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# Investigation of Cu based shape memory alloy as a reinforcement for metal matrix composite

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### *Abstract*

*This paper investigates the options and substitute of few Copper based shape memory alloys such as Cu-Zn-Al, Cu-Al-Mn, and Cu-Al-Be over the other conventional shape memory alloys used as a reinforcement in metal matrix composite. Copper based shape memory alloys are commercially attractive but due to their limited properties their application is limited. There are several reasons which are still covered due to lack of experiments and research. With the help of this present study few gaps were identified and develop synthesizing routes to enhance the use of Cu- based shape memory alloy.*

***Keywords:***Matrix, Alloys, Synthesis, Copper

## INTRODUCTION

Alloys are the homogenous mixture of two or more metals as well as non-metals. This is done to enhance the physical as well as mechanical properties such as strength, hardness, melting point, boiling point etc. Examples of alloys are brass, tin etc. In the presentscenario, most of the industries such as aerospace, automobile, telecommunications, metals etc. are mostly relay on alloys. The blending of metals and non-metals is totally depended on the properties required for the application for which the alloy is produced. Mixing of alloying elements in base metals can be done in weight percentage (wt%) of base metals or according to the ratio of base metal. Example: Cu-30wt%zn, it means 30% of zinc is added in 70% of copper. Mixing metals together or with non-metals offers many advantages. Since pure metal has a high boiling point, they tend to be very soft. Pure gold tends to be very malleable and is easily bent with a small amount of heat applied. This is the reason why most gold jewelry is actually an alloy.

There are two main types of alloys, substitution alloys,and interstitial alloys. When the atoms of one element are replaced with the atoms of another element roughly of the same size is called substitution alloys. Example: Brass, an alloy of copper and zinc. On another hand, if the atoms occupy spaces between the adjacent atoms of a base element is called interstitial alloys. Example: Steel, it is developed by adding carbon to iron.

Shape memory alloys are the special class of alloys which can retain their original shape when they are heated up to certain temperatures which can spontaneously modify the physical properties. These temperatures are austenite (high-temperature phase) and martensite (low-temperature phase). When SMA (shape memory alloys) undergoes a martensite phase transformation it transforms from its high symmetry i.e. usually cubic, austenite phase to a low symmetry martensite phase. Initial and final phase both coexist during whole phase transformation[1]. The transformation phenomena due to this temperature difference are called shape memory effect (SME)[2]. **According to L.C. Chang, T.A. Read,** it is found in the year 1951, after the study of Au-Cd alloy[3]. Shape memory effect is classified into two groups, i.e.one-way shape memory effect, in which the material remains in the deformed state even after the external force is removed and then recovers its original shape upon heating[4].Another classification of shape memory is a two-way shape memory effect under which the material remembers its shape in both the temperatures[5]. This can be obtained without the application of external forces. The complete transformation process of shape memory alloys lies between four temperature i.e. (As) where the heating process starts and ends up to (Af) where heating ends and then (Ms) cooling starts and ends up to (Mf) martensite finish.

There are many elements in the periodic table which possess the shape memory effect, all these elements belong to the transition group. Several alloys have been synthesizing yet with the help of these transition metals to obtain efficient alloys. Combination such as silver–cadmium (Ag–Cd), copper–aluminium–nickel (Cu–Al–Ni)[6], copper– aluminium–manganese (Cu–Al–Mn)[7], copper–gold-tin (Cu–Au–Sn), copper-gold–zinc (Cu–Au–Zn), copper–tin (Cu–Sn)[8], copper-zinc (Cu–Zn) [9], copper–zinc–aluminium (Cu–Zn–Al)[10], nickel-titanium (Ni-Ti) [11], iron–platinum (Fe–Pt), iron–palladium (Fe–Pd), etc. Among this list, Ni-Ti is one of the famous combinations to obtain shape memory effect.

## Cu-Zn-Al

Cu-Zn is one of the ductile combinations when added a particular %wt. More than 305wt in Cu as a base metal make it brittle. There are many experiments and research has been conducted in the past few years to identify the capabilities/potential of Cu-based alloys. Many compositions, quenching condition, the process of heat treatment, mechanical deformation and grain refinement of alloys has been done. Cost of synthesis of Cu-Zn-Al is comparatively low but still,the application is limited due to the microstructural properties and structure [12]. Synthesis of Cu-Zn-Al SMA for the application of automobile was developed, this research results of two samplesoptimize that the composition 70% of copper and approximately 26% Zn and rest Al% is fair enough for the application [13].For another application such as actuators, this SMA can be used [14].

Synthesis of β Cu-Zn-Al alloy is produced by low energy ball milling which leads to the growth of γ crystallite growth with stabilizes β phase, while comparing with this technique all other are only able to synthesis α+β phase [15] and after obtaining the β phase,irradiation process loops, cavities, vacancy [16][17] and closed pack phase[18] can be stabilized [19], but application of external constant stress during aging, formation of single crystal reduces [20][21]. The discussion also shows that austenitization disoriented the α phase precipitation [22][23].

