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Effect of Age Hardening on the Mechanical Properties, Microhardness, and Corrosion Resistance of Zn-Cu-Al Shape Memory Alloy

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Abstract

Nowadays, shape memory alloys (SMA) are widely employed in various engineering applications, particularly in the fields of vibration control, electrical sensors, robotics, and aircraft. The primary issue stems from their mechanical properties' weakness. Thus, the goal of this research is to improve the mechanical qualities by using age hardening. Cu-Zn-Al shape memory alloy was created in this paper. Specimens of the Cu-Zn-Al shape memory alloy were subjected to general microstructure, microhardness, and corrosion tests throughout the as-cast and after-age hardening processes. It was discovered that there was a noticeable improvement in microhardness, which rose by 25.17% following age hardening and 19.8% following corrosion.

Keywords: *Copper, Corrosion, Microhardness, Shape Memory Alloys.*

1 Introduction

NiTinol is one of the famous SMAs that is used in various engineering aspects, and it has been stated to take precedence in medical applications as well [1]. Cu-Al-Mn and Cu-Al-Be are recently studied and exhibit excellent shape memory properties at room

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temperature, [2]. The influence of phases on SME in Cu-Al-Mn and Cu-Al-Ni SMAs indicated that control over composition could improve their shape memory properties, [3]. A gold-cadmium alloy, which exhibited rubber-like characteristics, was first described by the Swedish metallurgist Olander in a meeting of the Swedish Metallurgical Society on 27 May 1932. [4]. Materials with shape memory are designed to undergo large distortions but are then able to regain those distortions through temperature or stress variations. This results in a martensitic phase change and induced elasticity at high temperatures. These materials were continuously improved in the engineering field to increase the quality of achievements. Shape-memory alloys (SMAs) are a class of novel materials that exhibit two outstanding unique properties namely the shape-memory effect and super elasticity. Because of the diffusion-less transformation in solids, these materials differ from ordinary materials. In other words, shape memory is one of the unique properties that allow materials to regain their actual shape after being deformed by heating. This means that the material can regain its original shape after being deformed. As a result of the way super elasticity works in a hysteretic loop, large strains can be recovered (up to 8 %). With hot fluid flowing through them, they are used as wires or tubes. Material such as this is ideal because it can retain its shape even if heated. SMAs are also employed in the civil engineering field. For example, bridges have been constructed using SMAs. The vibrations of various structures can be tuned with SMAs by dampening vibrations. An enormous degree of elasticity is achieved in just a limited range of temperatures, just above the transformation temperature; heating is not needed to get a deformed shape to recover; this is also accompanied by significant non-linear recoverable strains. Smart materials are described as materials with adaptive or innovative properties using sensors, actuators, and micro-controllers, thus resulting in a weight and volume increase for the associated machine components. Technology is expanding rapidly at the moment. The lives and education of individuals with disabilities should be enhanced and positively impacted by this advancement, giving them the opportunity to take the lead, develop, and launch projects, [5]. Many scientific researchers and many technical firm sectors are drawn to the Internet of Things (IoT) because of its amazing potential. With wired and wireless connectivity, a variety of devices exchange numerous services and applications through Internet of Things devices, [6, 7]. Applications using 'smart materials' and high 'functional density' must consider technical and commercial factors, including the available space, the environment, the response time, and the allowable cost, [8, 9], the mechanism of shape memory alloys is shown in Figures 1and 2 below.

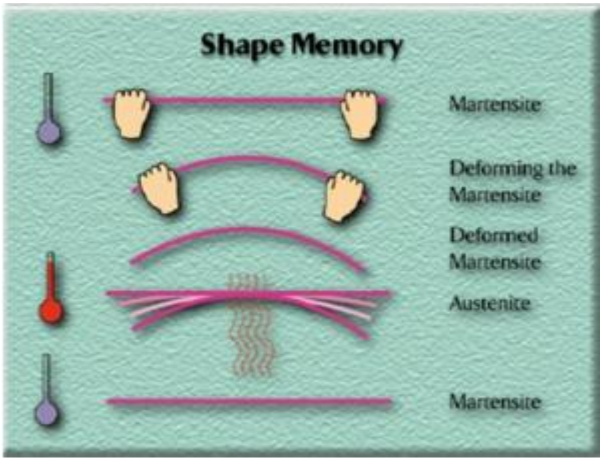


Fig. 1: Shape memory alloy transformation [10]

