



## The influence of additions on the properties of a CuZnAl shape memory alloy. A review

Zaineb Hassan Chalab  
College of Materials  
Engineering, University of Babylon  
Babylon

Ekbal Mohammed Saeed  
College of Materials  
Engineering, University of

[mmad92888@gmail.com](mailto:mmad92888@gmail.com)

[Mat.ekbal.moh@uobabylon.edu.iq](mailto:Mat.ekbal.moh@uobabylon.edu.iq)

### Abstract

Shape memory alloys can revert to their original shape after being deformed by temperature (shape memory effect) or stress (pseudoelasticity). Because of the unique and peculiar properties of SMAs, there has been a lot of research and concentration on diverse applications during the last several years. Furthermore, it has been the subject of numerous investigations. This review focuses on shape memory alloys and their applications in the past, present, and future. Several experiments have also been discussed, demonstrating how various additions alter the shape memory capabilities of the CuZnAl alloy.

**Keywords:** CuZnAl, shap memory alloy, pseudoelasticity, transformation temperature, alloying elements.

ذاكرة الشكل / رفيو CuZnAl دراسة تأثير الاضافات على خواص سبيكة

زينب حسن جلاب

اقبال محمد سعيد

جامعة بابل / كلية هندسة المواد

[mmad92888@gmail.com](mailto:mmad92888@gmail.com) الايميل/

### الخلاصة

السبائك ذاكرة الشكل هي سبائك تستطيع أن تعود إلى شكلها الأصلي بعد تشوهها بسبب درجة الحرارة (تأثير ذاكرة الشكل) أو الإجهاد (المرونة الزائفة). بسبب الخصائص الفريدة والمميزة للـ SMA، كان هناك الكثير من البحث والتركيز على التطبيقات المتنوعة خلال السنوات القليلة الماضية. علاوة على ذلك، فقد كان موضوع العديد من التحقيقات. تركز هذه المقالة على السبائك ذات ذاكرة الشكل وتطبيقاتها في الماضي والحاضر والمستقبل. كما تمت مناقشة العديد من التجارب، مما يوضح كيف أن الإضافات المختلفة تغير من قدرات ذاكرة الشكل لسبائك CuZnAl.

**الكلمات المفتاحية:** CuZnAl، سبيكة ذاكرة الشكل، المرونة الزائفة، درجة حرارة التحول، عناصر صناعة السبائك.

### Introduction

Shape memory alloys (SMAs) are one of the most important types of smart materials[1]. SMAs are defined by their ability to remember or retain a given shape or size prior to distortion by heating [2]. SMAs are used in a variety of applications, including medicine (cardiovascular, orthopedic, and surgical instruments), engineering application like (aerospace, industrial, electronics, and construction)[3], for example, dampers, actuators, solar panels, jet engine components, and stents. As the application field has grown, it is now easier to



obtain SMA, whose popularity has grown significantly. The most effective and extensively used alloys include Ni-Ti, Cu based alloys especially: Cu-Zn-Al, and Cu-Al-Ni. Arne Olander reported the first case of SMA in 1932 [5]. Because of features such as biocompatibility, corrosion resistance, and ductility, Ni-Ti-based SMAs are more suitable for application. Although Ni-Ti alloys exhibit 8% strain recovery, [7]. NiTi alloys are still expensive in comparison with other kinds of SMAs. This problem has led to the increase demand of the copper based alloys like Cu-Zn-Al and Cu-Al-Ni that are commercially available and 100 times less in price than NiTi alloys [8]. While shape memory alloys containing iron (Fe) have lower strength than other varieties, Cu-based alloys are less expensive and have a wider range of transformation temperatures. Copper and copper alloys are some of the most versatile engineering materials accessible, in addition to having acceptable transformative qualities. Copper is excellent for a wide range of applications due to its combination of physical qualities including as strength, conductivity, corrosion resistance, machinability, and ductility [9].

