A Review OF Shape Memory Alloy Cu-Zn-Al

Nur Amin, Sulistyo, Agus Suprihanto, Atik Setyani

Abstract – Shape memory alloy (SMA) is currently a material that is widely developed in various technologies such as automotive, orthopedic, aerospace, sensors, and actuators**.** SMA's ability to respond to changes in shape and temperature is very suitable for use in equipment that requires safety and functional intelligence. In the development of SMA, it is necessary to understand the process parameters which are one of the challenges in the development of SMA today, so that SMA with good properties is obtained.

Index Terms— Shape Memory Alloy, SME, Cu-Zn-Al, Material

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1 INTRODUCTION

Shape memory alloys (SMA) were first observed in 1930 and continue to grow today [1]. The development of SMA has been massive since 1963 when it was the first time that nickel-titanium (Ni-Ti) alloy or known as Nitinol was introduced and commercialized. Nitinol is usually in the health sector as a material for orthodontic wires, braces, and coronary stents. Nitinol has good shape memory effect (SME) properties, but on the other hand, it is expensive, the fabrication process is quite complicated, and the transformation temperature is low [1]. Therefore, the challenge of the current development of SMA is the exploration to find new compositions of various alloys with various compositions in the specified transformation range so that the application of SMA is even more comprehensive.

One of the material alternatives currently being developed is Cu-based SMA, namely Cu-Zn-Al, because of the low production costs, high material availability, and easy manufacturing process. In the last few years, the development of SMA materials has shown significant improvement because the industry's interest in SMA materials is increasing. So that this paper will review the development of Cu-Zn-Al-based SMA materials in terms of alloy composition, quenching methods, and cooling media.

2 DEVELOPMENT OF SHAPE MEMORY ALLOY

2.1 SMA (Shape Memory Alloy)

Shape memory alloys (SMA) are alloys that can return to their original shape despite having received considerable amounts of deformation. In SMA, the austenite phase, also called the parent phase, can transform bidirectionally from the austenite phase to the martensitic phase [2]. This transformation from a solid phase to another solid phase is of the diffusion-less type, where atoms undergo small-length ordered displacement [3]. The transformation from the austenite phase to the martensitic phase can occur through two mechanisms, namely due to rapid cooling or deformation addition, which results in different characteristic forms, namely twinned or multi-variant martensitic for those formed due to rapid cooling and detwinned or single-variant for martensite formed due to deformation [2,4]. The transition temperatures of the martensitic and austenite phases in the SMA are classified into four transitional temperatures, which were notated as M_s, M_f, A_s, and A_f [2,5].

Macroscopically, the behavior of shape memory alloy forms can be characterized through Shape Memory Effect (SME) and superelasticity. The SMA alloys with SME properties, the alloy can return to their original form when given heat treatment at certain temperatures. So that SME is sometimes also referred to as a thermoelastic material. The SMA alloys will have SME properties if, after quenching produces a martensitic phase. Applying stress to SMA material with SME properties will change the twinned martensitic phase to the detwinned phase and return to the twined martensite phase when heated. [2,3,5,].

The super elasticity (SE) property occurs in SMA when an austenite phase is formed after quenching or deformation treatment as a stage of SMA fabrication [6]. In the alloy material can immediately return to its original form without having to give temperature. The

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mechanism of phase transformation is that austenite becomes detained martensite and returns to the austenite phase. This occurs when the austenite phase is stable at ambient temperatures with no loading conditions. The mechanisms of SME and SE are schematically shown in

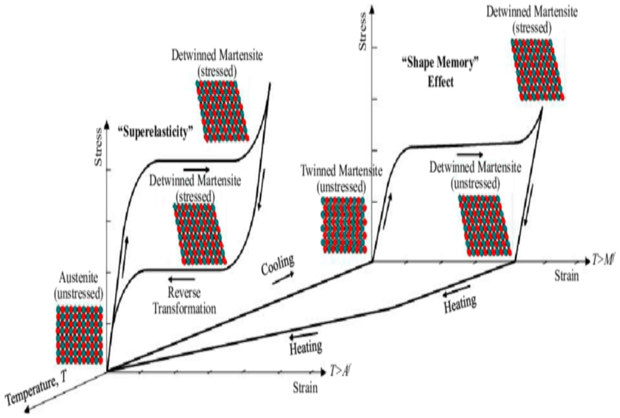

Fig. 1.

