BASICS OF CU BASED SHAPE MEMORY ALLOYS

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ABSTRACT

Where human workers are replaced by robots, drivers are replaced by autonomous vehicles, surgical operations with millisecond differences are made from miles away, when the black holes are photographed, capabilities of classical materials are not enough for today's technologies and right now the shape memory alloy has become an alternative to the help the designers. Shape memory alloys lose their present form temporarily due to environmental factors such as force, temperature or magnetic effect. They are defined as materials that can be returned to their existing forms by the abolition of environmental factors. These alloys are seen in different types based on Nickel-Titanium, copper and iron. Copper based alloys are an example of shape memory alloy with advantages such as formability, high electrical and thermal conductivity. Low cost and availability of copper element compared to titanium element, corrosion resistance and high electrical conductivity of iron element can be counted as advantages of copper element. In spite of this, low strain and tension recovery, low cycle number and very difficult shape memory operation compared to nickel-titanium based alloys can be considered as disadvantages of copper-based shape memory alloys. Copper-based shape memory alloys are used as copper-aluminum and copper-zinc double alloys. However, there are also variations of triple alloys such as copper-zinc-aluminum, copper-aluminum-nickel, copper-aluminum-beryllium and copper-aluminum-manganese with the addition of the third element to provide better phase stability and different properties to the alloy. This study was prepared as a review of researches about copper-based shape memory alloys in the literature.

KeyWords: Shape memory alloys, Martensitic transformation, Solid state transformatio

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Introduction

Nowadays, technology is developing rapidly in the face of increasing needs. Rapidly advancing technology comes with new generation materials and instruments. Innovative products in the enrichment of designs increase the added value of the items that we use in daily life, as well as new requirements. In order to meet the endless needs of mankind, scientists are working in this direction without stopping. Many different types of materials are used in industrial and daily applications such as ceramics, glass, polymer, metal and alloy. Although different types of materials can do the work of the same material, in some cases, due to insufficient properties, only one type of material may be required. Therefore, the high capability of the properties of materials in many areas will reinforce new generation designs. In addition to the physical properties of materials, different types of materials have been developed today [1]. High functionality can be ensured by the control and traceability of the high-tech smart materials and the changes in their internal structure by responding to environmental impacts [2, 3].

One of the most functional structures in smart metals is the Shape Memory Alloy (SMA). SMA are described by their ability to regenerate the material generally after heating due to severe deformations occurring at relatively low temperatures [4, 5].

The SMA are used in medical, aerospace, aerospace, machinery, electronics and construction sectors for example applications such as stents, jet engine parts, solar panels, actuators and dampers, as well as being subject to many scientific studies [6, 7]. Due to the expansion of the usage area, the SMA whose charm has been increasing rapidly have become easily accessible thanks to the alloys such as NiTi. SMA was first discovered by Arne Olander in 1932 [8]. When first discovered, SMA found as Au-Cd are divided into three main building groups as NiTi, Fe and Cu based [7, 9]. While the alloys based on Fe are weaker than others; NiTi-based SMAs are more expensive but more effective than Cu-based alloys [10, 11].

The Shape Memory Effect (SME) is realized by means of solid state phase transitions without diffusion in the material. These phase transitions are generally provided by the temperature or magnetic effect between the phases known as austenite (main phase) and martensite (product phase). Before transformation, the austenite phase of the solid state changes to the martensite phase by changing the crystal structure with external effects such as temperature. The internal structure of martensite contains the most twins of structural defects [9, 12, 13]. The transformation of the martensite phase into the austenite phase in the SMA is generally described as a thermodynamic cycle and it also exhibits a reversible structure. During the transformation between phases, the release of chemical free energy creates the driving force under the shape recall. This force creates the Shape Memory Effect. Although the displacement amounts of the atoms in phase transformation are very small, this movement is carried out in the same direction and causes large scale changes in the material. Crystal structure changes in the alloy provide high quality properties such as Shape Memory Effect and superelasticity [14, 15]. The temperature at which the martensite phase starts during phase transformation is expressed as M_s, while the temperature value at which the phase transformation is completely terminated is expressed as M_f. These abbreviations are used in the literature as A_s and A_f for the starting and ending temperature values of the austenite phase [16, 17].

It is important to choose the type and characteristics of SMA according to the application site to be used [18, 19]. The transformation temperatures of the shaft to be driven thermally in the desired range depends on many variables such as the ratio of alloying elements, thermal and mechanical processes. It has been observed that the physical properties of the alloy change as the transformation temperatures change after these processes [9]. Shape Memory Alloys quickly enter our lives and are located in many uses [11, 20].

Cu based Shape Memory Alloys

Due to their good formability, electrical and thermal conductivity, Cu-based shape-memory alloys are being used as an alternative and cheaper material. There are different alloy types such as CuZnAl, CuAlNi, CuAlBe and CuAlMn.

CuZnAl Shape Memory Alloys

Dual alloys are used as Cu-Al and Cu-Zn and generally require a third alloying element to provide phase stabilization and different properties [9, 21]. In Cu-Zn alloys containing at least 40% Zn alloy, M_s temperature was reported to be well below room temperature [22, 23]. To increase the M_s temperature and to stabilize the β phase Al, Ga, Si and Sn are added [9]. Because of the low cost and high processing performance, most studies were carried out on CuZnAl. Although CuZnAl alloys continue to be used in vehicles such as fire prevention, there are two main problems preventing industrial scale development. The first one is natural aging and a lack of grain growth in thermomechanical processes. These problems reduce SME ability. The second problem is the change in the thermoelastic transformation temperatures of the alloys after thermomechanical processes [24]. Because copper based SMA are very sensitive to heat treatment [25]. Many investigators have conducted different studies to regulate the martensite phase in the CuZnAl alloy [26, 27].

