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Characterization and Evaluation of Shape Memory Effect of Cu-Zn-Al Shape Memory Alloy

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Abstract

For shape memory applications, Cu-based shape memory alloys have been presented as the "heir apparent" and more cost-effective alternative for NiTi alloys, which have traditionally been used. The variables that have been cited as causes for this forecast includes low material costs, simplicity of fabrication, and good shape memory effect. The essential feature of martensitic phase transitions is the athermal movement of atoms, with no input from diffusion. However, diffusive events may have large effects on relative phase stability, and therefore on transformation temperatures and functional characteristics. Cu-based shape- memory alloys exhibit these behaviours particularly well, with atomic diffusion occurring at room temperature in both the austenite and martensite metastable phases. Nevertheless, it seems that peer- reviewed literature on the same subject is insufficient for accurately quantifying the influence of Zn on Shape Memory Effect (SME) of Cu-Zn-Al Shape Memory Alloy(SMA). Hence in the current study synthesis of Cu-Zn-Al shape memory alloy through liquid metallurgical method using induction furnace and examining the microstructure and phase transformation which is related to SME. The study reveals that for the selected composition the shape memory effect varies from 42-92% and with increase in Zn wt.% SME found to increase due to conversion of more austenite to martensite.

Keywords: *Shape Memory Alloy; Shape Memory Effect; Cu-Zn-Al; Martensite*

1.0 Introduction

Shape Memory Alloys (SMAs) are the special group of alloys that remembers the geometry. It finds its importance in various engineering application compared to normal metallic materials since it possess unique properties such as shape Memory Effect (SME) and Superelasticty. The SMAs were first discovered in the year 1932 by Arne Olander, Swedish physicist in Gold-Cadmium (Au-Cd)[1] and in 1938 similar properties were observed in Copper-Zinc (Cu-Zn) and Copper-Tin (Cu-Sn) alloys by Greninger and Mooradian [2]. Even though the SMA has been used for several application since its discovery, the name 'Shape-Memory' was coined by Vernon for his polymeric dental material in 1941[3]. SME were discovered in 1962 by William Bauechler and Fredrick Wang in nickel-titanium (NiTi) alloy [4] from then the demand and importance for SMAs in various engineering application were increased. SMAs are primarily categorized into two kinds: Nickel-based SMAs and Copper-based SMAs. However, despite the fact that NiTi-based SMAs exhibit great shape memory effect, superelasticity, high biocompatibility,

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and high corrosion resistance, the manufacturing process is complex because of its high melting temperature of the material, and the material is expensive [5, 6]. Manufacturing cost of Cu-based shape memory alloys is less and not much difficult process is involved due to its low melting point compared to NiTi-based SMAs with wide range of transformation temperature and good SME [7, 8]. Even though Cu-based SMAs tend to show intergranular cracks in coarse grained alloys due to its brittle and high anisotropy property it is considered as economical alternative to NiTi-based SMAs [9, 10] but efforts are in place to improve the mechanical properties through grain refining.

Cu-based SMAs, such as Cu-Al and Cu-Zn based SMAs, have been utilized extensively with ternary elements such as Al, Zn, and Mn, and during the years, Cu-Al-Ni [10], Cu-Zn-Al, and Cu-Al-Ni [11] have been investigated extensively [11, 12]. Cu-Al-Ni SMAs are used at high temperature for better thermal stability, among all Cu-based SMAs [13]. Shape memory alloys have been attracted towards design of vibration control devices due to their high damping properties along with their other properties viz. shape memory effect and peudoeleasticity [14,15]. High damping capacity is caused by martensite variant interface and parent martensite habit plane movement, which causes high internal friction during martensite transformation [16, 17]. In Cu-based and NiTi SMAs these damping properties have been observed partially. Especially Cu-Zn-Al shows superior damping property compared to other Cu-based SMAs [18-19] based on whether they are in martensite phase or austenite phase [20]. Cu-Zn-Al-based SMAs, on the other hand, are the subject of this study due to their low production cost and greater strain recovery when compared to other Cu-based SMAs [21]. Cu-Zn-Al SMAs synthesized using induction furnace has not acknowledged broad reportage in literature with respect to its composition on high strain recovery and its mechanical properties. Hence in this study complete focus is being given for the synthesis of Cu-Zn-Al SMAs using induction furnace and evaluating the microstructure and its effect on SME with respect to different composition.

