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INVESTIGATION THE EFFECTS OF ZIRCONIUM ADDITION ON WEAR AND CORROSION BEHAVIOUR OF ALPHA-BRASS ALLOY (Cu-Zn30)

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ABSTRACT

Brass alloys have extensive engineering uses as heat exchanger and condenser structures in salty water. Corrosion by pitting, cracking by stress corrosion and dezincification of the brass in water were broadly considered. Brass de alloying or dezincification might be cheerfully detected with bare eyes since the alloy changed a ruddy color that different with its yellowish color. In the previous period, various alloying elements have been used to reduce the dezincification and corrosion of brass alloys.

Current work is dedicated to investigating the effect of various amounts of zirconium additions (0.05,0.10, 0.15, and 0.20) wt.% to α-brass alloy (Cu-Zn30) produced by die casting on mechanical and corrosion behavior.

Several tests were conducted in this research includes XRF and XRD for the specimens after casting and heat treatment, microstructure test for specimens before and after addition of Zr, dry wear test with and without the addition of Zr.

The results from optical microscope images show that Zr additions cause refinement of the original grains for α-brass alloy (Cu-Zn 30).

Hardness test showed an increase of α-brass alloy (Cu-Zn30) hardness with increasing Zr amount, the average hardness of the specimen without Zr addition was (102HV) while the average hardness of specimen with (0.20%wt Zr) addition increased to (185 HV).

*The wear rate for α-brass alloy (Cu-Zn30) specimen decreased after the addition of Zr (0.05,0.10, 0.15, and 0.20) wt.%. The wear rate of the α-brass alloy (Cu-Zn30) was (12.3*10-6 cm3/ min.) while the wear rate of the specimen with (0.20%wt Zr) addition reduced to (5.66*10-6 cm3/ min) under load 30N for 30 minutes.*

The α-brass alloy (Cu-Zn 30) corrosion behavior with and without Zr has been studied by the electrochemical test in a salt solution (3.5% NaCl).

The corrosion rate for α-brass alloy (Cu-Zn30) specimen decreased after addition of Zr (0.05 ,0.10, 0.15 and 0.20)wt.%. The corrosion rate of the α-brass alloy (Cu-Zn30) was ($203*10^{-4}$mpy) while the wear rate of specimen with (0.20%wt Zr) addition reduced to ($2*10^{-4}$mpy) under same conditions.

Keywords: α-Brass Alloy, Zirconium, Electrochemical Test, Dry Wear Test.

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1. INTRODUCTION

Brass has been widely employed in numerous engineering applications and inspecting brass corrosive has excessive significance. Numerous methods are used to decrease brass corrosion in different mediums. One of the most important methods in the protection of copper and copper alloys against the corrosion is use of alloying elements. In general corrosion of brass tends to form a zinc oxide layer that coats its surface. The not dissolved layer of cuprous chloride is adsorbed on the brass surface when dipping in chloride ion media.

The refinement of grain is a good conventional procedure for numerous wrought and cast alloys. Decreasing the grains' size could improve the mechanical properties of the several alloys. Refinement is likewise recognized to develop the casting characteristics like hot tearing and fluidity. Copper-base alloys grains refinement is not extensively employed, particularly in the process of sand casting [1]. Though, in lasting frame copper alloys casting, it is currently mutual to practice alloyed elements to counter the issue of serious high-temperature tearing that likewise develops the pressure narrowness of plumbing apparatuses.

Initial effort on refinement of copper alloys grains presented numerous accompaniments are operative with dissimilar copper alloys. For gun and bronzes metals, (i) 0.3% Zirconium with Carbon and/or Nitrogen without sulfur, (ii) 0.2% Titanium with 0.03% Boron and Carbon) 0.1% Ferrous or Cobalt with 0.03% Boron are active. Edwards and Couture find Zr active in red brass and tin bronzes, nonetheless silicon bronze. Though sulfur devastate the refining of grain outcome of Zr, it was enhanced by addition of Mg [2]. Ruddle specified that 1% of iron or 0.05% of Zr was active for red brass and gun metals. Iron was active as grains refiner for manganese, bronze and Al. Iron-free Al, bronzes and Mn-bronzes and beta-brasses were refined in the mixture of 0.03% Zr and 0.02% Boron [3]. The mixture of boron (0.02%) and Zr (0.3%) was very effective in iron-free beta brass [4]. Wallace exposed that for Cu-Zn alloys, the effective iron powder was 1%; however, mixtures of 0.06% Zr and 0.02% boron was effective for iron-free alloys (e.g. Cu-33Zn4Al). Zr unaccompanied had tiny outcome, then boron unaided was active. Nevertheless, the mixture on 67Cu-33Zn [5] was not active yet. [5]. If the iron was supplemented or they comprised more than 1% iron, alpha-beta brasses would be refined. Though, alloys having little iron's amounts, boron was the greatest preservative

Ali.et.al. [6] studied the effect of adding aluminum to alpha brass alloy. A considerable enhancement in the resistance against oxidation had been yielded. In their study, a pure Al (1-2wt%) was added to the alpha brass alloy. Such alloys were melted and casted using metallic pot. Tests of cyclic oxidation were performed on the alpha brass alloy with/without adding Al under wide temperatures range (from 500 to 900 °C) for 52 hours in still air at 4 hours of cycle. The oxidation kinetics is exhibiting a breakaway behavior at 800 and 900 ° C for alpha brass alloy.

