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Effect of equal channel angular pressing and heat treatment on the microstructure of Cu–Al–Be–B shape memory alloy

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ABSTRACT

The combination of equal channel angular pressing (ECAP) and heat treatment was carried out to modify the microstructure of a Cu–Al–Be–B shape memory alloy. Microstructures of the alloy after ECAP and subsequent quenching were investigated by optical microscopy and X-ray diffraction (XRD). The alloy with 8 passes of ECAP at 743 K is characterized with ultra-fine grains (~2 μm), but with smaller fraction of martensites which implies the lower shape memory effect (SME). After reheated at 873 K and oil-quenched to room temperature, the grains become coarsen (~50 μm) but still finer than that of as-received (100–300 μm), and the fraction and order of martensites were increased simultaneously.

1. Introduction

Cu-based shape memory alloys (SMA) have been extensively investigated due to the low cost, good shape memory effect (SME), high pseudoelasticity and damping capacities [1,2]. However, their applications are still limited for the shortcomings of thermal stability, brittleness and mechanical strength [3]. The previous studies showed that these shortcomings are closely related with microstructure characteristic of Cu-based shape memory alloys [4,5], such as coarse grain sizes, high elastic anisotropies and the congregation of secondary phases or impurities along the grain boundaries.

Lu et al. found out that the proper addition of Be and B can improve the SME and thermal stability of Cu–Al alloys [1,6,7]. The powder metallurgy and rapid solidification techniques were developed to fabricate fine-grained Cu-based shape memory alloys [1,3,8,9]. However, powder metallurgy is difficult to be efficiently applied for its complexity, while rapid solidification technique is not capable of making fine-grained bulk alloys. Therefore, it is necessary to develop new techniques for refining the grain size and improving martensite structure of Cu-based SMA.

It has recently been demonstrated that ultra-fine grained bulk metallic materials can be obtained by equal channel angular pressing (ECAP) [10], which has many advantages over traditional metal process technologies [11,12]. The process has been successfully applied to produce various ultra-fine grained (UFG) materials, such as low carbon steel, Cu alloys, Al alloys, pure Ti and Ti–Ni shape memory alloy [13–19]. Considering the fact that ECAP was approved to be an effective process to enhance SME of Ti–Ni alloy, it is suggested that ECAP will be also a potential technique to improve SME and microstructure of Cu-based SMA. Thus, the present work focused on the microstructure evolution of Cu–Al–Bi–B shape memory alloy after ECAP and subsequent heat treatment. The present work focused on the microstructure evolution of Cu–Al–Bi–B shape memory alloy after ECAP and subsequent heat treatment.

2. Experimental procedures

The experimental alloy, with a composition of Cu–11.42 wt.%Al–0.35 wt.%Be–0.18 wt.%B, was prepared by induction furnace vacuum-melting, using high purity copper, aluminum, boron and beryllium–copper alloy. The alloy ingot was machined into billets with size of 10 mm × 10 mm × 40 mm, and then processed by ECAP using a solid die having an angle of 90° between the two channels. The inner contact angle (ϕ) and the arc of curvature (φ) at the outer point of contact between channels of the die were 90° and 0°, respectively. The die and billet were preheated at 743 K for 30 min before the first ECAP extrusion then the billets were extruded for 1 to 8 passes. The billet was inverted, and rotated by 180° on the same direction around its axis during repeated deformations (illustrated in Fig. 1). Graphite was used as lubricant to reduce the friction coefficient between the work pieces and die inner wall.

After being processed by 8-passes of ECAP, two groups of Cu–Al–Bi–B specimens were reheated to a certain temperature and followed with oil-quenching. One group of specimens was hold for 10 min at various reheating temperatures (T), where T = 623, 673, 723,773,823, 873, 923 and 973 K, respectively. Another groups of specimens were

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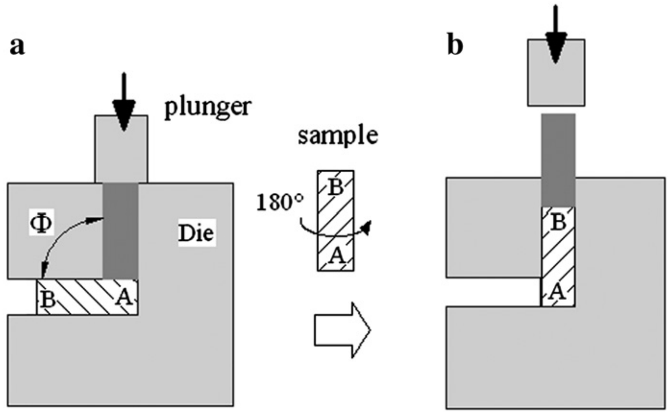

Fig. 1. The schematic illustration of the ECAP process.

hold at 873 K with different time (t), where $t = 10$, 20, 30, 40, 50, and 70 min, respectively.