2. Experiment

2.1. Material Preparation and Methodology

In this research pure conventional liquid metallurgy procedure has been followed in synthesis [22]. Initially the raw materials of high purity (99.99%) were preheated to remove the moisture content to avoid the oxidation during melting. The required amount of raw materials were weighed with Zn being 15-30 wt.% and Al 0-15 wt.% remaining Cu [23] as shown in Table 1. The preheated raw materials were melted in the induction furnace in argon atmosphere using graphite crucible to avoid oxidation and to avoid evaporation Zn will be added to the molten metal at the end. The liquid alloy is poured into the preheated cast iron die of dimension 120mm x 100mm x 3mm after thorough mixing to prepare the ingots. These ingots were reduced to approximately 1mm thickness through several pass of rolling at 900°C after homogenization for 4 hrs at 900°C to achieve uniform thickness. In order to achieve martensite structure, these rolled strips were betatized at 900°C for 30 minutes, followed by step quenching in water at 100°C and at room temperature, respectively. To ensure martensite development, the specimens were inspected optically to observe the formation of lath type martensite structures and the transformation temperature can be determined using Differential Scanning Calorimetry (DSC) by varying the heating and cooling speeds at 10°C per minute.

Bend test is being used to determine the Shape Memory Effect (SME) for each specimen. Figure 1 shows schematic diagram for bend test. The pre strain of the specimen is approximately estimated by ε=t/d, where, ε is the strain, t is thickness of the specimen, d= is diameter of the bent sample. The bent samples spring back after unloading at angle Θ_e. To recover the further strain Θ_m the samples were heated to their austenite temperature. By using the formula (Θ_m/180–Θe) SME is calculated.

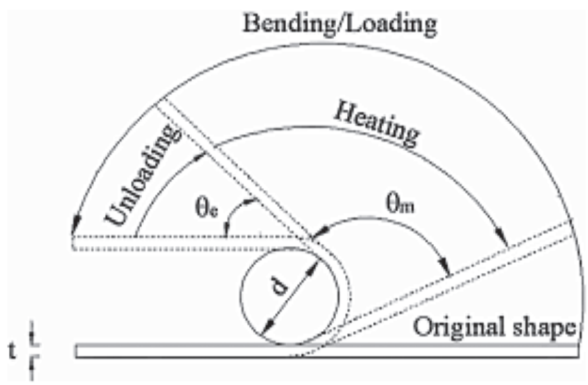

Figure 1: Schematic diagram for bend test

3.0 Result and Discussion

3.1 Alloy Composition

The composition selected for the Cu-Zn-Al SMA preparation [23] is shown in the Table 1. Since our major aim is to investigate the influence of Cu, Zn and Al composition on SME the compositions chosen have been in the range [23] will help us to investigate the influence of each material on SME.

3.2 Microstructure

The microstructure was examined and photographed using optical metallurgical microscope. Figs. 2 and 3 show the optical microscopic of samples

Table 1: Alloy composition and SME%

Alloy ID	Cu (wt.%)	Zn (wt.%)	Al (wt.%)	SME%
CZA-1	68	28	4	82
CZA-2	70	26	4	80
CZA-3	72	24	4	78
CZA-4	66	28	6	92
CZA-5	68	26	6	82
CZA-6	70	24	6	72
CZA-7	74	22	4	71
CZA-8	76	20	4	70
CZA-9	78	18	4	64

