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A Review on the Effect of Alloying Element on Physical Properties of Cu-Al-Mn Magnetic Shape Memory Alloy Material

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ABSTRACT

One of the best types of smart materials is magnetic shape memory alloy due to their unique combination of magnetic and shape memory properties this combination of these two properties has allowed them to have more applications in modern technology than many other types of materials. Among all types of magnetic shape memory alloy materials Cu-Al-Mn alloy is more focused on by researchers and scientists because it has some unique properties. Also, the behaviors of Cu-Al-Mn alloy can be improved by some techniques, one of these techniques is adding the fourth element into it. In this study, the structure and some important properties of Cu-Al-Mn magnetic shape memory alloy material were studied and the effect of adding elements by alloying process on the behaviors of Cu-Al-Mn magnetic shape memory alloy material such as transformation-temperature, grain size, superelastisity, and hardness has been reviewed.

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Introduction

Smart materials, which are an important type of advanced materials, occupy a significant position in the growth of technology throughout all of its fields. Shape memory alloys, that is one of the best types of smart materials, have attracted a lot of attention from technologists and researchers due to their attractive properties such as the shape memory effect and superelastisity [1, 2]. Shape memory alloys may be classified into a lot of groups based on the fundamental basic materials used in their production, including Cu-Zn-(X), Ag-Cd, Cu-Sn, Au-Cd, Cu-Al-Ni, Ni-Al, Mn- Cu, Fe-Pt, Ni-Ti, Ni-Ti, and Fe-Mn-Si. Among all types of shape memory alloys, both Cu-based and Ni-Ti-based have been the most popular in technology due to their cheapness, ease of preparation, resistance to corrosion and many other important properties [3, 4]. Cu-Al-Mn shape memory alloy is one of the Cu-based shape memory alloys which has achieved the magnetic property after adding the Mn element into Cu-Al alloy because Mn is one of the magnetic materials. Also, the behaviours of Cu-Al-Mn alloy can be improved by adding a fourth element. There has been a lot of research done on the addition of fourth elements to the Cu-Al-Mn alloy in the literature. US Mallik and V Sampath evaluated the effects of Zn, Si, Fe, Pb, Ni, Mg, Cr, and T on the transformation temperature of a Cu-Al-Mn alloy, and discovered that Zn and Ni increased the transformation temperature, whereas Fe, Cr, Ti, Si, and Mg decreased the transformation temperature and Superelasticity, whereas strain recovery and shape memory effect were enhanced. [5]. Y Sutou and colleagues also added some elements to Cu-Al-Mn alloy and The researchers discovered that the addition of Au, Si, and Zn enhanced the stability of martensite and raised the temperature at which martensite starts (Ms), whereas the addition of Ag, Co, Cr, Fe, Ni, Sn, and Ti reduced the stability of martensite and lowered the temperature at which martensite starts (Ms). [6]. According to research by Y. Sutou et al., the parent phase β's grain size and martensitic transformation temperature decreased when V and Cr were added in amounts greater than 0.1 at. % to the Cu-Al-Mn alloy. They also found that increasing V increased ductility while increasing Cr decreased it. [7]. In this review, the Cu-Al-Mn magnetic shape memory alloy has been reviewed. Also, the effect of alloying elements on the properties of Cu-Al-Mn magnetic alloy material including transformation temperature, grain size, superelastisity, and hardness has been reviewed.

Shape Memory Alloy

Shape memory alloys (SMAs) are a special type of intelligent material that is distinguished by their ability to return to their original state after distortion due to the influence of external forces. Also, SMAs have many uses in industrial and technological applications because they have two interesting behaviours: superelasticity (SE) and shape memory effect (SME) [8-11].

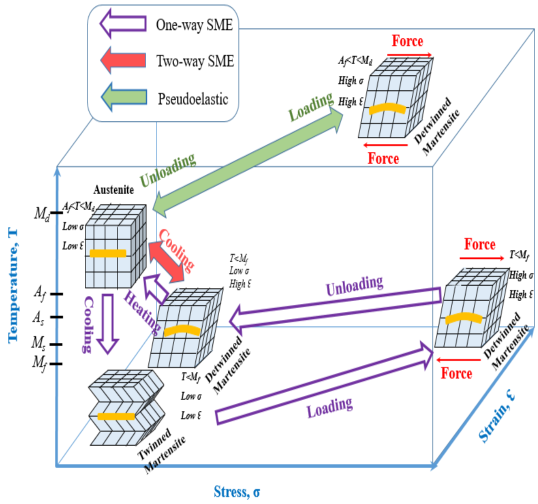

Figure 1 The phases and Shape Memory Effect (SME) of Shape Memory Alloy (SMA) [9, 12]

Also, shape memory alloys (SMAs) consist of two primary morphological phases: austenite and martensite. Austenite is a phase that occurs at high temperatures. And has a hard solid solution, but the martensite phase is called a low-temperature phase and it has a weak solid solution compared to the austenite phase [9, 13, 14]. Besides, the martensite phase undergoes a transformation into the austenite phase during the cooling and heating process, which is known as the shape memory effect (SME). Also, When SMAs are subjected to an external force within a specified temperature range, the austenite phase transforms into the martensite phase., this process is called pseudoelasticity (PE) or superelasticity (SE) (Figure 1) [9, 12]. SMAs can return to their original morphology after cancelling the effect of temperature and applied stress [15-17]. There are more groups of SMAs including Cu-Zn-(X), Ag-Cd, Cu-Sn, Au-Cd, Cu-Al-Ni, Ni-Al, Mn-Cu, Fe-Pt, Ni-Ti, Ni-Ti, and Fe-Mn-Si [15], but (Ni-Ti, Cu, and Fe) base more useful in technological application [18-24]. Among all families of SMAs Cu-base is more focused on by researchers because it has a high phase transformation temperature, low cost and simplicity in production processes [25, 26].