Claesson and Rod, O. [7] Studied the effect of alloying elements arsenic (As), antimony (Sb), and phosphorus (P) on the dezincification resistance of α-phase in brass. Samples alloyed with Sb showed a satisfactory resistance to dezincification and no grain boundary attack. Micro alloying with both As and Sb is capable of providing good corrosion resistance for the commercial brass alloy CB772.

Ali [8] improved the mechanical and corrosion properties by adding indium particles to CuZn30 alloy. He found that the addition of In with (0.5-2) wt% causes an increase in hardness of CuZn30 alloys. And improve the corrosion resistance of α- brass in NaCl solution up to 99.4% for 2wt% In. further Indium addition led to improve wear resistance and the highest wear resistance is for 2wt%In. Hussien R [9] found that the addition of (2,3 and 4)wt % cerium and 4wt% Aluminum to α- brass alloy improves the corrosion resistance in a salt solution (3.5% NaCl). The corrosion rate reduced and reached($0.84067*10^{-7}$) may for the specimen (α- brass+4 wt% Ce+4wt% Al) in comparison to ($4.024 *10^{-7}$) may for reference alloy. Further, the (α- brass+4 wt% Ce+4wt% Al) alloy showed more wear resistance than other α- brass alloys.

Current work aims to study the effects of zirconium addition (0.5,0.10,0.15 and 0.20) wt % on some properties including (microstructure, hardness, corrosion resistance and wear resistance) of (α-brass) alloys and discuss the results.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

Table1 shows chemical composition ofα-brass alloy (Cu-Zn30) without & with (0.05, 0.1, 0.15 and 0.2) wt% Zr additions.

Table 1: shows chemical composition α-brass alloy (Cu-Zn30) without & with (0.05,0.10,0.15 and 0.20) wt% Zr additions.

Zn	Pb	Sn	P	Zr	Mn	Fe	Si	Sb	As	Cu
32.56	2.54	0.675	0.019	-	0.0754	0.943	0.147	0.009	0.094	Bal.
32.45	2.87	0.643	0.016	0.06	0.0421	0.236	0.193	0.008	0.063	Bal.
33.56	2.54	0.721	0.018	0.13	0.0543	0.765	0.187	0.005	0.055	Bal.
32.57	2.92	0.654	0.012	0.17	0.0932	0.481	0.176	0.007	0.028	Bal.
33.87	2.54	0.698	0.013	0.24	0.0764	0.787	0.163	0.004	0.016	Ba.

2.2. Preparation of Specimens

The electric furnace was used for melting and pouring in the melting crucible. Addition (0.05,0.10,0.15 and 0.20 wt%) of zirconium to the α-brass alloy (Cu-Zn30), this alloy melting at 902˚C. The Zn melting point is 419.6˚C and the boiling point is 907 ˚C. Added 5wt % from zinc to compensate for the lost zinc ratio during melting. Mixed molten by graphite rod to homogenous the melting alloy. The metal is poured into the cylindrical metallic mold(inner diameter 10 mm and height 60mm). Heat treatment was conducted at a temperature (580˚C) for 8 hours then the furnace cooled to homogenize the composition.

2.3. Testing of Specimens

2.3.1. *Microstructure Test*
After grinding process by (3000) grit and then polishing process using 0.25μm diamond paste, the specimens were imaged. The specimens were etched utilizing (alcohol: 95mml+ $FeCl_3$: 5gm) for studying the specimens' microstructure [10].

2.3.2 *X-Ray Fluorescent Analysis (XRF)*
Handheld (XRF) analyzer type (DS-2000) American, was utilized for explaining the chemical composition for powders and alloys.

2.3.3 *X-Ray Diffraction Analysis*
X-ray diffraction analysis was conducted for the alloys using the XRD instrument (Mini flex2). The XRD generator having specifications of: Cu target at 30 mA, 40 kV, and speed of scanning equal to 6°/min was utilized. The rate of scanning was (20° – 90°).

2.3.4. *Microhardness Test*
Microhardness test was used to measure hardness values by microhardness Vickers (HV) device (HVS-1000) using a load of (500 g for 10 sec), Each reading was repeated three times and an average value of hardness was considered for each specimen.

2.3.5 *Electrochemical Test*
The corrosion resistance of the specimens α-brass alloy (Cu-Zn30) with and without (0.05, 0.10, 15 and 2wt.%) zirconium addition were studied in 3.5% NaCl solution at room temperature using polarization instrument type (WENKING M lap 0). The measurement of the current density of corrosion is obtained from equation [11]:

$$icor = Icor / A \quad \ldots\ldots\ldots\ldots (1)$$

Where: Icor = current density of corrosion in ($\mu A/cm^2$),
Icor = total current of corrosion in (μA), and
A = the exposed area of the specimen, cm^2 (equal to 3.4 cm^2)

2.3. Dry Sliding Wear Test
The wear test (dry sliding) was investigated using a pin-on-disc concept with (400 rpm) and constant radius that equals to 5.25 mm and the loads are equal to (10, 20 and 30) N. The specimen was weighted prior testing utilizing (0.0001) accurateness electrical balance. Afterward a passé of time (5 to 25 min: step 5 min) the examination specimen was weight again. The wear schematic which used in this work is shown in Fig. 1 [12].