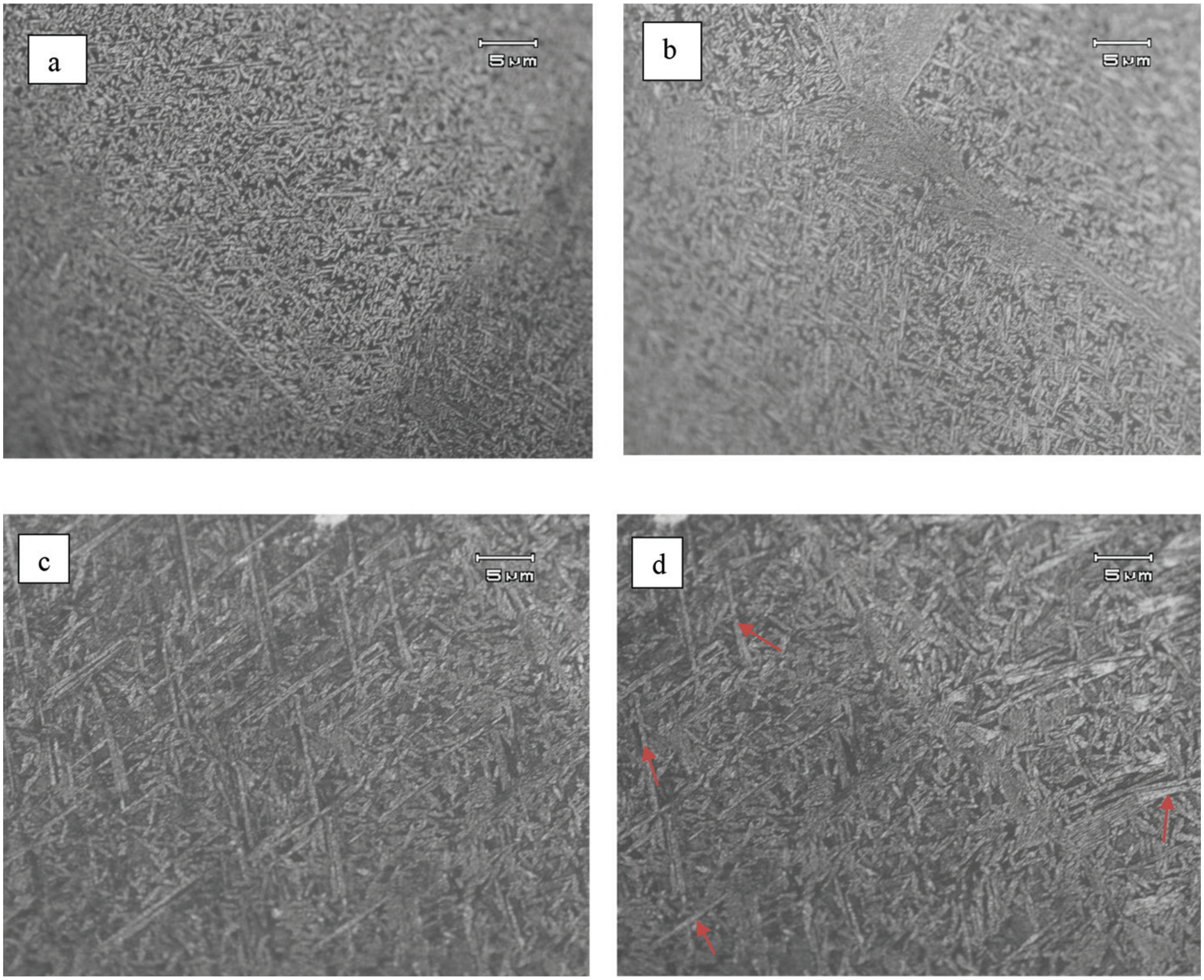

Figure 2: Optical microscope images for (a) CZA 1 (b) CZA 2 (c) CZA 3 (d) CZA 4

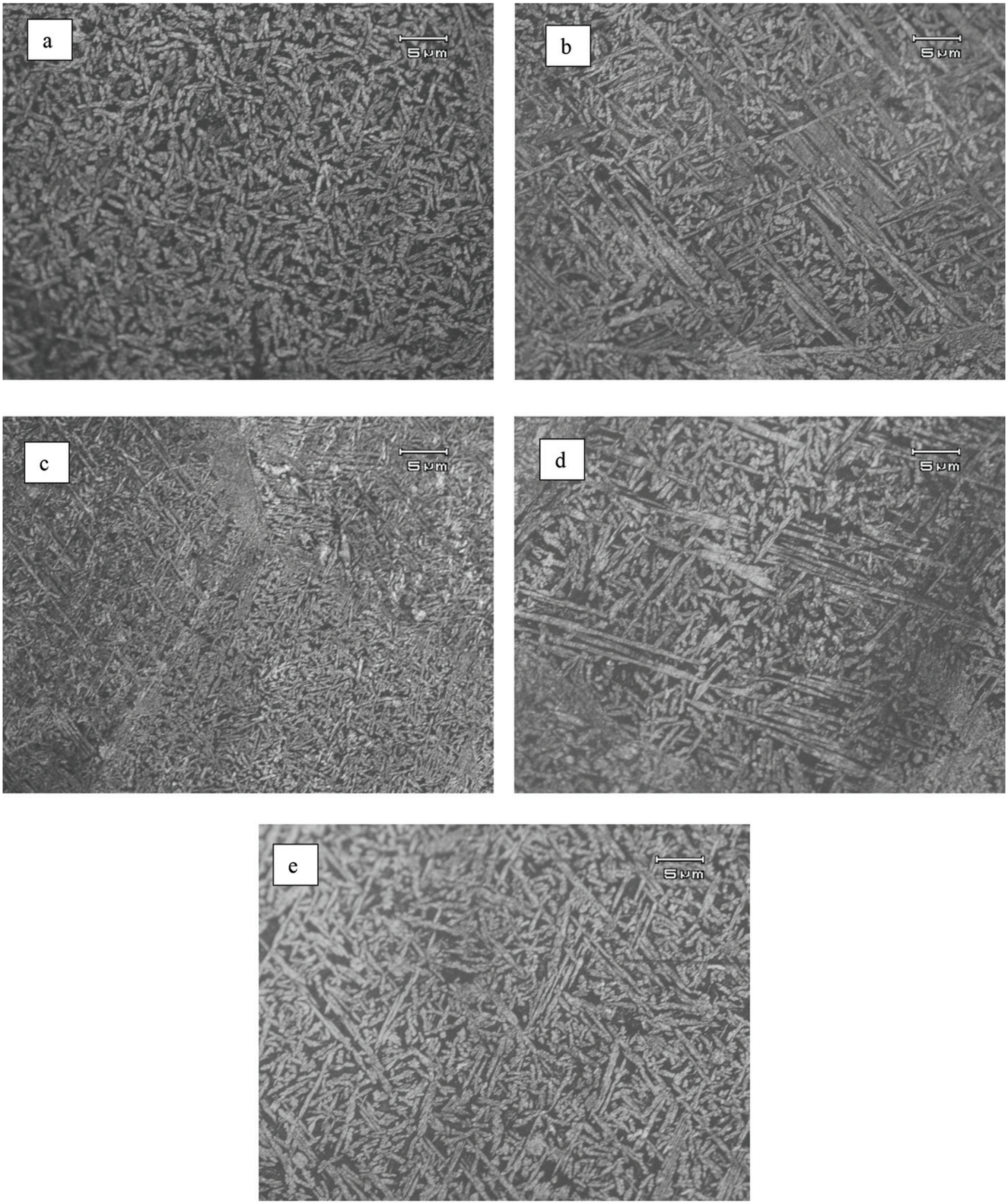

Figure 3: Optical microscope images for (a) CZA 5 (b) CZA 6 (c) CZA7 (d) CZA 8 (e) CZA 9

CZA. Figs. 2 and 3 show the microstructure of the martensite phase (α) in a Cu– Zn–Al alloy. The phase comprises the whole of the microstructure which is in martensitic phase. As seen in the micrograph, this phase crystallizes with a distinct shape. This phase occurs when the alloy has a specified composition, i.e., it is within the shape memory composition's boundaries. The Fig.2 and Fig.3 show the optical microscope images for the samples CZA1-CZA12. CZA1, CZA2 images were distinguished by a needle-like lath structure that has been identified as lath martensite structure. The lath structure observed in Figs.2a, 2b are similar to the lath martensite structure in Cu-Zn-Al alloys reported by many researchers [24, 25]. Fig.2a, and 2b show complete martensite with fine needle lath type structure. And high distribution of needle-like lath martensitic structure[26] can be observed in these figure. In Fig.2c and 2d, it is observed that some round and narrow structure and length of structure were seen slightly longer compared to Figs.2a and 2b. On step quenching, microscopic inspection of the samples indicates a full austenitic to martensitic transition, as seen in Fig.2a and b. The alloy samples (2c and 2d) show the formation of mainly lath type martensite with a small proportion of γ Austanite.

From Figure 2a-f which shows the optical microscopic images for different variation of Zn and Al, it is observed that (Fig.2b) with increase in percentage of zinc martensite phase increases proportionately With the increase in the amount of both aluminum and zinc the proportion of' the martensite plate thickness increases, due to more conversion of austenite to martensite for same of quenching. But in all the processed SMAs the domination of 18R martensite [27] can be found which places vital role in strain recovery.

