Synthesis and Characterization of Cuznal Based Shape Memory Alloys and to Optimize Behavior on Different Properties by Varying Weight Percentage

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Abstract: Shape memory behavior was studied in 1932 by ¨ Olander in his study of “rubber like effect” in samples of gold-cadmium and in 1938 by Greningerand Mooradian in his study of brass alloys (copper-zinc). Many years later in 1951 Chang and Read first reported the term “shape recovery”. They were also working on gold-cadmium alloys. In 1962 William J. Buehler and his co-workers at the Naval Ordnance Laboratory discovered shape memory effect in an alloy of nickel and titanium. He named it NiTiNOL (for nickel-titanium Naval Ordnance Laboratory). Copper, Zinc, Aluminium alloys are formed between 60% to 80% copper, 15% to 30% consists of zinc, 3% to 10% of Aluminium in various proportions. A Lamellar structure of metallic Al and Brass (Copper-Zinc) foils are introduced for Copper based or Aluminum based metal matrix composite in Muffle Furnace. Since Nitinol (Ni-Ti) shape memory alloy is too expensive when compared with CuZnAl shape memory alloys (SMA) the aim is to prepare CuZnAl shape memory alloys to give the same properties as that of Nitinol. By using Copper, Zinc and Aluminum for preparing CuZnAl based shape memory alloys the composition is kept in the range of Zn 15-30%, Al 3-10 % and rest of Copper. After taking this composition, the heat treatment process for manufacturing shape memory alloys was done in the muffle furnace. Hardness by quenching process has also been done. The prepared shape memory alloys based on Copper, Zinc and Aluminum provides a scope for dense, compact articles having good mechanical properties and other properties associated with the shape-memory effect.

Key words: Aluminum based shape memory alloys, Microscopic images, Hardness, Surface roughness, Spectrometer.

1. Introduction

It has already been proposed to produce shape-memory alloys of the Cu/Zn/Al by powder metallurgy (M. Follon et al. 1978)[1], starting with previously prepared alloys corresponding to the final composition. In such processes the prepared powder is encapsulated, cold compacted, hot pressed and extruded. However, these ‘methods are not adapted to all practical requirements and the finished articles often leave something to be desired in their mechanical properties. The necessary characteristics of these alloys is to ensure the long-time operation of a shape memory alloy. The intermetallic Cu-Zn-Al alloy has been considered for many applications as a consequence of low density, high thermal conductivity, high specific modulus, good creep and fatigue resistance[2][3].

In the alloys that display shape memory effect, only two alloy systems have achieved the level of commercial exploitation. These are NiTi (nickel-titanium) and copper based alloys [4][5]. Properties of both systems are quite different. The NiTi alloys have greater shape memory strain (up to 8% as compared to 4-5% for the copper based alloys), tend to be much more thermally stable, have excellent corrosion resistance and have much higher ductility. On the other hand, the copper based alloys are much less expensive, exhibit higher actuation temperatures (approximately in the range -200°C to +200°C) than NiTi alloys and are sometimes the only choice for high temperature applications (i.e. above 100°C). Copper based shape memory alloys have the advantage that they are made from relatively cheap materials using conventional metallurgical processes such as induction melting. Martensite (Ms) formation temperature, for ternary (three-element) alloys of copper, zinc and Aluminium can be made to vary over more than 400°C, as a result of only small changes in Composition. The shape memory alloys all lie in the copper–rich corner of the triangle, representing ternary mixtures. The amount of Aluminium varies from about 4 to 10%, the amount of zinc vary from 10 to 28 %. Addition of Aluminium to the binary alloy considerably increases the transformation temperatures. Varying the composition of aluminium between 5 wt.% (weight percentage) to 10 wt.% can shift the Ms temperature from −180°C to 100°C. However, the parent phase exhibits a strong tendency to decompose into its equilibrium phases when overheated or aged. Due to this, the operating temperatures are typically restricted to approximately 100°C or higher. The transformation temperatures of the alloy are extremely sensitive to composition and zinc can be lost during the melting process. Due to these factors, the fabrication process of the alloy needs to be precisely controlled.