Shape Memory Effect

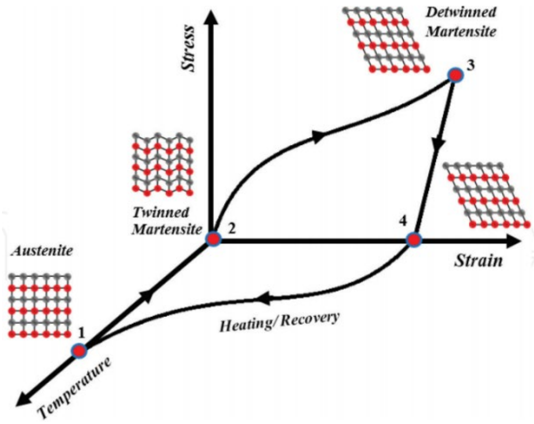

Figure 2. Schematic diagram of SME [27]

The Shape Memory Effect (SME) is a phenomenon in which a Shape Memory Alloy (SMA) returns to its original shape after undergoing plastic deformation, often by the application of heat. This property is the result of the reversible phase change of shape memory alloys (SMAs). SMEs rely on the martensite-austenite and austenite-martensite transformations that occur when subjected to heat or stress [28, 29]. Figure 2 demonstrates the schematic diagram of the SME process, which will occur in four steep, represented by (1→2→3→4→1) cycle [27]. After cooling the austenite phase SMA will start to phase transformation above Martensite start (Ms) temperature, and when it arrives at Martensite finish (Mf) the phase fully transformed to the twinned martensite (1→2) and twinned changed to de-twinned after adding mechanical stress through (2→3) process, and after removing the effect of applied stress during (3→4) process its crystal structure will not change, but at the final process (4→1) when we heated detwinned martensite above a particular temperature, its crystal structure changes. It can be recovered to an apparent permanent strain which is the higher temperature phase (austenite). There are two main types of SME, including, the one-way shape memory effect (OWSME) and two-way shape memory effect (TWSME) (Figure 3) [30]. As shown in Figure, in OWSME the alloy will return to its previous shape after heating process (Figure 3-a), but in TWSME the alloy will be changed to two different phase; one of them is (martensite) which is in lower temperature and the other is (austenite) that is the higher temperature phase (Figure 3-b), and the recovery strain in OWSME is usually greater as in TWSME in the certain material [9, 31].

Pseudoelasticity (Superelasticity) (SE)

Pseudoelasticity, or superelastisity, is one of the interesting behaviours of SMAs which is an elastic response to an external force, produced by a phase change between the austenite phase and martensite phase of an alloy, Pseudoelasticity will follow in the specific range of temperature which is indicated between M_f and M_d, in a way above M_d, the alloy cannot show this property [31, 32]. Figure 4 describes the Pseudoelasticity in the (stress-strain) diagram which is indicated by the isothermal process (A to B to C to D to E to F to A), as shown in Figure 4 when the stress is applied to the alloy above the Mf temperature, the alloy will be deformed elastically (A→B), and when the applied stress is increased from (B→C) the phase of the alloy will be transformed from austenite to martensite. In the figure martensite start denoted by σ^{Ms} while σ^{Mf} is the martensite finish, from (C→D), the alloy is totally in the martensite phase which has detwinned morphology, and when the stress is removed, the alloy can return to its parent phase (austenite) as shown in figure (D→E→F). Also, σ^{As} is the austenite start and σ^{Af} is austenite finish [33].

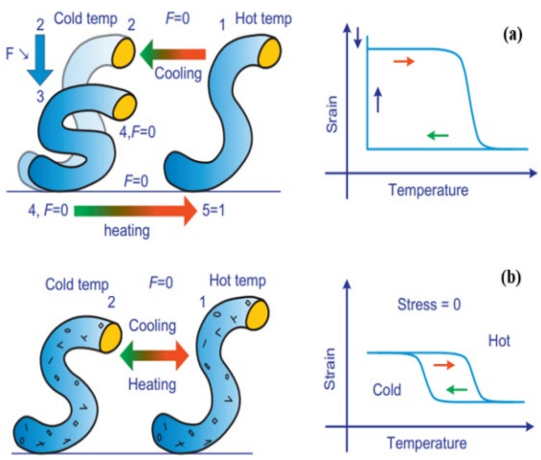

Figure 3. (a) Two-way, (b) One-way shape memory effect [30]

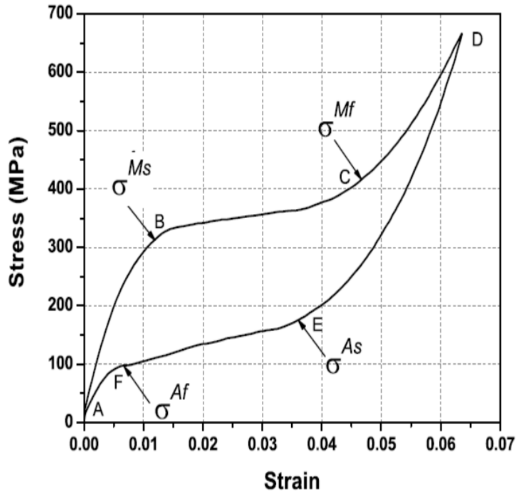

Figure 4. Schematic diagram of superelasticity [32]

Cu-Based Shape Memory Alloy

As we said before, SMAs have some types, one of them being Cu-based SMAs and Cu-based, Cu-Zn and Cu-Al are more attention by researchers and scientists because they have many advantages compared to other groups of SMAs such as good memory properties, high transformation temperature, good thermal property and electrical property, low coast and they can be easily manufactured [34]. Also, Cu-based SMA has three groups which are Cu-Al, Cu-Sn, and Cu-Zn, which are tabulated in Table 1 [35]. But Cu-Al and Cu-Zn have more technological applications because they have some interesting properties compared to other types of SMAs (Table 2).

