Preparation and properties evaluation of Cu-Al-Be Shape Memory Alloy

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Abstract

Recently it has been found that the small addition of Be has the ability to provide the wide range of transformation temperature in Cu-Al-Be Shape Memory Alloys (SMA) which is interesting in the industrial point of view. In this paper, we have described the processing of Cu-Al-Be SMA by gravity die casting technology. The specially designed heat treatment procedure was used to stabilize the SMA effect in this alloy. The microstructure examinations showed the presence of lath martensite phases at room temperature. The bend test was used to confirm the existence of shape memory effect in this alloy.

Keywords: Bend testing, Cu-Al-Be Shape Memory Alloys, Gravity die casting, Martensite.

I.

II. -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 thermoplastic 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 memory 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 investigations 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

III. 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

A) Methodology

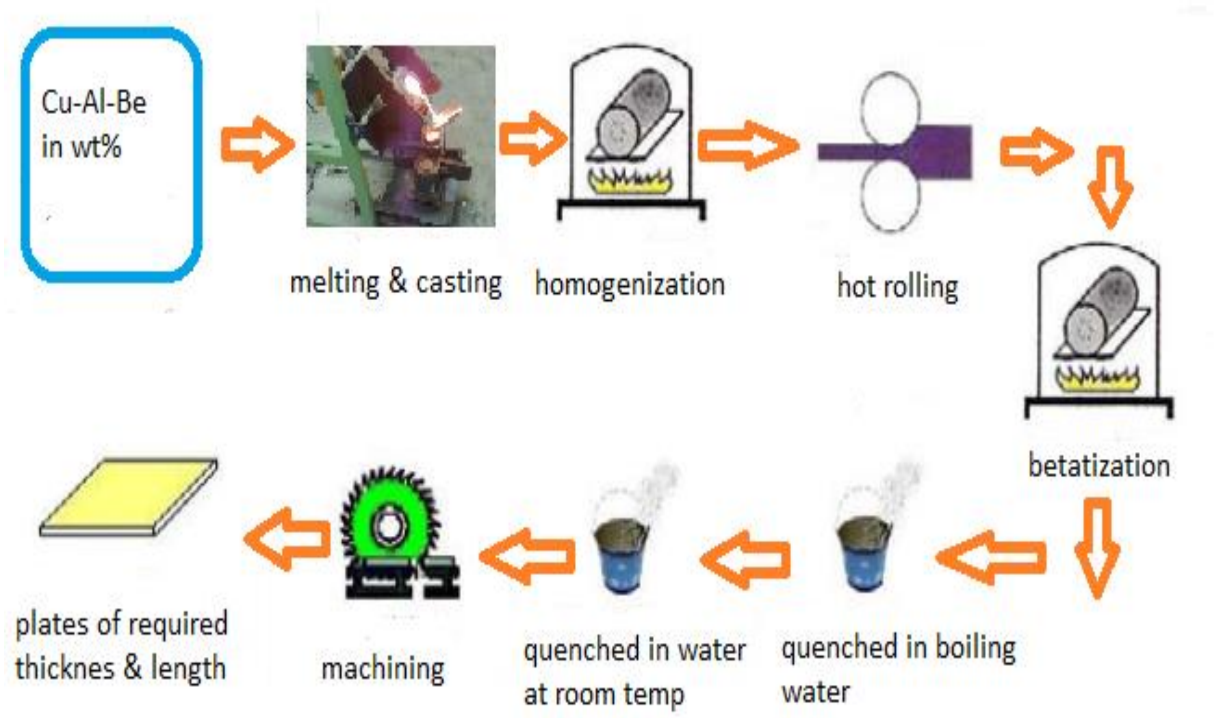
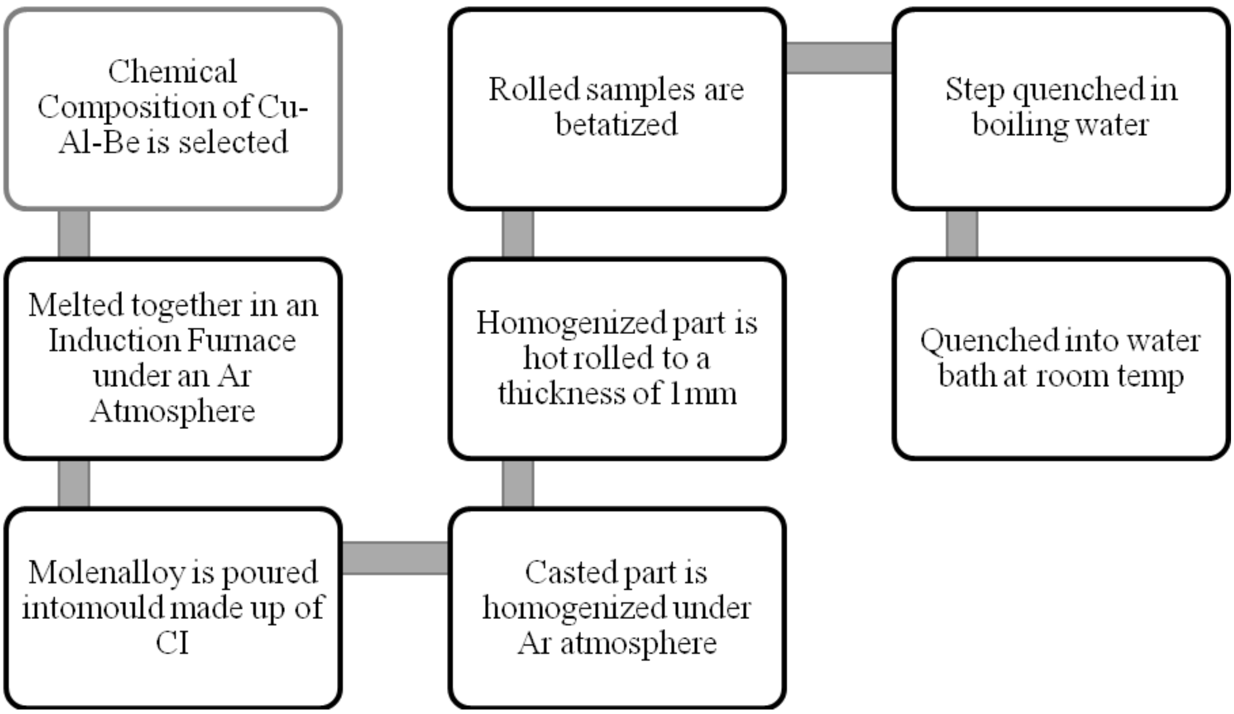


