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Typed-new multifunctional Mn-rich antiferromagnetic alloys

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Abstract

The lattice distortion of crystal structure can be formed and following fct martensitic transformation is induced with antiferromagnetic transition in Mn-rich antiferromagnetic alloys. The twin boundaries formed with fct martensitic transformation or tiny twin (antiferromagnetic domain boundaries) with antiferromagnetic transition have mobility and high damping property can be obtained under an alternate stress. With the help of the coupling between the second order antiferromagnetic transition and the first order martensitic transformation, the hysteresis between martensitic transformation and reversible one is decreased or even is disappeared, the martensitic transformation temperature, M_s, and its reversible transformation temperature, A_s, move closer to antiferromagnetic transition point, T_n, the shape memory effect formed by martensitic transformation and its reversible one may be related with a simplex temperature function and a non-hysteresis on temperature can be formed. Because the tiny twin boundaries and the fct twin boundaries have movability under applied magnetic field, the magneto-driven strain and magneto-controlled shape memory effect may be shown. Now the new-typed multifunctional antiferromagnetic materials are being researched and developed in theoretically and practically.

Keywords: Antiferromagnetic materials; Transformation coupling; Multifunction; High damping; Non-hysteresis shape memory effect; Magnetic-controlled shape memory effect

1. Introduction

Since antiferromagnetism of Pt, Pa, Mn, Cr, etc., materials was discovered by Neel in 1932, up to now the antiferromagnetic structure and mechanism have been carried on. But a lot of research was focused on its magnetic structure and magnetic properties, practical application of antiferromagnetic materials is very limited in material field compared with paramagnetic and magnetic materials which were widely developed for example soft magnetic alloys (low carbon steel, Ni–Fe, Fe–Co, Fe–Al, Fe–Si–Al, silicon steel sheets, etc.) and hard magnetic alloys (Fe–Co–Mo, Fe–Co–W, Fe–Ni–Al, Fe–Ni–Al–Co, Alnico, Fe–Co–Cr, rare earth-cobalt, NbFeB, etc.). So it is considered that functional properties and practical application for antiferromagnetic materials are a new field which is not known and opened out. Now it is shown that antiferromagnetic materials have multifunctional characteristics which is high damping, no hysteresis temperature shape memory effect and magneto-controlled shape memory effect, it would become a potentially typed-new multifunctional material.

In 1948, a high damping property of Mn–12(wt.%)Cu alloy with fct martensitic (0 1 1) twin was discovered by Zener [1], the alloy takes on both antiferromagnetic transition and martensitic transformation, its high damping properties deal with stress-induced twin boundaries movement. The high damping alloys were practically produced and applied, the research on Mn–Cu damping mechanism was carried on up to now. Now high damping in rich-Mn based-Mn alloys has been investigated in Mn–Ni [2] and Mn–Fe [3] alloy series in order to obtain typed-new no magnetic high damping materials.

The shape memory materials are a new kind of functional materials in the 70's of the 20 century. Now NiTi, Cu-based alloys and Fe-based materials were successfully obtained in practical field, but thermo-hysteresis of direct

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and inverse martensitic transformation and stability, which are important keys for a high sensitive drived component, are not finally overcame. Nosova and Vintaikin [4] reported a two-way shape memory effect with a very small hysteresis in antiferromagnetic γ-Mn-based alloys. The hysteresis of the change is very little, i.e., less than 1 °C [5]. That provided a new way for temperature-controlled shape memory alloy.

Since a 0.2% magnetic-field-induced strain (MFIS) in a single crystal of Ni_2MnGa was first by Ullakko et al., in 1966 [6], the investigation on magnetic shape memory (MSM) alloys has attracted substantial interest recently. There are a number of alloys that exhibit magnetic shape memory effect (MSME), including Fe–Pd, Fe–Pt, Fe–Ni, Fe–Co–Ni–Ti, Co–Ni, etc. But all of some materials are exclusively ferromagnetic. However, the magnetically driven strain in antiferromagnetic materials has not been paid any attention to, although the magnetically induced transition of antiferromagnetic materials was reported in 1995 [7], and Lavrov et al. [8]. Have also observed the movement of twin boundaries in LSCO high-temperature superconductor under a strong applied field of 14 T in 2002. Recently magnetic-induced strain in Mn-rich γMn-based alloys was reported and that could be to develop out a typed-new antiferromagnetic shape memory materials.