The shape memory effect is concerned with the shape recovery of alloys if the material can be returned to its previous geometry after being deformed by heat. This shape memory effect is aided by the martensitic transition available up to the critical temperature. (SME) is produced through solid state phase transitions without material diffusion [6]. Magnetic or thermal interactions between the phases austenite (the parent phase, which is characterized as a hard and disorder phase at high temperatures) and martensite (the product phase, which is characterized as a soft and order phase at low temperatures) frequently result in phase transformations [10]. Smart materials are sensitive to external influences such as stress, temperature, moisture, pH, and electric and magnetic fields. Before undergoing a phase transition, the austenite phase in the solid phase will transform into martensite by modifying its crystalline structure. It will induce external signals, such as temperature fluctuations, and this transformation cannot be overestimated by the influence of associated structural defects in the internal martensite structure [11]. When the martensite phase of the SMA transitions into the austenite phase, it is frequently observed as a reversible structural and thermodynamic cycle. The driving force behind the form recall is the discharge of chemically free energy during phase transitions [12]. The SME is the product of this force. Even though the atoms do not move much during phase transformation, they always go in the same direction, causing the material to undergo significant changes. Modifications to the alloy's crystal structure produce high-end features such as super elasticity and the SME [13].  $M_s$  is the temperature at which the martensite phase starts during phase transformation, while  $M_f$  the temperature at which the martensite phase transformation is completely [14]. In the literature, the starting and ending temperatures of the austenite phase are represented by the abbreviations  $A_s$  and  $A_f$ , [15]. The type and quality of SMA should be chosen based on the use location [16], [17].

Several variables, including mechanical operations, thermal processes, and alloying element proportion, influence the transition temperatures of the shift that must be driven thermally to the required range. The physical properties of the alloy have been demonstrated to change after these operations when the transformation temperatures shift [6]. Memory for Design Alloys enter our life rapidly and serve a variety of functions. Alloys are generally stronger, tougher, more durable, and, in some cases, more corrosion-resistant than pure metal counterparts. The precise composition of an alloy depends on the type of base metal and the alloying components [8], [18].

## 1. Cu-based shape memory alloy

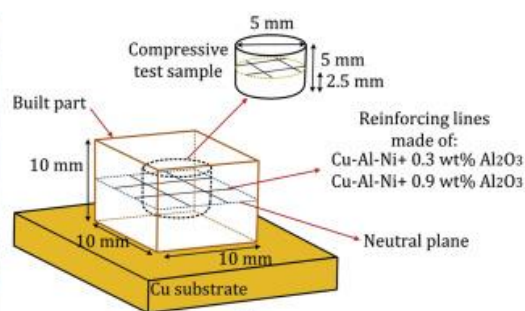
Cu-based shape-memory alloys are a less expensive alternative because to its excellent formability and electrical and thermal conductivity. CuAlNi, CuAlBe, CuAlMn, and CuZnAl are some of the alloys available.

### 1.1 CuAlNi Shape Memory Alloys

The martensitic transition can be detected in Cu-Al-based alloys with aluminium weight percentages ranging from 9% to 14% [19]. Cu-Al alloys, like Cu-Zn alloys, use a third element addition to stabilize the  $\beta$  phase and boost SME [20]. Because of its thermal stability at temperatures above 100 °C, CuAlNi alloy has been recognized as a shape-memory alloy with high-temperature capabilities [21],[22]. Because of its coarse-grained morphology and anisotropic elastic behavior, the CuAlNi alloy has a very brittle microstructure similar to the CuZnAl alloy. This issue limits the topic's practical application [23],[24]. While the addition of fourth alloying elements such as V, Y, B, Mn, Zr, Ti, and rare earth elements has an effect on the properties of the standard CuAlNi alloy, it is important to note that minor additives have little effect on particle sizes are shown in Fig1 (a,b). Furthermore, the use of a large number of coarse second-phase particles compromises the product's mechanical qualities. Cu-Al-Ni shape memory alloys (SMAs) have been developed for high-temperature applications due to their ability to return to their pre-deformed shape after heating above the transformation temperature, as well as having a low hysteresis and a high transformation temperature when compared to other shape memory alloys. [25]



a



b

Fig. 1. (a) Laser system used in this study; (b) neutral plane of the partially reinforced Cu–Al–Ni shape memory alloy fabricated using selective laser melting[23].

