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Synthesis, XRD & SEM Studies of Heusler Ferromagnetic Shape Memory Alloys

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***Abstract* - Ferromagnetic Shape Memory Alloys (FSMAs) are the materials that responds to externally applied magnetic field similar to magnetostriction, but with vastly greater strain. These alloys are becoming an important element of sensor and actuator materials due to their large magnetic-field-induced strain and shape memory effect in recent years. In this work the structural parameters of relatively new Ni-Mn-Al and Ni-Mn-Sn Heusler FSMA were observed by X-Ray diffraction (XRD).In order to investigate the morphologies and microstructures of the inter layer matrix and filler of the prepared alloy, Scanning Electron Microscope (SEM) wasused for the observations. The alloy samples were prepared using vacuum arc melting technique. The average crystalline size was determined by using Scherrer equation.**
***Keywords:* FSMA, Heusler Alloy, Vacuum Arc Melting, Ni-Mn-Al, Ni-Mn-Sn, XRD, SEM,**

I. INTRODUCTION

Shape memory alloys (SMAs) show fascinating thermo-mechanical properties such as shape memory effect and super elasticity. They are able to recover from large permanent deformation by slightly increasing their temperature or from large strains upon loading and unloading the material. The key characteristic of all SMAs is the occurrence of a martensitic phase transformation. In this phase transformation, the crystal structure changes from the parent martensite phase having tetragonal or orthorhombic crystal structure to a high symmetry cubic austenite phase.

Ferromagnetic Shape Memory Alloys (FSMAs) also called as Magnetic Shape Memory Alloys (MSMAs) are novel active materials which are receiving considerable interest among the scientific community and industry. They are next generation to SMAs, sharing many common properties. Conventional SMAs has less potential efficiency due to slow mechanical response to temperature changes. Hence FSMAs are promising materials which show larger Magnetic Field-Induced Strain (MFIS) with quick response at low frequencies than other smart materials. Much of the research work on MSMAs is based on Ni-Mn-Ga heusler alloys because of their large field induced strain [2-4], unique material properties such as martensite crystal structure, transformation temperatures and magneto mechanical properties. However, Ni-Mn-Ga alloys have some common problems for their industrial applications. The transformation and curie temperature of this alloy is low. The brittleness of the alloy is high. Sutou et al. studied the properties of some Ga free Heusler alloys as potential FSMAs [13]. Since recently Ni-Mn based Heusler alloys such as Ni-Mn-Sn and Ni-Mn-Al have been focus as FSMAs exhibiting martensitic transformation, with the purpose to overcome these problems. Ni-Mn-Sn is less brittle than Ni-Mn-Ga [5].The cost of pure gallium is high and its melting point is low. The austenite and martensite have the same crystal structure as the corresponding phases of Ni-Mn-Ga. Ni-MnAl alloys have also been studied and were initially developed as modifications of binary Ni-Al alloys to improve their brittleness[6-8]. The ductility of Ni-Mn-Al alloys is improved with respect to binary Ni-Al, due to precipitation of γ phase region. Depending upon the composition Ni-Mn-Al alloys form similar structure as that of Ni-Mn-Ga alloys [6,7].

In this work the structural parameters of relatively new Ni-Mn-Al and Ni-Mn-Sn Heusler FSMA are observed by X-ray diffraction. Morphological studies of the prepared samples were performed by high resolution scanning electron microscopy (SEM). One alloy of each composition was prepared using standard experimental setup of vacuum arc melting furnace.

II. EXPERIMENTAL

Two alloys samples i.e. $Ni_{50}Mn_{30}Sn_{20}$ and $Ni_{55}Mn_{24}Al_{21}$ (at%) were fabricated by vacuum arc melting technique. Approximate mixture of alloy elements (99.5% purity) was introduced into the furnace and melted at ~ (2200^0C). Heating was carried out using tungsten electrode with a standard power source. A batch of alloys (about 15g of metals) to be melted were placed in the small crucibles of water cooled copper hearth. Before melting, the furnace chamber was evacuated and filled with high purity argon. Repeated melting was performed by turning over to improve the homogeneity of the alloy.

