



# MICROSTRUCTURAL STUDIES OF CU AND NI ADDITION IN FE BASED SHAPE MEMORY ALLOY

G. Antony Wilbert Singh

Assistant professor, Dept. of Mech. engg, Dr. Sivanthi Aditanar college of Engineering, Tiruchendur  
E-mail id: info.antonywilbertsingh@gmail.com

## Abstract

The Fe-Mn-Si shape memory alloys (SMA) produced by powder metallurgy technique for various compositions with the addition of alloying elements nickel and copper were tested for its tensile strength. A maximum tensile strength of 290 MPa was exhibited by the alloy having Fe-35%Mn-8%Si-2%Ni. It was compacted by applying a pressure of 550 MPa and sintered at a temperature of 750 °C. The SMA revealed a maximum hardness of 85 in Rockwell hardness. The effect of alloy additions on the microstructure and formation of various compounds of shape memory alloy were examined by Optical Microscope.

## Introduction:

Shape memory alloys can be classified into two broad categories one is ferrous alloys and another one is nonferrous alloys. The ferrous SMA consists of 'Fe', 'Mn', and 'Si' as major alloying elements and 'Ni' is added to these alloys to enhance corrosion resistant properties. The costs of the ferrous SMA's are less than non-ferrous alloys. But the shape memory effect exhibited by these alloys are one way, further, certain limitations are shown by these alloys on shape memory effect itself. Therefore, a need arises to investigate by adding alloying elements and varying the parameters to study the SMA effect. A shape memory alloy keeps the original shape in memory after deformation and regain its original shape when it is heated. A shape memory material has unique characteristics of relationship between stress, strain and temperature and is based on crystallographic reversible thermoplastic martensitic transformation. The phase transformation taking place at low temperature is martensite and the transformation taking

place at higher temperature is known as austenite as in steel.

The structure and shape memory effect of 60%Fe29%Mn-11%Si alloy was studied by Karolina Gaška et al. The powders were mechanically alloyed for 30 hours in a planetary ball mill, compacted and sintered at 1027K. The investigations revealed  $\gamma$ -FCC and  $\epsilon$ -HCP phases formed after mechanical alloying for 30 hours. These sample after mechanical alloying showed shape memory effect. Chenglao Li et al described the effect of Fe-Mn-Si-Cr-Ni shape memory alloy with the addition of alloying elements namely 'Ce', 'Ti' and 'N'. The shape memory effect was raised with the addition of 'Ce', on the other hand addition of 'Ti' and 'N' enhanced shape memory effect to a very high level. Nevin Balo et al studied the oxidation behavior of Fe-Mn-Si and Fe-Mn-Si-Cr SMA's under isothermal conditions. The oxidation of Fe-Mn-Si alloy was less with the addition of 'Cr' in Fe-Mn-Si alloy. The oxidation activation energies of the Fe-Mn-Si and Fe-Mn-Si-Cr alloys were found to be 126.79kJ/mol and 105.74kJ/mol, respectively. The formed oxides for the Fe-Mn-Si and Fe-Mn-Si-Cr alloys were determined by XRD patterns. Shipu Chen et al investigated the effect of nitrogen on properties including shape memory effect, mechanical behavior and corrosion behavior of Fe-Mn-Si-Cr based alloys. The shape memory effect was improved with the addition of small amounts of nitrogen in Fe-25%Mn-6%Si-5%Cr alloys. The tested alloys containing more than 0.12 weight percentage of nitrogen showed an excellent shape memory effect. Nitrogen is an austenite stabilizing element; therefore, it strengthens the austenite phase by raising the critical stress to offset the slip planes and dislocations.

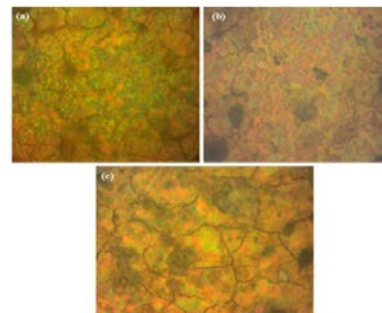
**Experimental Work:**

Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shape known as compacting, and then heating the compressed material in a controlled atmosphere to bond the material which is known as sintering. The powder metallurgy process generally consists of four basic steps: powder manufacture, powder blending, compacting, and sintering. Compacting is generally performed at room temperature but in few cases it is carried out at higher temperatures. , 'Fe', 'Mn', 'Si', 'Cu' and 'Ni' metal powders are purchased from LOBA metal powder company. The average particle size of powders is in the range of 40-45 microns. The cold compactions of powders for various compositions were done by using a cylindrical die having a bored hole dimension of 20 mm diameter and 50 mm height. The experiments are conducted by varying the composition of the alloying The process parameters are set at two levels.