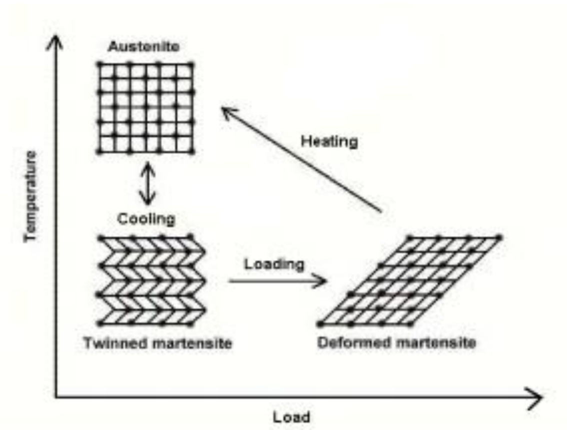


Fig. 2: Load-temperature relationship of a shape memory alloy [10]

It will be impossible for all metals and their alloys to display the Shape memory effect because different metals and alloys have different crystal structures. A solid-state phase change is what causes internal structural changes that give a solid-state material its particular properties such as shape memory and super elasticity. The changes occur at an atomic level, which causes close-packing of the molecules that give the solid-state material its particular properties. There are two phases of SMA Three crystal structures exist for these phases (twinned marten sites, de-twinned marten sites, and austenite) that can undergo six possible transformations. Having a yield strength of 35000 to 100000 psi, the parent Austenitic phase is quite strong. In contrast, the daughter Martensitic phase has only a yield strength of ten thousand psi. 8% of the recovery strain can be absorbed by the deformation stress of up to 20000 psi. [9]. A single X-ray diffraction method and least square analysis were used to determine the structure of the high-temperature Austenitic phase of Nitinol alloy. The mechanical properties of low-temperature martensite and high-temperature Austenite differ considerably from those of monoclinic martensite found in β-phase alloys. There are two types of martensite transformations: thermoelastic and non-thermoelastic. A thermo elastic martensitic transformation usually occurs in ferrous alloys one occurs in non-ferrous alloys Austenite and martensite define an interface between the two phases. This is based on Otsuka et al. When being rescinded, shrinkage of martensitic plates will be preferable to nucleation of Hoch-temperature austenitic phases, which cause a crystallographic ally reversible transformation. The unique properties of SMA result from its thermo elastic martensite transformation, including the Shape memory effect and super elasticity. Nickel Titanium (Ni-Ti), copper-zinc aluminum, and copper alnico are the most effective and widely used alloys. Since the last two decades, there has been a large number of SMAs developed. Zn Cu Al alloys serve as a cost-effective alternative to Ni-Ti and are the most popular SMA, [10-16]. Zn Cu Al It has the advantage of being simple and inexpensive, although its transformation temperature is too high, so it is not recommended for use in most practical applications. Zn Cu Al is the result of adding zinc to the system, producing a ternary system with commercial significance. Zn Cu Al alloy typically has properties such as a melting temperature of 950-1020*c, density of 7.64 cm*3, resistivity of 8.5-9.7, strain of 4%, transformation range *120, and transformation hysteresis of 15-25^c. [17] [18]. Different alloys are used in Cu-based SMAs, though Cu-Zn-Al and Cu-Al-Ni are the most widely used alloys due to their low cost and the ability to resist aging-related deteriorations of properties. Cu-Al-Ni SMAs have a few distinguishing features compared with other shape memory alloys, including their lower cost than Ni-Ti alloys and high transformation temperatures, [19, 20]. The main objective of this study is to investigate the effect of the age hardening process using 4, 8, and 10 aging time and the dead sea water on the microhardness and corrosion resistance of Cu-Zn-Al shape memory alloys.

This paper is organized as follows; introduction, the main materials, equipment, and experimental procedures followed by results and its discussions.