Table 1. Types of Cu-based SMAs[35],

Cu-based SMA	Cu-Zn	Cu-Al	Cu-Sn
Ternary	Cu-Zn-X X= AL, Ga, Si, Sn, Mn	Cu-Al-X X=Be, Zn, Mn, Ni	Cu-Sn-X X=Al, Mn
Quaternary	Cu-Zn-Al-Ni Cu-ZN-Al-Mn	Cu-Al-Ni-Mn	
Comercial	Cu-Zn-Al Cu-Zn-Al-Mn	Cu-Al-Ni Cu-Al-Ni-Mn	

Despite these good properties that we mentioned, Cu-based SMAs have some deficiencies in chemical and physical properties such as brittleness, but these deficiencies can be treated by heat treatment and alloying technique, for example when Al is added into Cu-Zn or added Al and Mn into Cu-Sn caused to increasing the transformation temperature. Likewise, adding Ni to Cu-Al caused to change in the mechanical properties of Cu-Al alloy [35]. In the heat treatment technique, the quenching media that causes to change in both the transformation temperature and microstructure of the treated sample has a main effect on the characteristics of a sample.

Table 2. Some important properties of Cu-based SMAs [36]

Cu-based SMAs	Transformation temperature(oC)	Temperature Hysteresis(oC)	Strain recovery%	Features
Cu Al Ni	100-400	21.5	60-90	İt is cheap high shape memory brittleness Its phase is stable at around 200°C

Cu Zn Al	120	15 to 25	70–85	good thermal conductivity Its shape memory strain is high İts a cheap It's a brittle
Cu Al Be	150 to 200	20 to 25	80–90	It has high shape memory strain good transformation temperature Its corrosion resistance is good.
Cu Al Ni Be	230 to 280	15 to 20	90–100	good shape memory properties good transformation temperature Its corrosion resistance is good.
Cu Al Ni-Ti	120 to 260	12 to 20	90–100	good shape memory properties good transformation temperatures Its corrosion resistance is good.
Cu Al Ni Fe	210 to 250	12 to 15	40	low shape memory properties high ductility low cost good transformation temperatures Its corrosion resistance is good.

Dagdelen and coauthors carried out the heat treatment to Cu-Al-Ni-Ti they kept the samples at 930 ℃ for 30 min, and they cooled the sample by using three different quenching mediums including liquid nitrogen at -196 ℃, iced brine at 6 ℃, and alcohol at 0 ℃, and they investigated that alcohol and the ice-brine quenching medium was caused to increase the transformation temperature by 100 K, and the enthalpy of them was increased, besides, they showed that some other properties of Cu-based SMAs have been improved after heat treatment processes such as grain size, microhardness, and stability [37]. Also, the alloying process has a sensitive effect on the transformation temperature of SMA. Increasing or decreasing a small amount of composition elements can cause changes in the transformation temperature, for example, adding aluminium into Cu-Zn alloy between (5-10 % weight) will be caused to increase the martensite start (Ms) by (-90 →370 K). [13], and Y.Sutou, et al. found that the Mn has a positive effect on Cu-Al alloy, they investigated that Cu-Al-Mn has good ductility and SM characteristics and it shows a high damping property [38].

Cu-Al-Based Shape Memory Alloy

Figure 5 represents the phase diagram of binary Cu-Al alloy, which is one of the most important phase diagrams in Cu-based shape memory alloy [39, 40]. As shown in Figure 5-a the β (A2) phase which is a disordered phase is only in the range (20 to 30 % at) of Al composition and can be stable above 650 ℃ of the temperature range. Also, it can be seen that $\beta \rightarrow \beta_2$ (CuAI: B2) $\rightarrow \beta_1$ (Cu3AI: DO3) the reaction occurs during quenching at low temperatures but it cannot occur at fast quenching. In this range of Al composition, the martensitic transformation will be occurred. The transformation temperatures will reduce after increasing the composition of the Al element. Figure 5-a shows that there are three different phases in the different ranges of Al composition including α' (3R: disordered fcc), β_1' (18R), and γ_1' (2H) [39]. The stability of β phase and SM properties of Cu-Al alloy can increase by adding a third element such as Ni, Zn, and Mn. But, β_2 and β polycrystalline ordered structures are too brittle in the high composition of Al content and this brittleness is caused to decrease the fatigue strength of Cu-Al alloy. Also, several reasons caused to decrease in the ductility of polycrystalline Cu-Al alloys such as large grain size, high elastic anisotropy, grain boundary separation, and a high degree of order, but researchers have attempted to improve the ductility and other properties of Cu-Al shape memory alloy by adding the third element especially Mn into it [6].