The γ Mn–Cu, γ Mn–Ni and γ Mn–Fe alloy show a second order antiferromagnetic transition from paramagnetism to antiferromagnetism at T_n, Neel point and a following first order martensitic transformation from face-centred cubic lattice (fcc) to face-centred tetragonal one (fct) at M_s, T_n and M_s decrease with the decrease of Mn content. T_n point and M_s temperature is dependent on the composition of alloys for Mn–Cu [9], Mn–Ni [10] and Mn–Fe [11] alloys. The T_n point and M_s temperature are closed each other in some rich-Mn Mn–Cu, Mn–Ni and MnFe alloys and cannot be distinguished.

In generally, the magnetic structure in the some alloys have spin direction along [0 0 1], [1 1 0] and [1 1 1]. The first two have tetragonal symmetry and the last has cubic symmetry [12]. The magnetic structure along [0 0 1] is called collinear spin structure or single-Q form and [1 1 1] is non-collinear spin structure or triple-Q. The collinear spin structure results in lattice distortion.

The (0 1 1) twin is formed by fct martensitic transformation after antiferromagnetic transition with [0 0 1] spin structure and it is considered that martensitic twin boundary is consistent with antiferromagnetic domain boundary in Mn-rich γMn-based alloys. Previously the investigation on γMn-based alloys was focused on the physical characteristics and properties of antiferromagnetism, however the practical application of antiferromagnetic materials and the coupling between antiferromagnetic transition and martensitic transformation have not been paid an attention to. The mobility of the twin boundaries and the antiferromagnetic domain boundaries under applied stress or magnet field results in multifunction of Mn-rich γMn-based alloys which is developed and researched recently.

2. Twin-typed high damping

Though high damping Mn–Cu alloys were commercially used, but it has been investigated about the decomposition of the γ phase [13,14], the martensitic transformation [15], the thermodynamic criterion of spinodal decomposition [16] for further improving its damping property and clarifying damping mechanism up to now. Recently the investigation of high damping properties in other Mn-rich Mn-based alloys has been developed [17]. The high damping in Mn–Fe [18] and Mn–Ni [19] alloys are researched, as shown in Figs. 1 and 2. It is shown that there is fct twin-typed high

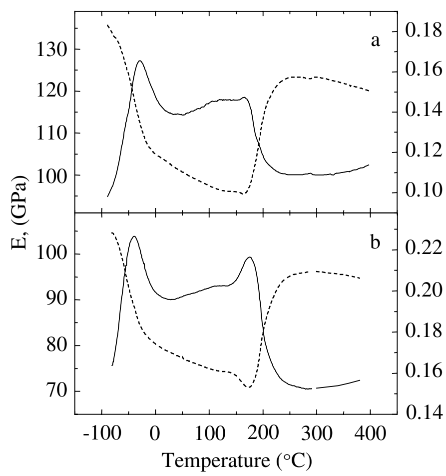

Fig. 1. The damping in (a) $Mn_{85.5}Fe_{9.5}Cu_5$ and (b) $Mn_{80.8}Fe_{14.8}Cu_{4.4}$ alloys.

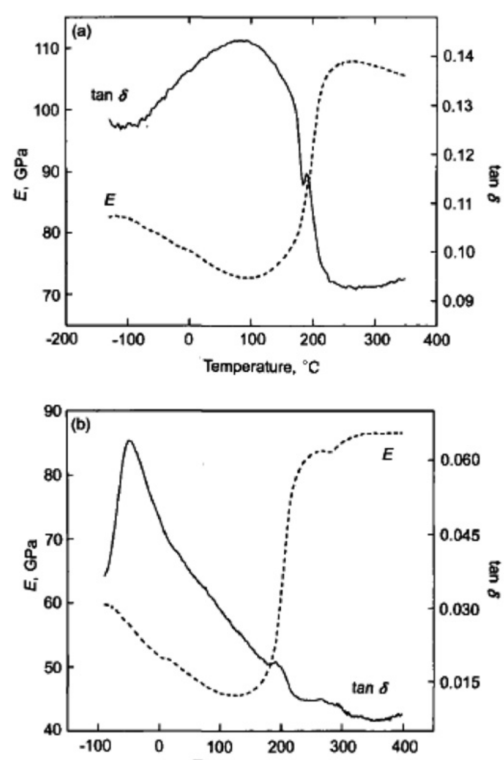

Fig. 2. The damping in: (a) $Mn_{82.2}Ni_{17.8}$ and (b) $Mn_{81.6}Ni_{18.4}$ alloys.