IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
ISSN: 2278-1684, PP: 01-06
www.iosrjournals.org

Characterization of Cu-Al-Be Shape Memory Alloys

Ranganatha Swamy MK[1], Prashantha S[2], U.S.Mallikarjun[3]

[1](P.G Student, Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur-572103, Karnataka, India)
[2](Asst.Prof. Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur-572103, Karnataka, India)
[3](Prof. & Head, Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur-572103,Karnataka, India)

Abstract: *Shape memory alloys are the materials that 'remember' their geometry. A sample of SMA after being deformed from its original crystallographic configuration with residual strains up to 15%, it regains its original geometry by itself during heating (one-way effect) or, at higher ambient temperature, simply during unloading (pseudo-elasticity or superelasticity). Other characteristics include a strong damping effect, high mechanical strength and resistance to corrosion, mainly its metastability. Cu–Al–Be shape memory alloys in the range of 2–15 wt.% of aluminum and 0.01–3wt.% of Beryllium, exhibiting β-phase at high temperatures and manifesting shape memory effect upon quenching to lower temperatures, were prepared through ingot metallurgy. They were subsequently characterized by optical emission spectrophotometry, differential scanning calorimetry and optical microscopy. The shape memory properties of the alloys were studied by bend test. The objective of present investigation is to synthesis and characterize the Cu-Al-Be shape memory alloys.*

Keywords: *Shape Memory Effect, Microstructure, Bend Test, X-ray Diffractogram, Differential Scanning Calorimetry.*

I. INTRODUCTION

Shape memory alloys are materials that 'remember' their geometry. After a sample of SMA has been deformed from its original crystallographic configuration with residual strains up to 15%, it regains its original geometry by itself during heating (one-way effect) or, at higher ambient temperature, simply during unloading (pseudo-elasticity or superelasticity). Other characteristics include a strong damping effect, high mechanical strength and resistance to corrosion, mainly its metastability. These fundamental properties of SMAs distinguish them from other metallic alloys and have been known since the 1930s. The first reported steps towards the discovery of the shape memory effect were taken in the 1930s. According to Otsuka and Wayman (1998), A. Olander discovered the pseudoelastic behavior of the Au-Cd alloy in 1932. Greninger and Mooradian in 1938 observed the formation and disappearance of a martensitic phase by decreasing and increasing the temperature of a Cu-Zn alloy [1].

The basic phenomena of the shape memory effect governed by the thermoelastic behavior of the martensite phase was widely reported a decade later by Kurdjumov and Khandros in 1949 and also by Chang and Read in 1951. In the early 1960s Buehler and Wiley at the U.S. Naval Ordinance Laboratory discovered the shape me mory effect in an equiatomic alloy of nickel and titanium, which can be considered a breakthrough in the field of shape memory materials. This alloy with a composition of 53 to 57 % nickel by weight was named Nitinol (Nickel-Titanium Naval Ordnance Laboratory). It exhibited an usual effect: severely deformed, specimens of the alloy, with residual strains of 8-15 %, regained their original shape after a thermal cycle. This effect became known as the shape-memory effect, and the alloys exhibiting it were named shape-memory alloys. On the other hand, many investigation have been reported on Cu-base shape memory alloys consisting of economical materials, such as Cu-Zn-Al, Cu-Al-Ni, Cu-Zn-Si, and Cu-Zn-Ga. Among them, Cu-Zn-Al alloy has become very popular as a Cu-base shape memory alloy [2].

II. EXPERIMENT

Cu-Al-Be SMAs with 11.5 wt.% of Aluminum, 0.9 wt.% of Beryllium and rest is Copper were chosen for the

present study, as the alloys exhibit β-phase at high temperatures and manifest shape memory effect on quenching to form martensite in this composition range. The alloys were prepared in such a way that, small pieces of pure copper, aluminum and beryllium cut from the respective metal ingots were taken in the right quantities to weigh 500 g of the alloy and were melted together in an induction furnace. The molten alloy was poured into a cast iron mould of dimensions 150mm×100mm×5mm and allowed to solidify. The ingots were then homogenized at 900ºC for 6h. The compositions of the cast alloys were determined using an integrally coupled plasma-optical emission spectrophotometer. The alloy samples were then hot rolled at 900ºC to a thickness of 1 mm. The rolled samples were betatized for 30min at 900ºC and step quenched into boiling water (100ºC) and then quenched into a water bath at room temperature (~30ºC). The microstructure and morphology of martensites formed were studied using an optical microscope, and the shape memory effect was determined by bend test.

