Advances in Mechanics and Materials
Eds. Amar N Nayak and Ajaya K Nayak

Analysis of Martensitic Transformation in Ni-Mn-Sn FSMA

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Abstracts

Ferromagnetic shape memory alloys (FSMA) are a new class of potential multifunctional materials with advancement over the conventional heat-driven shape memory alloys due to their exceptional properties. FSMAs can be controlled by magnetic field have attracted considerable attention as a type of magnetic actuator materials. Among the Heusler alloys that exhibit magnetic shape memory effect, the most extensively studied are those of the Ni-Mn-Ga system. However, to overcome some of the problems related to practical application, such as the high cost of gallium and the low martensitic transformation temperature that they usually present, the search for Ga-free alloys has been recently attempted. This paper aims to represent the behavior of Ga free Ni-Mn-Sn Heusler FSMA by varying the weight percentage of Sn. Three alloys i.e. $Mn_{50}Ni_{50-x}Sn_x$ (x = 5, 7.5, and 10) were produced as bulk polycrystalline ingots by arc melting. The structural austenite-martensite transformation was checked by Differential Scaning calorimetry (DSC). It is found that, the transformation temperatures gradually decrease as increasing the Sn content. Multiple martensitic transformations, such as two- or three-step martensitic transformations, occur in all these alloy systems. Microstructure and elemental composition of prepared specimen were examined by using a Scanning Electron Microscope (SEM) equipped with a microanalysis system. Therefore, the present Ga-free Ni-Mn-Sn Heusler FSMAs have the great possibility to use in high temperature application and can present a large magnetic-field-induced strain.

Key words: Ferromagnetic Shape Memory Alloys (FSMAs); Ni-Mn-Sn; martensitic transformation.

1. Introduction

Ferromagnetic shape memory alloys (FSMA) are of considerable interest because of their exceptional magnetoelastic properties [1-3]. The shape memory effect (SME) can not only be controlled by changing the temperature, as it occurs in traditional shape memory alloys, but also by varying the magnetic field up to moderate field values. The latter makes them of note worthy interest for developing new thermal or magnetically driven actuators [4]. Among the FSMAs, the most extensively studied are the Heusler alloys, defined as magnetic ternary intermetallic systems with L_21 or B_2 crystal structure. Their generic formula is X_2YZ. Where, X is usually a transition metal 3d (Fe, Co, Ni, Cu, Zn), 4d (Ru, Rh, Pd, Ag, Cd), or 5d (Ir, Pt, Au). The position of Y is usually occupied by 3d (Ti, V, Cr, Mn), 4d (Y, Zr, Nb), 5d (Hf, Ta) or by lanthanides (Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) or actinides (U). The Z is a group-B element: III-B (Al, Ga, In, Tl), IV-B (Si, Ge, Sn, Pb) or V-B (As, Sb, Bi) [5]. The extensively studied of Ni–Mn–Sn Heusler alloys due to its low cost of constituting element which leads economical processing. Various property of Ni–Mn–Sn was studied by many researchers [6-9]. martensitic transformation in these alloy is a diffusionless first-order solid-solid phase transformation from the high-temperature austenite to low-temperature martensite phase by releasing total stress in it (shown in figure-1), which proceeds by the small cooperative movement of the Atoms [10]. By lowering the temperature a cubic high temperature parent austenite phase transforms into a tetragonal, orthorhombic or monoclinic martensite phase. The transformation temperatures of shape memory alloys strongly depend on the composition and their values spread in a very wide range [11].

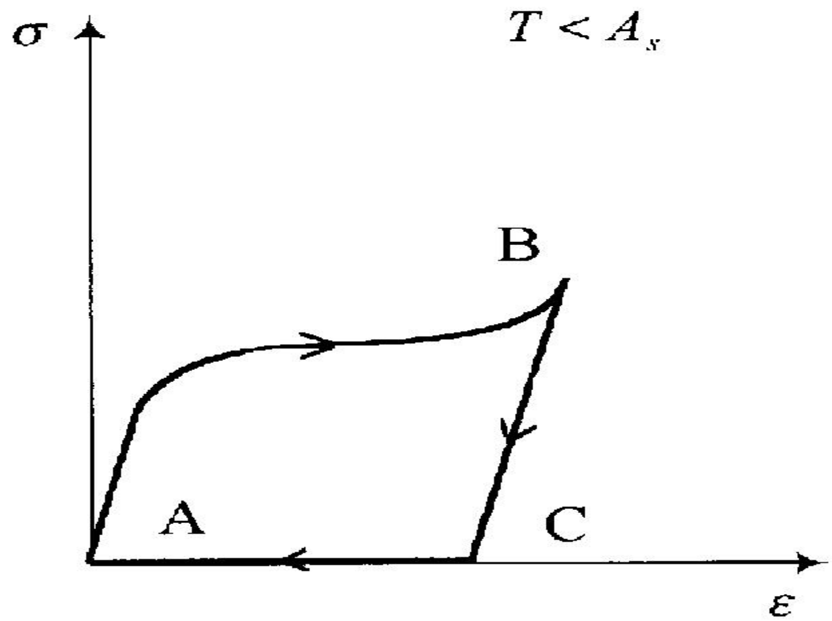

Fig: 1 represent stress (σ) Vs strain (ε) graph showing shape recovery during transformation from austenite to martensite.

