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Effect of precipitation during parent phase aging on the microstructure and properties of a refined CuAlMn shape memory alloy

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ABSTRACT

Effect of precipitation during parent phase aging on the microstructure and properties of a CuAlMn shape memory alloy (SMA) refined by CuZr inoculant was investigated by means of scanning electron microscopy (SEM), X-ray diffraction (XRD), differential scanning calorimetry (DSC), Vickers hardness tester (VHT) and dynamic mechanical analyzer (DMA). It was found that after aging in parent phase at relatively low temperatures, such as 500 °C, the precipitation of α phase and γ_2 phase in the CuAlMn SMA was uncontrollable because it was highly sensitive to aging time. While the aging in the temperature range of 530–620 °C could give rise to controllable precipitation, and by optimizing the microstructures in this way, the hardness and damping of the CuAlMn SMA could be significantly improved. Therefore, proper aging treatment is a convenient and feasible method to control the microstructure and properties of the Cu-based SMAs.

1. Introduction

Cu-based shape memory alloys (SMAs) have broad application prospects in the fields of automobile, navigation, aviation and sensor because of their excellent properties [1,2]. However, these alloys are still suffering from their intergranular brittle fracture, short fatigue life and unsatisfactory mechanical strength due to their very coarse grains [3,4]. In order to solve these problems, in our previous work a CuAlMn SMA refined by a novel inoculant was successfully fabricated [5]. It was found that with the decrease of average grain size, both the mechanical properties and the damping capacity of the CuAlMn SMA were significantly improved, which is of great significance for further widening the application scope of Cu-based SMAs.

It is well known that in addition to grain refinement, heat treatments can also remarkably influence the microstructure and properties of Cu-based SMAs [6,7]. Especially aging, as the last step of heat treatment following quenching, usually directly determines the final properties of Cu-based SMAs [8,9]. In order to get a Cu-based SMA with excellent comprehensive properties, it is very necessary for us to further study the aging treatment of the refined CuAlMn SMA on the basis of previous work. According to the literature, aging treatment of Cu-based SMAs has been extensively studied [10–12]. However, in the past, aging is mainly used to eliminate quenching stress and quenched-in vacancies with the aim of reducing the tendency of martensite stabilization and improving the order degree of parent phase [11,13,14]. In this paper, the previous research methods will no longer be adopted, and the precipitation during aging in parent phase will be used to affect the microstructure and properties. It is expected the present study can give clear physical images of mechanical and damping behaviors and correlated mechanisms of the aged CuAlMn SMA with refined grains, and find reasonable processing technology and applications.

2. Experimental

The alloy investigated has a composition of Cu-11.85Al-2.47Mn (wt %), and was prepared from high purity elements (purity = 99.9 wt%) in an intermediate frequency induction electric furnace. When the temperature of the CuAlMn melt reached 1100 °C, 1.0 wt% CuZr inoculant (preparation details of the CuZr inoculant can be referred to our previous work [5]) was added, and after efficient stirring, the CuAlMn melt was poured into a steel mould with a diameter of 20 mm and a height of 130 mm. Subsequently, the as-cast CuAlMn SMA was heated to 900 °C in a tube furnace under the protection of argon gas, and then quenched into water after holding at that temperature for 600 s [15,16]. After that, the resultant CuAlMn SMA was subjected to aging treatment within the temperature range of 500–620 °C for different time.

The samples used for microscopic observation were grinded with

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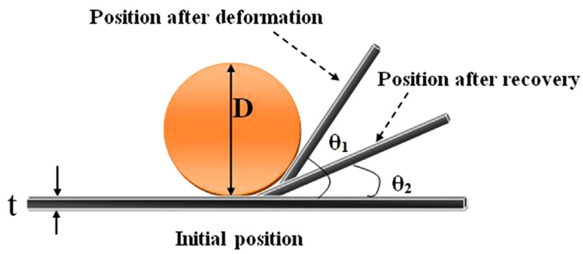

Fig. 1. Arrangement for the measurement of SME.

240 up to 2000 grit emery papers, and then polished with diamond paste and etched with corrosion solution (5 g $FeCl_3$ + 10 ml HCl + 100 ml H_2O). A Hitachi S-4800 SEM equipped with an energy dispersive spectrometer (EDS) was employed to characterize the microstructure. The martensitic transformation (MT) temperatures were measured using a TA Q20 DSC with a temperature changing rate of 10 °C/min. Phase identification was carried out by a Bruker D8 DISCOVER XRD with Cu Kα radiation. The measurement of micro-hardness was performed on a HMV-2T VHT, and the load and loading time were 200 g and 15 s respectively. Internal friction (IF), Q^{-1}, was used to characterize the damping property of the samples, and it was measured using the method of forced vibration on a TA Q800 DMA.