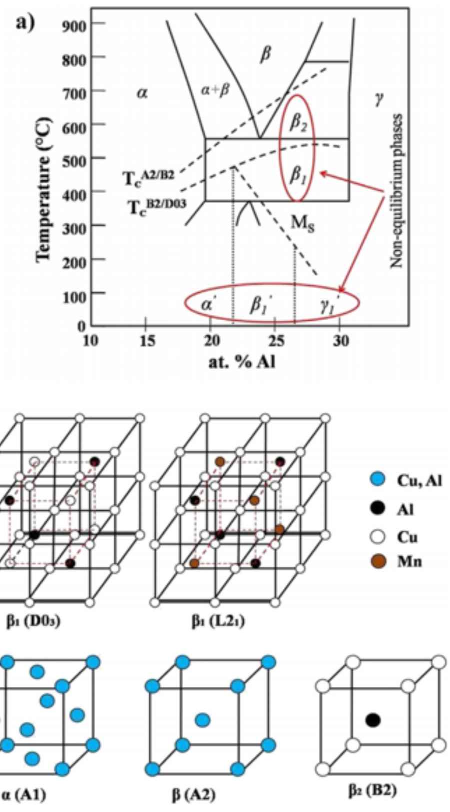

Figure 5. (a) Phase diagram of Cu-Al alloy, and (b) Lattice structure of different phases in Cu-Al alloy [39]

As we mentioned previously binary Cu-Al-based shape memory alloy has some imperfections, for example, enormous grain size, large elastic anisotropy, high grain boundary separation, and a high degree of order, which these imperfections cause to decrease the ductility of Cu-Al alloy, but these limitations can be removed by addition the element, Mn is one of these elements that have a positive effect on Cu-Al which it will cause to increase the ductility of it, and it caused to improve some SM properties such as crystallography and morphology of martensite transformation temperatures [41, 42], and phase stability [39, 43], and ageing effect [44]. Table 3 displays the common important behaviors of the Cu-Al-Mn alloy in comparison to the Ni-Ti alloy. The behaviours of Cu-Al-Mn exhibit a strong shape memory compared to Ni-Ti. In comparison, Ni-Ti alloys are more costly than Cu-Al-Mn alloys, and they are more complicated to machines, especially for pipe coupling applications, therefore Cu-Al-Mn alloys have more application in pipe coupling compared to Ni-Ti alloys [45].

Table 3. Comparison of properties between Ni-Ti and Cu-Al-Mn SMAs [45]

Property	Ni-Ti SMA	Cu-Al-Mn SMA
Tensile Strength (MPa)	800 to 1 000	700 to 800
Elongation (%)	40 to 50	10 to 12
Maximum One-Way-Effect (%)	8 to 9	6 to 7
Maximum Two-Way-Effect	4	3
Developed stress (MPa)	600 to 700	500 to 600

Besides, Cu-Al-Mn will create the β (bcc) for diffusion decomposition and reduce this reaction [39], And the β phase will become a metastable phase, therefore, Cu-Al-Mn alloys are preferred over other Cu-based SMAs for specific technical applications because they may obtain more acceptable shape memory behaviours. Cu-Al-Mn alloys exhibit magnetic behaviour; the fundamental properties of an alloy are dependent upon its crystallographic phase and structural composition. Thus, the Cu2Mn-Al phase exhibits ferromagnetic properties with a moderately high temperature (630 K) while Cu3Mn2Al exhibits antiferromagnetic properties [46]. These properties depend on the interaction between the atoms of Mn in the crystal lattice [47, 48]. The structure of Cu-Al-Mn alloys can arrange with crystal structures of type B2 β2, D03 β1 or L21 β3. After fast cooling down these phases can be converted to martensite. [7]. Upon cooling the β (A2) phase region, the alloys go through several ordering changes of β-(A2) to β2-(B2) to β3-(L21). Also, the properties of Cu-Al-Mn shape memory alloy can be improved by alloying process [46].

Alloying Process into Cu-Al-Mn

As mentioned earlier, Cu-Al-Mn has many important and attractive properties, but some shortcomings hinder the development of its use in modern technology that needs to be addressed. Also, previously we discussed that there are some techniques or processes to improve the behaviors of Cu Al Mn alloy, and the alloying process is one of these processes. The alloying of chemical elements can enhance the mechanical properties and thermal properties also other physical properties of Cu Al Mn, in the next sections we will try to discuss the effect of quaternary alloying on the properties of Cu-Al-Mn alloy.

Effect Of Alloying Elements on The Transformation Temperature of Cu-Al-Mn SMA

One of the important behaviors of SMAs is phase transformation temperature in them the SMAs change their phases from one phase that has a specific crystal structure to another phase and its structure differs from the first. Figure 6 demonstrates the phase transformation temperatures in SMAs, the temperature at which the alloy started to change its phase from martensite to austenite is called austenite start (As), but the austenite finish (Af) is the temperature at which the alloy totally at austenite phase and the transformation process is finished. The martensite start (Ms) is the temperature at which the alloy will start to convert its phase from austenite to martensite this transformation process is finished at martensite finish (Mf) and the alloy is totally at martensite finish after this temperature. [49]. Also, the temperature hysteresis is a temperature difference between (Af) and (Ms) (Figure 6). Several studies have investigated the effect of adding the fourth element into the Cu-Al- Mn alloy. Y. Sutou and coworkers have added two groups of chemical elements into Cu-Al-Mn, the first group are (Au, Sn, Zn, Ag, and Ni) which are highly soluble solute elements, the martensite start (Ms) temperature increased by adding Zn and Au (Figure 7-a), but it decreased after adding Ag, Sn, and Ni. Also, they added another group of elements (Si, Cr, Fe, Ti, and Co) which have low solubility, they investigated that only Si was caused to increase the Ms temperature and after adding all of the Ms was decreased (see Figure 7-b) [6].

