International Journal of Advances in Applied Sciences (IJAAS)
Vol. 2, No. 4, December 2013, pp. 205~208
ISSN: 2252-8814

Martensitic Transformation Characteristic of Ni-Mn Based Ferromagnetic Shape Memory Alloys

Ajit Behera[1], Asit Behera[2], S.C. Mishra[3]
[1] Departement of Metallurgical and Materials Engineering, Indian Institute of Technology, Kharagpur-721302
[2] Departement of Mechanical Engineering, National Institute of Technology, Rourkela-769008
[3] Departement of Metallurgical and Materials Engineering, National Institute of Technology, Rourkela-769008

Article Info

Article history:

Received Feb 6, 2013
Revised Aug 23, 2013
Accepted Sep 3, 2013

Keyword:

Austenitic Transformation
Ferromagnetic Shape Memory Alloys (FSMAs)
Martensitic Transformation
Ni-Mn-Sn

ABSTRACT

Ferromagnetic shape memory alloys emerge as new functional materials which have interesting magnetomechanical coupling effects such as the ferromagnetic shape memory effect. These types of materials significantly change their shape and dimensions under the application of external fields i.e. either by using thermal energy or magnetic energy. Among them, some are the magnetostrictive alloys which in turn can change their shape by magnetic field up to 0.1 percent and by mechanical stress up to 10 percent in martensitic state. Up to 6 percent deformation can be obtained in materials under the action of the magnetic field which undergo the thermoelastic transformation into ferromagnetic phase. Due to higher processing cost and costly elements for alloying, ferromagnetic shape memory alloy have not so broadly utilization and satisfactorily use. Among different type of Ni-Mn based Heusler ferromagnetic shape memory alloys, Ni-Mn-Sn alloy have potential properties and exhibits lower cost. In this paper martensitic transformation of $Ni_{50}Mn_{50-y}Sn_y$ (y= 5, 10, 12.5) alloys were investigated. By differential scanning calorimetric measurement, it has been observed that, by keeping one element i.e. Ni as constant weight percentage, if we increase the weight percent of Sn; then martensitic starting temperature as well as austenitic starting temperature gradually decreases.

Corresponding Author:

Ajit Behera,
Departement of Metallurgical and Materials Engineering,
Indian Institute of Technology,
Kharagpur-721302.
Email: ajit.behera88@gmail.com

1. INTRODUCTION

The characteristic behavior of ferromagnetic shape memory alloys (FSMAs) is, by combining shape memory effect (SME) and the bulk ferromagnetic behavior. FSMAs have been used as potential microactuator materials because they show a large recovery strain upto 10% and a high responding frequency (KHz) [1]-[4]. New alloy systems are investigated in this decade, which exhibits 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 because of 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 Ni-Mn based Heusler alloys have been focus as one of the typical magnetocaloric effect material. Among them, it is found that Ni-Mn-Sn FSMA 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 $L2_1$/ 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 are insufficient for FSMA actuators [9].

2. EXPERIMENTAL PROCEDURE

A ternary intermetallic polycrystalline compound series of $Ni_{50}Mn_{50-y}Sn_y$ (y= 5, 10, 12.5) 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 of 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 10-5torr. 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 1. This composition transforms Martensite at room temperature (Ms= 67°C) with Martensitic Curie temperature, Tc close to room temperature (14°C). The ingot was sealed in a quartz ampoule filled with helium gas and solutionized at 1000°C for 24 hour for homogenization. The Martensitic and austenitic transformations in these alloys successfully characterized by using Optical Microscopy and Differential Scanning Calorimetry.