The sintering process for the powder preforms were carried out in the temperature range of 950-1050° C for 2 hours followed by furnace cooling. The optical microscopic examination of the samples was carried out by polishing them using different grades of silicon carbide abrasive sheets. Finally, the samples were polished with Alumina compound to obtain mirror finish. The polished surfaces are etched with a chemical etchant containing 5 g CuCl<sub>3</sub>, 15 ml ethanol and 10 ml HNO<sub>3</sub>. The mechanical properties of the Fe–Mn–Si cylindrical specimens were evaluated by conducting tensile test and hardness assessment on the rectangular section of 6 mm width and 2 mm thick specimens. The tensile test specimens were of 2 mm in diameter and 15 mm in gauge length. The tensile test is conducted using a specially designed fixture, to hold the specimen and this fixture is held in a tensile testing machine of 200 ton capacity. The load range of the machine is very high, therefore, a load cell having 7000 N capacity is used to measure the tensile load applied on the small test specimens. The broken tensile test specimens are shown in Figure 1 (c). The shape memory properties were evaluated by carrying out bend test on thin strips of rectangular section specimens with the dimensions of 3 mm × 0.5 mm × 30 mm.

**RESULTS AND DISCUSSION****Optical microscopy**

The optical micrograph shown in Figure 2 (a), (b) and (c), corresponds to the three samples namely sample 1, sample 2 and sample 3 as given in Table 2. The micrographs reveal a combination of fine grains and coarse grains. The micrograph in Figure 2 (a) has nearly 85% ferrite and 15% austenite phase. The brown color regions in the micrograph are identified as ferrite phase and the regions in green color are identified as austenite phase. Austenite phase is present because of 30 % Mn addition in this alloy. Manganese has 50% austenite and 50% ferrite stabilizing effect. At the grain boundary triple points segregation of compounds such as secondary phase particles and intermetallic compounds are seen. At few places some spherical dark phases are noted which is identified as secondary phase particles. The secondary phases are FeO<sub>2</sub> and Fe<sub>3</sub>C. The thick and dark grain boundaries at few places reveal the precipitation of Mn<sub>3</sub>Si compound. In Figure 2 (b), Fe-Mn-Si-Ni alloy microstructure is shown. Only at few places grain boundaries are seen. Close look at the micrograph reveals the presence of very fine grains in the alloy. The percentage of ferrite and austenite phases is 80% and 20%, respectively. The brown colour regions in the micrographs are identified as ferrite phase and the regions in green colour are identified as austenite phase. Austenite phase is present because of 30 % Mn and 1% Ni addition in this alloy. Manganese has 50% austenite and 50% ferrite stabilizing effect. At few places some spherical dark phases are noted which are identified as secondary phases. The secondary phases are identified as FeO<sub>2</sub> and Fe<sub>3</sub>C. Thickening of grain boundaries are not found in this micrograph. The micrograph shown in Figure 2 (c) reveals the presence of large grains in the microstructure. Grain growth is observed in this alloy combination Fe-Mn-Si-NiCu processed at 1050°C.



**Figure:1,2 & 3 OM images**

The sintering temperature is closer to the melting point of copper, therefore, eutectic compound might have formed at few places. Also, the molten copper binds the alloy and improves the mechanical properties. At the top right side of the micrograph few recrystallized grains or region resembling eutectic mixture is seen. The average grain size is less than 25 microns. The microstructure consists of ferrite and austenite phases. The ratio of ferrite and austenite in this alloy is 75:25. This alloy has austenite stabilizing elements such as 'Mn', 'Ni' and 'Cu', therefore the austenite content is more. At few places some spherical dark phases are noted which are identified as secondary phases. The secondary phases are classified as FeO<sub>2</sub> and Fe<sub>3</sub>C. Thick grain boundaries are not found in this micrograph.

## CONCLUSION

The shape memory alloys Fe-Mn-Si with the addition of 'Cu' and 'Ni' were produced by varying the parameters such as composition, compacting pressure and sintering temperature. These alloys possessed good machinability, moderate 301 MPa was exhibited by a Fe-30%Mn-6%Si1%Ni alloy. The sample failed in a ductile manner. Brittle fracture was prevalent in the shape memory alloys such as Fe-30%Mn-6%Si and Fe-30%Mn-6%Si-1%Ni-1.5%Cu. The hardness values of the samples were not so high. A maximum hardness of 78 in Rockwell hardness B scale ductility and strength. A maximum tensile strength of was recorded.

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