Mechanical Properties and Fracture Analysis of Mn-rich Ni-Mn-Ga Polycrystalline Alloys

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Abstract. In present paper, the mechanical properties and fracture graphs of Mn-rich polycrystalline alloys are investigated by compression tests and scanning electron microscope (SEM) observations. It is shown that the fracture strength and the rupture strain decrease with the increase of Mn content. It is suggested that the substitution of Mn for Ga reduces the ductility of Ni-Mn-Ga alloys. SEM observations of fracture surface show us typical intergranular crack. There are many little holes and micro-cracks on the grain boundary, which weakens the bond strength of grain boundary causing the intercrystalline cracking.

Introduction

In recent years, as a candidate actuator material, Ni-Mn-Ga ferromagnetic shape memory alloys (FSMAs) have been widely studied for its large magnetic field induced strain (MFIS) and high response speed [1, 2]. Nearly 10% MFIS has been obtained in a Ni-Mn-Ga single crystal with [100] direction [3]. Such a MFIS is about 50 times larger than magnetostrictive materials such as Terfenol-D. The exact mechanism of magnetic field induced deformation in Ni-Mn-Ga alloy is discussed in many reports. It is believed that the reorientation of twin variant in martensite state driven by external field caused the MFIS [4,5]. Only in single crystal should relatively large MFIS be obtained while polycrystalline is more suitable for practical application. However the serious brittleness of polycrystalline Ni-Mn-Ga alloy limits its uses. The fracture mechanism of polycrystalline alloy is seldom reported. The aim of this paper is to find out the effect of Mn content on mechanical properties of this alloy and investigate the fracture mechanism of Ni-Mn-Ga polycrystalline alloy.

Experimental

A range of alloys with the nominal composition of Ni₅₀Mn₂₆₊ₓGa₂₄₋ₓ (at%) (x= 0,2,4) weighing about 80g were prepared. The alloys were firstly fabricated by arc melting and remelted four times for homogeneity under an argon atmosphere. At last the melted alloy was cast into a chilled copper mold to obtain a master rod with the dimensions of 7 mm in diameter and 70 mm in length. The master rod was sealed in a quartz tube under a vacuum, followed by annealing at 1073 K for 24 h
and quenched into ice water for homogeneity. Then the experimental samples were taken from this ingot by spark cutting.

Compression experiments were performed on Instron-1168 stretcher with a strain rate of 0.1mm/min. The mechanical tests were conducted at room temperature (T=293K) in laboratory air condition. The compression samples were 6mm in length and 4mm in diameter and wet polished before the experiments. Hitachi S-4700 SEM was used to examine the fracture surface in order to analysis the fracture mechanism.

Results and Discussion

Mechanical properties. Figure 1 shows compressive stress-strain curves of Ni_{50}Mn_{26+x}Ga_{24-x} (x=0,2,4) polycrystalline alloys at room temperature. For Ni_{50}Mn_{26}Ga_{24} alloy, during compression the stress-strain curve shows three stages: elastic deformation when the stress is lower than 260MPa, yield deformation though it is obscure and plastic deformation until the fracture. Ni_{50}Mn_{28}Ga_{22} and Ni_{50}Mn_{30}Ga_{20} alloys also exhibit the same compression procedure as Ni_{50}Mn_{26}Ga_{24} alloy. It should be noted that stress-induced martensitic transformation and stress-induced reorientation of martensite variants take place when Ni_{50}Mn_{28}Ga_{22} and Ni_{50}Mn_{30}Ga_{20} alloys are compressed. The main parameters of compression deformation according to Fig.1(a) are summarized in Fig.1(b). It can be seen that with the increase of Mn content, fracture strength(σ_f), yield stress(σ_y) or reorientation stress(σ_r) and the rupture strain(ε_r) decrease. It indicates that the increase of Mn content in Ni-Mn-Ga polycrystalline alloys reduces the ductility. Besides, it shows that the strength of martensite phase is lower than that of parent phase in NiMnGa polycrystalline alloy.

Fracture surface analysis. To explain the micro-mechanism of the brittleness of NiMnGa polycrystalline alloys, the fracture surface of Ni_{50}Mn_{26+x}Ga_{24-x} (x=0,2,4) samples are examined by SEM. Fig.2 shows the fractographs of Ni_{50}Mn_{26}Ga_{24} alloy. On the fracture surface obvious grains can be observed indicating the sample undergoes a typical intergranular cracking. Furthermore, the river marking which is the characterization of cleavage fracture is also observed, as shown in Fig.2(b). In some areas, there are some impurities and holes indicated by the arrows. Fig.3 displays the SEM images of fracture surface of Ni_{50}Mn_{28}Ga_{22} alloy. The images show that the intergranular cracking is the main fracture mechanism and cleavage fracture is found in some regions. Besides
the holes shown in Fig.3(b), a lot of needle-like micro-cracks exist on the grain boundary. These cracks lower the bond strength of grain boundary resulting in the reduction of the strength. The fractographs of Ni$_{50}$Mn$_{30}$Ga$_{20}$ alloy shown in Fig.4 supply us the same fracture information as Ni$_{50}$Mn$_{28}$Ga$_{22}$ alloy.

As mentioned above, all these three samples undergo typical intergranular cracking. It suggests that the bond strength of grain boundary is very small for NiMnGa polycrystalline alloys, which leads to the serious brittleness of NiMnGa alloys. For Ni$_{50}$Mn$_{28}$Ga$_{22}$ and Ni$_{50}$Mn$_{30}$Ga$_{20}$ alloy, a large amount of micro-cracks damage the grain boundary, which causes the reduction of ductility resulting from the substitution of Mn for Ga in NiMnGa alloys.

Fig.2 SEM fractographs of Ni$_{50}$Mn$_{26}$Ga$_{24}$ sample: (a) fracture surface showing a mixture of intergranular and transgranular fracture; (b) the magnification of region A in (a); (c) the magnification of region B in (a)

Fig.3 SEM fractographs of Ni$_{50}$Mn$_{28}$Ga$_{22}$ sample: (a) fracture surface showing a mixture of intergranular and transgranular fracture; (b) the magnification of region A in (a); (c) the magnification of rectangular region in (b); (d) the magnification of region B in (a)
Conclusions

The fracture strength and the rupture strain decrease with increasing Mn content, which suggests that the addition of Mn reduces the ductility.

The typical intergranular crack is found on the fracture surface of Mn-rich polycrystalline alloy. Besides the impurities and holes, a lot of needle like micro-cracks distribute on the grain boundary, which weakens the bond strength of grains resulting in the reduction of ductility by increasing Mn content.

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References