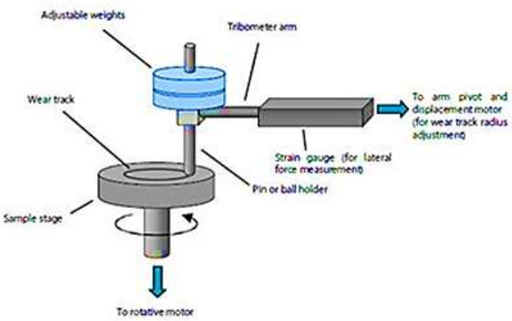

Fig.1 Pin-on-disc concept [12]

3. RESULTS & DISCUSSION

3.1. Microstructure Examination

A light optical microscope was utilized for examining the etched specimens' microstructure. Optical images of 40X magnification showed the microstructure was achieved off the α-brass alloy (Cu-Zn30) after addition (0.05,0.10,0.15 and 0.20 wt %) zirconium with compared to α-brass alloy(Cu -Zn30) (Fig.2).

3.2. X-Ray Diffraction analysis

Fig. 3 showed X-ray diffraction for αα-brass alloy (Cu-Zn30) with 0,20 wt% Zr alloy specimen and doesn't indicate any peak belong to zirconium. This is due to the very low content of zirconium that cannot be indicated by this analysis.

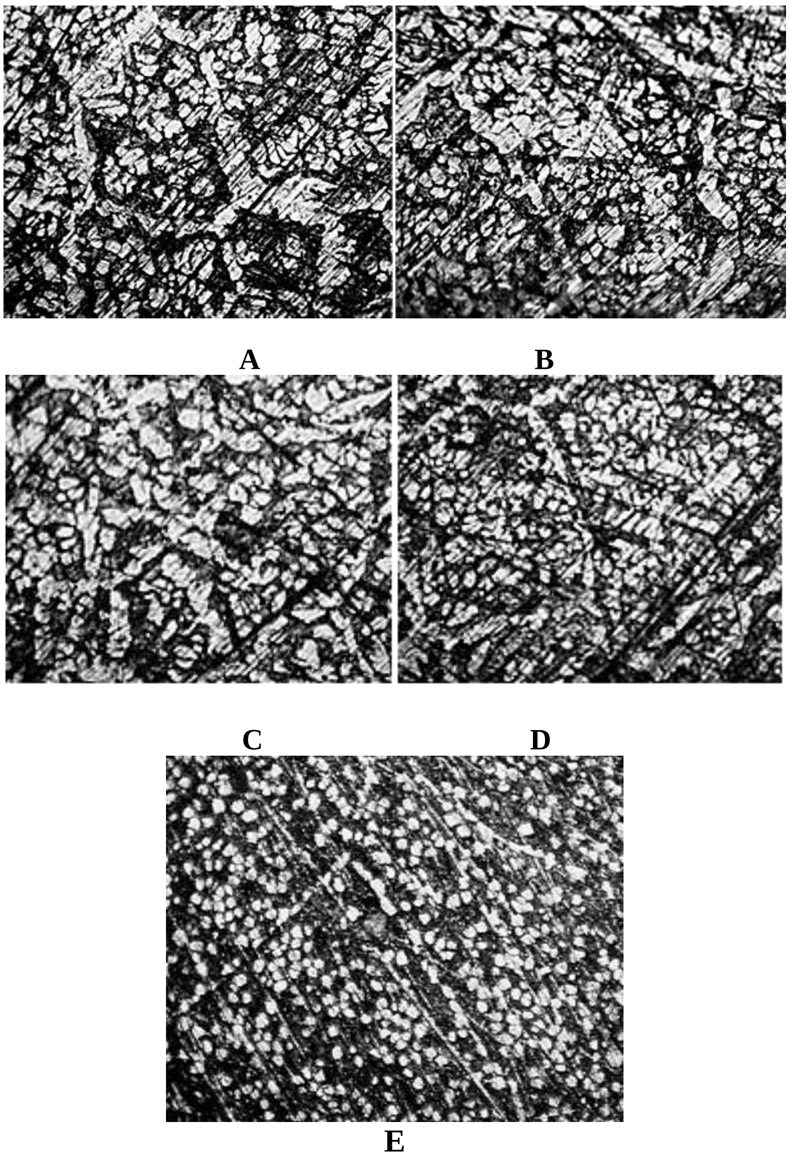

Fig.2: Light optical microstructure for α-brass alloy (Cu-Zn30) (A) after heat treatment, (B) 0.05 wt % of Zr, (C), 0.10 wt % of Zr, (d) 0.15 wt % of Zr and (E) 0.20 wt % of Zr at (40X)