CuAlNi Shape Memory Alloys

Alloys with an aluminium content of wt. 9% to 14% in Cu-Al based alloys show the martensitic transformation. [28]. In Cu-Al alloys, as in Cu-Zn, a third element such as Zn, Ni, and Mn is added to stabilize the ß phase and increase SME [29]. The CuAlNi alloy is considered to be a high-temperature shape memory alloy due to its thermal stability at high temperatures above 100 °C [30, 31]. Similar to the CuZnAl alloy, the CuAlNi alloy has a highly brittle structure due to its large grain structure combined with its anisotropic elasticity. Due to this problem, practical use is restricted [32, 33]. Although the fourth alloying elements such as Ti, Zr, Mn, B, Y, V, and rare earth elements regulate the properties of the classic CuAlNi alloy, small additions do not adequately limit the grain sizes. In addition, the use of high amounts of coarse second phase particles, which, if used highly, endangers its mechanical properties [34].

CuAlBe Shape Memory Alloys

CuAlBe alloys offer the sum of the advantages offered by CuZnAl and CuAlNi alloys. By adjusting the element ratios in the alloy, the transformation temperatures can be increased up to 200°C, while at the same time it is possible to adjust to low temperatures. However, similar to the CuAlNi alloy, it is formed at a high temperature of 600°C. Another disadvantage of this type of alloy is that beryllium is a harmful structure for the health of beryllium oxide. In spite of this, beryllium is used very little in the alloy [35].

CuAlMn Shape Memory Alloys

The high order sequence and the high elastic anisotropy of the ß phases of CuAlNi and CuZnAl alloys lead to the brittle structure of these alloys [36]. However, in the studies conducted by researchers to search for new products, it has been observed that the mechanical properties, in particular, the ductility, have been observed to be quite good by discovering that the low-grade sequence of the main phase in the use of CuAlMn alloy is relatively low in aluminium [37]. In addition, Mn element in the CuAlMn alloy can exhibit magnetic properties [38]. As with all other Shape Memory Alloys, alloying elements and their quantities [39, 40] and heat treatment methods [4, 41] offer the possibility of introducing different properties to the user by changing the physical and mechanical character structures shown by the materials.

Usage areas of SMA

SMA have great advantages for designers. The SMA type of material, which has many different physical characteristics, has made considerable progress in terms of transformation temperature and working life [13]. Today, NiTi and Cu based SMA are commercially available as commercial products. However, both alloys have very different properties. While NiTi alloys have 8% strain gain, Cu based alloys have 4-5% strain gain. Besides, NiTi alloys are more suitable for use due to their properties such as biocompatibility, corrosion resistance, and high ductility. On the other hand, the fact that Cu-based alloys are cheaper and have a wider range of transformation makes the use of the alloy attractive [42]. In the research conducted between USA and Canada, studies on future technologies, market areas and application areas of SMA were conducted. As a result of the studies, they found that they would be given more chance for effective use in the market [43, 44].

Nowadays, SMAs are frequently used in many main sectors. Medical, automotive, robotics, aerospace, space technologies, and construction are the leading ones [12]. The SMAs used in these applications are also considered to provide qualifications for the drive element or proportional motion control, except for free return shape recovery [42]. Application drawings of SMA are shown in Figure 1.

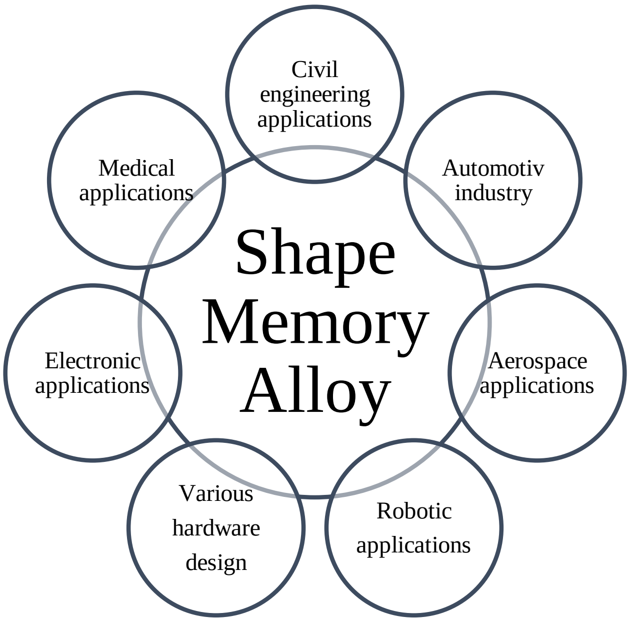

Figure 1. Usage area of SMA

Conclusions

Shape Memory Alloys are used in many fields such as medical, construction, aerospace, machinery industry and energy, and they are in the group of smart materials. Super elasticity, single and double way shape memory effect characteristics which are not seen in classical materials are considered as unique advantages of shape memory alloys. As a result of long-term studies, shape memory alloys have started to be seen in areas such as polymer and ceramics other than metal alloys.

The following parameters are taken into consideration in the design of the shape memory alloy.

- Operating temperature range
- Force selection for deforming
- Deformation and recycling speeds

In the future, efforts to make the shape memory alloys, which are intended for use in a wide range of industrial areas, more stable and more durable, will continue without slowing down. Progress will be made by using different materials (hybrids, composites) as well as new production techniques. The emerging global economy will influence the growth of demand growth in line with new markets and the needs of these markets in the use of shape memory alloys.

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