## 1.2 CuAlBe Shape Memory Alloys

The advantages of CuZnAl and CuAlNi alloys are combined in CuAlBe alloys. Transformation temperatures may be increased to 200°C while remaining low by adjusting the element ratios in the alloy. It is produced at a high temperature of 600°C, similar to the CuAlNi alloy. The fact that beryllium is hazardous to beryllium oxide's health is another issue with this type of alloy. In spite of this, very little beryllium is used in the alloy [26].

## 1.3 CuAlMn Shape Memory Alloys

Because of the high-order sequence and elastic-solid anisotropy of their  $\beta$  phases, CuAlNi and CuZnAl alloys have brittle structures [27]. When using CuAlMn alloy, aluminum has been demonstrated to have a comparatively low-grade sequence of the main phase, indicating that the mechanical properties, notably ductility, are rather good [28]. The Mn component of the CuAlMn alloy is also magnetic [29]. All other SMAs, including alloying elements and their concentrations [30],[31] and heating remediation techniques, share the capacity to introduce new features to the user by altering the mechanical and physical feature structures supplied by the materials. Because the Cu-Al-Mn-based SMAs exhibit outstanding ductility and high SMA properties, and is highly expected to be applied in a variety of medical and engineering fields. As an example, we briefly discuss the application of Cu-Al-Mn-based SMAs to medical guidewires [1] [32].

## 1.4 CuZnAl Shape Memory Alloys

Copper-based SMAs have some advantages over NiTi alloys, including a lower cost and a simpler manufacturing procedure. Copper, zinc, and aluminum alloys (CuZnAl) were the first copper-based SMAs to be used commercially. CuZnAl alloys, which were originally generated from the copper-aluminium binary alloy, have the advantage of being made using traditional metallurgical procedures from relatively inexpensive metals. Cu Zn Al alloys, like other SMAs, have minor form characteristics with a maximum recoverable strain of roughly 4-7% in the absence of additives that limit particle growth[33]. Another way to define a SMA is that it generates thermoelastic martensite. In this case, the alloy undergoes a martensitic transformation, allowing twinning to bend the alloy below the transition temperature. The distortion is undone when the twinned structure returns to the parent phase after heating [34]. Dual alloys, such as Cu-Zn and Cu-Al, frequently require a third alloying element to provide

phase stability and varied properties [6],[35]. Ms temperature was substantially lower than room temperature in Cu-Zn alloys containing at least 40% Zn alloy [36],[37]. To raise the Ms temperature and stabilize the  $\beta$  phase, Sn, Si, Ga, and Al are introduced [6]. Because of its low cost and high processing performance, CuZnAl has been used in the majority of trials. There are two main challenges hindering the development of CuZnAl alloys on an industrial scale, despite the fact that they are still used in cars for fire prevention. The absence of particle formation hinders thermomechanical progress and these limitations limit the ability of SMEs. The second obstacle is the shift in elastic transition temperatures resulting from thermomechanical activities [38]. Copper SMAs are subjected to heat treatment [39]. Many researchers have conducted studies to manage the martensite phase in CuZnAl fluid connectors and couplings, motors, safety valves, and other safety devices. [40].

### Usage areas of SMA

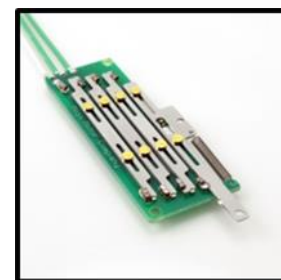
The alloy's application is enticing because Cu-based alloys are less expensive and have a wider variety of transformations [31]. The research project between the United States and Canada looked into future technologies, market sectors, and SMA application areas. The results of the testing suggested that they would be more likely to be used effectively in the market [50],[51]. SMAs are currently widely used in a variety of critical sectors. Medicine, autos, robots, aircraft, space technology, and building are among the most important [9]. Shape memory alloys (SMAs) used in these applications are thought to have capabilities for the actuation component or proportionate control of movement in addition to permitting free return shape recovery [31]. Figure 2 depicts SMA application drawings.



