Low Cost Heusler ferromagnetic shape memory alloy

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Abstracts

Ferromagnetic shape memory alloys (FSMA) exhibiting ferromagnetic martensites emerge as new functional materials with interesting magneto-mechanical coupling effects such as the ferromagnetic shape memory effect. These classes of intelligent materials, which can significantly change their shape and dimensions under the application of external fields. Among them are the magnetostrictive alloys which in turn can be deformed by magnetic field (up to 0.1 percent) and shape memory alloys, which can be deformed by mechanical stress (up to 10 percent) in martensitic state. The deformations (up to 6 percent) under the action of the magnetic field can be obtained in materials, which undergo the thermoelastic transformation into ferromagnetic phase. It is well known that ferromagnetic shape memory alloy has diversified utilization, but not satisfactorily use, mainly because of high cost of processing and high cost of alloying elements. Among Heusler ($Ni_{50}Mn_{50-y}X$) (X=Ga, Sn, In) FSMA, Ni-Mn-Sn alloy have potential properties and exhibits lower cost. Martensitic transformation of $Ni_{50}Mn_{50-y}Sn_y$ (y= 5, 10, 12.5) alloys were investigated by differential scanning calorimetric measurement. It is observe that, by keeping weight percent of Ni, if we increase the weight percent of Sn; then martensitic starting temperature decreases.

Key words: FSMA, Cost, Ni-Mn-Sn, martensitic transformation

1.Introduction

The characteristic behavior of FSMAs is, by combining shape memory effect and the bulk ferromagnetic behavior. FSMAs have considerable potential microactuator materials because they show a large recovery strain upto 10% and a high responding frequency (KHz) [1-4]. In this decade, new alloy systems are investigated, which show magnetic shape memory related phenomena. Magnetic shape memory effect in these materials involves the movement of twin boundaries which results in the growth of one of the twin variants at the expense of the other in response to an applied magnetic field below the martensitic transformation temperature [5]. Formation of martensite variant is accompanied by a defined shape strain; the microscopic shape of the material does not change as a whole before or after the transformation. This is due to self-accomodation of martensite formation [6]. Stoichiometric Ni-Mn-Ga heusler alloy involving complete substitution of ga with sn, where chosen from a number of candidate alloys exhibiting martensitic transformation as suggested by Wutting et. al. [4]. In recent study Mn-based Heusler alloys have been focus as one of the typical magnetocaloric effect material. Among them, it is found that Ni-Mn-Sn SMA is a less cost material due to lesser cost of Sn element. By considering cost, the goal of this investigation is to find a magnetic alloy exhibiting a martensitic phase transformation that would provide a large controllable displacement with the application of low magnetic field at reasonable operating temperature. In many experiment Ni-Mn-Ga alloys are widely examined for which it serves as a reference alloy. But the husler alloys the choice of Ni-Mn-Sn alloy is due to: (i) Ni-Mn-Sn not expensive as gallium, (ii) It does not contain toxic as that of gallium [7], (iii) Ni-Mn-Sn is less brittle than Ni-Mn-Ga [8], (iv) Low transformation and curie temperature of stoichiometric Ni-Mn-Ga than Ni-Mn-Sn, (v) The austenite and martensite phase of Ni-Mn-Sn have the same crystal structure as the corresponding phases of Ni-Mn-Ga and have the same magnetically easy axis[5], (vi) Ni-Mn-Sn alloys are known to have comparably high L_21/ tetragonal transition temperature as that of Ni-Mn-Ga, (vii) Stoichiometric of Ni-Mn-Sn alloys reveals similar magnetostrictive behavior with respect to temperature as that of Ni-Mn-Ga alloys[5], (viii) Ni-Mn-Ga alloys is insufficient for FSMA actuators[9].

2. Experimental Procedure

A series of $Ni_{50}Mn_{50-y}Sn_y$ (y= 5, 10, 12.5) ternary polycrystalline Heusler alloys were prepared by nonconsumable arc-melting under high purity atmosphere (99.996%). The commercial purity of Ni, Mn, Sn are 99.95%, 99.9%and 99.99% respectively. For the preparation of alloy ingot, the melting chamber was evacuated to a pressure of 10^{-5} torr and then was purged with pure argon. The process of evacuation and purging was repeated three times. The melting was carried out in an argon atmosphere and at a chamber pressure of nearly 500Mtorr. The entire melting process was repeated several times in order to get complete homogenization of the alloy. Then the alloy was cast into a rod form. The composition has been reported to form a martensite at room temperature (M_s= 335K) with martensitic curie temperature, T_c close to room temperature (287K). the ingot was sealed in a quartz ampoule filled with helium gas and solutionized at 1000^{o}C for 24 hour for homoginization.

