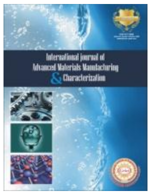

Advanced Materials
Manufacturing & Characterization

journal home page: www.ijammc-griet.com

Determination of Magnetic Field Induced Strain in CoNiAl based Ferromagnetic Shapememory Alloy using Strain Gauge

B. Rajini Kanth and P.K. Mukhopadhyay

Department of Physical Sciences Lab for Smart Materials and Structures (LSMS), T.K.R.College of Engineering and Technology, Medbowli, Meerpet, Hyderabad-97
Department of Condensed Matter Physics and Materials Science Lab for Condensed Matter Physics (LCMP) S.N. Bose National Center for Basic Sciences, Salt Lake, Kolkata-98

ARTICLE INFO

Article history:
Received 07 Nov 2012
Accepted 26 Dec 2012

Keywords:
Ferro-magnetic shapememory Alloys,
Magnetic Field Induced Strain,
Strain Gauge,
Resistivity

ABSTRACT

The magnetic field induced strain (MFIS) is key parameter for determining the ferromagnetic shape memory alloys (FSMAs) for the application of sensors and actuators. NiMnGa based FSMAs, having higher magnetic field induced strain in both polycrystalline and single crystalline formats found to be prototypes for this applications. But, because of their brittleness and higher cost of its constituent metals using them practically is very difficult and cost effective. As an alternate to these alloys, CoNiAl alloy has emerged due to its higher ductility and high T_c, good magnetic properties, large range of transformation and Curie temperatures. In view of these factors, CoNiAl alloy samples were prepared using the arc melting method and annealed in a furnace and characterized using X-ray diffraction(XRD), Scanning Electron Microscope(SEM) and EDAX. The transformation temperatures were obtained from the resistivity measurements (from 80 K to 400 K). The MFIS at room temperature for CoNiAl alloys was determined using a strain gauge attached to the sample which is kept in a d.c. electromagnet of maximum field 2T and data was obtained from a data logger. The results of such measurements are presented in this paper.

Introduction

Ferro-magnetic Shapememory Alloys (FSMAs) are being intensively studied because of their smart nature and potential candidates for the applications in sensors and actuators. In FSMAs the martensitic transformation and lattice reorientation processes can be controlled or triggered not only by stress or temperatures but also with the magnetic field unlike in ordinary SMAs[1, 2]. The prototypes for this application are NiMnGa based FSMAs, because of their brittleness using them practically is very difficult[3]. Many systems have been investigated [4-8] which include Ni_2MnGa, Ni_2MnAl, $Fe_{70}Pd_{30}$ all of which produce large strains with the application of magnetic field. Recently, CoNiAl based alloy system has received lot of interest because of their higher ductility and high Tc and good magnetic properties, large range of transformation and Curie temperatures. In addition these alloys have low density, high melting point, good corrosion resistance and high strength, even at higher temperatures as high as 573 K. Moreover, the constituent elements are cheaper compared to above mentioned FSMAs [9-11]. The CoNiAl alloy system undergoes a martensitic transformation from β-phase (B_2, cubic) austenite to $L1_0$ (tetragonal) martensite at temperatures between 93 K to 393 K depending on composition, annealing and preparation conditions [12, 13]. The Single β-phase in polycrystalline materials is extremely hard and brittle, but the presence of a secondary γ-phase, which has an Al disorder face centered cubic (FC) structure[10, 14], significantly increases the ductility[15, 16].

The main purpose of this work is to prepare and characterize the CoNiAl FSMA alloy and obtain its transformation temperature and measure its MFIS using a strain gauge. The MFIS which is a useful and important parameter that gives the information of magnetic field induced strain of the sample which in turn decides the application of the present samples. In the literature, there were similar studies on different CoNiAl alloy samples H. Morito et.al[17] studied MFIS on a single crystal of $Co_{37}Ni_{34}Al_{29}$ obtained reversible magnetic field induced strain of 0.06%. J. Liuet.al[18] made an directional solidified sample of the same composition and obtained a MFIS of 130 ppm. I.I. Kositsynaet.al[19] studied on $Co_{38}Ni_{34}Al_{28}$ in the microcrystalline format obtained an MFIS of 3.7 mkm. We made an attempt to

- Corresponding author: B. RajiniKanth
- E-mail address: rajani75@gmail.com
- Doi: http://dx.doi.org/10.11127/ijammc.2013.02.010

study the MFIS of these CoNiAl alloy samples and the results are presented in this paper.