Figure 1. Prepared sample of $Ni_{50}Mn37.5Sn_{12.5}$ Heusler FSMA

3. RESULTS AND DISCUSSION

3.1. Optical Microscopy

In the Figure 2(a), different martensitic layers are present with different orientation in each grain of the sample at room temperature. The phase transformation results from a cooperative and collective motion of atoms on distances smaller than the lattice parameters. The absence of diffusion makes the martensitic phase transformation almost instantaneous. Figure 2(b) shows magnified image of martensitic layer with 20X magnification, present at Ni_2MnSn sample. The crystal lattice of the martensitic phase has lower symmetry than that of the parent austenitic phase so that several variants of martensite can be formed from the same parent phase crystal. 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. The microstructure of Ni_2MnSn sample taken from Optical Microscope is given below:

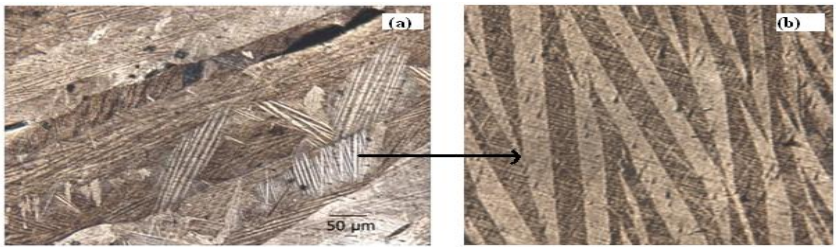

Figure 2. (a) A number of Martensitic layers present in $Ni_{50}Mn_{45}Sn_5$, (b) enlarged martensitic layer at 20X magnification

3.2. 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, the temperature was raised from 300°C to 500°C and lower from 500°C to 300°C at a rate of 5°C/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°C, 403.73°C, 428.36°C, 452.99°C respectively.

In Figure 4, the temperature was raised from 100oC to 200oC and lower from 200oC to 100oC 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.

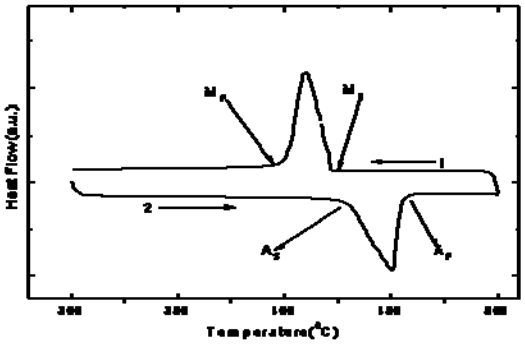

Figure 3. Martensitic transformation for sample $Ni_{50}Mn_{45}Sn_5$

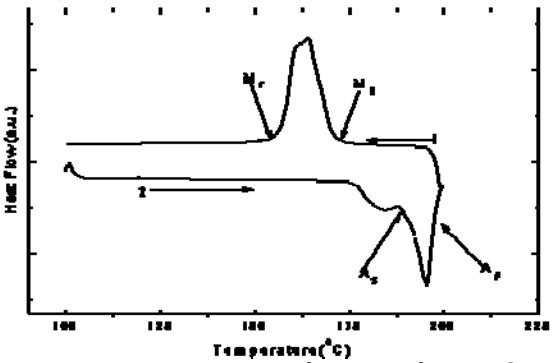

Figure 4. Martensitic transformation for sample $Ni_{50}Mn_{40}Sn_{10}$

In Figure 5, 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.

From above three figures, a graph drawn in Figure 6; 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°C [10] and $Ni_{50}Mn_{36}Sn_{14}$ alloy have -53°C [11] .