3. Results and Discussion

3.1 Differential Scanning Calorimetry

Transformation temperatures determined under zero stress by using Differential Scanning Calorimeter. 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. In below figures number-1 represent as forward martensitic transformation and number-2 represent reverse martensitic transformation. 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 figure-3.1, the temperature was raised from 300^oC to 500^oC and lower from 500^oC to 300^oC at a rate of 5^oC/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 423.02^0C, 403.73^0C, 428.36^0C, 452.99^0C respectively.

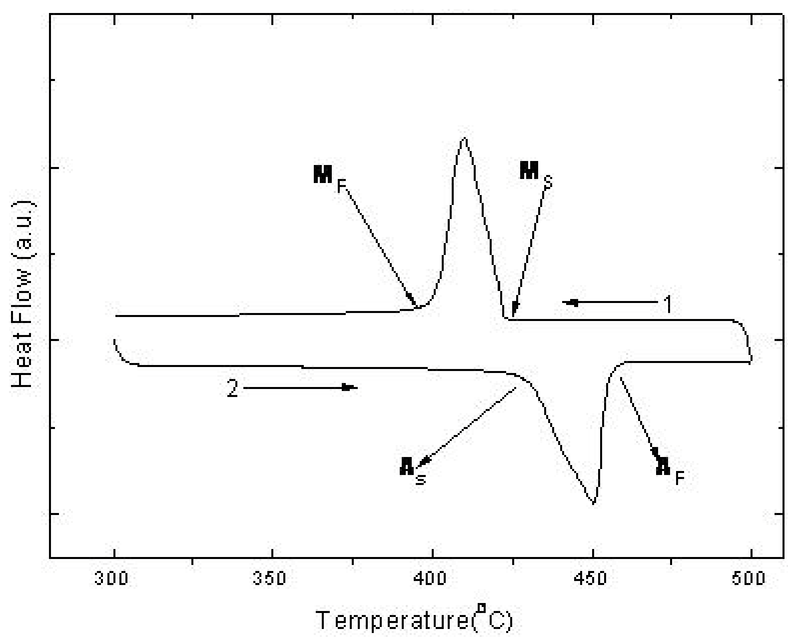

Figure: 3.1 martensitic transformation For sample $Ni_{50}Mn_{45}Sn_5$

In figure-3.2, the temperature was raised from 100^oC to 200^oC and lower from 200^oC to 100^oC at a rate of 5^oC/min. M_s, M_f, $A_s$and A_f temperature obtained are 169.89^0C, 156.59^0C, 188.94^0C, 195.52^0C respectively.

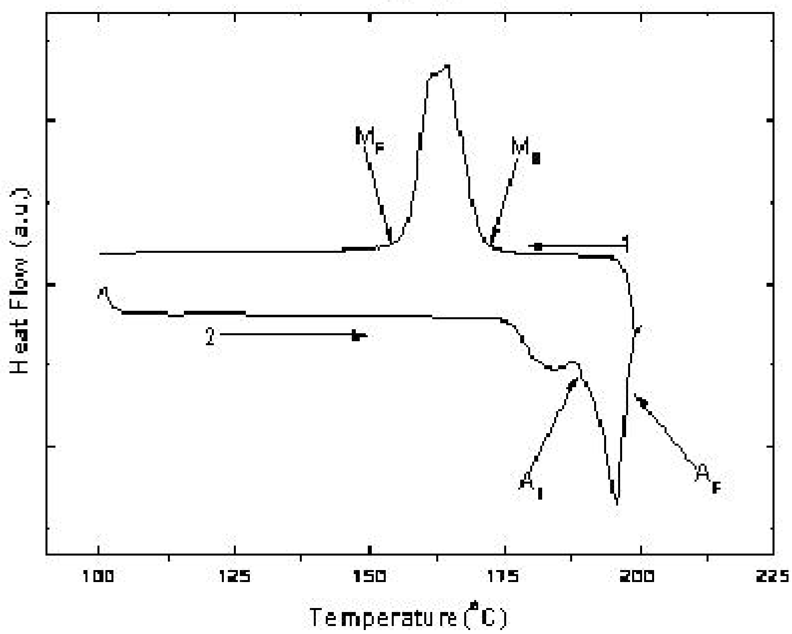

Figure: 3.2 martensitic transformation For sample $Ni_{50}Mn_{40}Sn_{10}$

In figure-3.3, the temperature was raised from 100°C to 200°C and lower from 200°C to 100°C at a rate of 5°C/min. M_s, M_f, $A_s$and A_f temperature obtained are 169.89°C, 156.59°C, 188.94°C, 195.52°C respectively.