2. Experimental Procedure

Three ternary intermetallic polycrystalline compound of composition Ni50Mn50-xSnx (x = 5, 7.5 and 10) FSMAs Heusler alloy was prepared by non-consumable arc-melting. The commercial purity of used Ni, Mn, Sn are 99.95%, 99.9% and 99.99% respectively. The melting was carried out under high purity atmosphere (99.996%). For the preparation of alloy ingot, the melting chamber was evacuated to a pressure about 10^{-5} torr and then was purged with pure argon. The process of evacuation and purging was repeated up to three times. The melting was carried out in an argon atmosphere and at a chamber pressure of nearly 500Mtorr. For complete homogenization of the alloy, the entire melting process was repeated several times. Then the alloy was cast into a rod form shown in Figure 2. The ingot was sealed in a quartz ampoule filled with helium gas and solutionized at 1000^{0}C for 24 hour for homogenization. The Martensitic Transformation and phase in these alloys successfully characterized by using Optical Microscopy, X-Ray Diffraction and Differential Scanning Calorimetry. microstructure are viewed under optical microscope fitted with computer. DSC carried out in Mettler device working with a liquid nitrogen cooling system. in XRD, Cu-Ka radiation (k = 1.5418 A °) used and was carried out in the interval 30º≤2Ө ≤ 75º with a step increment of 0.05º.

Fig: 2 Prepared sample of NiMnSn Heusler FSMA

3. Results and Discussion

3.1 Micrograph Study:

Ni-Mn-Sn sample having different Sn content is studied by Optical Microscope, which are shown in figure-3.Here it is clearly observe that different grain have different orientation at room temperature.

Fig: 3 Martensitic layers are present in different Ni-Mn-Sn FSMAs at 50X magnification.

3.2 thermal analyses:

To determine the transformation temperatures under zero stress, Differential Scanning Calorimeter was used. To characterize the material behavior, it is important to identify the regions where the martensite phase exists. The magnetic shape memory effect is only present in regions consisting of stable martensite. These regions of stability however, are temperature dependent. Temperatures over which the phase transformation begins and ends are called transformation temperatures. The alloy absorbs, or emits, heat over a small change in the specimen temperature, when there is a phase transformation occurs in the material. Martensitic start temperature, Martensitic finish temperature, austenitic starte temperature and austenitic finish temperature are denoted as M_s, M_f, A_s, A_f respectively. In DSC test graph arrows indicate cooling (up: martensite to austenite) and heating (down: austenite to martensite).

In figure-4, the temperature was raised from 575°K to 675°K and lower from 675°C to 575°C at a rate of 10°K/min, while the baseline heat flow rate vs. temperature was recorded by the data acquisition computer. Here M_s, M_f, A_s and A_f are 625°K, 597°K, 618°K, 667°K respectively.

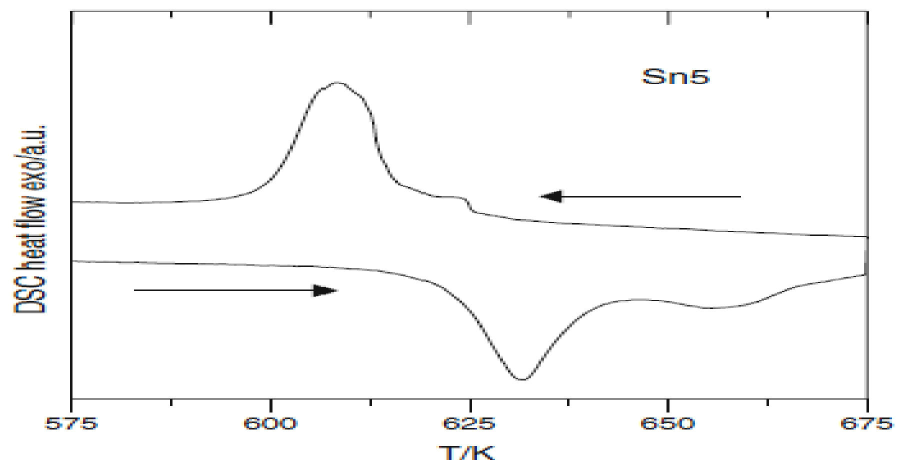

Fig. 4 DSC plots for $Mn_{50}Ni_{45}Sn_5$ FSMA at a rate of 10°K/min.

In figure-5, the temperature was raised from 375°K to 500°K and lower from 500°K to 375°K at a rate of 10°K/min. M_s, M_f, $A_s$and A_f temperature obtained are 436°K, 407°K, 389°K, 444°K respectively.