2. Composition and Transformation Temperature

CuZnAl SMA's usually contain 15-30% zinc and 3-7% Aluminium, with the rest being copper. The addition of small quantities (usually less than 1%) of boron, cerium, cobalt, iron, titanium, vanadium and zirconium are commonly added to control grain size. Use of grain growth control additives keeps grain size down and overcomes brittleness issues. However, additions should be made carefully as they can upset the stability of the structure, thus affecting the shape memory characteristics.

3. Experimental

Pure copper, zinc and nickel were taken in right quantities to weigh 300 g of the alloy in total and were melted in Muffle furnace. The molten alloy was poured into a cast iron mold of dimensions 120 mm × 80 mm × 10 mm and allowed to solidify. The solid material was then homogenized at 850˚C for 2 hour. The chemical composition of the alloy was determined using SPECTROMAXX MAKE AMETEK, which has the capability to analyze compositions up to an accuracy level of second decimal place. The homogenized alloy sample was hot rolled at 800˚C. The hot rolled sample was homogenized for 5 hour at 800˚C and step quenched into a boiling water bath (~100˚C), followed by quenching into a water bath at room temperature (~30˚C). Step quenching was used to prevent the quench cracks and the pinning of martensitic plates by excess dislocations retained on quenching from high temperature. The shape memory effect is a temperature-dependent effect. During shape memory effect, if the recovery of shape is constrained/hindered, then the alloy generates a force that can be used to do some useful work. The transformation from austenite to martensite and the reverse transformation from martensite to austenite are diffusionless in character and occur over a temperature range. The microstructure and morphology of martensite formed was studied using an optical microscope.

CuZnAl alloys can be produced using conventional processes such as muffle furnace. Nitrogen or other inert gases are used for shielding purposes over the melt and during pouring to prevent zinc evaporation. But in the alternative proposed method the copper melted at 1083°C, then added zinc for 1-2 minutes. Then added Aluminum for 15-30 seconds and took out the melted material and poured into the die for taking desired shape. Alloys with lower Aluminum contents can be cold worked with interpass annealing. Cold working becomes increasingly more difficult with increasing Aluminum content. Following hot working, they are subject to a suitable solution heat treatment involving controlled cooling (often water quenching), which help to dictate properties such as transformation temperature. Prolonged solution heat treatment should be avoided as the zinc tends to evaporate and the alloys excessive grain growth can occur. Post quench ageing was required to establish the transformation temperature, as the quenched transformation temperature is usually unstable. If quenched too rapidly into the martensite phase, CuZnAl alloys are susceptible to martensite stabilization. This effect inhibits and may totally negate the shape memory effect. In practice it increases the reverse transformation shift temperature. Slower quenching or step quenching may be necessary for alloys. The figure below represents flow chart for the production of Copper Zinc Aluminum SMA.

