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Two-way shape memory effect of Cu-Zn-Al alloys induced by a constrained heating method

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Two-way shape memory effect (TWSME) is a phenomenon that a material can alternate between two distinct shapes as it undergoes a thermal cycle. The TWSME is not an intrinsic property of shape memory alloy but can be obtained by several training methods, most of which are based on the thermomechanical cycling [1, 2]. Although there have been some reports on the realization and improvements of TWSME in Cu-Zn-Al alloys using the thermomechanical cycling [3, 4], there are few reports of the induction of the TWSME without employing the repetitive cycling method.

In this study, we have used a simple constrained heating technique to realize the TWSME and have investigated the effect of heating time and temperature. An alloy of 65.6Cu-33.1Zn-1.3Al (wt%) was prepared by an induction furnace and subsequently forged and hot-rolled. Finally, rectangular specimens with dimensions of 170 mm × 12 mm × 2.2 mm were machined from an ingot. The specimens were then betatized at 800 °C for 30 min, and quenched into water at 25 °C. The transformation temperatures were calculated by measuring the electrical resistance of the sample, indicating that $M_s = -70\,^\circ\mathrm{C}$, $M_f = -100\,^\circ\mathrm{C}$, $A_s = -48\,^\circ\mathrm{C}$, and $A_f = -20\,^\circ\mathrm{C}$ (M_s = start of the martensitic transformation, M_f = end of the martensitic transformation, A_s = start of the austenitic transformation, and A_f = end of the austenitic transformation).

The specimens were subjected to the constrained heating to obtain the TWSME. The specimens were bent around a cylinder mold of 50 mm diameter in liquid nitrogen, and subsequently thermally heated in the temperature range of 40–220 °C, in the constrained state. The amount of TWSME was assessed by cycling the samples in the unconstrained state between the temperature below M_f and above A_f. Measurements were carried out in the manner indicated in Fig. 1, in which the distances AB, CD, EF, GH were measured at both ends of the sample. AB represented the distance in the cold state after the constrained heating treatment, CD the distance in its hot state after the treatment, EF the length of sample and GH the deformation imposed during the treatment. In this work, the TWSME was assessed using the following relation:

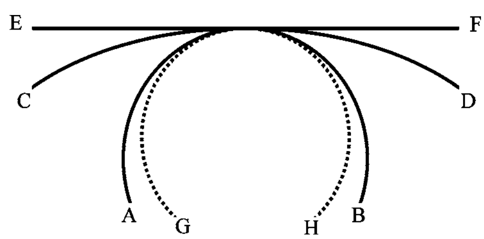

Figure 1 Schematic representation of the shape of sample. AB: cold shape after the constrained heating; CD: hot shape after the constrained heating; EF: original shape; GH: deformation imposed during the constrained heating.

