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Effect of Zr addition on the microstructure, phase transformation and mechanical property of $Ni_{50}Mn_{25}Ga_{17}Cu_8$ alloy

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ABSTRACT

This study investigated the microstructure, phase transformation and mechanical property of $Ni_{50}Mn_{25}Ga_{17}Cu_{8-x}Zr_x$ (x=0, 4 and 8) alloys. The microstructure of alloys changed from a single martensitic phase to a dual phase consisting of martensitic/austenitic matrix and second γ phase after substituting Cu with Zr and the volume fraction of second phase increased with increasing Zr content. The martensitic transformation temperature and transformation enthalpy were reduced after adding Zr, which was related to the introduction of second phase that changed the composition and reduced volume fraction participating in martensitic transformation of the alloy. The decrease of transformation hysteresis after introducing the second phase was thought to be caused by the martenstic structure change of the matrix from tetragonal to orthorhombic that reduced the lattice deformation of austenite→martensite transformation. The mechanical strength of the Cu8 alloy was increased firstly after substituting 4 at% Cu by Zr and then decreased after completely substituting Cu by Zr. The change of mechanical performance was related to the fracture character of the alloys. The intergranular fracture of matrix and second phase dominated in the Cu8 and Zr8 alloys, respectively, but the fracture of Cu4Zr4 alloy was determined by a mixture of intergranular fracture of second phase and transgranular fracture of matrix.

1. Introduction

The Ni–Ti based shape memory alloys (SMAs) have been widely investigated due to their good pseudoelasticity and shape memory effect, which are based on the thermoelastic martensitic transformation [1]. For applications as coupling or sealing elements, the SMAs are required to exhibit a wide transformation hysteresis to ensure the effectiveness of the elements in a wide temperature range. Ti–Ni–Nb is a typical SMA with wide hysteresis [2,3], in which the second β-Nb phase was thought to be the main factor to increase the transformation hysteresis by hindering the recovery of austenite transformation or relaxing the elastic energy stored by martensitic transformation [3].

Ni–Mn–Ga based ferromagnetic SMAs have also drawn much attention due to their high response frequency and large magnetic-field induced strain (MFIS) [4]. Unfortunately, the most reported transformation hysteresis of these alloys is commonly small (< 20 °C) [5,6]. It has been reported that the introduction of a second γ phase in the Ni–Mn–Ga alloy is helpful to increase the transformation hysteresis [7]. Recently, Jiang et al. [8,9] reported that a Cu doped Ni–Mn–Ga ($Ni_{50}Mn_{25}Ga_{17}Cu_8$) alloy with a single phase has been found to exhibit a wide transformation hysteresis (> 40 °C). In our recent studies, it was found that the substitution of Cu with Zr in the $Ni_{46}Mn_{33}Ga_{17}Cu_4$ alloy is effective to introduce a Zr-rich second γ phase in the alloy [10] and meanwhile the mechanical strength of the alloy was apparently improved [11]. However, it remains unknown how the transformation hysteresis and mechanical property of $Ni_{50}Mn_{25}Ga_{17}Cu_8$ alloy change by introducing second phase through replacing Cu with Zr. Therefore, in this article, Zr was added to substitute Cu in the $Ni_{50}Mn_{25}Ga_{17}Cu_8$ alloy and the microstructure, phase transformation and mechanical property of the alloys were systematically investigated.

2. Experimental procedures

The polycrystalline ingots with nominal compositions of $Ni_{50}Mn_{25}Ga_{17}Cu_{8-x}Zr_x$ (x=0, 4 and 8) were prepared by arc-melting high purity elements of Ni, Mn, Ga, Cu and Zr under argon atmosphere. The as-cast ingots were sealed in vacuum quartz tubes and annealed at 900 °C for 12 h followed by quenching into water for homogeneity. For simplicity in description, the

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alloys for $x=0$, 4, and 8 were represented by Cu8, Cu4Zr4 and Zr8, respectively. The microstructure was observed using an Olympus-311U optical microscope and a FEI Quanta200 scanning electron microscope (SEM) equipped with energy dispersive spectrometry (EDS) analyzer. The phase identification was carried out at room temperature using a Panalytical X-pert PRO diffractometer with Cu Kα radiation. Phase transformation behavior of the samples was measured using a Perkin-Elmer Diamond differential scanning calorimeter (DSC) with a heating/cooling rate of 20 °C/min. The compression tests with a deformation velocity of 0.5 mm/min were carried out at room temperature using an Instron universal testing machine (Model 3365).