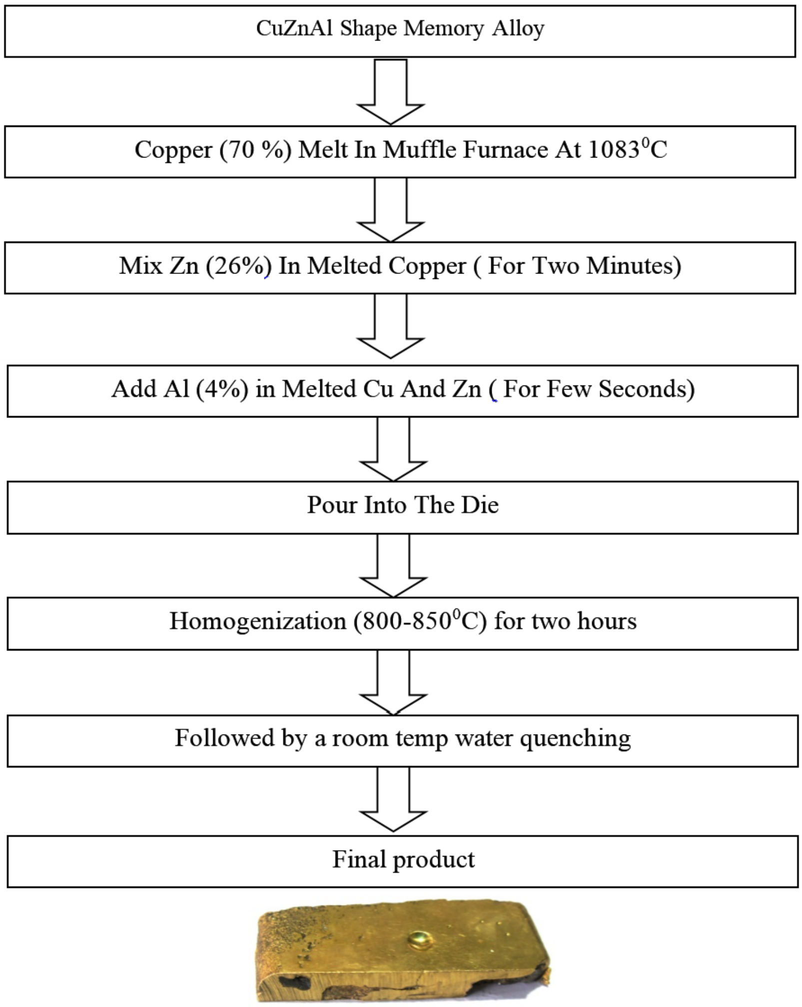

Fig. 1. Flow diagram showing that the production of Copper Zinc Aluminum shape memory alloys.

4. Results and Discussion

4.1. Spectrometer Result

The actual composition of various CuZnAl shape memory alloys is given in Table1. The composition were determined by Spectromaxx Ametek.

Table 1. Composition Table

Sample .No	Cu	Zn	Sn	Pb	Fe	Al	Ni	Mn	P	Si	bi
1	72.38	21.65	0.791	1.67	0.182	3.0105	0.228	0.00227	<0.0010	<0.01	<0.0033
2	75.73	18.52	0.403	0.986	0.245	4.0049	0.0268	0.0017	0.013	<0.01	0.0022

In the above composition table, the compositions were changed, because the melting point of copper is too high and the zinc melting point is too low, likewise the melting point of Aluminium is also low. The composition results shows that the copper composition increased to 72.38 % and zinc composition decreased to 21.65%, Aluminum composition also decreases from 4% to 3.0105%. In the second sample the copper composition increased to 75.73% and the zinc composition decreased to 18.52% and the Al composition also decresed to 4.0049%. It is due to the difference of melting temperature.

4.2. Hardness Test Results

The result of hardness test was carried out by Rockwell hardness tester (MODEL 250 MAKES FIE SR.NO 8069). The various hardness results have been summarized in the Table 2.

Table 2. Rockwell Hardness of SMA.

Sample .NO	Material Composition	BHN	VHN
1	Cu 70 % Zn 26% Al 4%	95-96	210-216
2	Cu 75 % Zn 20% Al 5%	88-90	180-185

It shows that when the percentage of Copper and Zinc is increased the hardness gets increased. In sample the value of Copper is 70% and Zinc is 26% so the hardness is 210-216 VHN. Use of grain growth control additives keeps grain size down and overcomes brittleness issues. However, additions should be made carefully as they can upset the stability of the structure, thus affecting the shape memory characteristics. The recoverable strain is approximately 4 to 5% with good electrical conductivity and mechanical strength.

4.3. Roughness Test

The result of roughness test was carried out by Roughness tester Mitutoyo model no. (sj-210). The various results are summarized below.

Sr No.	Material Composition	Rx	Ry	Rz
1.	Cu 70 % Zn 26% Al 4%	0.659µm	0.808 µm	4.157 µm
2.	Cu 75 % Zn 20% Al 5%	0.236 µm	0.332 µm	2.245 µm

In the above results Rx= X axis, Ry= Y axis, Rz= Z axis

The comparison of the above results shows that sample no. 2 is more smooth and the composition of sample no. 2 is sufficient for the automobile sector for making pistons and piston rings

5. Applications

In one of the well-developed application, shape memory alloys provide simple and virtually leak proof couplings for pneumatic or hydraulic lines (VicenceTorra et al. 2001)[5]. The alloys have also been exploited in mechanical and electromechanical control systems, for example a precise mechanical response to small and repeated temperature changes (Worden K et al. 2003[6]; Hodgson D. E. et al.; Van Humbeeck J. et al.

1994)[7][8]. Shape memory alloys are also used in a wide range of medical and dental applications (healing broken bones, misaligned teeth) (Divecha. A. et al. 1990; Hodgson D. 2006). The various application points of SMA in auto mobiles is shown in Fig. 2.