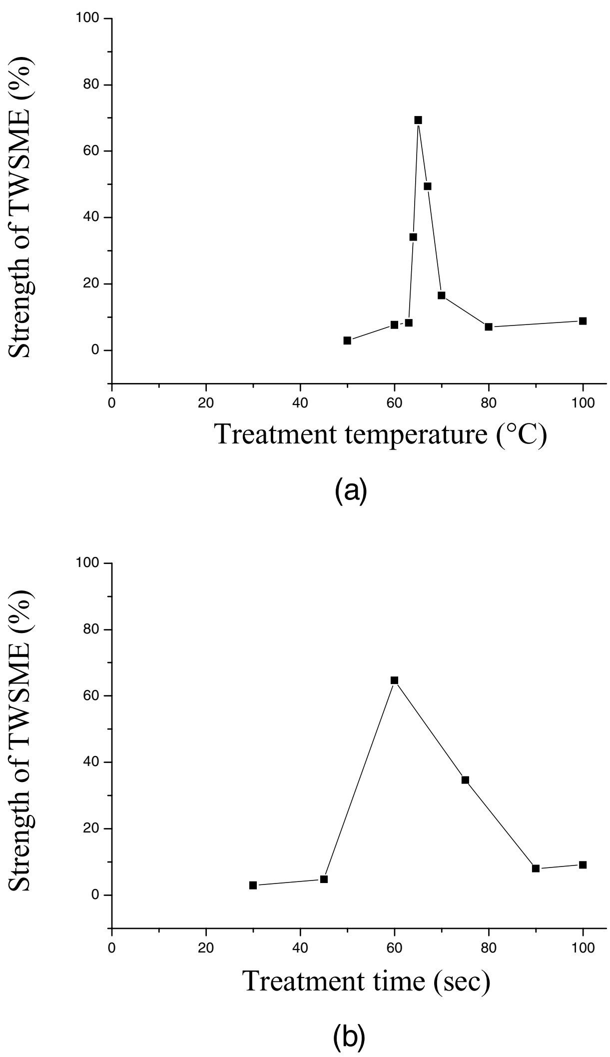

Figure 2 (a) Variation of the strength of TWSME with varying the constrained heating temperature at a time of 60 s. (b) Variation of the strength of TWSME with varying the constrained heating time at a temperature of 65 °C.

