MECHANICAL PROPERTIES STUDIES OF CU AND NI ADDITION IN FE BASED SHAPE MEMORY ALLOY

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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 it's 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 950 °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 it's 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 Gąska et al. The powders were mechanically alloyed for 30 hours in a planetary ball mill, compacted and sintered at 1027K. The investigations revealed γ-FCC and ε-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^{o} 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 Cucl3, 15 ml ethanol and 10 ml HNO3. 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

TENSILE STRENGTH

The tensile test results of the various samples are shown in Table 3. The sample 1 has yielded a tensile strength of 290 MPa. The composition of the alloy is Fe-30%Mn-6%Si and the poor strength exhibited by this alloy is attributed to lower sintering temperature. A maximum tensile strength of 301MPa was observed for the sample 2. The maximum tensile strength obtained for this sample is attributed to dispersion of secondary phase particles and intermetallic compounds. Further, fine grains increases strength of the alloy. For the sample 3 containing Fe-30%Mn-6%Si-1Ni-1.5%Cu the tensile strength value obtained is 286 MPa. This tensile strength value is better than the strength value obtained for the sample 1. The increase in strength is attributed to the addition of more amounts of alloying elements and therefore more amounts of intermetallic compounds are formed because of this dispersion strengthening effect is imparted. The graphical plot between the sample number and tensile strength of the samples is shown in Figure 3. The sample 2 has exhibited maximum tensile strength compared to all the other samples. The samples 1 and 3 exhibited limited ductility and failed in a brittle manner in comparison with the sample 2.

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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