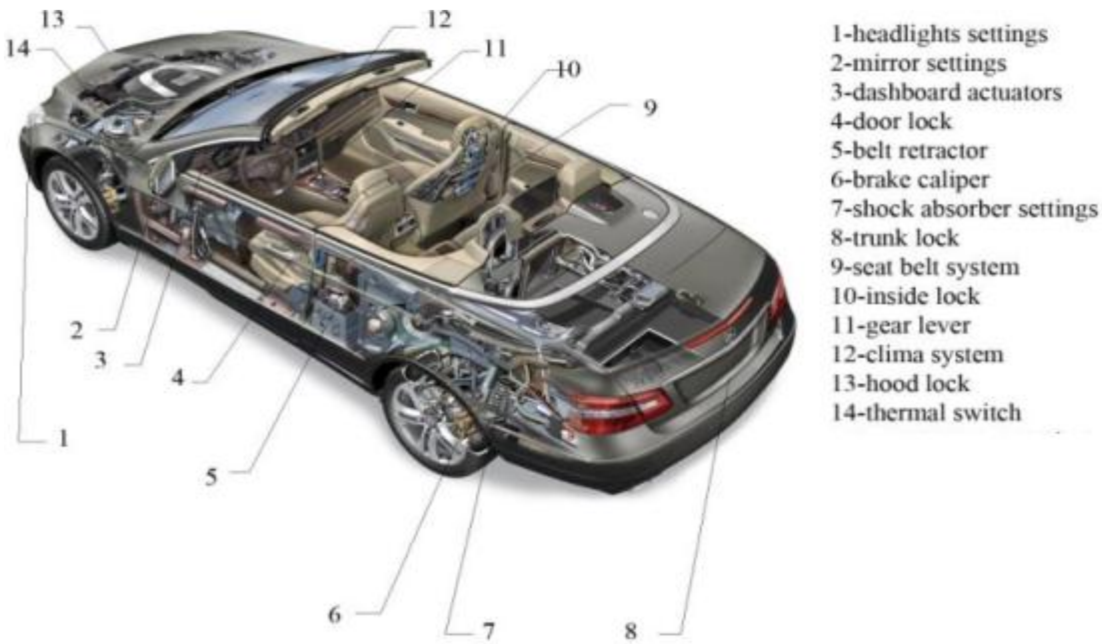

Fig. 2. Application points of SMA in automobiles.

5. Conclusion

The SMA with different composition is molded and studied and it is found that the hardness of sample numbered 1 with Copper composition of ~70%, Zinc Composition of ~26% and Aluminum Composition of ~4% (refer table 2) is good enough for automobile application. The sample No. 2 can be used in pistons, piston rings and helicopter blades and furthermore if the percentage of Zinc is increased the hardness gets increased but if the Zinc percentage is made greater than 30% then the material becomes brittle.

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Refrences

[1] Follon, M., & Aernoudt, E. (1978). Powder-metallurgically processed shapememory alloys, *Proceedings of the 5th European Symposium on Powder Metallurgy*, Stockholm (pp. 275-281).
[2] Divecha, A. P., Farrando, W. A., Hesse, P. W., & Karmarker, S. D., U.S. Patent #4,958,763, (1990).
[3] Van, H. J., & Cederstrom J. (1994). The present state of shape memory materials and barriers still to be overcome. *Proceedings of the first international conference on shape memory and superelastic technologies*, (1–6), March 1994.
[4] Hodgson, D. E., Wu M. H., Biermann R. J., Shape Memory Applications, Inc., Memory Technologies, Harrison Alloys, Inc., http://web.archive.org/ web/20030605085042/ http://www. sma-inc.com/SMAPaper.html.
[5] *Smart Structure and Materials* (2001), Damping and Isolation, D.J. Inman, (Eds.), 4331, 324-332.

[6] Worden, K., Bullough, W. A., Haywood, J. (2003). Smart technologies, World Scientific, 109–135.

[7] Possibilities to use SMA in car systems (http://mercedesbenzblog.blogspot.com/2010_03_08_archive.html)

[8] Hodgson, D. E., Wu M. H., Biermann, R. J., Shape Memory Applications, Inc., Memory Technologies, andHarrisonAlloys,Inc.,http://web.archive.org/web/2000605085042/http://www.smainc.com/SMAPaper.html

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