A thin film of Cu-Zn-Al was developed by a sputtering process in the presence of argon gas[24]. The films in the β phase had shown $L2_1$ structure 18R structure was present in the martensite phase. Shape memory effect. With the sputteringprocess, shape memory effect was grown first time [10][25] and the defects can stabilize by quenching [26]. The properties of shape memory alloys based on themartensite-austenite phase transformation depends on the temperature used. 2H martensite structured is possibly obtained by fixing the valence electron concentration per atom (e/a)=1.53 and with the thickness of 5μm with fine grain, this results in films with 18R martensite structure in which hysteresis percent an increment compared to bulk samples [27]. In 2004, Fricoteaux and Rousse[9], reported the possibilities of nanowires made by Cu-Zn-Al from 1-butyl-1-methylpyrrolidinium bis(trifluoromethyl sulfonyl)imide ionic liquid.Microstructure study of Cu1-xZn1-yAl1-z has been done, which shows that the variation in %wt. of x, y and z range in between ($0.29<X<0.30$; $0.74<Y<0.75$; and $0.83<Z<0.96$) results in a significant difference in shape memory effect and pseudoelastic properties. When Zn is concentration is increased by 13% and Al is increased by 12.9% results in good shape memory effect[28]. Addition of Mn and Zr as other alloying material in Cu-Zn-Al shows good mechanical behavior, with high tensile strength and high ductility. It also demonstrates excellent thermal stability against aging so that the alloy is less stabilization in the martensite phase[29]. Change in Ms and Af temperature when the amount of Zn and Al are constant. Transformation temperature is lowered when Ni is lower than 2%wt and again rose when added more than 2%wt [12]. The shape memory effect is (SME) of alloys with transformation temperature below 347K is larger than the alloys beyond 361K by 20% to 40%[30]. The martensite transformation can be described from the disorder of structure from BCC to FCC phase. This also shows an electronic property of Cu-Zn-Al [31]. Addition of 0.1%wt B in Cu-14%Zn-8.5%Al results in a 50% increase in the elongation as well as 130% increases in tensile strength. Adding boron also refines the grain size which helps to increase the ductility and strength[32][33].

Shape recovery rate lies between in the range of 88% to 97% in all Cu-Zn-Al-X elements were evaluated, but it is totally depending on the quaternary elements [34]. Addition of 0.1-0.4% Ni as a quaternary element shows the damping capabilities and grain refinement which is directly associated with the strength of the alloy. While accumulation of 0.4% Ni the solidification is directional which also reduces the damping capabilities but it reduces to 0.2% the damping is maximum [35][36]. Adding 0.25% of Ce reduces the grain size which helps to resist the fatigue crack propagation which depends on the microstructural properties and on the loading condition and the key role played by austenite and martensite transformation [37][38] and adding Gd in range from 0.08–0.12 wt.% has good shape memory effect that helped in manufacturing of helical spring [39] but there is no change in martensite transformation temperature [40][30]. But while adding Ti and Zr reduces the shape memory effect [41] but Tiand Co can refine the grain size [42][43][44].

Successive heating rate 5 ◦C/min up to 450 ˚C shows different results controlled diffusion process and growth of an asymmetric martensite phase the restraint of the restraint of the α phases distributed along the boundary of the newly formed martensite variants [45]. The two-way effect was also studied deeply [46]–[48].

### Cu-Al-Mn

Cu-Al-Mn is another group of Cu based SMA. Many experiments have been done on this combination which explains the shape memory effect, transformation temperature,and mechanical properties. Cu-Al-Mn shows excellent ductility as well as efficient damping properties [49], magnetic properties [50][51][52]due to microstructure control such as grain size [53][54]. Cu-Al-Mn was successfully synthesized by ball milling, in which milling time and RPM vary the crystal structure and lattice parameter. Grain size decreases[55] with the increase in milling time [56]. A study also says that an increase in environmental temperature maximizes the logarithmic decrement [57]. Addition of ternary and quaternary alloy effects on grain size as well as on the shape memory effect, the addition of Al up to 5% and 1-3% of Zn, Si, Fe, Pb, Ni, Mg, Cr,andTi as quaternary element increases the transformation temperature. Zn and Ni as quaternary additions [58][59] were found to increase the transformation temperatures, whereas Fe, Cr, Ti, Si,and Mg decrease them [60][61], also the addition of Au, Si and Zn to the Cu73–Al17–Mn10 alloy stabilized the martensite (6M) phase increasing the Ms temperature, while the addition of Ag, Co, Cr, Fe, Ni, Sn,andTi decreased the stability of the martensite phase, decreasing the Ms temperature but it increases the ductility [62][63][64][65]. In the process of martensite transformation, grain size grows with a decreasein temperature and shrinks when warmed up[66]. The significance of adding Ce is that it develops the refine grain and cause the formation of Ce rich phase, which increases by the increase in the Ce %wt and maximizes the tensile strength and damping capacity [67][1]. The aging study was conducted in the temperature range from 800-950℃ on Cu based SMA in which Al content 11.4–12.3 wt.% and Mn-content 5.0–6.9 wt.%, results in increases in damping with an increase in temperature [68][69]. In the same content when Ag is added at 3%wt and quenched after 1127K temperature it was found that it dissolves with the mixture completely and when quenched at about 527K that the rich amount of Ag precipitates were formed [70]. Addition of Nitrogen in the quenching process reduces the Ms.Temperature and provides a good shape memory effect. Addition of 1% of Mn and Al increases the hardness but decreases the Ms temperature of the tested samples [71]. The effect of grain size investigation shows that the grain size d/D (d: grain size, D: wire diameter) on the yield stress and pseudoelasticity increases with increase in d/D ratio [72][73], also the loading rate and temperature can also be varied by changing the diameter ratios [74]. Synthesis of Cu-Al-Ni-Mn by Mechanical alloying was systematically studied and fabricated at the speed of 100 rpm and 300 rpm different milling time with and without process control agent. Results show that with increased milling time the grain size has significantly decreased. 98 % of shape recovery was monitored when the sample is aged at 120℃ for 10 days. Before aging, the quenched sample was hot extruded at the rate of 50:1, 100% recovery was monitored when 250 ℃ oil bath for 40 sec is provided [75][76].It isfound that the shape recovery rate decreases as the heating rate decreases. It can reach 75% when the heating rate is 20 ℃/min, whileit is only 8% when the heating rate is 1℃/min [7]. Welding test experimented on Cu-Al-Mn wires which show that superelastic alloy had a very high weldability and superior properties compared to other laser welded shapememory alloys, such as NiTi. The experiment also shows that an increase of fine grain increases the ductility of material [77].