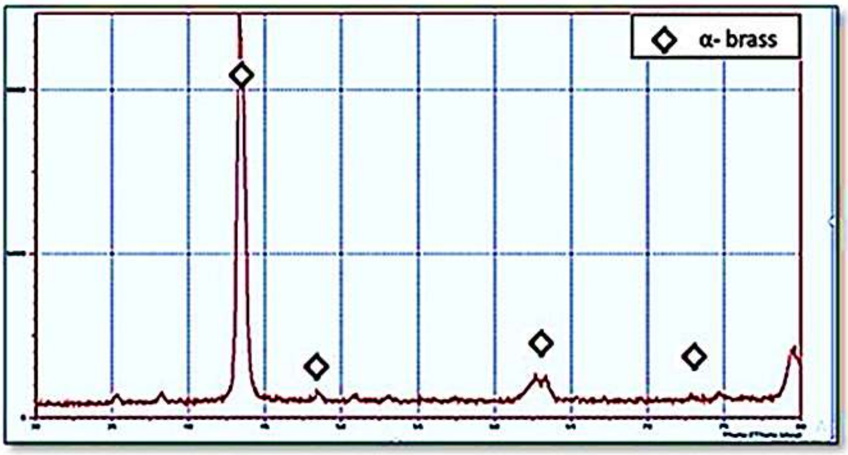

Fig.3: X-ray diffraction analysis for α-brass alloy (Cu-Zn30) with 0.20wt% Zr

3.3. Microhardness Tests

In this work, the specimens' hardness of all alloys was measured using the Vickers hardness test. From Fig.4, it can be observed α-brass alloy (Cu-Zn30)with zirconium presented higher hardness values in comparison with α-brass alloy (Cu-Zn30) and the hardness increased as the zirconium content increases. This is attributed to zirconium particles.

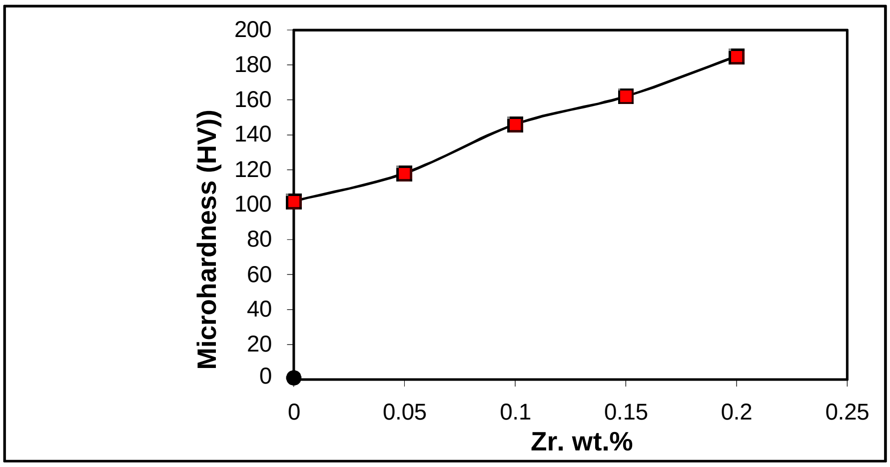

Fig.4: Effect of zirconium content on micro hardness for α- brass alloy (Cu-Zn30) without &with (0.05, 0.10 ,0.15, and 0.20) wt%.

3.4. Dry Sliding Wear Test

All specimens of (10) mm in diameter subjected to wear test under various loads (10, 20, and 30)N and for varied periods (5 to 30 min: step 5 min) at 25 ℃. The results have been presented in Figures (5- 9).

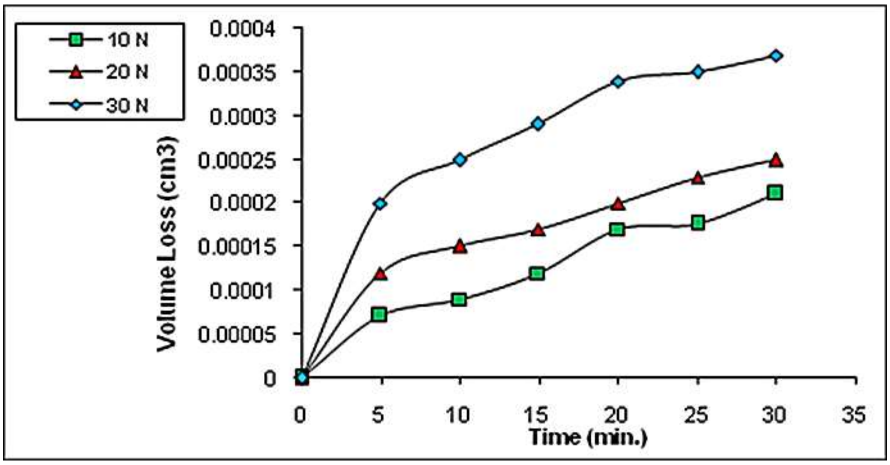

Fig. 5 Volume loose vs time for α- brass alloy (Cu-Zn30) under (10, 20 and 30 N)load

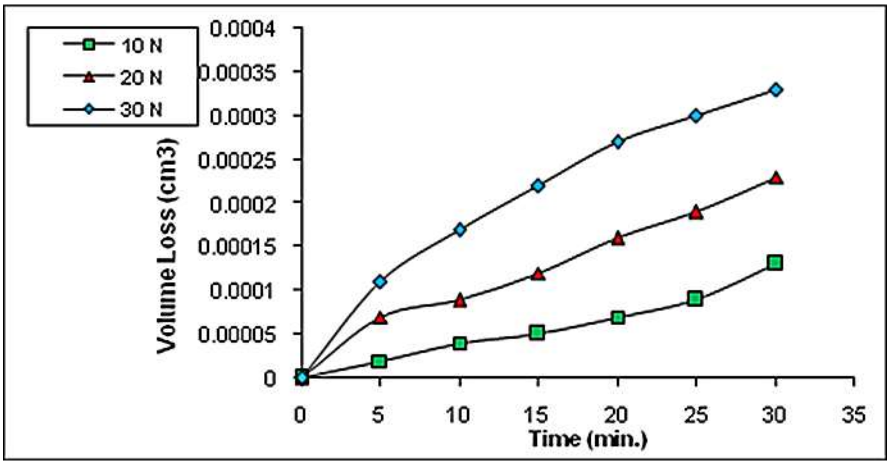

Fig. 6: Volume loose vs time for (α- brass alloy (Cu-Zn30- 0.05 wt.% Zr) under (10, 20 and 30N) load