Robotic application



Aerospace application



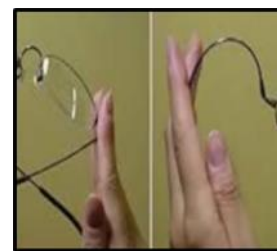
Linear SMA Actuator



Orthodontic arch wire



Connectors



Eye glass frame

Figure (2): Shape memory alloy applications

## 2. Previous Studies of the Properties on Cu-Zn-Al Shape Memory Alloy

Kenneth K. et al [41] studied the microstructural features, phase characteristics, and mechanical properties of Cu-Zn-Al alloys that were increased by the introduction of micro-alloying additives using Fe, B, and Fe-B mixes in 2017. Casting procedures with and without the presence of microelements such as Fe, B, and Fe-B were used to produce Cu-Zn-Al alloys. The particle shape of the alloys varied significantly. The unimproved alloy was characterized by a needle-like lath martensite structure with sharp particle edges. The enhanced Cu-Zn-Al alloys, on the other hand, had significantly bigger transverse particle sizes and particle morphologies that were either curved-edged or near elliptical. The baseline Cu-Zn-Al alloy had a higher hardness than the changed alloys, resulting in hardness decreases ranging from 32.4 to 51.5%. Tensile strength, on the other hand, decreased significantly as compared to the changed alloy grades. The addition of micro-alloying elements resulted in a significant increase in tensile strength, ranging from 28.37 to 52.74%.

Similarly, the improved alloy grade outperformed the unimproved alloy grade in terms of fracture toughness and percent elongation (10-23% increase). Kenneth K et al. [42] investigated the microstructure, mechanical behavior, and damping properties of Cu-18Zn-7Al alloys with and without (0.1-0.4) Ni alterations. Elongated, sharp-edged particle morphologies matching to directed solidifications were seen in the unimproved and 0.4% Ni-improved CuZnAl alloys. Nonetheless, the Ni enhanced CuZnAl alloys with 0.1, 0.2, and 0.3% Ni significantly changed the particle structure, resulting in granular structure, narrow particle width with fewer sharp edge particles, and curved/round particle edges, respectively. The mechanical properties of unimproved and 0.4% Ni-improved CuZnAl alloys are typically worse than those of 0.1 and 0.3% Ni-improved alloys. The enhanced CuZnAl alloy with 0.4% damping capability does not appear to be suitable for use as a damping material.



The enhanced CuZnAl alloy with a damping capability of 0.2% Ni, on the other hand, has the most amazing damping capability of all the CuZnAl alloy compositions. Kenneth K. et al. [43] observed unique structural microstructures in both the unimproved- and B, Fe improved- Cu-Zn-Al alloys, as well as in both the aged and unaged conditions. The impact of thermal ageing on the microstructure was difficult to quantify exactly due to the resolution limit of the light microscopy approach used for characterization. At 200 and 450 degrees Celsius, the hardness of the unimproved Cu-Zn-Al alloy and the B-improved Cu-Zn-Al alloy increased significantly with ageing. The Fe-improved Cu-Zn-Al alloys, on the other hand, were the least vulnerable to ageing, with hardness magnitudes just slightly changing with thermal ageing treatment.

(0.1-0.5) In wt% Cu-Zn-Al SMAs were explored by Chanmuang et al. [44]. Investment casting (lost-wax casting) was carried out at 1100 degrees Celsius melting temperature and 650 degrees Celsius mold temperature. Bending tests and subsequent heating for shape recovery were used to investigate the shape memory capabilities of the alloys. SEM, TEM, energy X-ray diffraction, and selected area diffraction spectroscopy were used to characterize the microstructures. XRD measurements were also taken to further understand the effect of indium on microstructure. The data revealed indisputably that including Cu-Zn-Al SMAs triggered the second phase and significantly altered the SME. It was discussed how the microstructure and orientation connection of twinned and ordinary martensite differed. Jia Wen Xu [45] and others (XRD), optical microscopy (SEM), and the bending process were used to investigate the properties of Cu-Zn-Al alloys with varying concentrations of rare earth Gd addition. The findings show that the Gd additive refines the particles of Cu-Zn-Al alloys and that tiny spherical Gd-rich phases have precipitated in the alloys' matrix. Gd additive has no effect on the martensitic transformation type martensitic transition temperatures of Cu-Zn-Al alloys. The form recovery ratio improves as Gd is added, and the SME of the Cu-Zn-Al alloy is greatest when the Gd concentration is between 0.08 and 0.12% of the total weight.