2 Materials, Equipment, and Experimental Procedures

The main chemical composition of Cu-Al-Zn shape memory alloy is shown in Table 1

Table 1: Chemical composition of Cu-Zn-Al SAM

Element	Cu	Zn	Tin	Lead	Anatomy	Al	Pb
Wt.%	60,69	28,21	0,35	6,75	0,17	3,9	0,044

Mixing the three materials namely; 70 % Cu, 26% Zn, and 4% Al is used to prepare the Cu-Zn-Al SAM as shown in Fig.3.

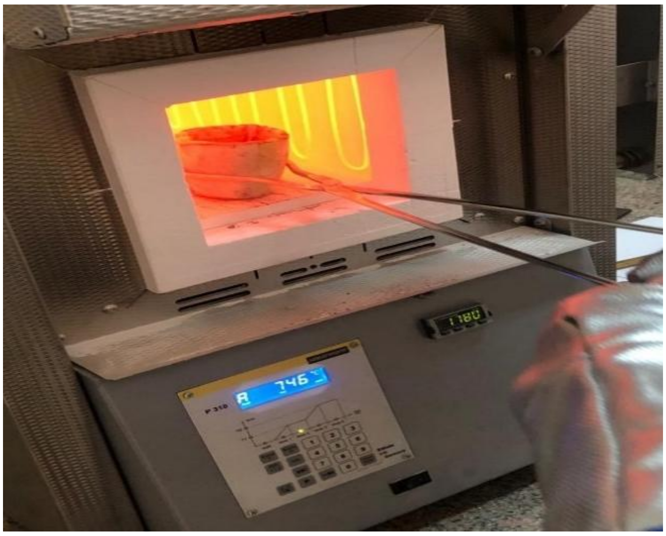


Fig. 3. Preparing the shape memory alloy using an electric furnace

Where the mechanical properties of that material are shown in the following Table 2.

Table 2: Mechanical properties of used materials

	Cu	Al	Zn
Atomic number	29	13	30
Atomic weight	63.546	26.98	65.39
Melting point (ºC)	1083	660	419
Boiling point (ºC)	2595	2480	907
Modulus of elasticity(GPa)	117	68.3	96.5

2.2 Preparation of Cu-Zn-Al shape memory alloy

In order to create the Cu-Zn-Al SMA, a predetermined quantity of high-purity copper was melted at 1250 °C. Pure Al and pure Zn were then added to the melt in a graphite crucible. After two minutes of steering, the melt was placed into a steel mold to harden and allowed to cool in the air. Using melting and casting processes, the Cu-Zn-Al shape memory alloy was created as cylindrical rods with a diameter of 14 mm and a length of 70 mm. Fig. 4 and Fig.5 display the shape memory alloy that was created.

Fig.4. Produced Cu-Zn-Al

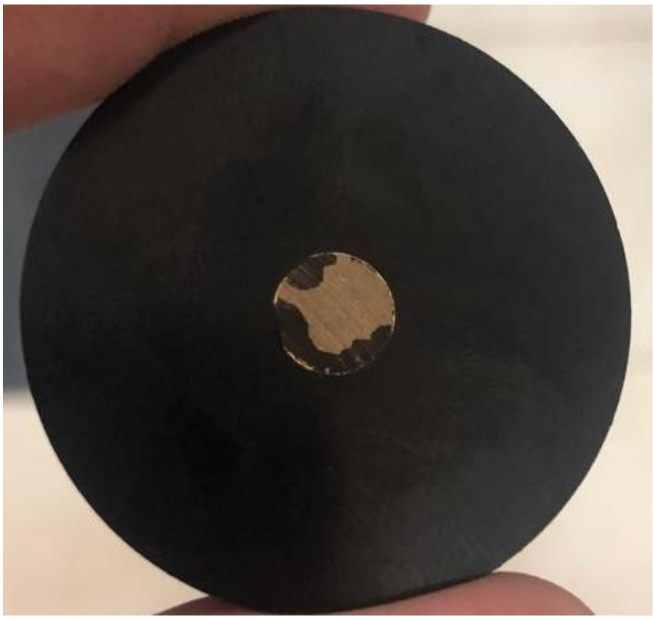


Fig. 5. Shape memory alloy specimen after mounting process

The generated alloy was then subjected to the subsequent procedures.