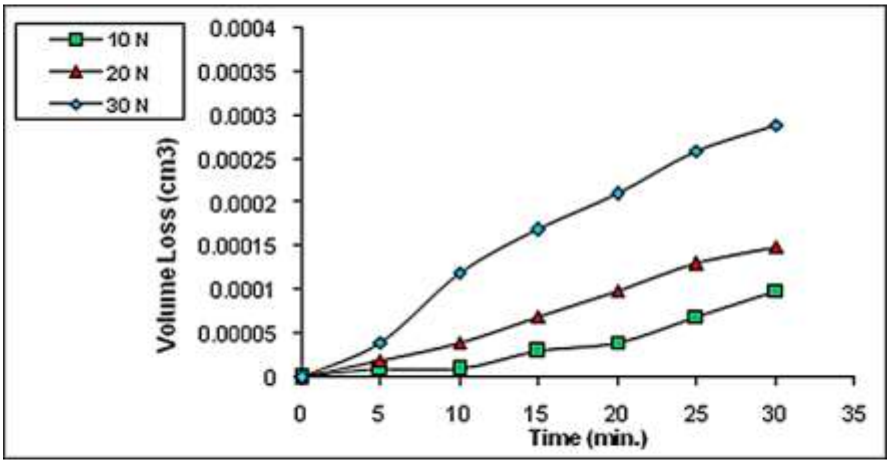

Fig. 7 Volume loose vs time for (α- brass alloy (Cu-Zn30-0.1 wt% Zr) under (10, 20 and 30 N) load

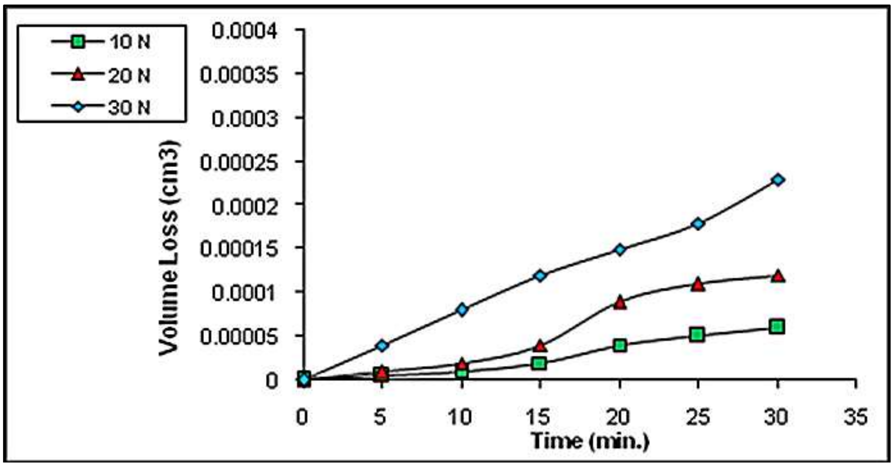

Fig. 8: Volume loose vs time for (α- brass CuZn30 -0.15 wt% Zr) under (10, 20 and 30 N)load

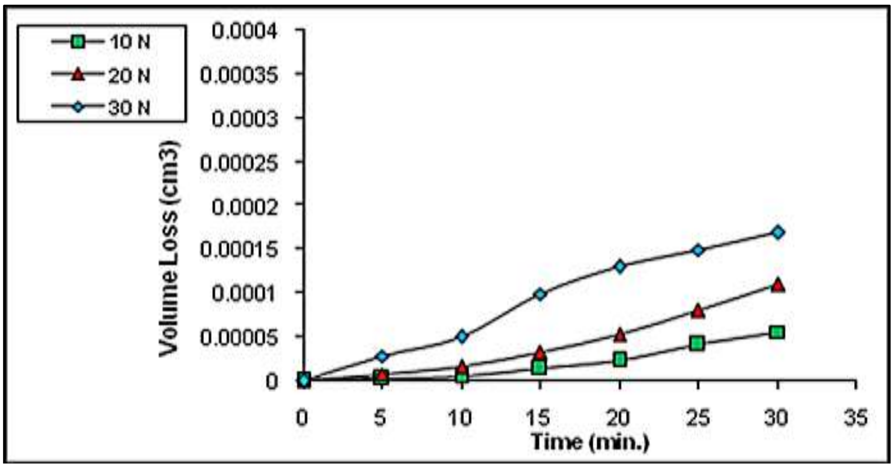

Fig. 9 Volume loose vs time for (α- brass CuZn30 -0.2 wt% Zr) under (10, 20 and 30 N) load

From the above figures, it was noticed that wear rate of the tested specimens under 30N load was higher than that of 10N and 20N. This is according to an upsurge in abrasion at the external surface as the applied weight on the substantial upsurges [13].

