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FORMATION OF Cu-Al-Ni SHAPE MEMORY ALLOY WITH THE ADDITION OF ALLOYING ELEMENTS Mn AND Si

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Abstract— The Cu-Al-Ni shape memory alloy billets were prepared using powder metallurgy technique by varying composition of major alloying elements such as copper and aluminium, and minor alloying elements manganese, and silicon. The sintered billets of 20 mm in diameter were machined to 18 mm in size in a lathe. The machinability of the sintered powder compacts were good. The tensile strength of the Cu-Al-Ni alloy sample without any minor alloying elements was 308.36 MPa. The hardness assessment carried out on the specimens revealed a maximum hardness value of 64 in rockwell hardness 'B' scale for the alloy Cu-Al-Ni with 'Mn' and 'Si' in it. The optical micrographs revealed the presence of fine grains and intermetallic compounds.

.**Index Terms**—*Alloy, powder metallurgy, shape memory effect, tensile test*.

1 INTRODUCTION

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 martensitic transformation temperatures can be "adjusted" between -200°C and 200°C. The shape memory properties are based on properties of the high temperature binary Cu-Al phase known as β, having a body centre cubic structure. Among various shape memory alloys, the costs of copper based shape memory alloys are less and have commercial significance. Cu-Al-Ni shape memory alloys are the only suitable alloys for high transformation temperatures requirement.

Li et al fabricated Cu–Al–Ni–Mn shape memory alloy by adopting mechanical alloying and vacuum hot pressing followed by hot extrusion. The samples were examined with scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis. Presence of intermetallic compounds and their distribution was revealed in the above examinations. Morin and Trivero studied the thermo mechanical fatigue behavior of Cu–Al–Ni shape memory alloy. They studie d the effect of fatigue cycles and applied stress on shape and transformation temperature of SMA.

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The shape memory recovery of the hot-extruded sample solution-treated at 850 °C for 10 min and quenched in water was 100% as it was immersed in boiling water bath for 40 s after deformed to 4.0%. The shape memory recovery of the sample remains 100% as it was subjected to cyclic loading conditions for 100 times.

Cortes et al prepared multilayer shape memory alloy thin films with different Cu–Al–Ni composition. This multilayer's were thermally treated to produce alloys by solid solution diffusion and characterized for the martensite phase. Aydogdu et al investigated the role of long-term ageing on martensite characteristics and stabilization in two Cu–Al–Ni alloys. Each sample was heat-treated for long time and the heat-treatment time was selected in such a manner that the difference in time between each sample was very long. The XRD performed on the samples revealed variation in'd' spacing among the selected pairs of selected diffraction planes in the martensite formed

Segui et al presented the changes in the martensitic transformation of a two different composition Cu-Al-Ni-Ti alloy by hot-rolling at two different temperatures 600 and 800 °C. Mechanical properties of the alloy and internal friction were significantly improved by thermal treatments. Dagdelen et al revealed the martensitic transformation behavior, morphology and transition temperatures in copper-based shape memory alloys were strongly influenced by heat treatments. The effects of various quenching methods such as up-quenching and step-quenching in a water bath at 100 °C and in an oil bath at 200° C was studied on two way shape memory Cu–Al–Ni alloys. The changes in entropy and enthalpy at the martensitic transition were determined by means of differential scanning calorimeter (DSC) measurements. The quenching heat-treatment performed on the samples had influence on the transformation temperatures. The SMA's are light in weight and replaces conventional hydraulic, pneumatic and electrical actuators in var-

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ious fields. The SMA's are used in automotive, aerospace, robotics and in biomedical industries.

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2 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 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. Cu-Al-Ni-Mn-Si metal powders are purchased from MEPCO metal powder company, Madurai. The average particle size of powders is in the range of 27-44 microns. The cold compactions of powders for various compositions were done by using cylindrical die with bored hole to produce billets of dimension of 20 mm diameter and 30 mm height. The experiments are conducted by varying the composition of the alloying elements as shown in Table 1. The process parameters are set at two levels and the values are shown in Table 2.

. Table 1 Composition of Cu-Al-Ni-alloys.