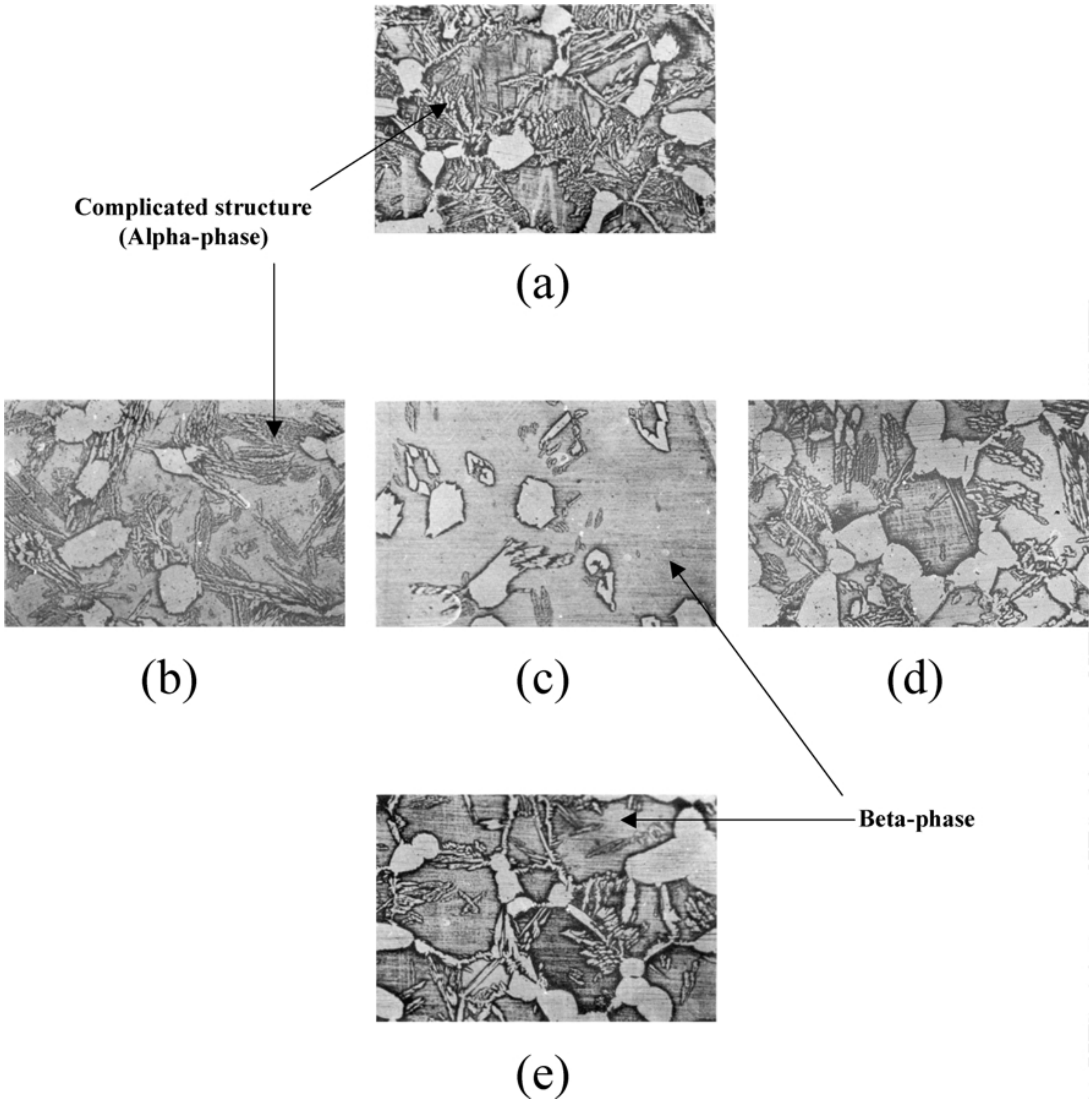

Figure 3 Optical microscope images showing the structure of constrained heated sample: (a) at 65 °C for 45 s, (b) at 63 °C for 60 s, (c) at 65 °C for 60 s, (d) at 70 °C for 60 s, and (e) at 65 °C for 100 s.

Strength of TWSME = 2(CD − AB)/EF × 100(%). The structural characteristics of the films were analyzed by X-ray diffraction (XRD) using Cu Ka1 radiation (λ = 0.154056 nm) and by optical microscopy (OM) (Nikon FX-35). The etchant for the OM sample preparation was composed of water, hydrochloric acid (HCl), and $FeCl_3$. The transmission electron microscopy (Jeol 200 CX) was used to determine the phase of the microstructure.

Fig. 2a shows the variation of the strength of TWSME with varying the constrained heating temperature for 60 s. It is revealed that the strength of TWSME is higher than 30% in the temperature range of 64–67 °C. Fig. 2b shows the variation of the strength of TWSME with varying the constrained heating time at a temperature of 65 °C, indicating that strength of TWSME is higher than 30% in the range of 60–75 s. It is surmised that the treatment time and temperature of the constrained heating play a crucial role in strengthen the TWSME of Cu-Zn-Al alloys.

The influence of the constrained heating temperature and time on the microstructure in our Cu-Zn-Al alloy has been investigated. The XRD analysis indicates that samples are composed of α/β microstructure regardless of the time and temperature of the constrained heating temperature (not shown here). Fig. 3 shows the OM images of constrained heated structure at various temperature and times, indicating that the decrease of the TWSME is related to the increase of the complicated structure (by comparing with Fig. 2). TEM analysis indicates that the complicated structure is indexed to an α-phase, while the residual structure is indexed to a β-phase (not shown here). Further systematic study is necessary to disclose the detailed mechanism of TWMSE in Cu-Zn-Al alloys by investigating the role of α and β phases.

In summary, the induction of TWSME in Cu-Zn-Al alloy by a simple constrained heating method has been realized without employing the repetitive cycling. The importance of time and temperature effects in the constrained heating on the strength of TWSME has been demonstrated. The constrained heated alloy which has a greater amount of β-phase and thus a less amount of α-phase showed a stronger TWSME.

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References

1. M. A. MORRIS, *Acta Metall. Mater.* **40** (1992) 1573.
2. R. STALSMAN, V. HUMBEECK and J. DELAEY, *Mater. Trans. JIM* **33** (1992) 289.
3. J. PONS, M. MASSE and R. PORTIER, *Mater. Sci. Eng.* A **273–275** (1999) 601.
4. J. CEDERSTROM, V. KOLOMYTSEV, A. KOZLOV, P. TITOV, G. ZATULSKII and S. KONDRATJUK, *ibid.* **273–275** (1999) 804.

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