The specimens used for microstructure observation were cut perpendicular to the ECAP pressing direction, polished and etched by a solution with the composition of 10 g $FeCl_3$, 8 ml HCl, 50 ml C_2H_6O and 50 ml H_2O. Microstructure characteristics were examined by optical microscopy (OM, OlympusBX51M). Phase constitutes were analyzed by X-ray diffraction (XRD, D8 Advance) with the Cu Kα radiation (wavelength $\lambda = 1.54056$ Angstrom) at 40 kV and 40 mA. The transformation temperatures of M_s (martensite staring) M_f (martensite finishing), A_s (austenite staring) and A_f (austenite finishing) were measured using a differential scanning calorimeter (DSC, STA409PC/4/H) at heating and cooling rates of 5 K/min.

3. Results and discussion

3.1. Phase constitutes of Cu–Al–Be–B alloy in various states

The copper–aluminum equilibrium diagram [20] shows that upon cooling from the β phase, the alloy described above becomes ordered to form β_1 austenitic phase, then transforms martensitically to β_1' phase with an 18R structure. During the process of rapid quenching, part of β_1 austenitic phase can be retained below the temperatures of martensitic transformation, along with small amount of α phase precipitate on the grain boundaries.

Fig. 2 presents room-temperature XRD patterns of the Cu–Al–Be–B alloy samples in various states. Clearly, the as-received alloy consists of β_1 austenitic, β_1' martensite (18R) and α-phase (A1). After ECAP at 743 K for 8 passes, β_1'-phase disappeared and γ_2 phase occurred. Therefore, the subsequent heat treatment, reheating at 873 K followed by oil-quenching to room temperature, impelled the formation of martensites (18R) again, as shown in Fig. 2.

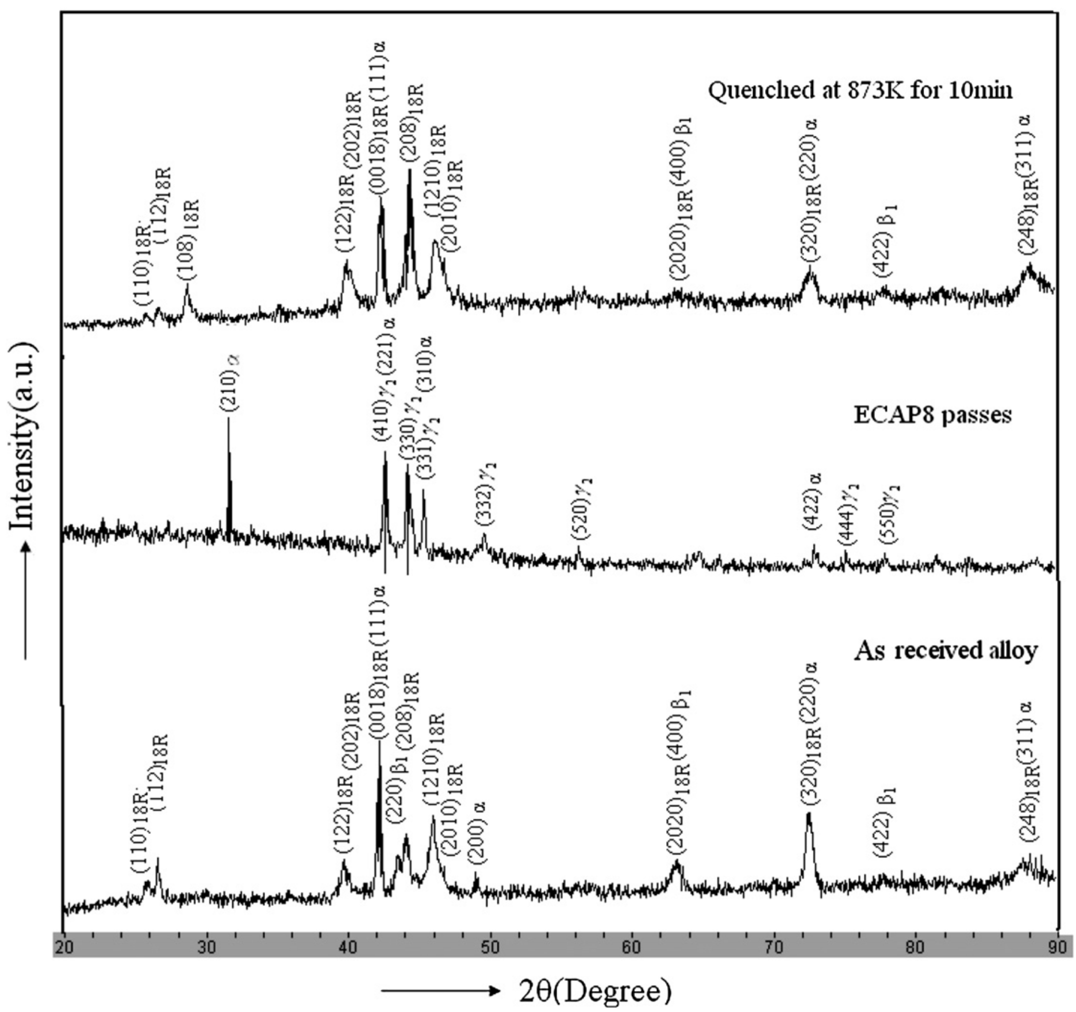

Fig. 2. XRD patterns of the Cu–Al–Be–B alloy in obvious states.