Fig. 2: Experimental Complete procedure



B) Alloy Composition

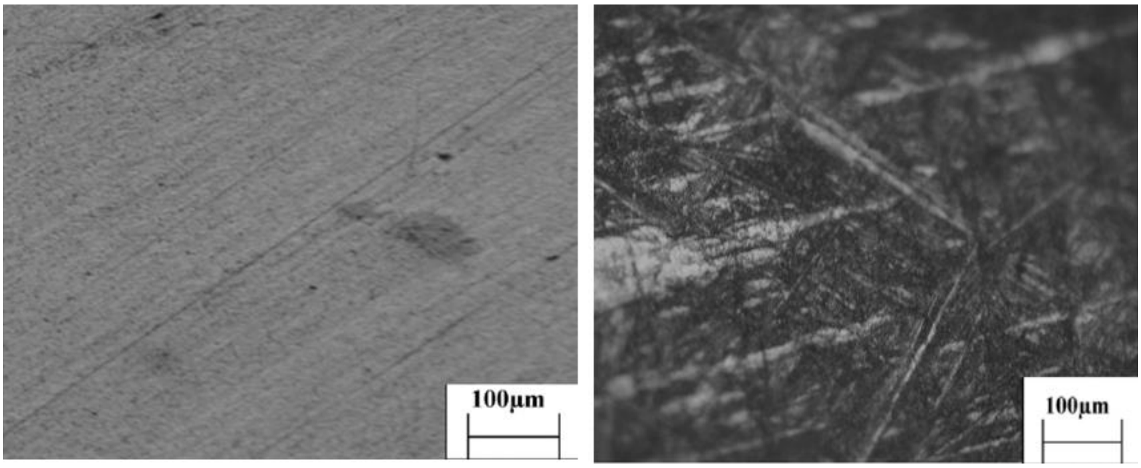
Alloys have been prepared with compositions ranging between Al - (9-15) wt% Be - (0.1-4) wt% Al and rest is of copper. To change transformation temperature, physical properties or mechanical properties, various ternary alloys are being developed. Among these, Cu-Al-Be alloys are most important from the 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 I. 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

C) 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.3 (a) Surface picture showing microstructure of parent phase, (b) martensite.