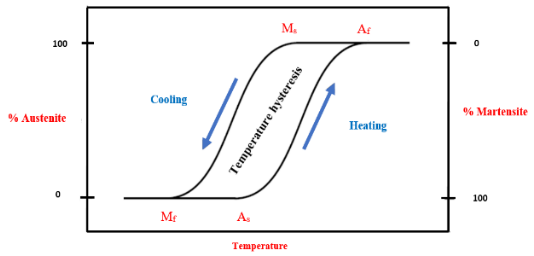

Figure 6. Schematic diagram of phase transformation temperatures of shape memory alloys [50]

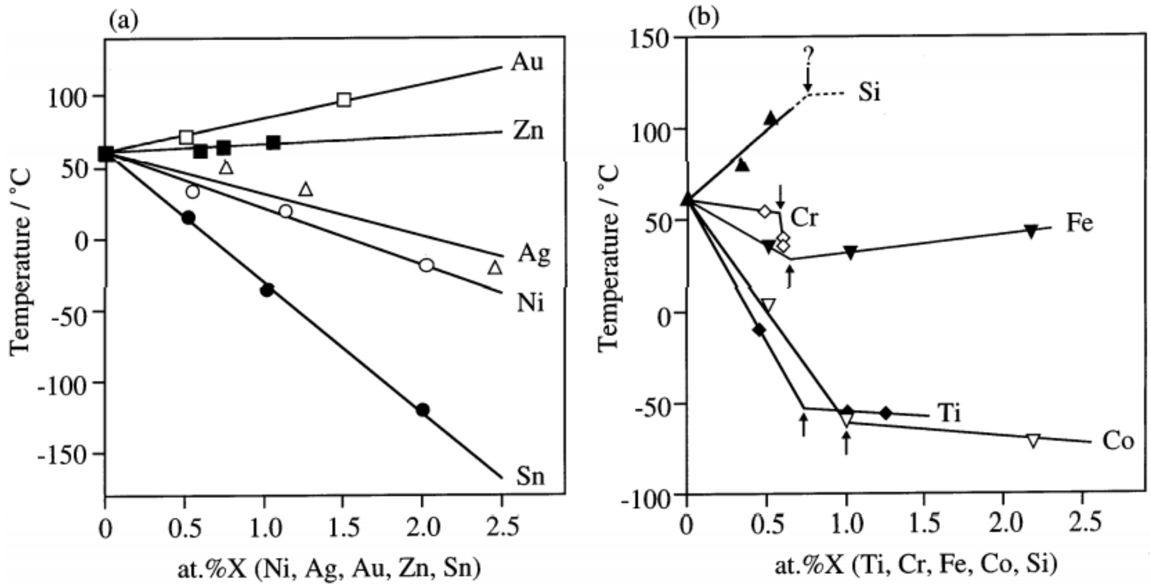

Figure 7. Change of martensite start temperature with (a) alloying elements which have high solubility, (b) alloying elements which have low solubility[6]

Also, V. Sampath and U.S. Mallik added Zirconium (Zr) and Boron (B) to Cu-Al- Mn alloy, and they saw that Boron additive was caused to increase the transformation temperatures by 15 ℃ of Cu-Al-Mn in different compositions, but after adding Zirconium (Zr) the transformation temperatures have fluctuated, in other words, in some composition of zirconium transformation temperatures were increased while in some composition rate of zirconium they were decreased (see Figure 8) [51].

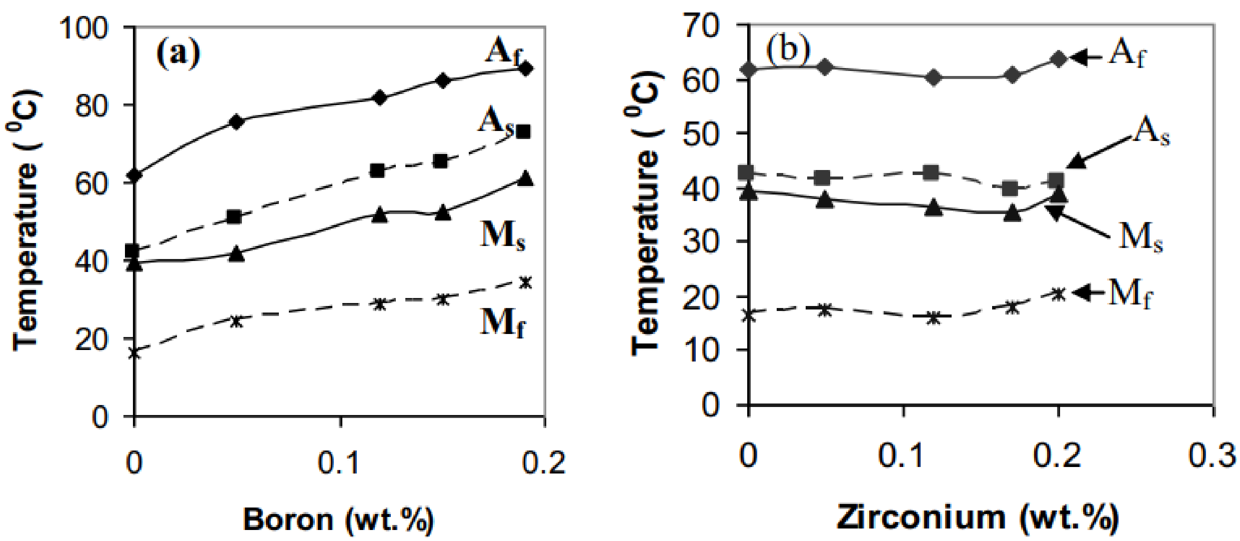

Figure 8. The effect of (a) Boron, and (b) Zirconium on transformation temperatures of Cu-Al Mn [51]

Effect of Alloying on Superelastisity of Cu-Al-Mn Alloy

The superelastisity of SMAs was discussed previously. The superelastisity of Cu-Al-Mn alloy can be affected by adding the fourth element. When the elements are added to the Cu-Al-Mn alloy, they result in the formation of either a solid solution or precipitation within the alloy. As a consequence, the limitations on strain will intensify and the thickness of the martensite plates will decrease. Consequently, a greater amount of stress is required to produce stressful martensite.