Further, the loss of volume upsurge as the period upsurge for all examined samples. This is surely since a further period of abrasion incline to eliminate additional material from the exterior. Additionally, it has been recognized to the upsurge in the plastic distortion of the material’s surface, particulates of the substantial material pulled out [14,16]. To show the effect of Zr addition on the wear rate of α- brass alloy (Cu-Zn30), the wear rate with zirconium content under 10, 20, and 30 N load at 30 min plotted in the following figure 10.

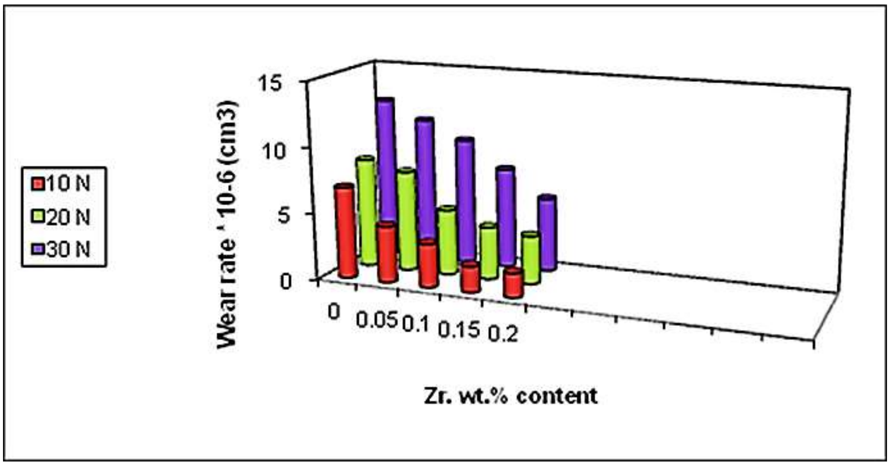

Fig.10: Wear rate vs zirconium content for the specimens under (10, 20, and 30 N) load (30 min)time.

It can be noted from figure 10 that the wear rate decrease as the zirconium content increases. The reason behind these reduces in wear rate related to the zirconium role in increasing the hardness then the wear rate will be reduced.

Figure 11 shows by light optical microscope the worn surfaces of specimens, proof of abrasion wear which can be clear in tested specimens. The mentioned figures illustrated the effect of the wear process on the surface of the specimen. The mechanism of wear during all the tests is abrasive wear is the same for all samples, but the penetration depth is less for α-brass alloy (Cu-Zn30- 0.20 wt% Zr). The existence of zirconium could reduce the frictional force between the surface of specimens and the press indentor, i.e. lowering the coefficient of friction. The result small grooves aligned parallel to the sliding direction and lost in metal weight.

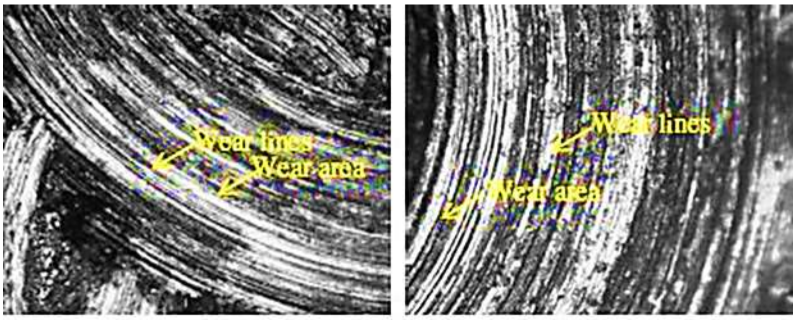

Fig. 11 Light optical microscopy for (A) α-brass alloy (Cu-Zn30) (B) α-brass alloy (Cu-Zn30- 0.20 wt % Zr) after wear teat under 30 N load for 30 minutes (40X).

3.5. Electrochemical Tests

The corrosion behavior of all used specimens in 3.5%NaCl solution has been studied to give an estimation of the corrosion behavior of all alloys. Polarization curves for α-brass alloy (Cu-Zn30) specimens without and with Zr addition are illustrated in Figures (12-17) respectively. The corrosion factors are current of corrosion (Icorr.), the potential of corrosion (Ecorr.), and (rate of corrosion) caused by the test of corrosion for the specimens in stated solutions were demonstrated in table 2. From this table, it could be understood that there was an important development in resistance against corrosion of the alloys with altered addition of zirconium. Icorr. for the specimens were graded from 1.101 (μA/cm²) for α-brass alloy (Cu-Zn30-0.05% Zr) to 0.048 (μA/cm²) for α-brass alloy (Cu-Zn30- 0.20 Zr)which were lower than Icorr. For Cu-Zn30 alloy which was 4.05 (μA/cm²). This improvement in corrosion resistance can be attributed to the behavior of the zirconium element as a grain refiner and as a noble element which enhanced the corrosion resistance of α-brass alloy (Cu-Zn30). Finally, the corrosion rates were calculated based on the following equation [15]:

Corrosion rate= 0.13 I_{corr} (EW)/ ρ …….(2)

Where:
E.W= equivalent weight (g/eq.)
ρ= density (g/cm³)
0.13 = metric and time conversion factor
Icorr.= current density of corrosion (μA/cm²).
mpy = rate of corrosion (mils per year)