Experimental:

The CoNiAl alloy with the composition $Co_{37}Ni_{35}Al_{28}$ was melted several times in the arc furnace and annealed at 1200C for 24 hours and quenched in water. The sample was then characterized by using the XRD, SEM and EDAX. For taking the SEM photographs the sample was cleaned and polished several times by following a series of polishing emery papers and finally etching the sample in methanol. The resistivity measurements were studied with-in the temperature range of 80 K to 400 K. The room temperature MFIS measurements were done using a Polytronicd.c. electromagnet which can produce a maximum field of 2T in both the directions and TML TDS data logger (Tokyo Sokki Kenkyujo co., Ltd) and a TML cryogenic strain gauge attached to the sample. The arrangement was first calibrated using a Terfenol-D sample (we have taken it as a standard sample) which has highest value of magneto striction. The strain gauges were attached to the samples with the appropriate epoxy and kept in the tapered poles of the magnet.

Results and Discussion:

Figs. 1 &2 shows the XRD pattern and SEM microstructure of the present CoNiAl annealed alloy. From Fig. 1 it is observed that the sample has predominantly β phase (the peak with more intensity), while in Fig. 2 which shows the microstructure which has both β phase and γ phase showing the grain and grain boundary corresponding to β phase and γ phase(white patches) respectively.

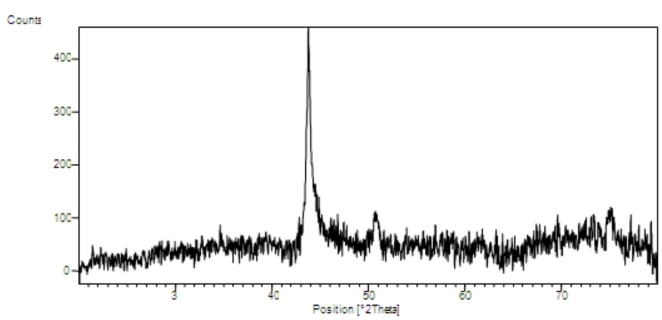

Fig.1

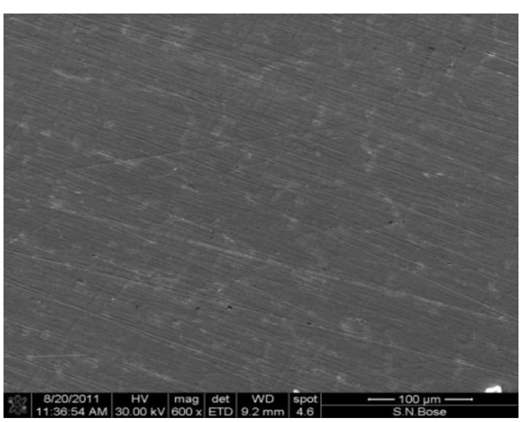

Fig.2

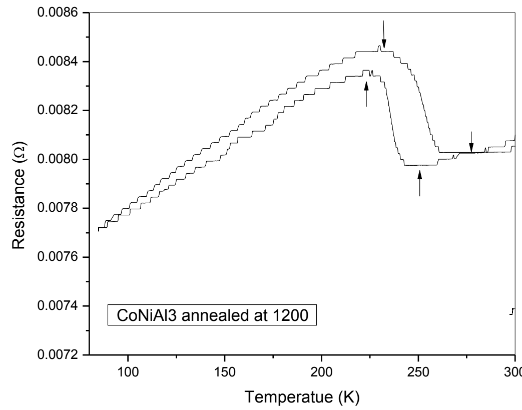

Fig.3

Fig. 3 shows the variation of resistance of the present sample as a function of temperature during a heating and cooling cycle. While cooling there was a minimum at around 250 K, then there was a rise till 210 K, followed by the normal lowering of resistance below that temperature. Evidently the minimum and maximum occurred due to structural changes only, the higher temperature corresponds to the T_{Ms}, the martensitic start temperature and the lower one is T_{Mf}, the martensitic finish temperature. The changes in resistance during structural transition is a well known phenomenon [20, 21]. While heating we encountered a maximum temperature which should be ascribed to the austenitic start temperature, T_{As}. The resistance curve had a minimum at a higher temperature that we suggest as T_{Af}, the austenitic finish temperature. All these temperatures are marked with arrows in the figures. Final values of transformation temperatures for this alloy are 250 K, 210 K, 230K and 290 K respectively.