D) Shape Memory Effect by Bend Test

The shape memory effect was evaluated by bending a sheet specimen with dimensions of 1×4×50mm[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 II: 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

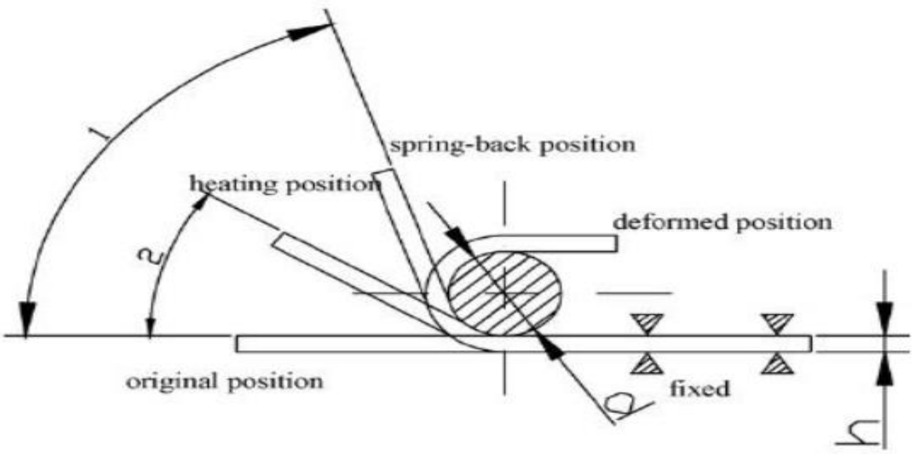


Fig. 4: Schematic illustration of the bending test.

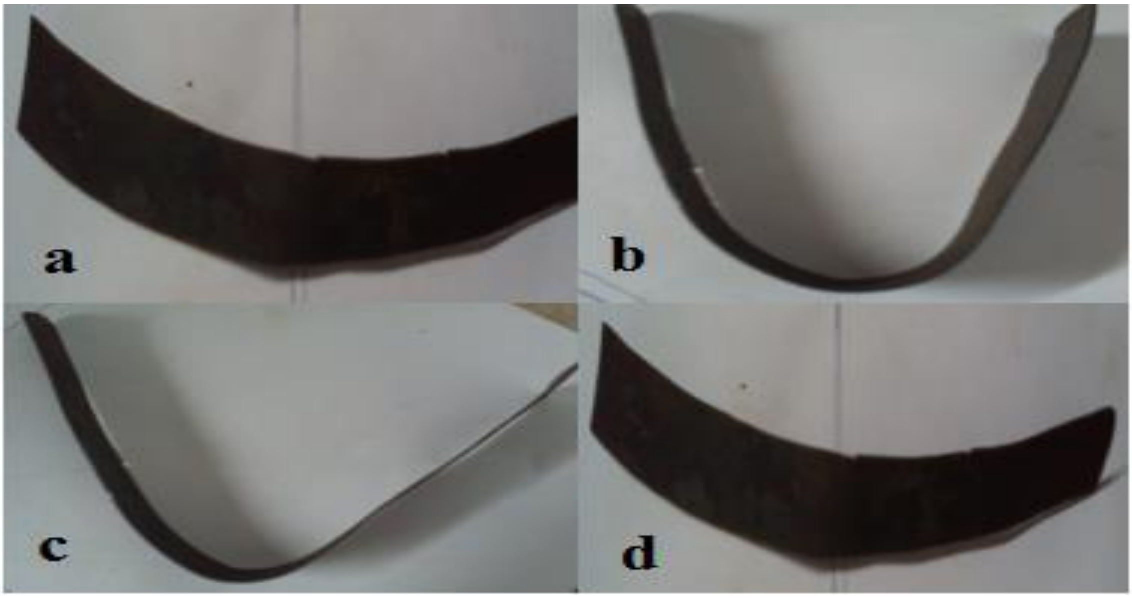


Fig. 5: Shows the shape memory behaviour of Cu-Al-Be strip: (a) the austenitic sample at room temperature; (b) the bent sample in the cold water while it is in the martensite phase; (c) and (d) the occurrence of shape memory behaviour during the heating from cold water temperature to room temperature.

After production, the strip shown in Fig. 5. (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 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%.
6. Not much work has been carried out on the characterization of Cu-Al-Be SMAs and it requires a through investigation before using it as a potential SMA for various applications.

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