- For 10 minutes, heat the Cu-Zn-Al cast to 820 ^{o}C.
- Using oil to quench the cast material for five minutes at 120 ^{o}C.
- Using room temperature water to cool the cast.

2.2 Hardness test

A hardness test is a method employed to measure the hardness of a material. Hardness refers to a material’s resistance to permanent indentation. There are numerous techniques to measure hardness and each of these tests can identify varying hardness values for a single material under testing. Hence, hardness test as a method can be dependent and each test's outcome needs to be labeled to determine the kind of hardness test used. The hardness was taken by using the digital microhardness tester (model Falcon 400) at 300 gf as shown in Fig. 6.

Fig.6. Microhardness tester Type Falcon 400

2.3 Age-hardening procedures

The age hardening process starts by heating the set of alloys to 600 °C for 6 hr, then fast cooling in oil after, after aging each alloy at 300 °C as shown in Table 3 below.

Table 3: Aging conditions

Alloy	Heating temperature ºC	Aging temperature ºC	Aging/ time (hr)
A(Ref.)	-	-	0
B	600	300	4
C	600	300	6
D	600	300	8
E	600	300	10

Where the aging process is illustrated in Fig.7 below, starting by heating the samples to 600 °C then them cooled in oil to room temperature, then reheating them to 300 °C for 4, 6, 8, and 10 hr respectively followed by cooling to room temperature.

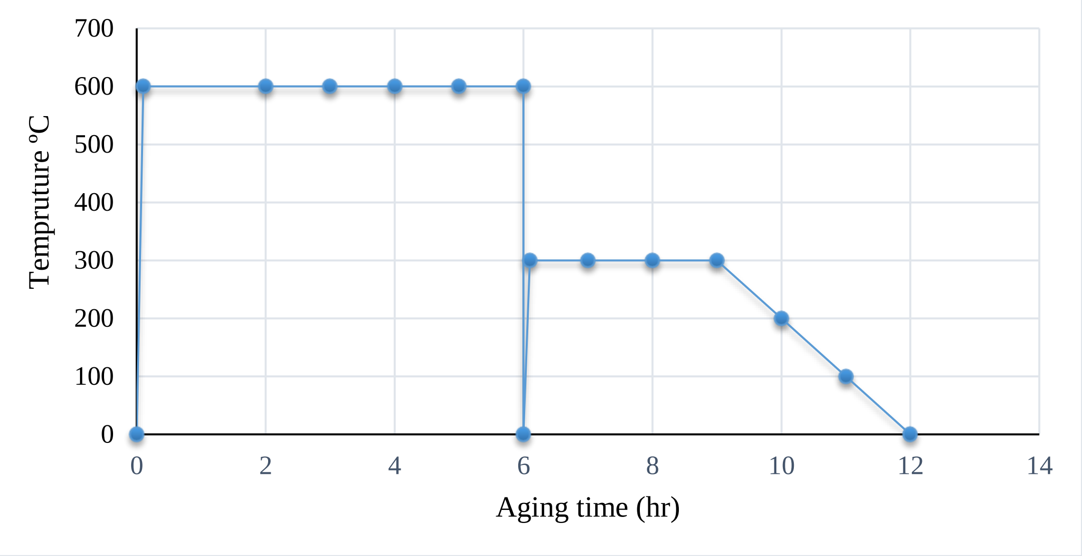


Fig. 7. Aging process used in this work

2.4 Corrosion test

Corrosion testing refers to the processes conducted by laboratories to solve, prevent, or mitigate problems related to corrosion. These processes can be applied in industrial materials and infrastructure products, and are often used in failure analysis. Making a liquid from 53% of Magnesium chloride, 37 % of potassium chloride, 8% sodium chloride, and 2% of sulfate and bromide. By taking the hardness before and after butting the alloys for 10 days.