The MFIS measurement was done on the sample after calibrating the apparatus with the standard sample, here we have used Terfenol-D sample as the standard and we have checked its data and compared with the present data, which is shown in Fig.4. The data is directly given by the TDS data logger in terms of microstrain. From the plot it can be observed that, the magnetic field initially increased from a small value by increasing the current in the d.c. electromagnet power supply and then after reaching the maximum value the current decreased to 0A and then the current increased in the reverse direction and decreased after words after reaching the negative maximum. This process was done for the sample strain gauge arrangement parallel to the field and perpendicular to the field. The plot obtained is also called as butterfly plots. In the upper half of the plot, strain is positive and goes to a maximum and saturates. Similarly in the down half of the plot the strain is negative and goes down to a minimum value and gets saturated.

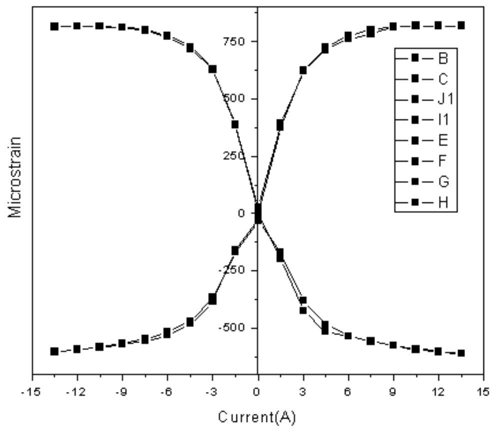

Fig.4.

In the present study the sample was also attached to the strain gauge similar to the standard sample and then the experiment was also performed in both the directions. Fig.5 shows the arrangement of sample parallel with the field. Here in the present sample the field is increased from 0 G to 7.5kG, the sample strain increases to certain field around 3kG and then decreases to 14.5 micro-strain. Once the field is decreased from the maximum value the strain increases to maximum value of 17.5 micro-strain and then decreases to a small value and there after the sample has demagnetized with a demagnetizing coil. The value of micro-strain starts increasing in sample and reaches a maximum of 12.5 micro-strain near around 3kG and then starts decreasing to reach a minimum value in the negative direction. Similarly when the field is decreased in this cycle it follows almost same path and reaches to zero strain when the field is zero Gauss. The experiment was performed with the strain gauge sample arrangement length perpendicular to the field. Fig. 6 shows variation of the strain when the sample length arranged perpendicular to the field. As the field is increased the micro-strain decreases in the negative direction and falls quickly till 3kG and then fall slowly. Similarly when the field is decreased from the maximum value, the strain increases and reaches maximum value. In the negative side when the magnetic field is applied in the reverse direction, the strain decreases to a minimum values as earlier and then when the field is decreased the strain increases to maximum value. There is no difference in this plot as was observed in the earlier case. This asymmetry in the butterfly plots is may be due to the fact that present samples are polycrystalline, the domains will be randomly oriented once magnetized they will align with the field direction. Further study of oriented samples and directional and single crystalline samples is underway.

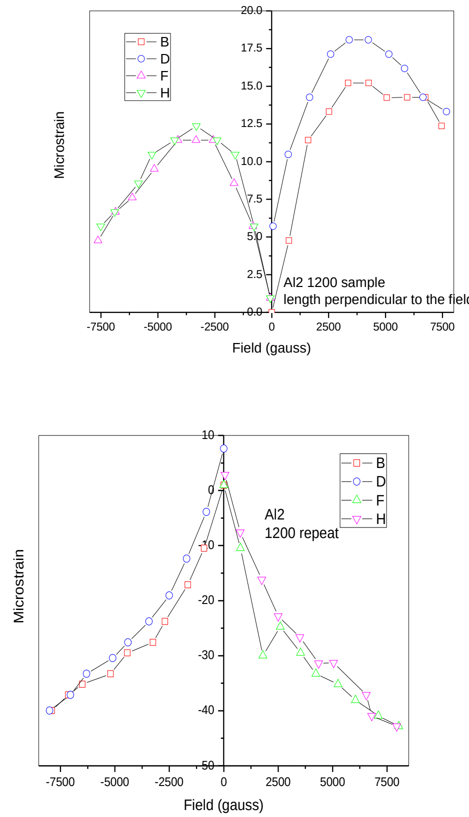

Fig.5

Conclusions:

The CoNiAl alloy with the composition $Co_{37}Ni_{35}Al_{28}$ was prepared using arc furnace and annealed in a high temperature furnace. The sample was then characterized by using the XRD, SEM and EDAX. The resistivity measurements were studied by homemade set-up with-in the temperature range of 80 K to 400 K. The room temperature MFIS measurements were done using a d.c. electromagnet and TMLTDS data logger and a TML cryogenic strain gauge attached to the sample.