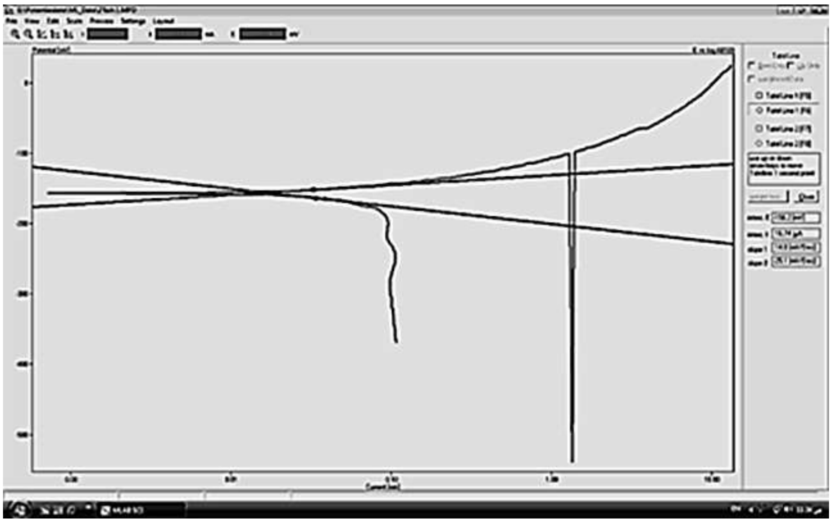

Fig. 12: Polarization curve for α- brass Cu-Zn30 alloy in 3.5%NaCl solution.

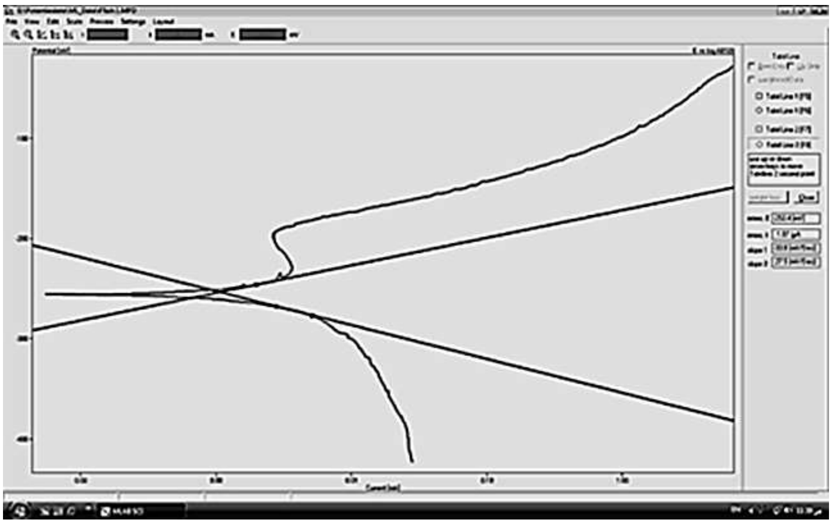

Fig. 13: Polarization curve for α- brass Cu-Zn30-0.05Zr alloy in 3.5%NaCl solution.

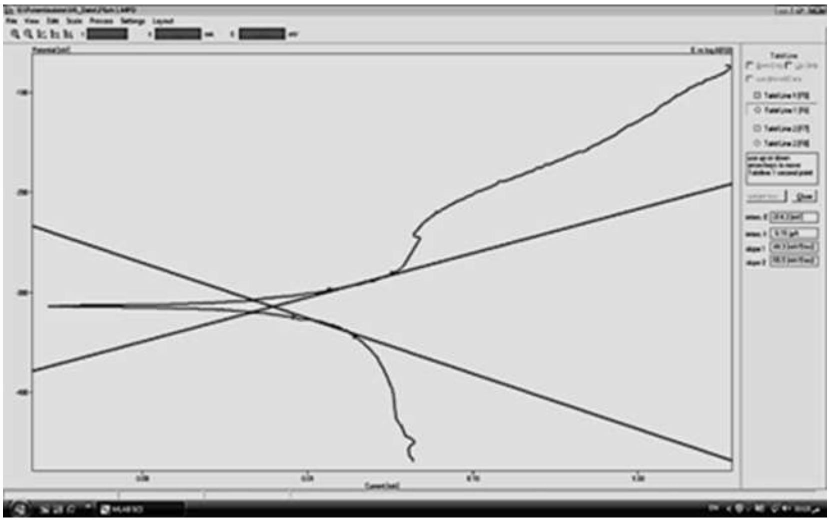

Fig. 14: Polarization curve for α- brass Cu-Zn30-0.10 Zr alloy in 3.5%NaCl solution.

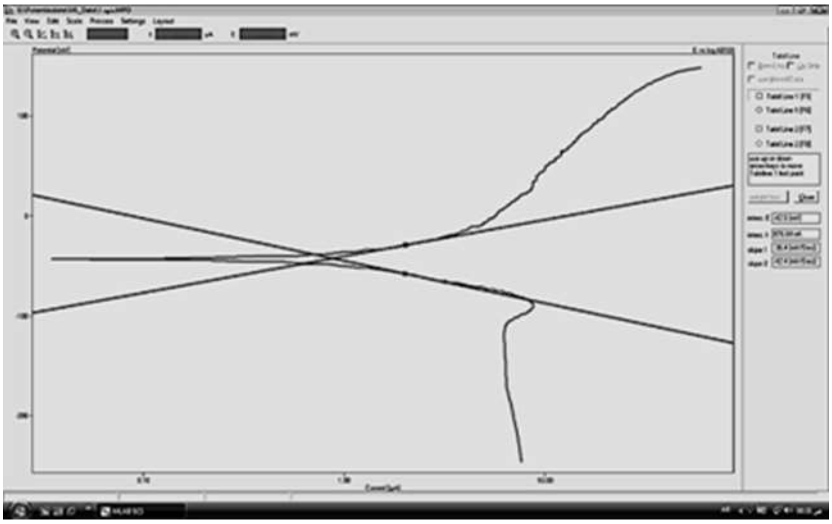

Fig. 15: Polarization curve for α- brass Cu-Zn30-0.15Zr alloy in 3.5%NaCl solution.