3 Results, Analysis, and Discussions

3.1 General microstructure of Cu-Zn-Al shape memory alloy

In this section, the effect of aging on the microstructure of Cu-Zn-Al shape memory alloy and the corrosion of the Cu-Zn-Al shape memory alloy will be presented and discussed. It can be seen from Figure 8 that the microstructure consists of Al, Zn, and $CuZn_4$ intermetallic compound

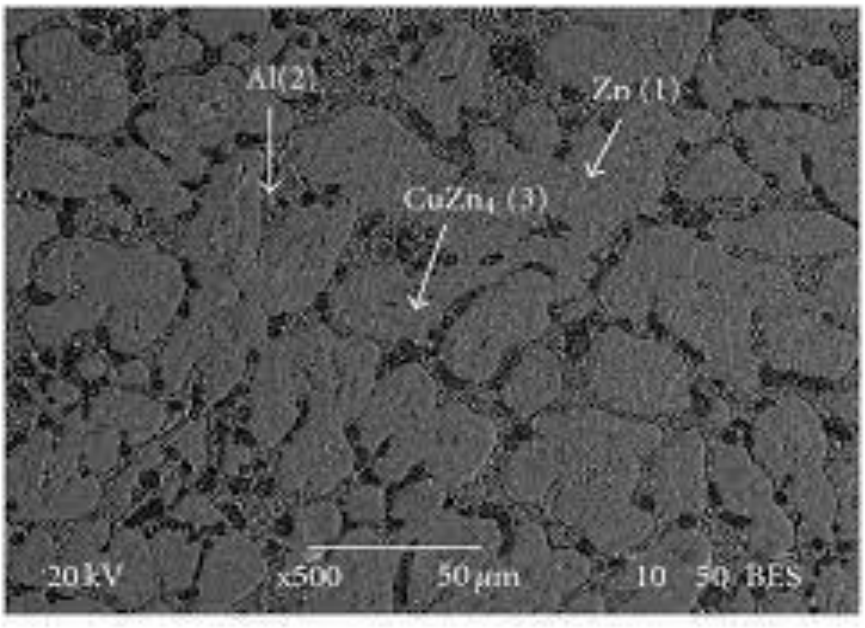


Fig. 8: Photomicroscan of Cu-Zn-Al at 500x

It is obvious from Fig. 9 that about 64 % Cu and 36 % Zn are allocated in the (111) plane, this is consistent with the photomicroscan shown in Figure 6.

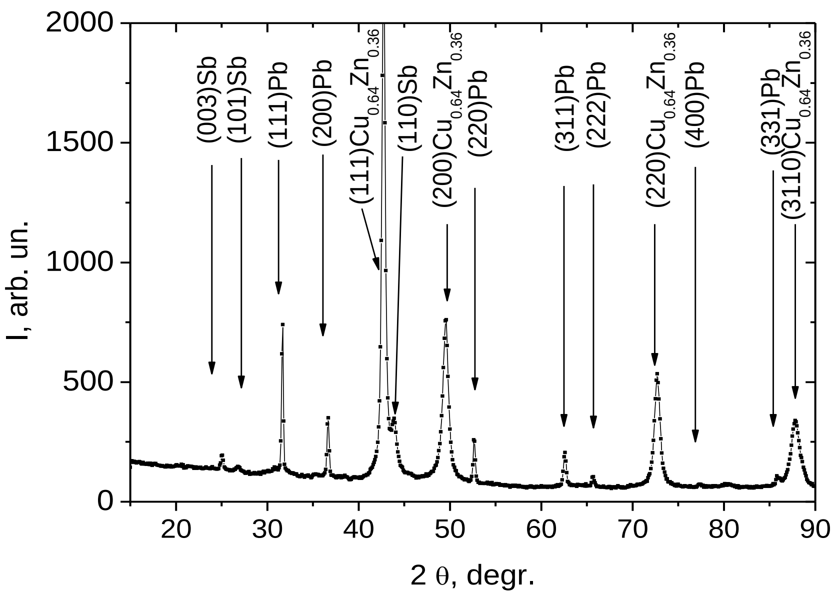
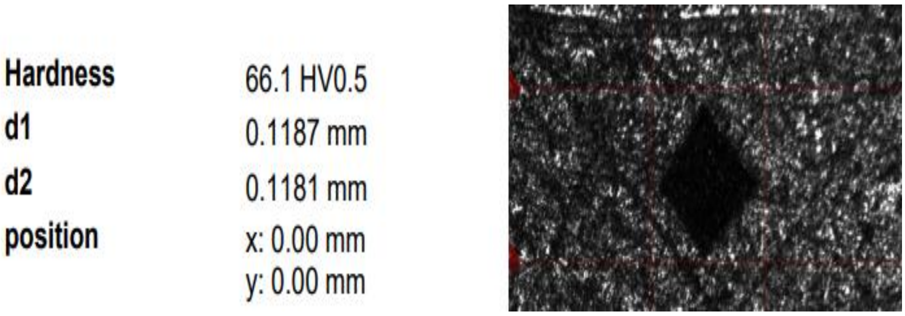