Fig. 1 The schematic mechanism of Shape Memory Effect and Superelasticity in Shape Memory Alloy [7]

2.2 Cu-Based Shape Memory Alloys

The currently available Cu-based shape memory alloys are derivatives of three primary binary alloys: Cu-Zn, Cu-Al, and Cu-Sn alloy [8]. Cu-Sn alloys have poor thermoelastic characteristics because they have decreased SME properties due to the alloys being quickly aged, even at low temperatures. Some elements added to the Cu-Sn binary alloy include Al, Si, Sn, Ga, or Mn. As for Cu-Zn are Ni, Be, Al, Mn [8-9]. Increasing the mechanical strength is usually done by adding grain-refining elements such as B, Ce, Co, Fe, Ti, V,
and Zr [3,8-10]. Cu-based shape memory alloy classification shown in figure 2

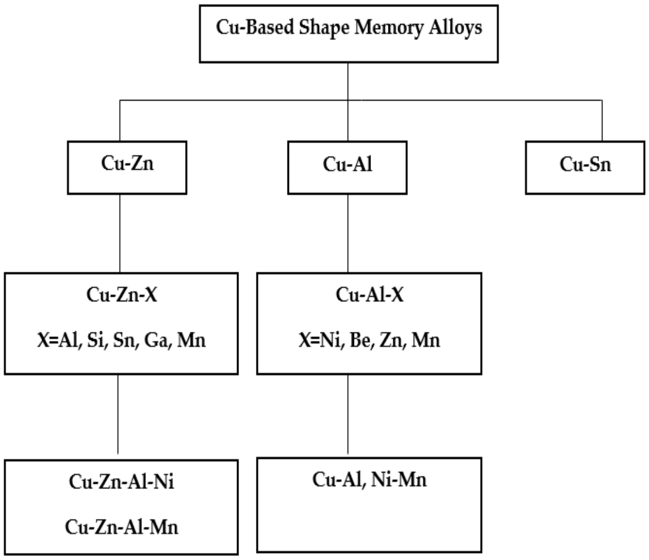

Fig.2 Cu based shape memory alloys classification

The properties and characteristics of SMA Cu Based are quite sensitive to the addition of alloying elements, both in terms of transformation temperature, thermal stability and mechanical properties. Martensitic phase transformations in Cu-based form alloys generally occur in phase β which have a BCC crystal structure [3].

2.3 Cu-Zn-Al Shape Memory Alloys

Cu-Zn-Al alloy is one of the Cu-based alloys that is widely developed today. The application of the transformation temperature of the Cu-Zn-Al alloy which is in the range of 100 °C causes this alloy to be projected for sensor applications and some materials in automotive [1, 6]. The development challenges are to expand phase transformation, improve SME properties, decrease aging and avoid martensitic stabilization. Process parameters such as composition, quenching method, and heat treatment are important stage in the fabrication of Cu-Zn-Al SMA alloys.

2.4 Composition on of Cu-Zn-Al Shape Memory Alloy

The composition of the Cu-Zn-Al alloy is one of the factors that determine the success rate of strain recovery in SMEs. Cu-Zn-Al alloys can have SMA properties on compositions containing 16–30 wt.% Zn and 4–8 wt.%Al [11]. This composition is in the area of the α and β phases. Composition becomes very important because it can affect the temperature of phase transformation (Ms, Mf, As, and Af), grain size, and general mechanical properties of alloys [8]. Some researchers have conducted studies of composition variations and produced different SME capabilities. Jatimurti et al [12]. Conducted a study with the composition of Cu-21- Zn-5Al in obtaining SME 16.67 %.

Setyani et al. [13] conducted a study with the composition of Cu-28Zn-3Al wt. %, the results of the SME test showed that the alloy had SME in the range of 27.2-36.3%. The Cu-Zn-Al alloy with the composition in the game area was developed by Lohan et al. [14] and produces alloys with SME properties. The composition of the alloy in the duplex regions αβ and βγ shows SME properties, while in the Full β area it shows super elastic properties characterized by the crystalline structure of ful austenite. Table 1 shows data on the composition and nature of the SMA.

