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Synthesis, microstructure and mechanical properties of ZrB_2 nano and microparticle reinforced copper matrix composite by *in situ* processings

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ABSTRACT

Copper matrix composite reinforced with ZrB_2 particles was prepared by *in situ* reaction in two different ways: by mechanical alloying and subsequent hot pressing, i.e. mechanical alloying and followed by laser melting process. Microstructural changes during mechanical alloying, hot pressing and laser melting of Cu, Zr and B powder mixtures were studied using scanning electron microscopy and X-ray diffraction. In particular, changes in the Cu particle size, structural parameters of the powder mixtures and formation of new ZrB_2 and CuZr phases during hot pressing, i.e. laser melting were investigated. The mechanisms of *in situ* formation of reinforcement particles and hardening effects in the copper composite were also studied. Large supersaturation which is possible with laser melting process results in homogeneous nucleation of CuZr precipitates and the presence of finer CuZr precipitates and ZrB_2 reinforcements in the Cu matrix. This affected on significantly higher degree of Cu matrix hardening compared to composites obtained by mechanical alloying and hot pressing.

1. Introduction

Extraordinary results obtained in the research of rapidly solidified as well as mechanically alloyed copper-based composites have widened the possibilities of their application, primarily in the military industry for components in submarines and other floating machines [1], as well as rocket parts [2,3]. Apart from existing implementation of precipitation and dispersion hardened copper alloys in electrical engineering and electronics [4,5], potential usage of these alloys is in the first walls of fusion reactor, gas turbine blades, shields for neutron radiation [6,7].

Current studies are focused on few families of copper-based systems. The first class were those that form elemental and copper-x precipitates from solution in copper, such as Cr, Cu_5Zr, Ag, Nb, and others having low solid solubility in copper. The second class of alloys was formulated to produce precipitates or dispersions of stable copper-free intermetallic compounds. Third type of alloys was designed to produce reinforcements of metal-borides. Generally, borides of metals having low solid solubilities in copper were preferred, so that any excess of boride forming elements would precipitate rather than remain in solid solution and adversely affect conductivity.

Aside from TiB_2 particles, whose formation is a result of reaction processes between structural components in solid [8,9] or liquid state [10], ZrB_2 particles are potential candidates for reinforcement of Cu alloy. Direct manufacture of Cu–ZrB_2 from Cu and ZrB_2 starting material does not yield composites with acceptable microstructural properties: strong interfacial bonding between the ceramic particles and matrix and coarse ZrB_2 particles. *In situ* formation of ZrB_2 by reaction appears to be necessary and recently, an *in situ* technique was developed to fabricate ZrB_2 particle-reinforced alloys [11,12]. *In situ* reinforced alloys exhibited improved mechanical strength and remained electrically conductive. However, the achievement of high strength and high hardness is dependent on sacrificing the conductivity due to the limitation of reinforcement particles volume fraction.

The purpose of this work was to study the formation of Cu–ZrB_2 by mechanical alloying and subsequent hot pressing (formation of copper matrix composite predominantly in the solid state), i.e. the formation of Cu–ZrB_2 by mechanical alloying and subsequent laser melting (formation of copper matrix composite predominantly in the liquid state), with an aim to produce a Cu–ZrB_2 alloy with high hardness at room temperature as well as elevated temperatures.

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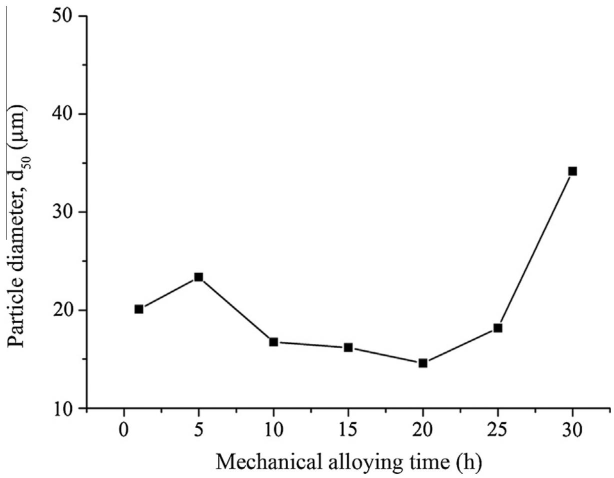

Fig. 1. Variations of average powder particle size versus milling time in Cu–Zr–B powder mixtures.