Acknowledgements:

The first author (BRK) acknowledges the support extended by DST in granting DST FAST TRACK Scheme SR/FTP/PS-108/2009 for Young Scientists. Mr. PalasBiswas, Scientist, Fiber Optics and Photonics division and Mr. Kamal Das Gupta Acting Director, CGCRI, Kolkata were acknowledged for allowing us to do the MFIS measurements with their instrument. The first author BRK is thankful to both the Directors of S. N. Bose Center and T.K. R College of Engineering and Technology for allowing the collaboration work. **T**he first author also records his gratefulness to the Secretary and the Treasurer of TKR College for their constant help and support.

References:

1. M. A. Marioni, R. C. O'Handley and S. M. Allen, Appl. Phys. Lett. 83 (2003) 3966.
2. C. P. Henry, D. Bono, J. Feuchtwanger, S.M. Allen and R.C. O'Handley, J. Appl. Phys. 91
3. (2002) 7810.
4. V.A. Chernenko, E. Cesari, J. Pons and C. Segui, J. Mater. Res. 15 (2000) 1496.
5. [K. Ullakko, J.K. Huang, C. Kantner, R. C. O'Handley, V. V. Kokorin ., Appl. Phys. Lett.
6. 69 (1996) 1966
7. G. Mgylnyy, I. Glavatskyy, N. Glasvatska, O.Soderberg, Y. Ge, V.K. Lindroos., Scripta
8. Mater 48(2003) 1427
9. G.D. Liu, J.L. Chen, Y.T.Cui, Z.H. Liu, M. Zhang, G.H. Wu, etal. SolidstateCommun 130
10. (2004) 687Fujita, K. Fukamichi, F.Gejima, R. Kainuma, K.Ishida., Appl. Phys. Lett.77(2000) 3054
11. R.D. James, M. Wuttig., Philod. Mag.A 77 (1998) 1273
12. W.H. Tian, M. Hibino, M. Nemoto. Intermetallics 6 (1998) 121
13. K. Oikawa, L. Wulff, T. Iijima, F. Gejima, T. Ohmori and A. Fujita, Appl. Phys. Lett. 79
14. (2001) 3290.
15. Y. Tanaka, K. Oikawa, Y. Sutou, T. Omori, R. Kainuma and K. Ishida, Mater.Sci. Eng., A
16. 438 (2006) 1054.
17. H.E Karaca, I. Karaman, , D.C Lagoudas, H. J.Maier, Y.I. Chumlyakov, Scripta Mater. 49
18. (2003) 831
19. B. RajiniKanth, N. V. Ramarao, A.K.Panda, R. Gopalan, A. Mitra and P. K.
20. Mukhopadhyay, Journal of Alloys & Compounds 491 (2010) 22
21. R. Kainuma, M. Ise, C.C. Jia, h. Ohtani, K. Ishida, Intermetallics 4 (1996) S151
22. P.J. Brown, K. Ishida, R. Kainuma T. Kanomata,K.U. Neumann, K. Oikawa, et at.., J. Phys.
23. Condens Mat 17 (2005) 1301
24. R.F. Hamilton, H. Sehitoglu, C. Efstathiou, H.J. Maier, Y. Chumlyakov, X.Y. Zhang, ,
25. Scripta Mater. 53 (2005) 131
26. H. Morito, A. Fujita, K. Fukamichi, R. Kainuma, K. Ishida and K. Oikawa, Appl. Phys.
27. Lett. 81 (2002)1657.
28. J. Liu, H. Zheng, Y. Huang, M. Xia, J.Li, ScriptaMateriallia 53 (2005)29
29. I.I. Kositsyna, V.A. Zavalishin, Materials Science Forum 635 (2010)75
30. G´erardGuenin, 1989 Phase Transitions14165
31. K.S. Sokhey, M. Manekar, M. K. Chattopadhyay, R. Kaul, S. B. Roy and P. Chaddah, J.
32. Phys. D: Appl. Phys. (2003) 1366–1370.