The shape memory effect (SEM) was measured through a bending method [17], and its principle is shown in Fig. 1. Before the measurement, the samples were cut to a strip with the dimension of $50 \times 2 \times 0.85/1.28\ mm^3$. The strip was then bent to 90° at room temperature around a cylindrical mould with a diameter of 20 mm. After unloading the strip spring-back to θ_1. Subsequently, the bent strip was annealed at 450 °C for 600 s, and then the angle θ_2 was measured. The shape recovery ratio η and the pre-strain ε were calculated by using the following two formulas:

$$\eta = (\theta_1 - \theta_2)/\theta_1 \times 100\% \quad (1)$$

$$\varepsilon = t/(t + D) \times 100\% \quad (2)$$

where t is the sample thickness, and D stands for the diameter of the cylindrical mould.

3. Results and discussion

Fig. 2 shows the SEM images of the aged CuAlMn SMAs refined by 1.0 wt% CuZr inoculant. It is apparent that after aging at 500 °C for

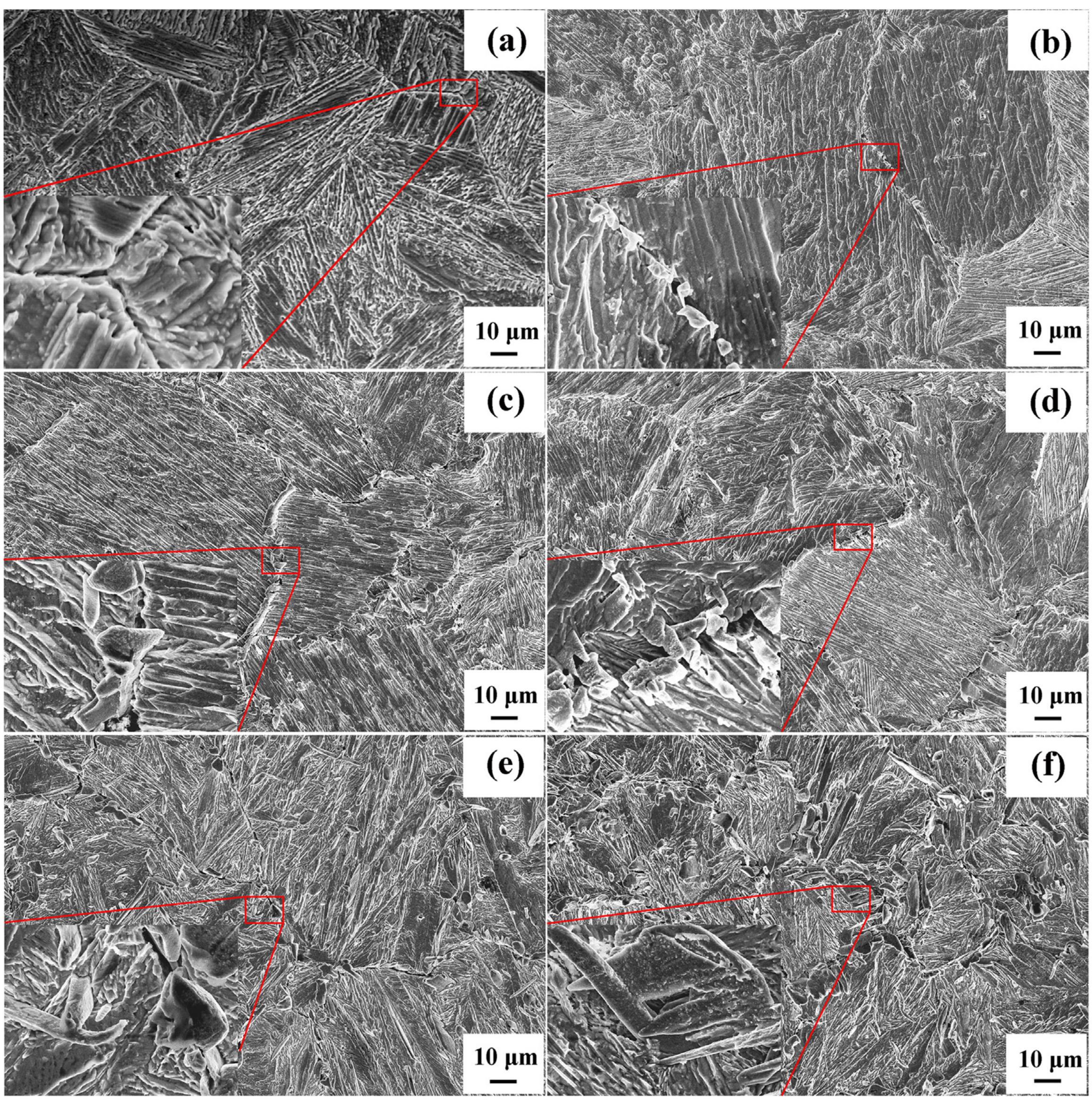

Fig. 2. SEM images of the CuAlMn SMA aged at 500 °C for different time (min): (a) 0; (b) 15; (c) 30; (d) 45; (e) 75 and (f) 105.