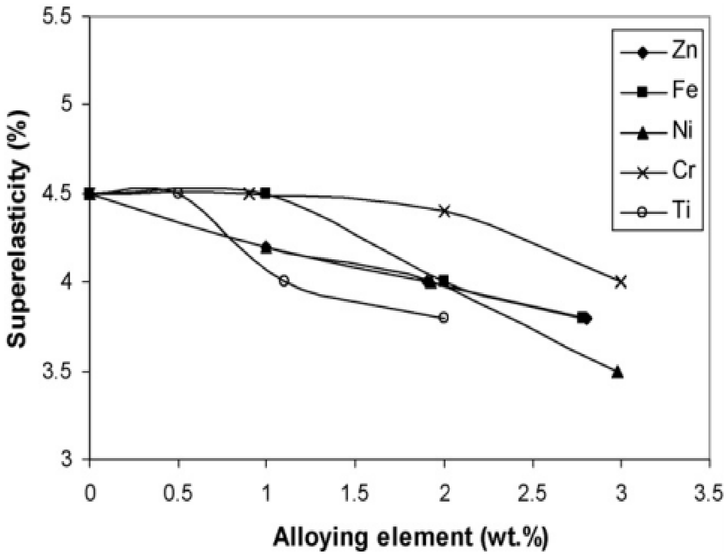

Figure 9. Change of SE with change in the composition rate of alloying elements [5].

Hence, the superelastisity (SE) will be decreased [5]. U.S. Mallik and V. Sampath proved this decreasing process of SE when they added Zn, Fe, Ti, Cr, and Ni into Cu-Al-Mn as a fourth element, as shown in Figure 9 the superelasticity was decreased after adding these elements into Cu-Al-Mn alloy [5]. Also, in another work, they investigated whether adding Zirconium (Zr) and Boron (B) were caused to reduce the superelastisity of Cu-Al-Mn alloy (Figure 10) [51].

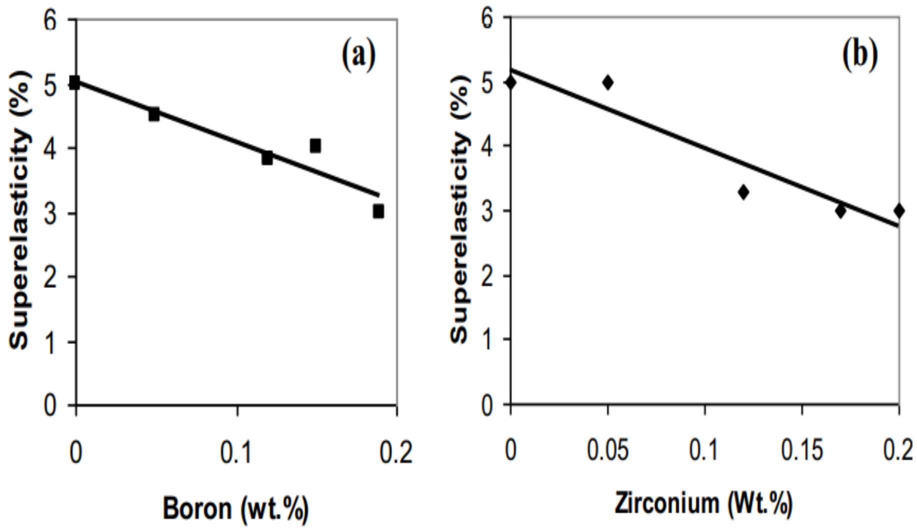

Figure 10. Relationship between superelastisity and (a) alloying B, (b) alloying Zr [51]

Effect of Alloying Elements on The Grain Size of Cu-Al-Mn Alloy

Grain size can be defined as the diameter of the individual grains in metals or metal alloys, and it is an important parameter that can control corrosion behaviour, yield strength, ductility, hardness, and so on, of materials and alloys [52]. Grain size is one of the behaviours of shape memory alloys that can be affected by quaternary alloying elements. Mallik and V. Sampath added Zr and B into Cu-Al-Mn SMA by the amount (0.05 to 0.2 wt.%). As shown in Figure 11 Zirconium was caused to decrease the grain size by 75 % of its initial value, and the grain size with Boron addition was reduced by 25 % whereas its value decreased from 468 μm to 340 μm [51].