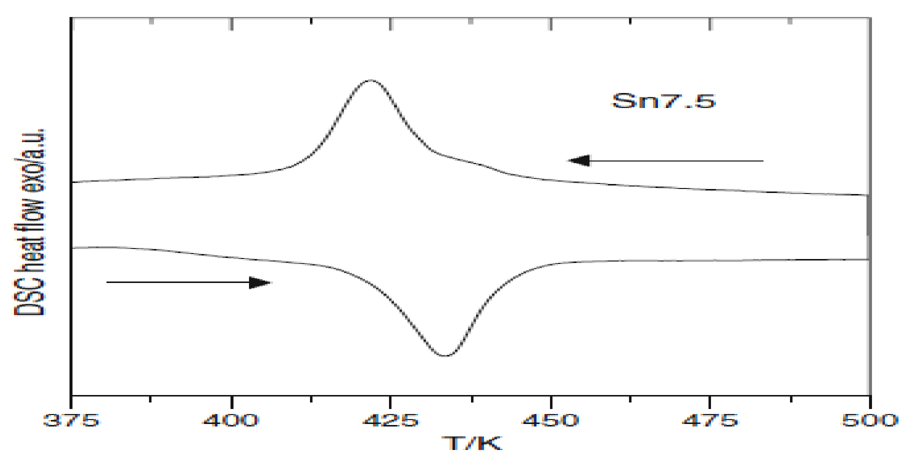

Fig. 5 DSC plots for $Mn_{50}Ni_{42.5}Sn_{7.5}$ FSMA at a rate of 10°K/min.

In figure-6, the temperature was raised from 175°K to 275°K and lower from 275°K to 175°K at a rate of 10°K/min. M_s, M_f, A_s and A_f temperature obtained are 228°K, 202°K, 205°K, 246°K respectively.

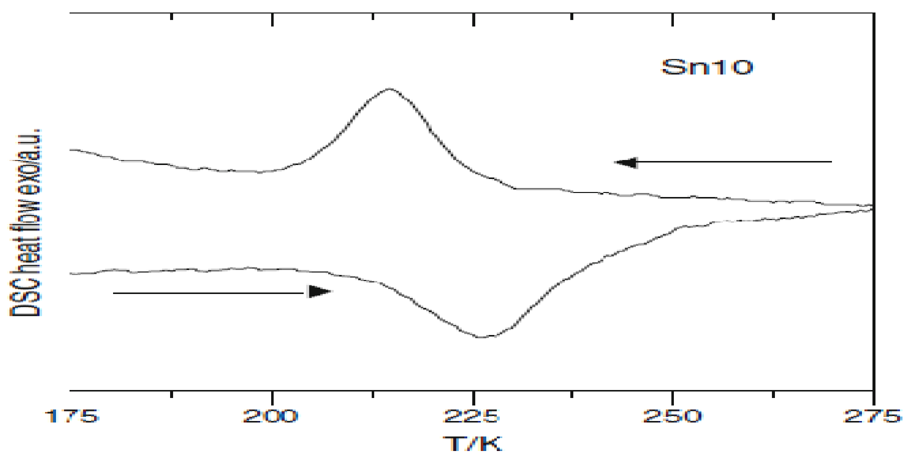

Fig. 6 DSC plots for $Mn_{50}Ni_{40}Sn_{10}$ FSMA at a rate of 10°K/min.

In figure-7, the value of M_s, M_f, A_s and $A_{f.}$ of three prepared specimen are ploted. It is observed that with constant weight percent of Ni, by increasing weight percent of Sn (i.e. fron 5 to 10), there is decrease in all the value of transformation temperature (M_s, M_f, A_s and A_f). So for high temperature application the Sn content should be low.

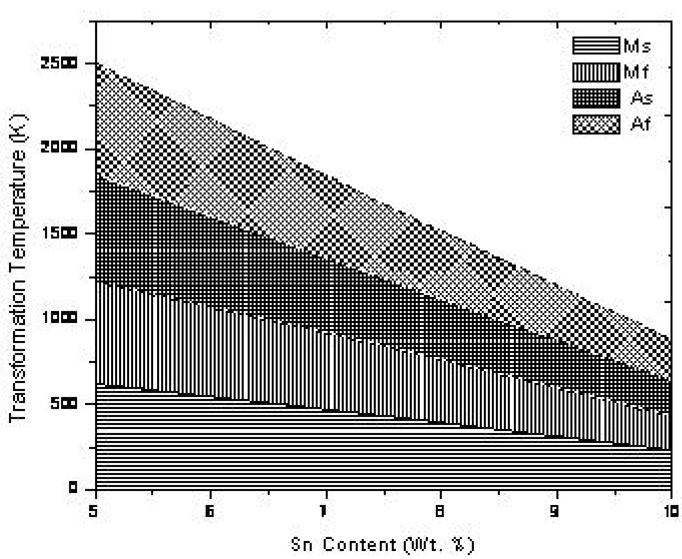

Fig: 7: Transformation temperature Vs Sn content showing decreasing range of M_s, M_f, A_s and A_f value.

5. Conclusions

For $Ni_{50}Mn_{50-x}Sn_x$ (x = 5, 7.5 and 10) series Alloy, as the Sn content increases from 5 to 10, the transformation temperature from martensite to austenite decreases.

6. References

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