Composition in wt.%	Cu	Al	Ni	Mn	Si
Cu-Al-Ni	Bal	14	4	-	-
Cu-Al-Ni-Mn	Bal	14	4	2	-
Cu-Al-Ni-Mn-Si	Bal	14	4	2	0.5

Table 2 Experimental parameter setting

Sample No	Composition	Pressure MPa	Temperature °C
1	Cu-14Al-4Ni	620	850
2	Cu-12Al-5Ni-2Mn	560	900
3	Cu-14Al-4Ni-2Mn-0.5Si	560	900

The sintering process for the powder preforms were carried out in the temperature range of 850-900 °C for 2 hours followed by furnace cooling. The optical microscopic examination of the samples was carried out by polishing the samples 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 $FeCl_3$, 15 ml ethanol and 10 ml HCl. The mechanical properties of the Cu–Al–Ni cylindrical pieces were evaluated by conducting tensile test and hardness assessment on the 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 as shown in Figure 1 (a) to hold the specimen and in turn the fixture is held in a tensile testing machine of 200 ton capacity as shown in Figure 1 (b). The load range of the machine is very high, therefore, a load cell having 7000 N capacity is used. The shape memory properties were evaluated by carrying out bend test on thin strips of rectangular section specimens with the dimensions of 30 mm × 3mm × 0.5 mm. The shape recovery ratio (SRR) due to one-way SME was estimated using following expression:

$$\epsilon = \left(\frac{t}{D+t}\right) \times 100\% \text{------------------1}$$

$$\eta = \left(\frac{90^0 - \theta_1}{90^0}\right) \times 100\% \text{---------------- 2}$$

Where

η =% of recovery
θ= strip recovery angle in °
ε= strain deformation
t= thickness of strip in mm
D= diameter of roller in mm

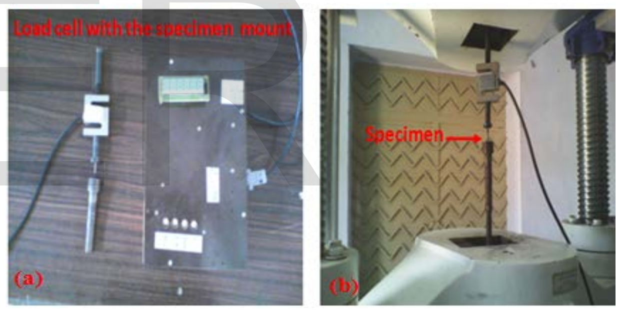

Figure 1 (a) Tensile test specimen fixed in a fixture and (b) mounted in tensile testing machine.

3 Results and Discussion

3.1 Optical microscopy

The optical micrograph shown in Figure 2 (a), (b) and (c), corresponds to the three samples namely sample 1, sample 2 and sample3 as given in Table 2. The micrographs reveal a combination of fine grains and coarse grains. The grain size is very small at few places because of grain refinement taking place with the addition of alloying elements 'Mn' and 'Si'. At few places dark phase is observed which indicates the presence of aluminium oxide and interemtallic compounds. In Figure 2 (a) at the central region few large grains are seen and the size of the large grin is less than 20 microns. But on the other sides of the central region and along the grain boundaries of large grains very fine grains are noted. These grains are of less than 5 micron in size. Also at few places in the large grains fine circular white and dark particles are seen and these

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particles are identified as $CuAl_2$, Al_2O_3 and Mn_3Si particles. At few places annealing twins are also seen. These annealing twins are formed because of one hour soaking time provided during sintering of the powder compacts.

In Figure 2 (b) at the centre interdendritic growth of copper rich region is observed which is identified as reddish brown region. One can notice that these dendrites have fine grains in it. Also, few large grains are seen and the average grain size is less than 12 microns.

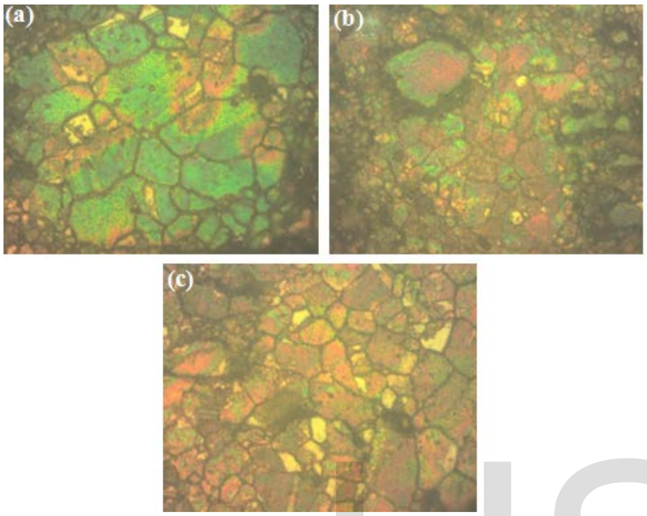

Figure 2 Optical micrographs of the (a) sample 1(b) sample 2 (c) sample 3

The microstructure reveals a combination of fine and coarse grains throughout the matrix and these grains are smaller than the grains seen in the Figure 2 (a). The green coloured regions in the micrograph reveal the presence of nickel aluminide and yellowish brown areas are identified as copper aluminides. At few places dark regions are identified as intermetallic compounds of 'Mn' and 'Si' and oxides of copper and aluminium.