Fig. 9: Fragment of the diffraction pattern of Cu-Zn-Al shape memory alloy

3.2 Effect of age hardening process on the microhardness of Zn-Cu-Al SMA

A sample of the microhardness test can be shown in Fig. 10, the trace of indenting is clear at 400 X magnification.



Hardness	66.1 HV0.5
d1	0.1187 mm
d2	0.1181 mm
position	x: 0.00 mm y: 0.00 mm

Fig. 10. Sample of microhardness test for A Sample of Cu-Zn-Al SMA at 400X

It can be seen from Fig. 11 that the hardness in general increased, the maximum was obtained at Alloy C that aged for 6 hr, however, it increased by 25.17 %, this can be explained by the formulation of hard intermetallic compound $CuZn_4$.

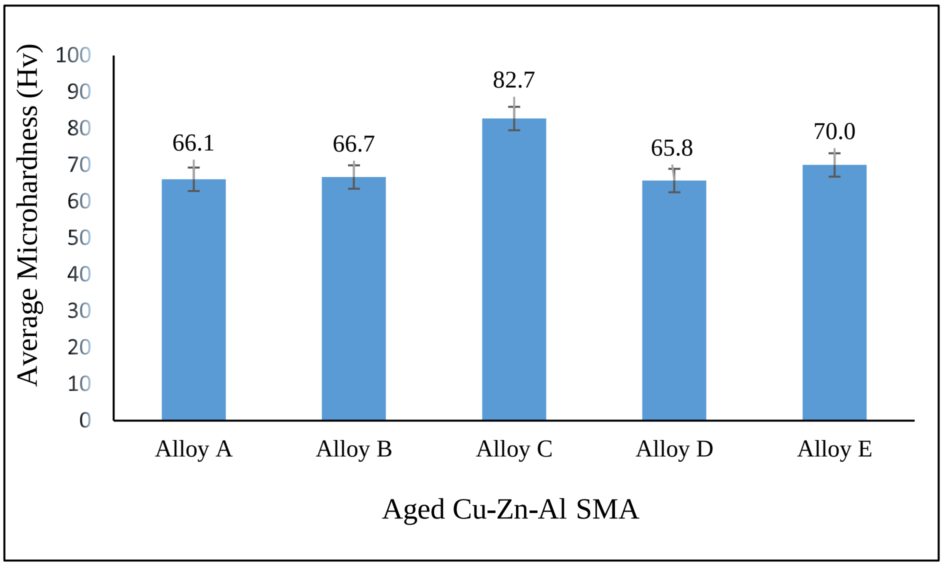


Fig. 11. Average microhardness of Cu-Zn-Al before and after the age-hardening process

3.2 Effect of age hardening process and corrosion on the microhardness of Zn-Cu-Al SMA

In this section the effect of insertion of the aluminum alloys in a liquid containing 53% of Magnesium chloride, 37 % of potassium chloride, 8% sodium chloride, and 2% of sulfate and bromide for 10 days. It can be seen from the histogram in Figure 12 that there is a decrease in average microhardness for A, B, and C, where there is an enhancement in hardness for D and E by 19.8 % and 10.3 respectively.