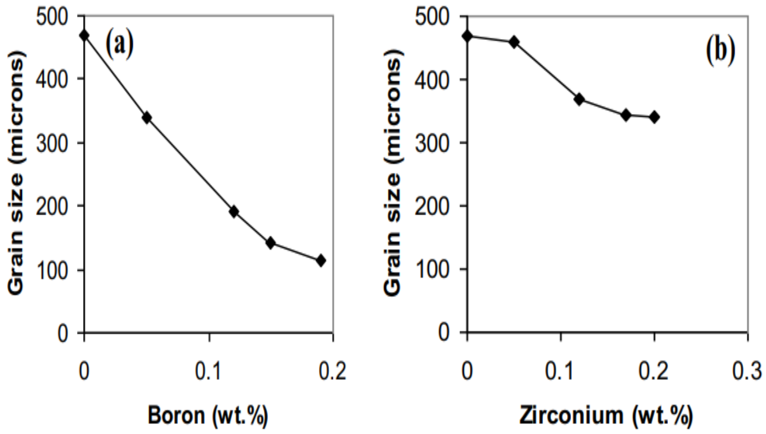

Figure 11. Changing of grain size with (a) Boron addition, (b) Zirconium addition[51]

Effect of Alloying Elements on The Hardness of Cu-Al-Mn Alloy

Hardness, which quantifies the material's resistance to penetration, is a significant property of SMAs. Hardness is also affected by factors like as heat treatment temperature, stress, grain size, transition strain, and alloying components. [13, 53, 54].

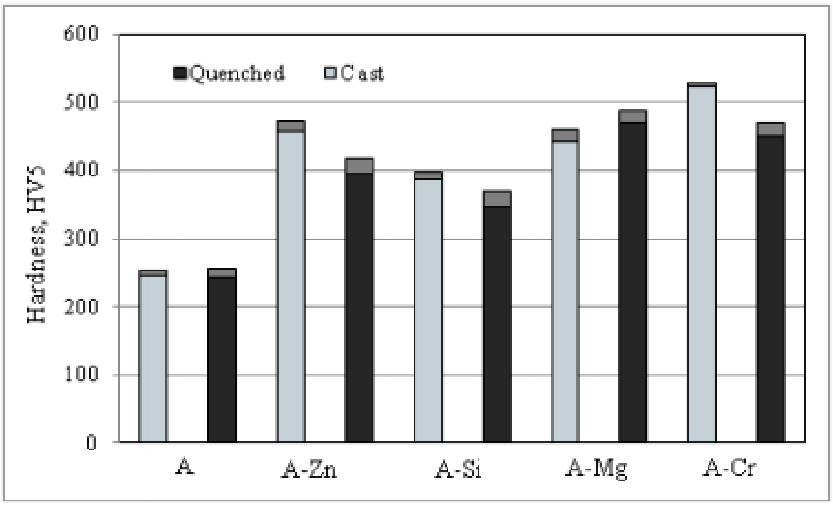

Figure 12. effect of element alloying on the hardness of Cu-Al- Mn [55]

Some works studied how hardness was affected by alloying the fourth element into Cu-Al- Mn SMA. Pravir Kumar et al. added Zn, Si, Mg, and Cr, they investigated that the hardness of Cu-Al-Mn alloy was increased after adding the fourth element, and they examined that Cr has more effect on increasing hardness than the other elements, also, the ageing process was reduced the hardness in all alloying process except Mg alloying which it caused to increase it (Figure 12) [55]. Abhishek Pandey and coauthors have tested the effect of alloying of niobium and silver into Cu-Al-Mn. The result showed that both niobium and silver were caused to enhance the hardness while the ageing process reduced it (Figure 13) [56].

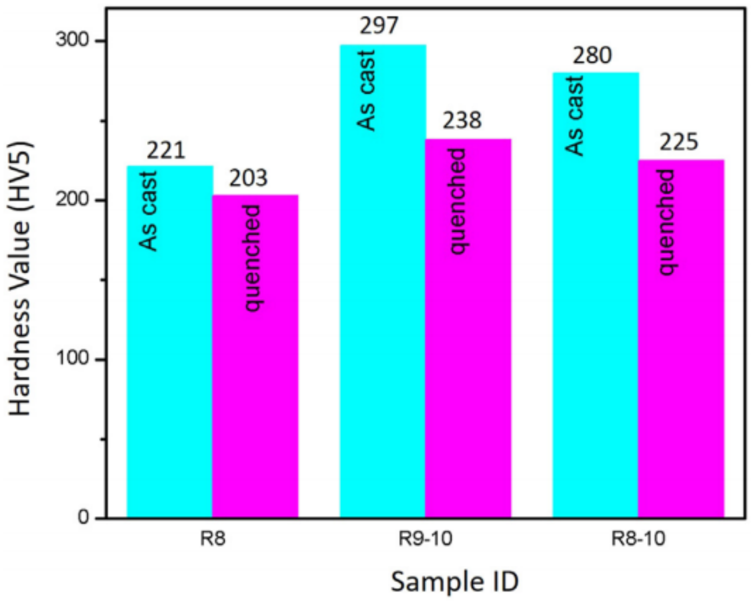

Figure 13. Showing the effect of niobium and silver on the hardness of Cu-Al-Mn [56]

Effect of Alloying Elements on The Magnetic Properties of Cu-Al-Mn Alloy

After adding Mn, Cu-Al becomes a magnetic alloy because Mn is a magnetic metal. This makes it more useful in some different fields of technology than other alloys or Cu-Al as the casted alloy. Also, these magnetic properties can be changed or improved by several techniques, including the addition of other chemical elements, such as Sn and Gd, which affect the magnetic properties of Cu-Al-Mn shape memory alloys. As can be seen from Figure 14, Sn has a positive effect on increasing the saturation magnetization of an alloy while Mn decreases that attribute [57]. Also, Zr and Hf have a similar effect on the magnetization behaviour of Cu-Al-Mn alloy (as shown in Figure 15), and they changed their magnetic behaviour from ferromagnetic to paramagnetic [58].