The structural parameters of relatively new Ni-Mn-Al and Ni-Mn-Sn heusler FSMA are observed by XRD. Morphological studies of the prepared samples were performed by high resolution scanning electron microscopy (SEM).

III. RESULTS AND DISCUSSION

Vacuum arc melting process is used to achieve higher purity and better microstructure. The copper crucible is surrounded by a water jacket used to cool the melt and control the solidification rate.

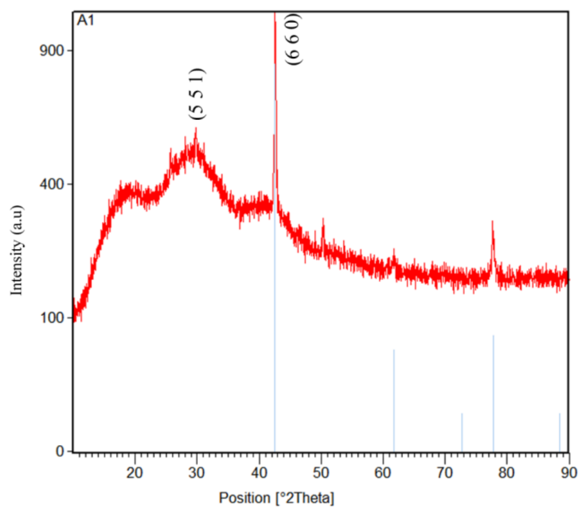


Fig.1 X-ray diffraction pattern of $Ni_{50}Mn_{30}Sn_{20}$ alloy

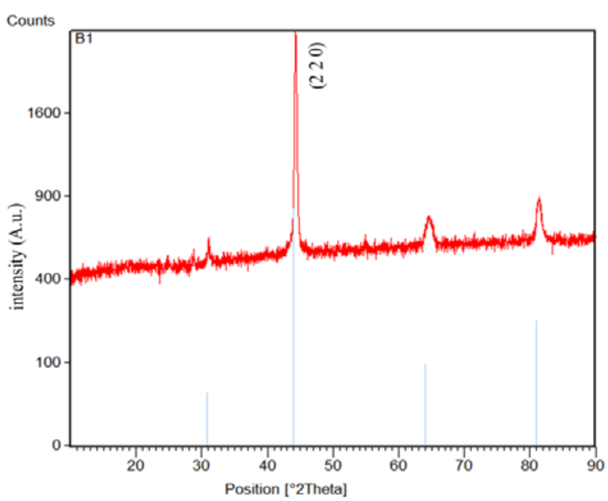


Fig.2 X-ray diffraction pattern of $Ni_{55}Mn_{24}Al_{21}$ alloy

Fig. 1and 2 presents the room temperature X-ray diffraction pattern of sample $Ni_{50}Mn_{30}Sn_{20}$and $Ni_{55}Mn_{24}Al_{21}$ respectively obtained by Cu Kα radiation. The main phases in samples are identified in the JCPDS Card. For Ni-Mn-Sn alloy the crystalline structure is cubic having lattice parameter a=b=c= 1.7980nm. Gaussian fit of the most intense peak (660) is used to calculate the full width at half maxima for the determination of crystallite size (D) by using the Scherrer Equation:

$$D = \frac{0.9\lambda}{\beta \cos\theta}$$

Where, D is the crystallite size, λ is the wavelength of Cu Ka radiations (λ =1.5405 Å), θ is the corresponding bragges diffraction angle and β is the full width at half maxima of the most intense peak (660).

For Ni-Mn-Al alloy the crystalline structure is cubic having lattice parameter a=b=c= 0.58240nm. Gaussian fit of the most intense peak (220) is used to calculate the full width at half maxima for the determination of crystallite size (D) by using the Scherrer Equation.

The average crystalline sizes calculated from prominent peaks are 37.36nm and 35.58nm for $Ni_{50}Mn_{30}Sn_{20}$ and $Ni_{55}Mn_{24}Al_{21}$respectively.

Fig. 3 and 4 are the SEM images showing the typical morphologies of the inter layer matrix and filler of the prepared alloy.