Table 1.
The Composition And Shape Memory Effect Of Cu-Zn-Al

No	Cu	Zn	Al	SME %	SE	Phase composition	Phase after quenching	Ref
1	balance	21	5	20	0	(α+β)	martensite	12
2	balance	28.2	2.94	36.3	0	(α+β)	martensite	13
3	balance	20.8	5.8	94	0	(α+β)	martensite	20
4	balance	22.3	5	91	0	(α+β)	martensite	24
5	balance	22	7	70	0	(α+β)	martensite	17
6	balance	25	4	0	0	(α+β)	martensite	22
7	balance	26.1	4.8	40	0	(α+β)	martensite	24
8	balance	30	4	0	SE	(β)	austenenite	22

So in general, the Cu-Zn-Al alloy when plotted on the ternary diagram [15] has the potential to have SMA properties in the αβ, βγ, and full β regions. The ternary chart plot is shown in Fig. 3

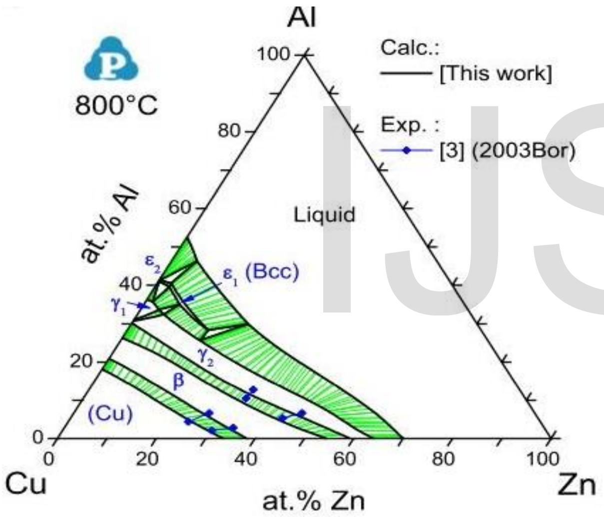

Fig.3 Ternary diagram of Cu-Zn-Al [15].

2. 5 Betatizing

Betatizing is a heat treatment by raising to a certain temperature to form the initial phase in a solid solution. Betatizing is done by heating at a temperature of one phase, namely β phase area. The betatizing temperature aims to make the alloy in the austenite phase which will receive quenching treatment into a martensite phase capable of producing SME properties.

From the literature study, heat treatment can produce different SME properties. This is in accordance with the research conducted by Jatimurti et al. [12] who carried out various heating variations at temperatures of 750, 850 and 900 °C on Cu-21 Zn-5Al alloys. From the test results it is known that SME increases with increasing temperature, but at a temperature of 900 °C SME decreases. The same thing was done by Xiaomin et al. [24], by varying the heat treatment at 700, 800, 850 and 900 °C for 30 minutes on Cu-26.1Zn-4.8Al wt.% alloy. The result is that as the heating temperature increases, the SME decreases because of the alloy vacancy increases. The provision of high heating temperatures also has an effect on accelerating the formation of the martensite phase [9].

Variations in temperature of betatizing can affect SME, so it needs to be studied further. The purpose of the betatizing variation is to get the right cooling rate in the process of forming the martensite phase so that the obtained phase is a metastable martensite phase that has SME properties.

2.6 QUENCHING METHOD

Quenching methods currently used in the development of SMA include direct quench, up quench and step quench. The quenching method is one of the important factors because it will affect the cooling rate and also as a medium when the phase transformation takes place so it will affect the characteristics of the martensitic phase [13, 16-17]. The schematic of the quick quenching method is shown in Fig.4.

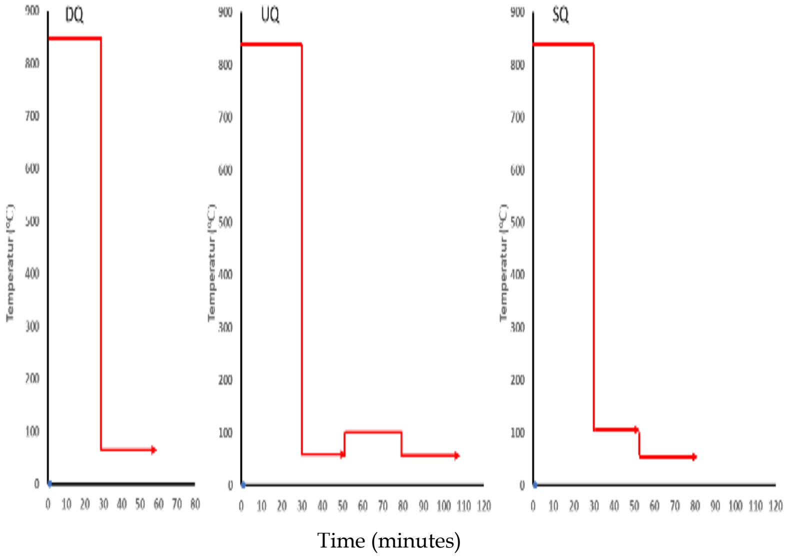

Fig.4 The schematic of quenching method

Direct Quenching (DQ)

The direct quenching process is carried out by quenching the specimen from high temperatures into the cooling medium. In the development of SMA, some who used the DQ method included Setyani et al. [13] in alloys and produced that SME of 27.2%. Jatimurti et al. [12] report that the use of DQ can allow SME 20-26 % with Cu-21Zn-5 Al wt. % alloy.