(a) (b)

Fig. 1 Schematic view of (a) Melting of alloy and (b) Alloy pouring into mould

III. RESULTS

3.1 Alloy Composition

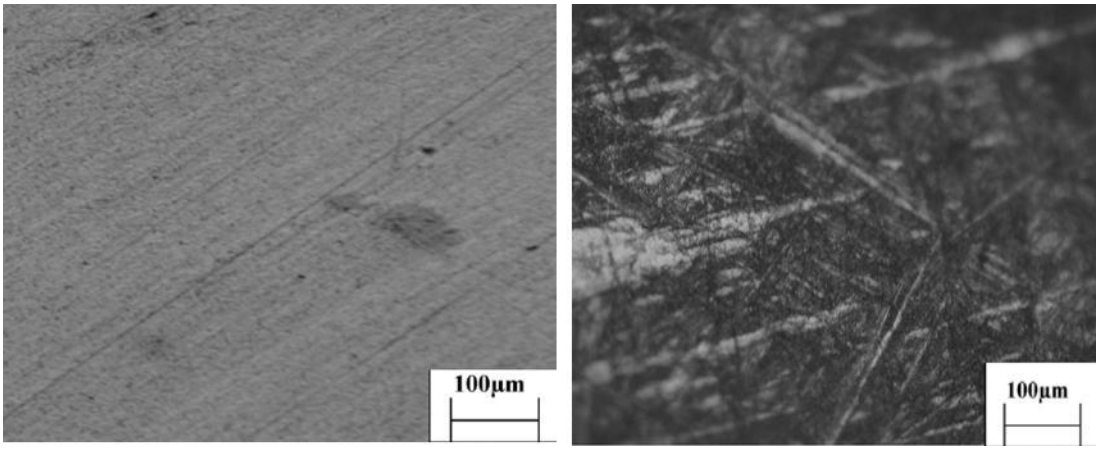
Alloys have been prepared with compositions ranging between Al - (9-15) wt% Be - (0.1-4) wt% Al and rest is of copper. To change transformation temperature, physical properties or mechanical properties, various ternary alloys are being developed. Among these, Cu-Al-Be alloys are most important from the reasons described above. The addition of Be exhibits various interesting effects, like there is change in the transformation temperature with change in Be content.

Table 1. Chemical compositions of the experimentally studied Cu-Al-Be alloys.

Alloy ID	**Chemical composition, wt%**		
	Cu	**Al**	**Be**
CAB 1	88.60	11.0	0.40
CAB 2	88.49	11.1	0.41
CAB 3	88.38	11.2	0.42
CAB 4	88.27	11.3	0.43
CAB 5	88.16	11.4	0.44
CAB 6	88.05	11.5	0.45
CAB 7	87.94	11.6	0.46
CAB 8	87.83	11.7	0.47
CAB 9	87.72	11.8	0.48

3.2 Microstructure

The Microstructure of a material strongly influence the physical and mechanical properties which inturn govern the application of these materials in industrial practice. The alloy shows the parent austenitic phase in the as- cast condition, whereas on step quenching it forms a completely lath type of martensite, indicating the complete transformation of austenite to martensite without leading to any precipitate formation. The martensite is formed by rapid cooling (quenching) of austenite which traps carbon atoms that do not have time to diffuse out of the crystal
structure.



(a) (b)

Fig.2 (a) Surface picture showing microstructure of parent phase, (b) Surface picture showing microstructure of martensite .