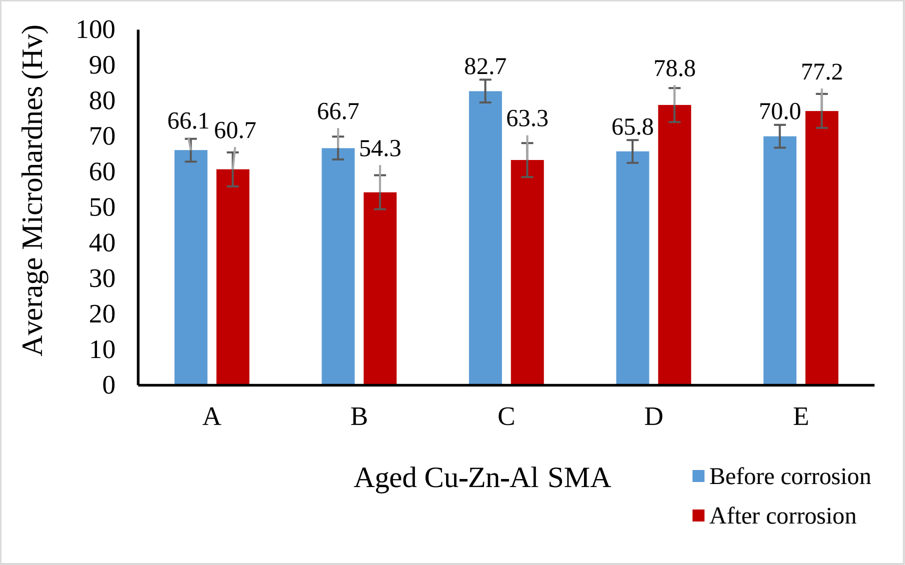


Fig. 12. Average microhardness before and after corrosion for aged alloys

3.3 Effect of age hardening process and corrosion on the microhardness of Zn-Cu-Al SMA

The Histogram of Fig. 13 shows the mass loss in mg after the insertion of Al alloys in a chemical solution for 10 days The best alloy that has high corrosion resistance compared to other sets is alloy B with 0.0009 mg loss.

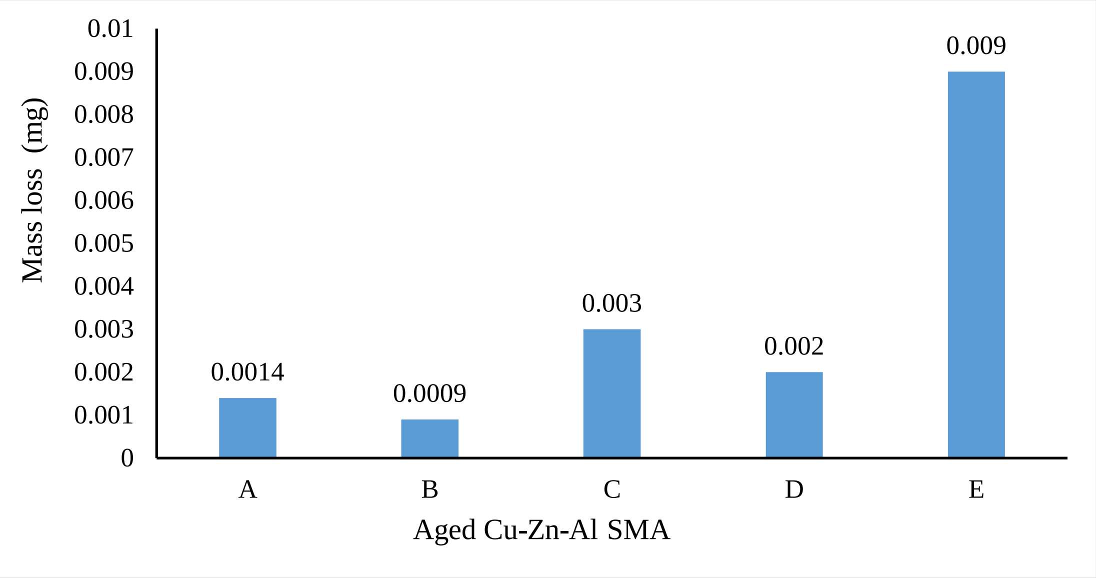


Fig. 13. Mass loss after corrosion test

4 Conclusion

The results of this inquiry showed that the hardness increased, with Alloy C obtaining the highest value at 25.17%. Additionally, after the corrosion test, the hardness of D increased by 19.8%. With a loss of 0.0009 mg, B has the best corrosion resistance of any set in the aluminum alloy.

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