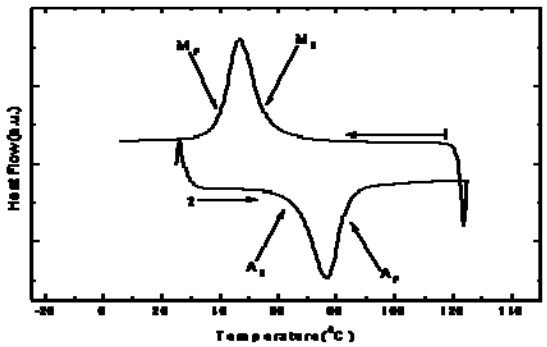

Figure. 5. Martensitic transformation for sample $Ni_{50}Mn_{37.5}Sn_{12.5}$

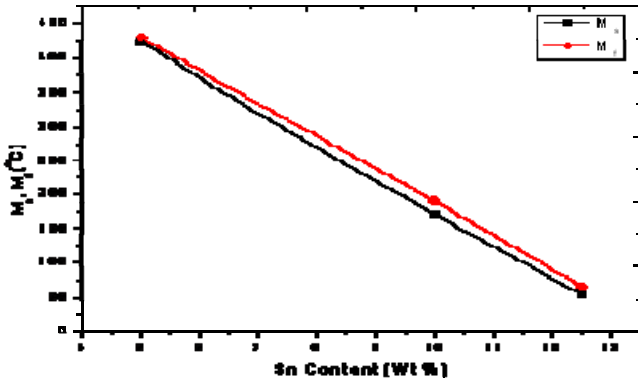

Figure 6. Comparision of M_s, M_f with respect to Sn weight percent

4. CONCLUSION

In Ni-Mn-Sn alloys, if we increase the Sn weight percentage, then Ms, Mf, As and Af temperature simultaneously decreases.

REFERENCES

[1] J. Pons, *et al.* "Structure of the layered martensitic phases of Ni-Mn-Ga alloys", *Materials Science and Engineering A*, Pp. 438-440, 93-934, 2006.
[2] Katsunari Oikawa, *et al*, "Martensitic Transformation and Magnetic Properties of Cu-Ga-Mn Alloys", *Materials Transactions*, Vol/Issue: 45(8). Pp. 2780-2784, 2004.
[3] S. J. Murray, M. Marioni, S.M. Allen, R.C. O. Handley, T.A. Lograsso. *Appl. Phys. Lett.*, Vol.77. Pp.886-888,2000.
[4] M. Wuttig, L. Liu, K. Tsuchiya, R.D. James. *J. Appl. Phys*. Vol. 87. Pp. 4707-4711, 2000.
[5] Byung Sang Choi. "Thermal, Magnetic and Magnetoelastic data on three different Heusler alloys based on Ni-Mn-X (X=Ga,In or Sn)", *IEEE Transaction on Magnetic*, Vol/Issue: 42(7), 2006.
[6] Kaushik Bhattacharya. "Self-accommodation in martensite", *Arch. Rational Mech. Anal*, Vol.120.Pp.201-244,1992.
[7] S. Chatterjee, *et al.* "Magnetic Investigations on Ni-Mn-Sn Ferromagnetic Shape MemoryAlloy", *Advanced Materials Research*, Vol. 52. Pp. 215-220, 2008.
[8] P. J. Brown et al. *J. Phys.: Condens. Matter*, Vol. 18. Pp. 2249, 2006.
[9] Y. Sutou. "Magnetic and martensitic transformations of $NiMn_X$ (X=In,Sn,Sb) ferromagnetic shape memory alloys", Vol/Issue: 85(19), 2004.
[10] D. L. Schlagel, *et al.* "Temperature dependence of the field-induced phase transformation in $Ni_{50}Mn_{37}Sn_{13}$", *Scripta Materialia*, Vol. 59. Pp. 1083-1086, 2008. DOI: 10.1016/j.scriptamat.2008.07.039
[11] Keiichi Koyama, *et al.* "Observation of field-induced reverse transformation in ferromagnetic shape memory alloy $Ni_{50}Mn_{36}Sn_{14}$", *Appl. Phys. Lett.*, Vol. 88. Pp. 132505, 2006. http://dx.doi.org/10.1063/1.2189916.

BIOGRAPHIES OF AUTHORS

Ajit Behera was born in 1987. He received B.Tech Degree in 2009 from Bijupatnaik university of technology, Rourkela and M.Tech degrees in 2012 from National Institute of Technology, Rourkela, India. Currently he is doctoral research scholar at Indian Institute of Technology, Kharagpur, India. He published some book in "Materials Engineering". He is working as a Reviewer/Editor in many international journals.

Asit Behera was born in 1991. He received Bachlor degree (Mechanical Engineering) from Bijupatnaik University of Technology, Rourkela. Currently he is doing research in Mechanical Engineering, Department in National Institute of Technology, Rourkela. His Working area is on Mechanical Material.

Prof. S.C Mishra, One of the senior most professor in the Department of Metallurgical and Material Engg., National Institute of Technology, Rourkela. He has also composed a chapter in a highly acclaimed book in scientific circles: "Advanced Plasma Spray Applications" titled "Analysis of experimental results of plasma spray coatings using statistical techniques. In addition to all the awards and recognition, The International Biographic Centre of Cambridge, England has nominated the professor for the "Olympian Achiever" award.