3.3 Differential Scanning Calorimetry

Transformation Temperatures, i.e. Ms, Mf, As and Af of the alloys were measured in Setaram DSC823 Differential Scanning Calorimeter under Nitrogen gas atmosphere. From the preliminary tests, temperature range of 30°C to 250/300°C, heating rate of 20 K/min and cooling rate of 10 K/min were found to be the optimum conditions for DSC testing of Cu-Al-Be alloys to determine the transformation temperatures. Due to strong composition dependence of the transformation temperatures of alloys, appropriate heating/cooling temperature ranges of each alloy were determined individually. Heating rates had to be optimized because high heating rates often decrease the resolution of the adjacent peaks and at very low heating rates sensitivity decreases and even the peaks may completely disappear. Cooling rates were limited to 10 K/min since at higher rates the detection of M_s and M_f temperatures becomes impossible due to reduced response time of the instrument. From this curve, A_s the austenite starting temperature, A_{max} the maximum phase transformation rate temperature and A_f the austenite finish temperature were determined as, 100, 125 and 140°C, respectively.

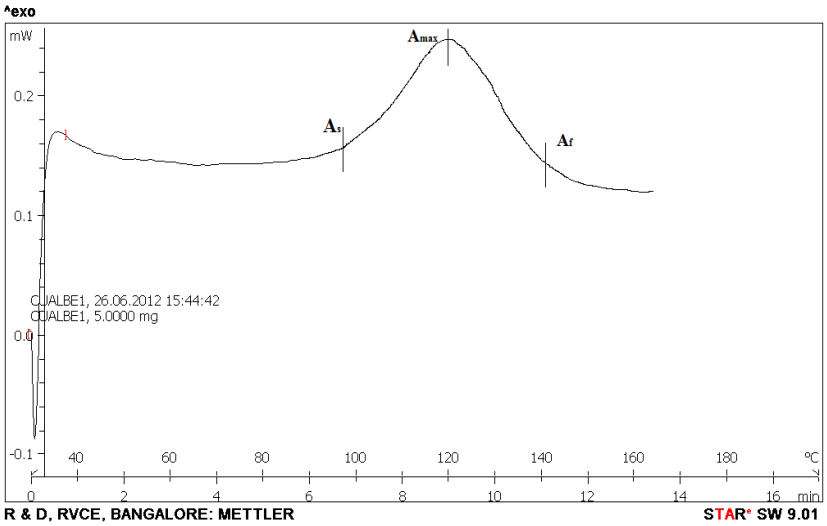


Fig 3. DSC plot of alloy CAB 13 showing the austenitic start and finish temperatures.

3.4 X-ray Diffractogram

Crystal structures of the alloys were determined using X-ray diffractogrammes taken in a Maxima Diffractometer. Diffractogrammes in the 2θ=20°-100° range were indexed by comparison with the master charts prepared for the possible martensite 18R and parent DO_3 crystal structures.

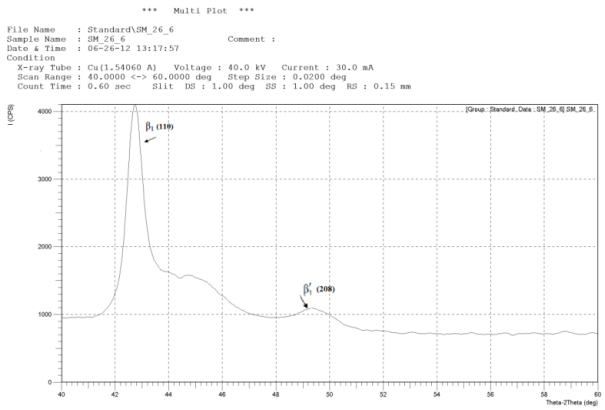


Fig 4. X-ray diffraction patterns of Cu–Al–Be SMA.

In order to determine the crystal structure of samples , X-ray diffractograms were taken from polycrystalline pieces of the alloys and. The alloys with aluminium contents above about 8 wt.% are subject to the formation of β-phase at high temperature, which upon slow cooling undergoes an eutectoid reaction α and γ_2.

Therefore, according to this composition, these alloys allow α, β, α_2 and γ_2 to be present. When the equilibrium cooling of these alloys take place, the peak having d=1.30 A° may correspond to a (2 2 0) plane and the peak having d=2.94 A° may correspond to γ_2 phase. Because of the rapid cooling has occurred while casting of these alloys, the equilibrium phases mentioned above have decomposed to the β_1 (DO_3) austenitic and β_1' martensitic phases. The X- ray diffractogram taken from sample 13 obtained from alloy with the composition Cu–11.70 wt.%Al–0.47 wt.%Be is shown in Fig 4. This diffractogram shows that sample 13 has included in both of the austenitic and martensitic phases. The peak in the middle of this diffractogram corresponds to the (110) plane of the β_1(DO_3) austenitic phase and the peaks on the right side correspond to the (208) planes of β_1' martensitic phases.