The micrograph shown in Figure 2 (c) reveals very fine grains at the centre and at the left side of the micrograph. At the bottom right side few large grains are noted. Even these large grains are smaller than the large grains seen in the micrograph shown in Figure 2 (a). Along the grain boundaries recrystallization has taken place because of this very fine grains are seen all over the micrograph. Also at few places in the large grains fine circular white and dark particles are seen and these particles are $CuAl_2$, Al_2O_3 and Mn_3Si particles. Further, few yellow grains are seen in the matrix, these fine grains are rich with aluminium. These yellow grains are formed because this alloy contains 14% Al in it. Melting point of 'Al' is only 660 °C, therefore, during sintering it melts and forms compounds and binds the other elements together to provide strength to the powder compacts. That is why recrystallization and grain refinement is inevitable in this alloy system because sintering is carried out above the melting point of 'Al'. Further, few very fine yellow grains are seen in Figure 2(b). But the yellow grins are dispersed as fine grains throughout the matrix. Compared to Figure 2 (b), the Figure 2 (a) reveals few yellow grains and they are larger in grain size.

3.2 Tensile strength

The tensile test results of the various samples are shown in Table 3. A maximum tensile strength of 308.36 MPa was observed for the sample 1 as given in Table 2. The maximum tensile strength obtained for this sample is attributed to lesser amounts of intermetallic compounds formed in the alloy. For the sample 2 the tensile strength was 288.76 MPa. This tensile strength value is better than the tensile strength value obtained for the sample 3. As the alloy content increases, the tensile strength decreases because of more amounts of intermetallic compounds formed in the alloy. The tensile strength of the alloy containing Cu-Al-Ni-Mn-Si exhibited a minimum tensile strength of 271.67 MPa.

Table 3 Tensile strength of the powder samples.

Shape memory alloys		Tensile strength MPa	Average tensile strength MPa
Cu-Al-Ni	Specimen 1	297	308.36
	Specimen 2	319.72	
Cu-Al-Ni-Mn	Specimen 1	284.24	288.76
	Specimen 2	293.29	
Cu-Al-Ni-Mn-Si	Specimen 1	277.08	271.67
	Specimen 2	266.27	

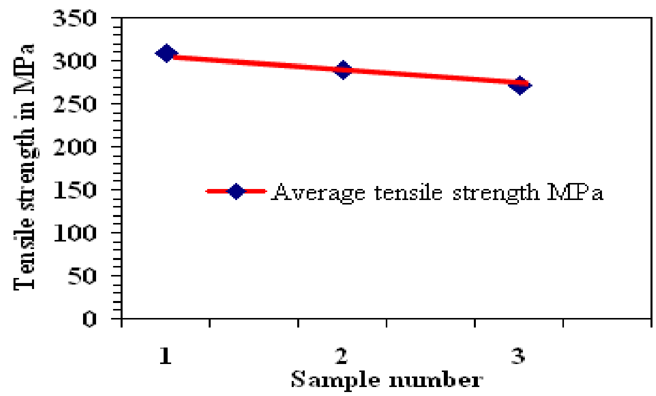

Figure 3 A graphical plot between sample number vs. tensile strength.

4 Conclusions

- The shape memory alloys Cu-Al-Ni with the addition of 'Mn' and 'Si' were produced by varying the process parameters such as composition, compacting pressure and sintering temperature.

- These alloys possessed good machinability, moderate ductility and strength.
- A maximum tensile strength of 308.36 MPa was exhibited by a Cu-Al-Ni alloy without 'Mn' and 'Si' addition. The sample failed in a ductile manner.
- Brittle fracture was prevalent in the shape memory alloys added with 'Mn' and 'Si' in Cu-Al-Ni alloys.
- The hardness of the samples was not so high. A maximum hardness of 64 in Rockwell hardness B scale was obtained.

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