3. Results and discussion

The Cu8 alloy exhibits a single martensite with different oriented lath substructures and the grain size is determined to be of 300–600 μm, as shown in Fig. 1(a) and (b). After substituting 4 at% Cu with Zr, the microstructure of alloy changed from a single martensite to a dual phase (Fig. 1(c)). The second phase exhibiting fish bone like-shape is widely distributed in the matrix. Fig. 1(d) with high magnification shows that some martensite laths can be observed in the matrix, as indicated by the arrows and dashed line. For the Zr8 alloy, the second phases have grown to dendrite shape and occupied the most part of the alloy, as shown in Fig. 1(e). After

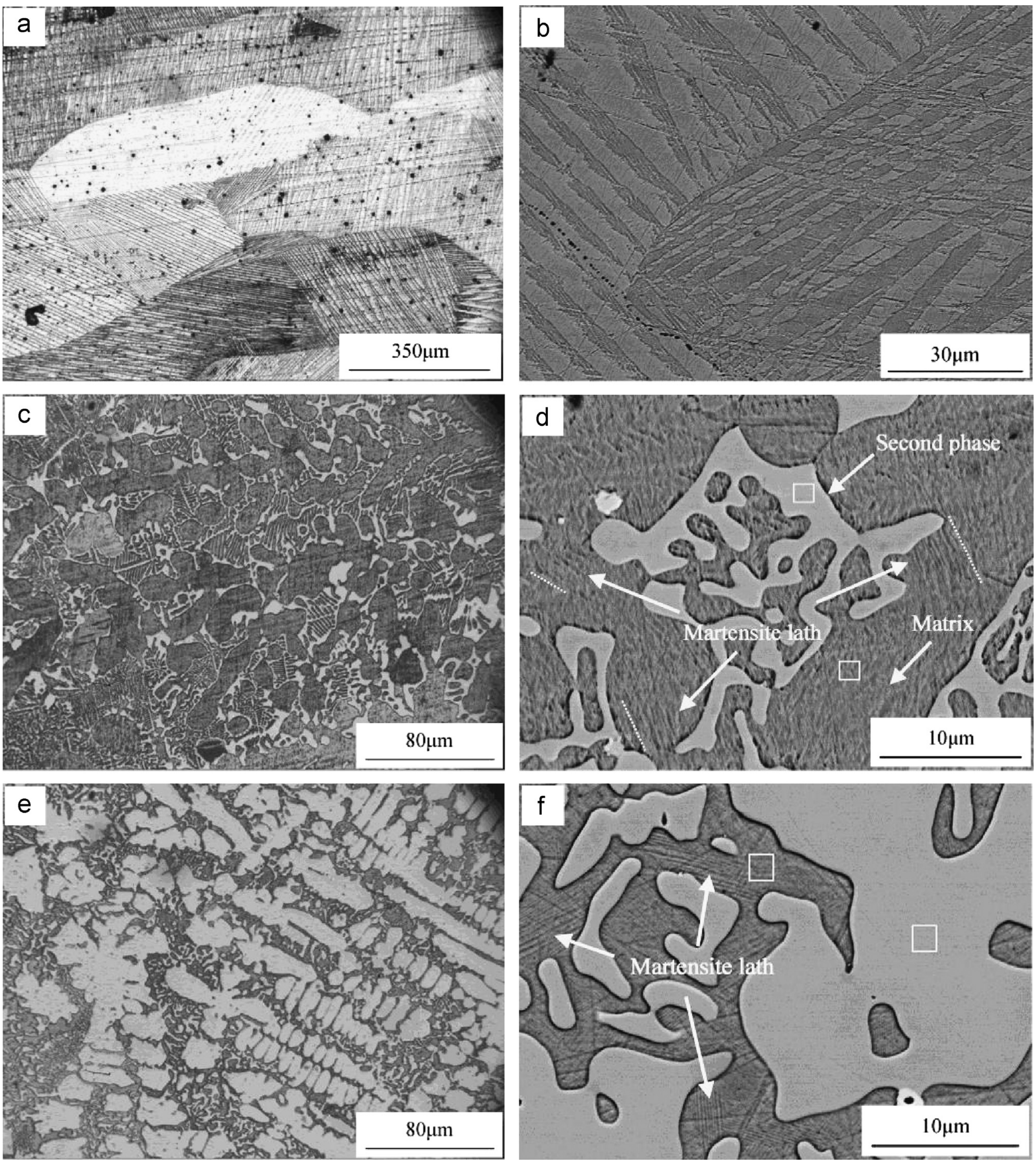

Fig. 1. The optical photos of (a) Cu8, (c) Cu4Zr4 and (e) Zr8 alloys, and SEM images of (b) Cu8, (d) Cu4Zr4 and (f) Zr8 alloys.