3.5 Shape Memory Effect by Bend Test

The shape memory effect was evaluated by bending a sheet specimen with dimensions of $1\times4\times50mm^3$ (thickness×width×length) into a flat strip shape at room temperature. The specimens were bent around a mandrel of known diameter at room temperature by the application of load. This treatment was resulted in the γ-ε transformation and bending of the sample. After bending the samples were recovered at 100ºC which resulted in the reverse transformation of stress induced (ε) martensite in to (γ) austenite and regaining original shape. During recovery treatment the bent samples were heated in the furnace at 600ºC for 5minutes and then cooled to room temperature. After recovery treatment the recovered angle (θ) was measured. To measure recovery angle the projection of the recovered sample was drawn on the paper and the angle was then measured with the help of a protector. A schematic diagram showing the procedure to conduct bend test is illustrated in Figure. The data recorded for bend test during training of our experimental alloy is presented in Table 2.

Table 2: Experimental data for measurement of shape memory effect by bend test.

Sample	d (mm)	t (mm)	ε_{sme} %	θ_m	SME %
CAB 9	32	1	2.0	60	66
CAB 10	32	1	2.5	72	80
CAB 11	32	1	3.0	78	87
CAB 12	32	1	3.5	80	89
CAB 13	32	1	4.0	85	95
CAB 14	32	1	5.0	90	100
CAB 15	32	1	6.0	90	100

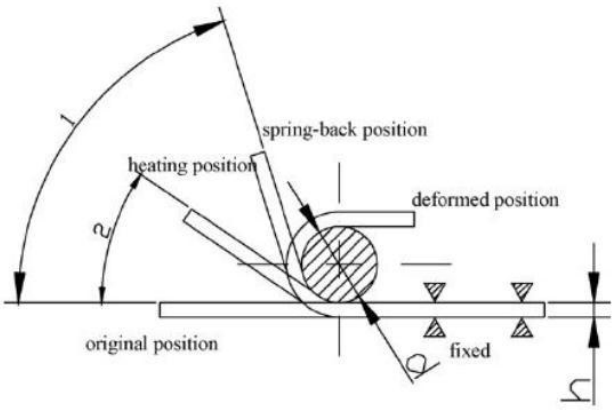


Fig.5. Schematic illustration of the bending test.

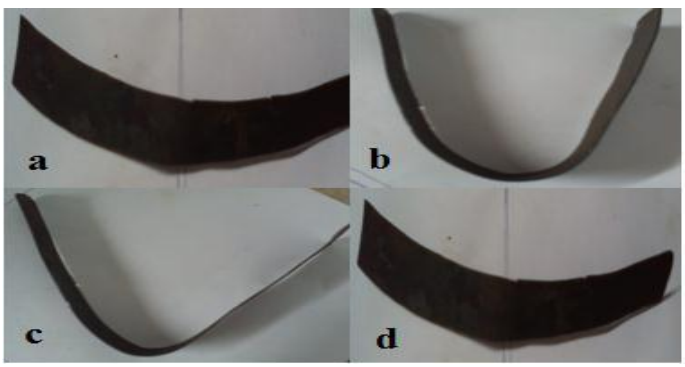


Fig.6. Shows the shape memory behaviour of Cu-Al-Be strip: (a) the austenitic sample at room temperature; (b) the bent sample in the cold water while it is in the martensite phase; (c) and (d) the occurrence of shape

memory behaviour during the heating from cold water temperature to room temperature.

After production, the strip shown in Fig. 6. (a) was homogenised at 800ºC for 30 min in the β-phase region and cooled in the water for stabilizing of the austenite phase. The austenitic strip sample was placed in cold water where the martensite phase occurred. Whilst the specimen was in the cold water, the martensite strip was bent and deformed plastically, as shown in Fig. 6. (b). During subsequent raising of the temperature from that of cold water temperature to room temperature, the bent ribbon become a flat strip by itself as shown in Fig. 6.(c) and (d). This is an important shape memory behaviour for samples producing from almost commercially pure elements.