## Cu-Al-Be

Synthesis of Cu-Al-Be alloys can also be done by previous routes mentioned above [78] . Cu-Al-Be reported as a alloys which can be used for low temperature application, samples with different composition tested and step quenched, and aged up to multiple temperatures, results that a special care need to be taken to avoid oxidation during the initial high temperatures [79]. Precipitation study has been conducted with the composition Cu-22.7 at. % Al-3.1 at. % Be, prepared by ingot route. After homogenization the ingots was water quenched to obtain the metastable phase at room temperature. XRD shows that (α+γ2) phases occursunder isothermal conditions. But furthermore precipitation discontinuous reported by SEM and optical microscopy

[80][81]. By applying the cyclic loading on the sample the microstructural study shows that increase in loading in martensite temperatures decreases the pseudoplastic properties [82][81], the crystal orientation measured by EBSD shows that there is uniform stress distribution throughout the sample [83]. A sample with a composition Cu–11.40Al–0.55Be (wt.%) polycrystalline alloy was selected for corrosion test, in which the sample was kept in NaCl solution and the results were studied by X-Ray diffraction. After a long time of immersion, the single β phase suffered by corrosion but in (β+γ2) microstructure γ2 precipitates protects β matrix from dealloying [84][85]. The grain size influences had studied on Ms temperature in β phaseCu-11.41Al-0.50Be (wt.%). It shows that the Ms temperature decrease and stress increase as the grain size decreases [86]. Aging treatment affects the shape memory effect of alloys, studied on various samples of different composition. The hardness of alloy increases with increase in ageing time. The strain recovery by SME decreases with increase in ageing time due to the formation of precipitates [78]. By adding the quaternary element as Mn the SME can be stabilize up to certain limit even after the aging at 250C and 500C. On other side adding Mn also a poor damping capacity [87]. Addition of quaternary element alloy exhibits ultimate tensile strength up to 630 MPa which is very closer to the conventional Ni-Ti SMA i.e 800 MPa, also good hardness over 200 BHN [88]. Abrasive, Adhesive brinelling and surface fatigue contribute a major part in wear characteristic [89][90].

## CONCLUSION AND RESULT

After reviewing Cu-Zn-Al, Cu-Al-Mn and Cu-Al-Be it can be determined that Cu-Zn-Al can be the possible substitute of conventional reinforcement used in metal matrix composites. Comparing with other two composition, results shows that the grain size is fine which develops a strong bonding between atoms that directly conclude that its strength requirement can be varied by changing the composition as per the requirement of application. Corrosion resistance is also another important factor which makes it useful in moisture condition. Stabilization of martensite temperature can be controlled by adding ternary and quaternary elements. Addition of Zinc increases the ductility without compromising the strength at higher extinct but zinc can be added upto only 30 %wt, after this % wt material become brittle. Also zinc enhance the shape memory effect while added up to 12 %wt. Addition of Mn and Zr as other alloying material in Cu-Zn-Al shows good mechanical behavior, with high tensile strength and high ductility. Boron addition increases the elongation up to 50 % and tensile strength up to 130%, it also reduce the grain size. Overall we can conclude that Cu based shape memory alloys can be the replacement of conventional alloys such as Ni-Ti and with proper synthesis it can be used in industrial application. In future if continuous casting of Cu based shape memory alloys can be developed then it will take the use of Cu based shape memory alloys to higher levels.

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