Further edax analysis has been carried out to confirm the presence of Cu, Zn and Al in alloy. From the edax spectrum (Fig.4a and 4b) the pinnacle for Cu, Zn and Al is observed, which acknowledges that the material used for synthesis of Cu-Zn-Al SMAs is pure materials. The wt.% of Cu, Zn and Al observed from edax spectrum is given in Tables 2 and 3. From the results it is confirmed that better judgment were

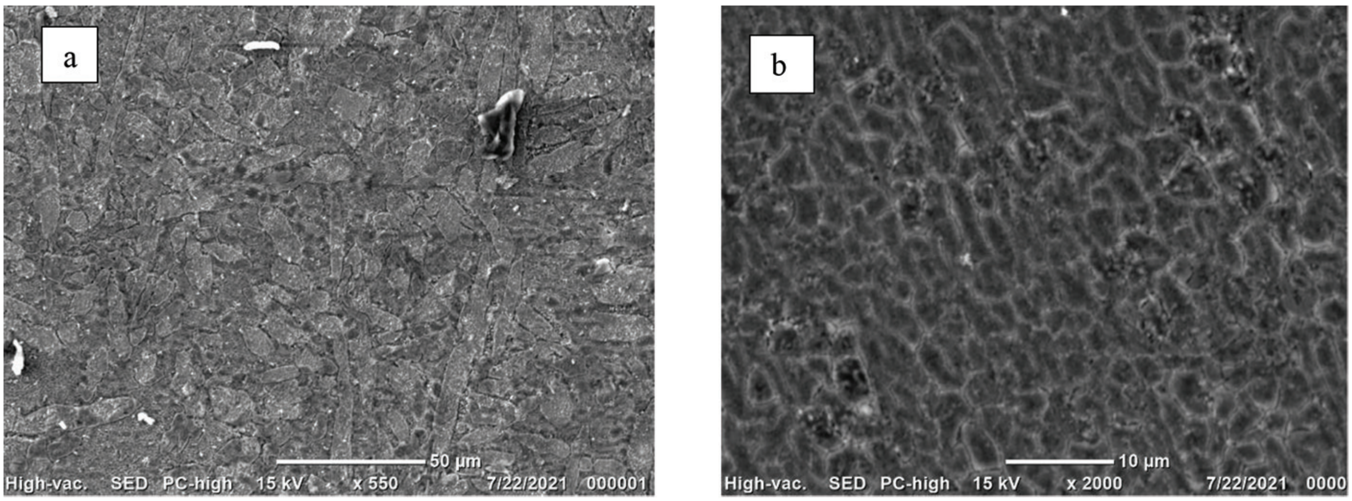

Figure 3: SEM micrographs (a) CZA-1 (b) CZA-2

Table 2 Edax of CZA-1

	C-K	O-K	Al-K	Si-K	S-K	Cl-K	K-K	Ca-K	Cu-K	Zn-K
Base (342)(292)(715)_pt1			1.72						73.32	24.97

Table 3 Edax of CZA-2

	C-K	O-K	Al-K	S-K	Cl-K	K-K	Cr-K	Mn-K	Fe-K	Cu-K	Zn-K
Base(342)(292)(716)_pt2			3.17							74.38	22.45