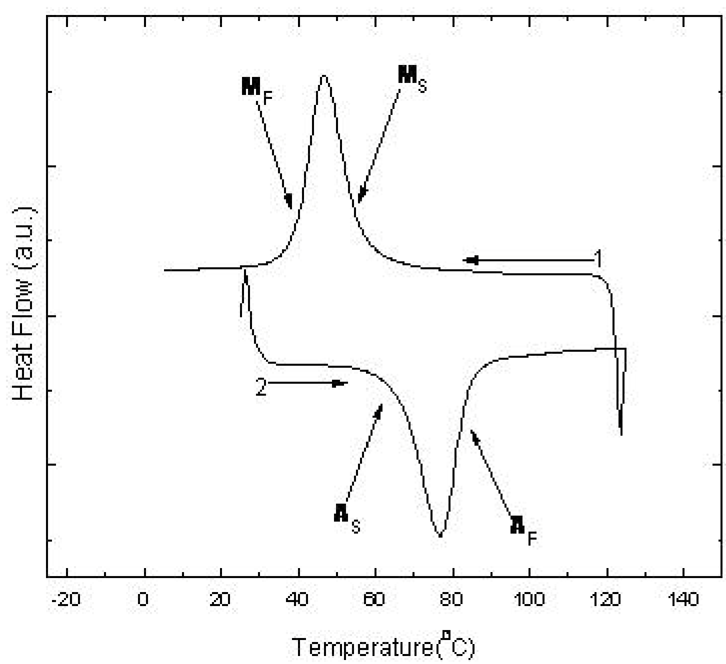

Figure: 3.3 martensitic transformation For sample $Ni_{50}Mn_{37.5}Sn_{12.5}$

From above three figures, a graph drawn in figure 3.4; it is well known that with constant weight percent of Ni, by increasing weight percent of Sn in an alloy; there is decrease in all the value of

M_s, M_f, $A_s$and A_f. it is known that, the martensitic starting temperature for $Ni_{50}Mn_{37}Sn_{13}$ alloy have 17^oC [10]and $Ni_{50}Mn_{36}Sn_{14}$ alloy have -53 ^oC [11] .

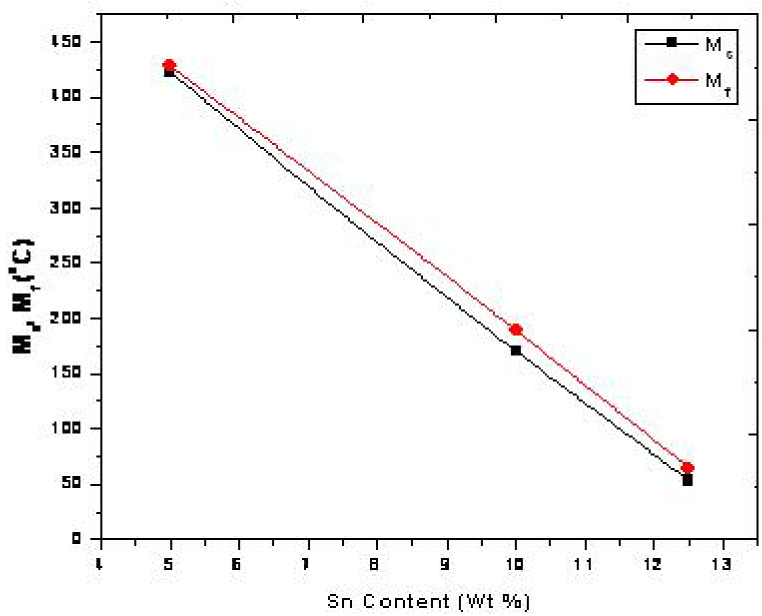

Figure: 3.4 : comparision of Ms, Mf w.r.t Sn weight percent

4. Conclusion

In Ni-Mn-Sn alloys, if we increase the Sn weight percentage, then M_s, M_f, $A_s$and A_f temperature simultaneously decreases.

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