alloys fabricated using this method exhibited improved mechanical

and wear properties [11,12]; however, partial surface oxidation of Al powder was induced by mechanical alloying, which reduced the sintering ability of the powders. It is also necessary to increase the ductility and fracture toughness of alloys formed through mechanical alloying to meet application requirements [12].

Recently, a dual-scale microstructure consisting of soft coarse-grain zones and hard ultrafine-grain zones was created in Al–Sn [3,13] and Al–Sn–Mg [12] alloys using a combination of mechanical alloying and dual-scale powder mixing. Greater improvement in terms of sintered density, ductility, and wear properties was achieved in these alloys. These improvements were attributed to the soft coarse grains enhancing the flowability and ductility of the powders, and the added alloying elements, such as Mg and Si, disrupting the passivation oxide layer of Al particles. In addition, the thermomechanical treatment can also be used to create a dual micro- and nanoscale structure in nanocrystalline or ultrafine-grain materials, which increases both the strength and ductility. This method was applied for several materials, such as a Cu sheet [14], Al alloy sheet [15–19], and a Ti alloy sheet [20]. Compared with dual-scale powder mixing technology, in situ formation of coarse grains by thermal treatment results in superior strength and ductility. Although previous works have mainly focused on metal or alloy sheets, they also provided guidelines for fabrication in powder sintering.

In the present work, the mechanical alloying of Al–Sn–Si powder was achieved using a conventional press-and-sinter process. This was followed by severe deformation of the bulk through room-temperature rolling combined with subsequent annealing treatment. The thermomechanical treatment method, which induced some Al grains to grow larger in the

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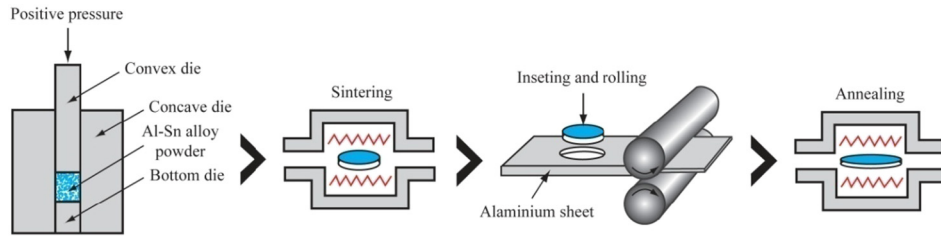


Fig. 1. Schematic representation of the preparation method for Al-Sn-Si alloys.

ultrafine-grain Al-Sn-Si matrix, markedly increased the strength and ductility. Thus, we have developed an effective method to produce dual-scale Al-based alloys with excellent mechanical and wear properties using mechanical alloying technology.

2. Experimental

The starting Al, Sn, and Si powders (~ 200 mesh size, 99.5% purity) were supplied by Aladdin Chemistry Co., Shanghai, China. Nanocrystalline

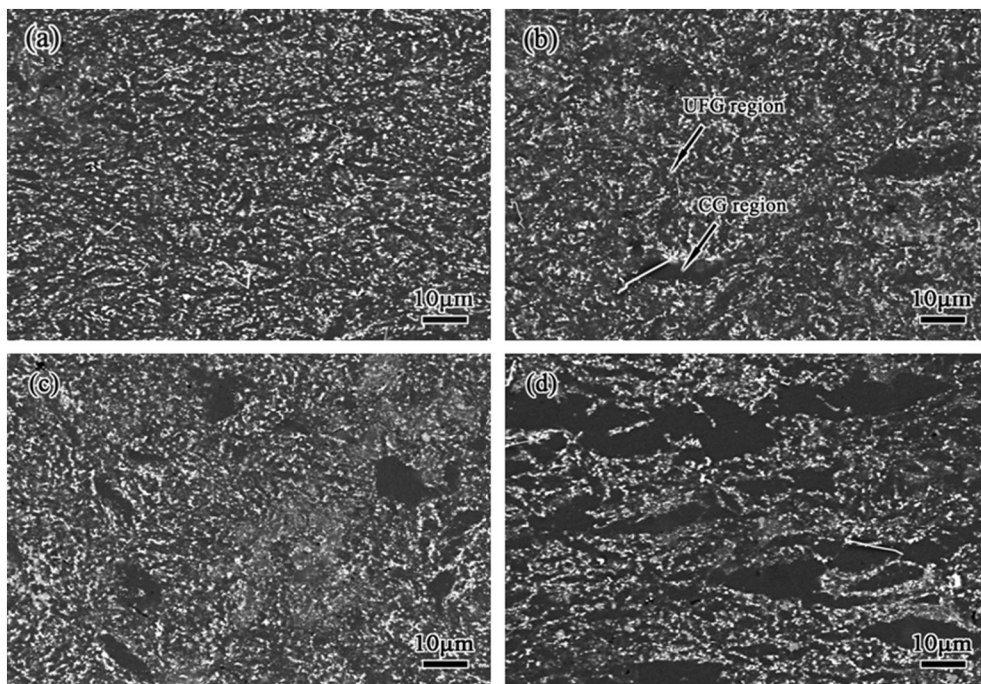


Fig. 2. SEM images of Al-12Sn-2.5Si (wt%) alloys rolled at room temperature with (a) no annealing and (b–d) annealing at 400, 550, and 600 °C, respectively.

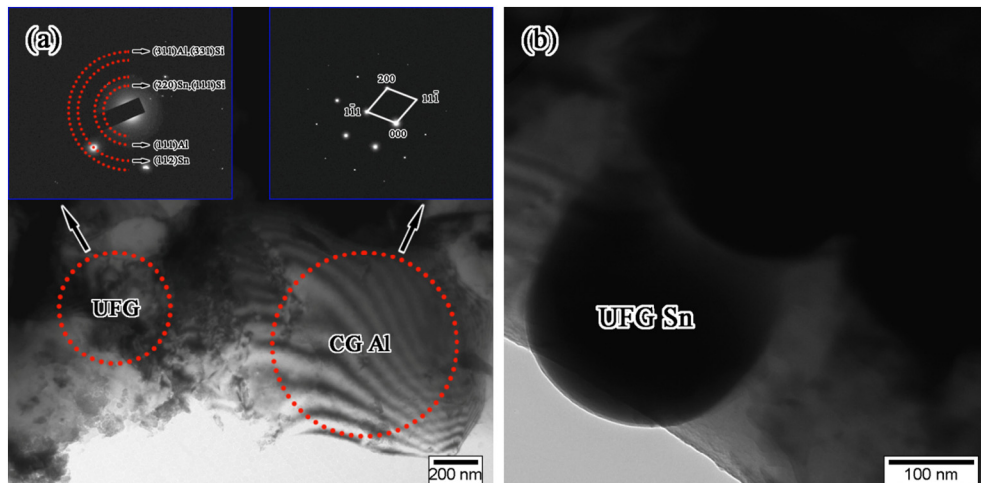


Fig. 3. TEM images of Al-12Sn-2.5Si (wt%) alloy rolled at room temperature with annealing at 550 °C.

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