2. Experimental details

The powders used as starting materials were copper (99.5% purity, 15 μm), zirconium (99.5% purity, 1 μm) and amorphous boron (97% purity, 0.08 μm). They were weighed to give stoichiometric Cu–2vol.% ZrB_2 and the mixture was homogenized for 1 h. The homogenized mixtures were mechanically alloyed in Netzsch attritor mill with ball-to-powder weight ratio of 5:1. Steel balls with diameter of 6 mm were used in the mill. Attrition milling was carried out in protective atmosphere (argon) for 1 and up to 30 h, with stirring speed of 330 rpm.

Mechanically alloyed powders were consolidated in two ways – by hot pressing and laser melting. One amount of mechanically alloyed powder was hot pressed at 950 °C for 2.5 h, at the pressure of 35 MPa in argon atmosphere. The pressing was conducted in graphite mold. Thermomechanical treatment of the hot-pressed samples comprised 40% cold plastic deformation, solution annealing at 950 °C for 1 h, water quenching and aging at 500 °C for 1 h in hydrogen.

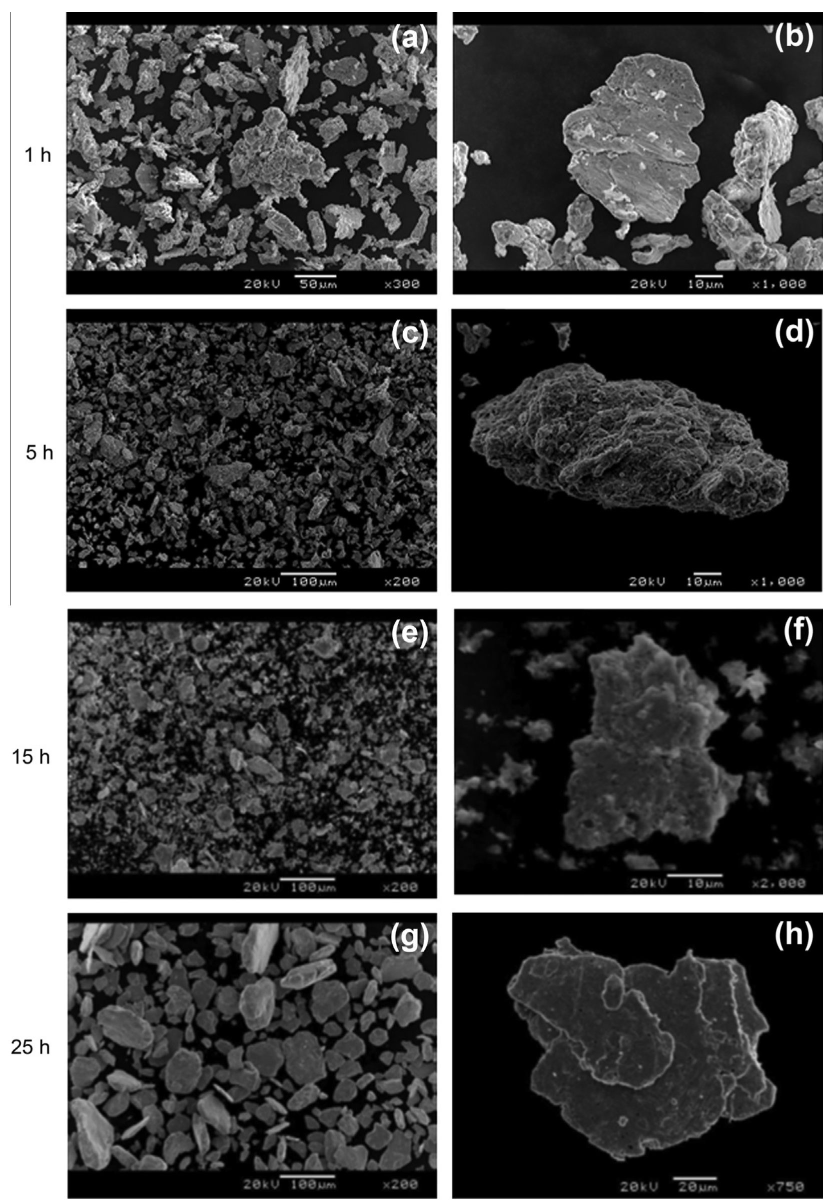

Fig. 2. The effect of milling time on particle morphology in the Cu–1.1Zr–0.3B powder.