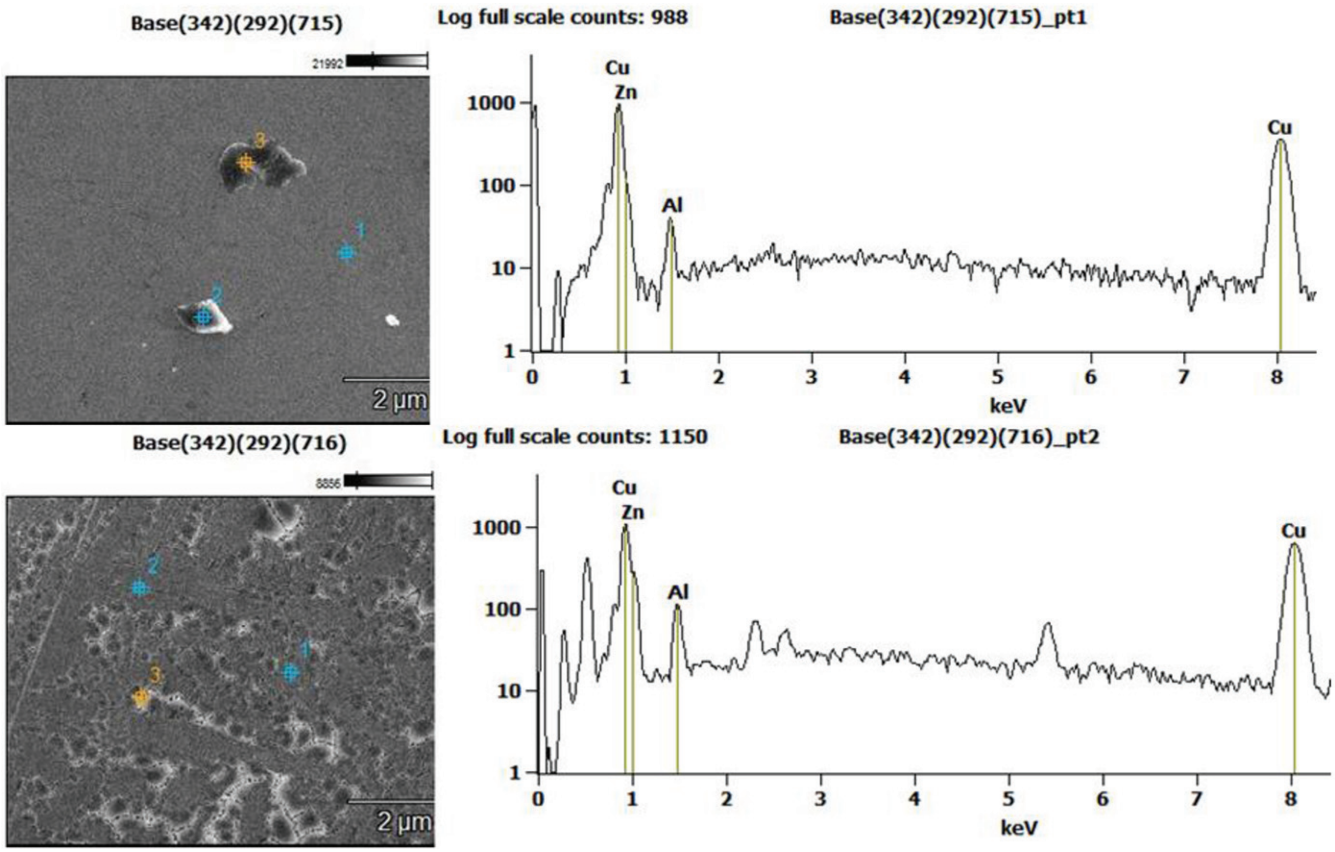

Figure 4: Edax analysis (a) CZA-1 (b) CZA-2

made during mixing of zinc to minimize its evaporation during melting.

3.3. Shape Memory Effect by Bend Test

As shown in the Figure 1 shape memory effect was found for alloy specimen using bend test and shape memory effect were recorded in Table 1. It is observed that SME varies from 40-92% for the selected composition. Furthermore, the development of martensite phase from the austenite phase is a significant factor in the shape memory effect. When FCC austenitic phase undergoes shear induced diffusion less transformation in which atoms get shifted by the application of shear force results in BCT unit cells. From the optical images 2d, 2a and 2a it is noticed that the absence austenite due to full transition of austenite to martansite phase impedes total strain recovery owing to the persistence of the FCC structure in the austenitic phase. It can also have been observed that with increase in Zn percentage the SME increasing due to conversion of austenite to marteniste in step quenching.

4.0 Conclusion

The present study focuses on the experimental investigation and characterization of microstructure and SME of Cu-Zn-Al SMAs. To accomplish this, pure copper, zinc, and aluminum were melted in an induction furnace under argon gas to provide the appropriate composition for the ingots. From the microstructure study it reveals that with increase in Zn wt.% there is increase in conversion of austenite phase to martensite phase. The Edax results shows that proper judgment has been made during mixing of material results in uniform distribution of Zn and Al particles without any agglomeration. In the bend test which is used to identify the shape memory effect of rolled samples reveals that with increase in Zn wt.% SME increases this intern attributed to increase martensitic phase which is in good agreement with many researchers. Further studies on these alloys will focuses on finding the transformation temperature at different quenching medium and its effect on SME.

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