Zainab Salim and colleagues [46] Cu-21%Zn-6%Al SMA's microstructure attributes were investigated in relation to the effects of Ag nanoparticle addition at various percentages (0.12, 0.15, 0.25, and 0.35 wt.%). Such effects were explored using optical and SEM technologies. Two 10-minute heat treatments (825 and 850 degrees Celsius) were accomplished before being quenched in ice water. Both heat treatments produced M18R martensite with a V-shape and needle-like structure; however, raising the heat treatment temperature from 825 to 850 degrees Celsius resulted in a reduction in phase development, which improved the shape memory capabilities. The particle size was refined as the amount of Ag nanoparticles supplied increased from 0 to 0.25 weight percent, reducing from 1551 nm to 212 nm with an 86.32 weight percent reduction.



Following quenching in cold water, the addition of Ag nanoparticles generates a multivariant-oriented martensite microstructure, according to the microstructure analysis. B. De Filippo and colleagues [47] The environment in which the specimens were tested had an effect on how they behaved. The martensitic lamellae are the target of corrosion attack in acidic circumstances. Corrosion rates and solution concentration have a linear relationship, and passivation phenomena are not observable. When tested in concentrated H<sub>2</sub>SO<sub>4</sub> and NaCl solutions, the alloys show a declining trend, lowering and stabilizing current density at high imposed potentials. As is the case with these occurrences, the decline is caused by the formation of a porous layer of corrosion consequence rather than appropriate passivation. Porosity allows chemical species to infiltrate from the metallic-corrosion result contact to the solution, allowing the corrosion to proceed. This layer ruptures at a high potential (above 1.2 V) and causes pitting.

After the potentiodynamic test, all of the specimens retain their SME. Oxidation conditions cause deep, superficial faults along the particle boundary, leading the material to fail by forming voids and intergranular fissures. Al-Hassani and colleagues [48], The alloy (Cu-(15-40) wt%Zn-6wt.%Al) was created using powder metallurgy technology using Zn (15, 20, 25, 30, 35, 40 wt%Zn) and a fixed proportion of Al quantity of 6.wt%Al to evaluate the impact of these components on SMA. The element (Si, Sn, Ni) was then added at a set weight percent of 6 to replace the aluminium. At these ratios, the addition of alloying elements has no effect on the current phases. The intermetallic CuZn combination, which influences hardness, became increasingly common as zinc increased. Aluminium is made less complex by the addition of Sn and Ni .

“The apparent porosity of alloys lacking additional alloying elements (Si, Ni, and Sn) was reduced. However, the bulk density of the alloy has increased since the alloy's representation of the alloying elements was included . Corrosion test findings in all fluids (HCl, NaOH, and seawater) reveal that the alloy with 35% Zn is more corrosion resistant. The introduction of alloying elements improves corrosion resistance as well. Al Haleem et al. [49] created Cu-25Zn-4Al SMAs using the powder metallurgy process with and without 0.5, 0.7, and 1 wt.% Ni or B. The effects of different amounts of boron oxide (B<sub>2</sub>O<sub>3</sub>), boron (B), and nickel (Ni) additions on the tribological, electrochemical, mechanical, and structural properties of Cu-Zn-Al SMAs were also investigated. In a vacuum tube furnace, the alloys were sintered in three steps. According to the electrochemical corrosion test results, adding Ni or B up to 1 weight percent improved the corrosion resistance of Cu, Zn, and Al SMA in 3.5 NaCl.

## Conclusion

Cu-based alloys, one type of SMA, have recently received a lot of interest due to their low manufacturing costs, greater memory capacities, ease of fabrication,



and improved thermal and electrical conductivity. Because of the combination of properties, Cu-Zn-Al alloys are a material used in industry for shape memory applications. SMAs are used in a variety of industries, including medicine, aircraft, industrial, electronics, and construction. Stents, solar panels, actuators, dampers, and jet engine components are a few examples.

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