Step Quenching (SQ)

The process is carried out by quenching the betatizing sample into boiling water at a temperature of 100 ℃ for 30 minutes, then the quenching process is carried out in ice water with a water temperature of 5-10 ℃ until it reaches room temperature. Martensite stabilization is one of the phenomena that can reduce SME properties due to the inability of the martensite phase to transform when subjected to deformation.

The step quench method is carried out to minimize the stabilization of martensitic that occur due to a large number of *vacancies* trapped due to rapid cooling of high temperatures [18-20]. However, on the other hand, the challenge of SQ is that the cooling medium is higher than Ms alloy so it cannot produce SME. Setyani et al. [16] reported the use of SQ with boiling water as cooling media followed by dry ice water media on Cu-28Zn-3Al wt. % alloy could not produce martensite or austenite phases. This is because of Ms the Cu-28Zn-3Al wt. % is below of boiling water medium.

Up Quenching (UQ)

UQ is done by dquenching the sample from betatizing into a cooling medium with a low temperature and then Quenching it into a medium that has a higher temperature than the first medium. Setyani et al. [16] was done UQ process is carried out by quenching the betatizing sample into cold water with temperature of 5-10 °C, then heating with boiling water for 30 minutes to remove excess residual stress due to the quenching process.

The UQ method can reportedly be an alternative to quenching media that can increase SME. In general, this method is done by quenching the alloy in the cooling media and then continuing with the post-heating treatment on a medium that has a higher temperature. This stage is effective for eliminating vacancy and rearrangement of atoms to reduce stabilization martensitic [20-21]. Asanovic et al. [20] reported the use of the UQ method resulted in higher SMEs compared to DQ which was 87 and 72% in Cu-21.6Zn-5.6Al alloys wt. %. The same thing was stated by Setyani et al. [13] where the UQ alloy has an SME of 36.3% while the DQ method is only able to form an SME of 27.2%. The UQ method was also applied by Stosic et al. [22] to the Cu-25Zn-4Al wt. % alloy and from the characterization carried out it was found that the UQ method was able to produce a martensite phase.

2.7 Cooling Media

Cooling media is one of the factors that need to be considered in the development of SMA because it will indirectly affect the cooling rate and become a medium as a facilitator of whether the material can produce a martensitic phase or not Saud et al. [23]. Each composition of Cu-Zn-Al alloy has a different hysterysis temperature. If the temperature is low, the cooling media used must also have a low temperature. The variation of quenching media and cooling rate shown in Fig. 5.

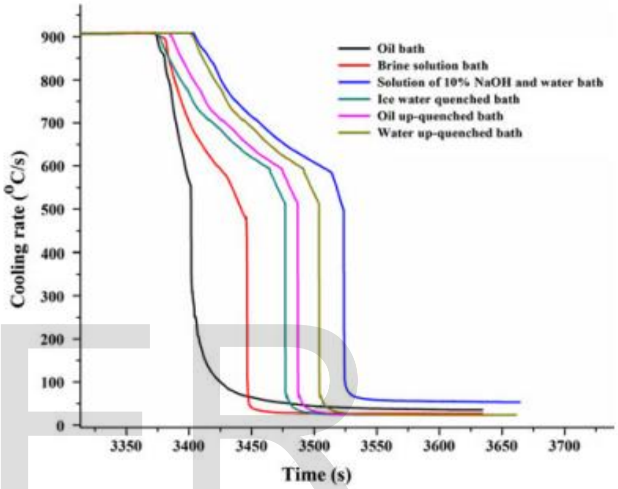

Fig. 5 The schematic quenching media and its cooling rate in the fabrication of Shape Memory Alloys.

Another study on the variation of quenching media on the development of CuZnAl was conducted by Wibisono et al. [17] using air, oil, water, and brine as media. The best SME was obtained in alloys treated with brine cooling media. The cooling rate is directly proportional to the increase in the SME of the alloy.

3 CONCLUSION

This paper presents a review of the process parameters that affect the fabrication and improvement of Cu-Zn-Al-based SMA. The parameters of such processes consist of the influence of the composition, method, and medium of quenching. Each of the parameters has an important and correlated role to produce SMA with high SME properties and a long period of use.

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