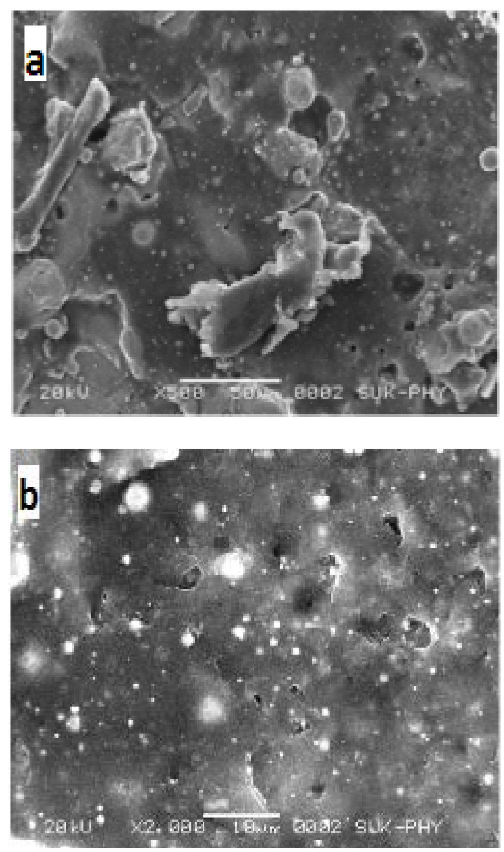
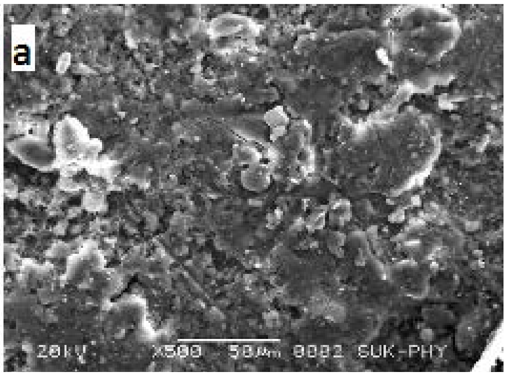


Fig. 3 (a) and (b). SEM micrograph of Ni-Mn-Sn sample at different magnification



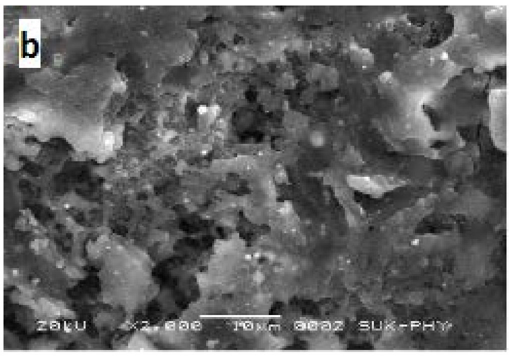


Fig. 4 (a). and (b). SEM micrograph of Ni-Mn-Al sample at different magnification

The different SEM images are examined at different magnifications. Fig. 3(a) shows honeycomb structure because of more concentration of Sn than Mn. Also another reason is the melting point of Tin is much lower (231.93 °C) than other two materials of the alloy. Fig. 3(b) shows similar agglomeration that contains fine crystallites. The white dots represent more percentage of alloyed composition which would have not melted fully for uniform flow as the other portion of the alloy.

Fig. 4(a) shows similar agglomeration with small and fine crystallites. Homogeneous microstructure is appeared.
Fig. 4(b) shows micrographic structure much smoother and uniform compared with Ni-Mn-Sn alloy sample.

IV. CONCLUSION

The Heusler FSMAs were prepared using vacuum arc melting technique to improve the quality of metal by achieving directional solidification. The structural and morphological parameters were observed. The result shows that the structural study confirms the presence of martensite structure in the alloys.

From XRD results it shows that the average crystallite size of Ni-Mn-Al alloy is smaller than average crystallite size of Ni-Mn-Sn alloy. From SEM results it clears that the microstructure of Ni-Mn-Al FSMA is more dense and homogeneous than the Ni-Mn-Sn heusler alloy. Agglomeration nature is present in the samples but the Ni-Mn-Al is perfectly dense and has closer size distribution of particles.

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