IV. CONCLUSIONS

1. Synthesis of Shape Memory Alloys by using ingot metallurgy process involves less time and also less manufacturing costs.
2. As per the experimental work it was found that Cu-Al-Be SMA's exhibits good SME.
3. The Shape Memory Effect of the Cu-Al-Be SMAs varies with variation in chemical composition of the alloys.
4. It is observed that the M_S temperature decreases with aluminium and beryllium compositions.
5. Experimental work shows that Cu-Al-Be shape memory alloy exhibits 100% of shape memory effect and recovery strain of around 6%.

REFERENCES

[1] U.S. Mallik, V. Sampath. *Effect of composition and ageing on damping characteristics of Cu–Al–Mn shape memory alloys-Materials Science and Engineering A 478 (2008) 48–55.*

[2] V. Sampath and U.S. Mallik. *Influence of minor additions of boron and zirconium on shape memory properties and grain refinement of a Cu- Al-Mn shape memory alloy-ESOMAT 2009, 05028 (2009).*

[3] S. Nevin BALO, Neslihan SEL and Ayse AYDOGDU. *The Effect of Ageing on the Martensitic Phase Transformation in Cu-Al-Be Shape Memory Alloy" Turkish Journal of Science & Technology Volume 4, No 2,103- 109, 2009.*

[4] S.N. Balo, M. Ceylan, *Effect of Be content on some characteristics of Cu-Al-Be shape memory alloys" Journal of Materials ProcessingTechnology 124 (2002) 200-208.*

[5] J.F. Beltran, C. Cruz, R. Herrera, O. Moroni, *Shape memory alloy Cu-Al-Be strands subjected to cyclic axial loads" Engineering Structures33 (2011) 2910–2918.*

[6] A. lliguchi, K. Suzuki , Y. Matsumoto , K. Sugimoto, S. Komatsu and Y. Nakamura, *SHAPE MEMORY EFFECT IN Cu-Al-Be TERNARY ALLOYS" JOURNAL, DE PHYS IQUE Colloque C4, supplernent au n^o 12, 'l'ome 43, decembre 1982.*

[7] Fevrier 1995, F. Moreau, A. Tidu, Ph. Barbe, A. Eberhardt and J.J. Heizmann, *Study of Cu-Al-Be Shape Memory Alloy by X-Ray Diffraction" JOURNAL DE PHYSIQUE IV Colloque C2, supplement au Journal de Physique III, Volume 5.*

Proceedings Papers

PAPERS PRESENTED IN NATIONAL LEVEL CONFERENCE

- A Review on Catalytic CVD Synthesis of Carbon Nanotubes : Towards High Yield and Low Temperature Growth – Siddaganga Institute of Technology, Tumkur.
- Cu-Al-Be Shape Memory Alloys-A Review - Kalpataru Institute of Technology, Tiptur.
- Damping Characteristics of Cu-Al-Mn Shape Memory Alloys-A Review- Acharya Institute of Technology, Bangalore.
- Variaton in Characteristics of Cu-Al-Be Shape Memory Alloys Due to Variation in Be Composition - Rajarajeshwari College of Engineering, Bangalore.
- Synthesis of Cu-Al-Be Shape Memory Alloys - A Study - Nagarjuna College of Engineering, Bangalore.
- Corrosion analysis of Stainless Steel, Mild Steel and Cast Iron in different mediums like water, hank solution, and sea water Shridevi Institute of Engineering and Technology, Tumkur.

PAPER PRESENTED IN INTERNATIONAL LEVEL CONFERENCE

- Synthesis of Cu-Al-Be Shape Memory Alloys - M S Ramaiah Institute of Technology-Bangalore. PAPER PUBLISHED IN PAPER PUBLISHED IN INTERNATIONAL JOURNAL
- Shape Memory Effect in Cu-Sn-Mn Ternary Shape Memory Alloy Processed By Ingot Metallurgy – Transtellar International Journals.