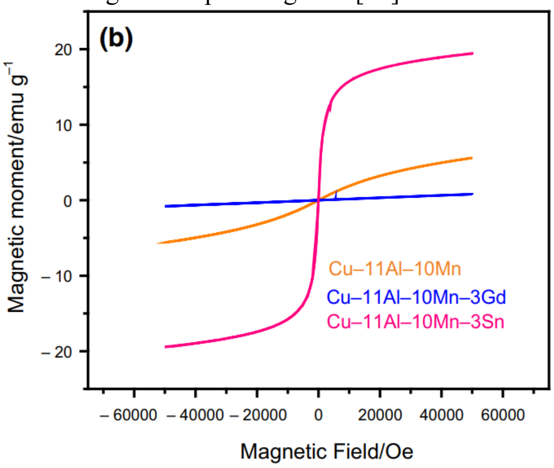

Figure 14. Represents the effect of Sn and Gd on saturation magnetization of Cu-Al-Mn [57].

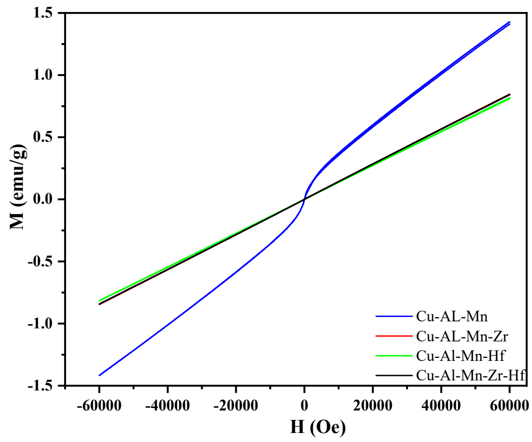

Figure 15. magnetization behavior of Cu-Al-Mn, before and after adding Zr and Hf [58].

Effect of Alloying Elements on The Corrosion Resistance of Cu-Al-Mn Alloy

Cu-Al-Mn shape memory alloys generally have good corrosion resistance. This property makes them suitable for various applications, especially in environments where corrosion resistance is crucial. However, the exact level of corrosion resistance can vary based on the specific composition of Mn and the treatment of the alloy. Also, the alloying element as a treatment process can improve this behaviour of Cu-Al-Mn alloy. It can be seen that the addition of vanadium (V) has a significant effect on improving the passivation layer and higher percentages of martensite phase $\beta 1'$ and $\gamma 1'$ lead to more stable and protective passivation films [59]. Ali Hubi Haleem et.al showed that after adding Ta and Into Cu-Al-Mn alloy the Erosion corrosion rate decreased as indicated in Table 4 [60]. Also, Table 5 represents Vrsalović and colleagues' work they found the same result as in Ali Hubi Haleem's work, after adding Ni to Cu-Al-Mn they found that the polarization resistance increased which caused to enhancing the corrosion resistance of the alloy [61]. There are some other reports in the literature which follow this result [61-64]

Table 4. Erosion corrosion rate of Cu-Al-Mn alloy before and after adding Ta and In [60].

Synthesized Composition	Erosion rate	Improvement %
Cu-8Al-9Mn	0.122	0
Cu-8Al-9Mn-1%Ta	0.027	77.86885
Cu-8Al-9Mn-2%Ta	0.0017	98.60656
Cu-8Al-9Mn-3%Ta	0.0059	95.16393
Cu-8Al-9Mn-1%In	0.188	……..
Cu-8Al-9Mn-2%In	0.044	63.93443
Cu-8Al-9Mn-3%In	0.0175	85.65574

Table 5. Polarization parameters of Cu-Al-Mn and Cu-Al-Mn-Ni alloy. [61]

Alloy	$\mathbf{E_{corr}}$ / V	$\mathbf{I_{corr}}$ / µA $\mathbf{cm^{-2}}$	$\mathbf{R_P}$ / k$\mathbf{\Omega}$ $\mathbf{cm^2}$
CuAlMn	-0.346	3.5	4.907
CuAlMnNi	-0.322	2.28	6.445

Conclusion

In conclusion, this study offers a thorough examination of how alloying elements impact the different physical properties of Cu-Al-Mn Magnetic Shape Memory Alloy (SMA). The Cu-Al-Mn alloy is a notable member of the shape memory alloy family due to its exceptional combination of magnetic and shape memory properties. Extensive research has been conducted on the properties of the alloy, as summarized below. Studies have demonstrated that the alloying elements can have an impact on the transformation temperatures of Cu-Al-Mn. This influence affects both the austenite and martensite phase transitions. The elements added to the alloy have different levels of solubility and can affect the transformation temperatures in different ways. In addition, the process of alloying has an impact on superelasticity. Specifically, when certain elements are added, it can result in a decrease in the overall superelastic properties. This information is crucial for applications where superelasticity plays a critical role, such as in pipe couplings. Alloying also affects the grain size of Cu-Al-Mn, as certain elements can cause a notable decrease in grain size. The hardness of Cu-Al-Mn is noticeably affected by alloying elements. The findings indicate that by carefully choosing and controlling the alloying elements, it is possible to adjust the physical properties of Cu-Al-Mn SMA. This can greatly improve its suitability for various technological applications. The alloying process can change the magnetic behaviour of Cu-Al-Mn alloy. Some elements can improve their magnetization property such as Sn, while some others cause to decrease in that attribute such as Zr, Hf, and Gd. Also, some reports have investigated that the corrosion resistance of Cu-Al-Mn alloy can be enhanced by adding the fourth element.

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