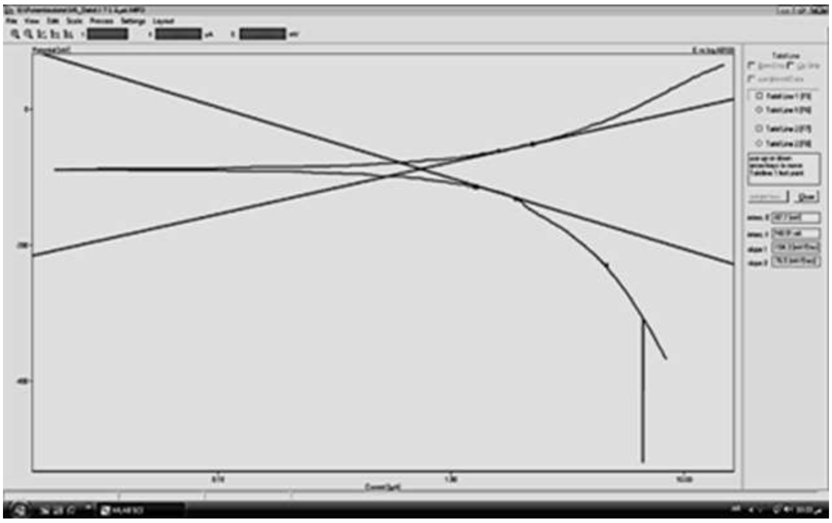

Fig. 16: Polarization curve for α- brass Cu-Zn30-0.20Zr aloy in 3.5%NaCl solution.

Table 2: Corrosion current (Icorr.), corrosion potential (Ecorr.) and corrosion rate for all used samples in NaCl Solution.

Sample code	Icorr. (μA/cm²)	Ecorr. (mV)	Corrosion Rate(mpy)	Improvement percentage%
Cu-Zn30	4.050	-553.1	0.0203	____
Cu-Zn30-0.05%Zr	1.995	-433.9	0.0100	50.73
Cu-Zn30-0.10%Zr	1.101	-478.9	0.0055	72.90
Cu-Zn30-0.15%Zr	0.259	-257	0.0013	93.59
Cu-Zn30-0.20%Zr	0.048	-532	0.0002	99.01

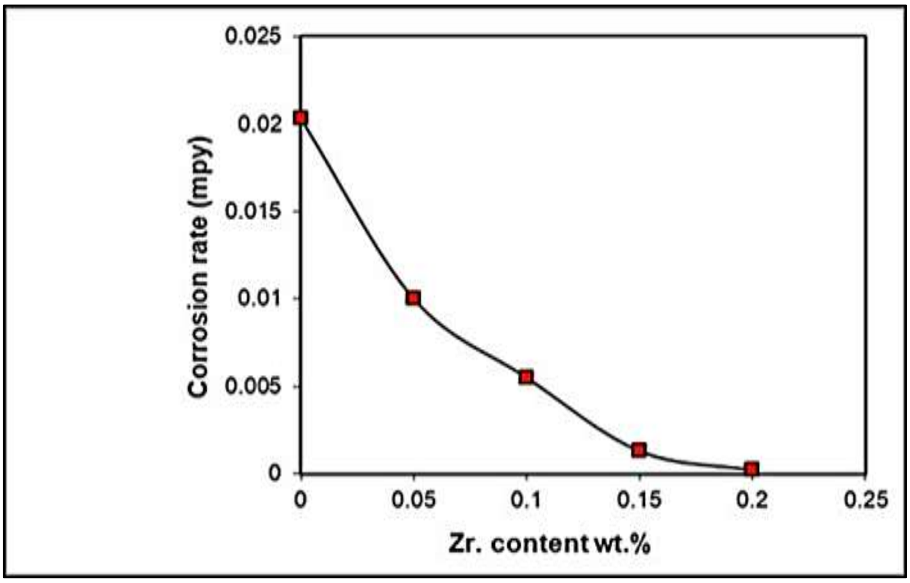

Fig. 17: Corrosion rate vs Zr content for the specimens in NaCl solution.

4. CONCLUSIONS

Zirconium addition to α- brass Cu-Zn30 alloy with 0.05, 0.10, 0.15, and 0.20 wt.% via casting process enhanced significantly mechanical and corrosion properties as following:

- Hardness increased with increasing the amount of zirconium. Whereas wear and corrosion rate is decreased by increasing the amount of Zr.
- The hardness enhanced by(45%)when added 0.20 %wt.% Zr to α- brass Cu-Zn30 alloy
- Wear rate is increased in general with increasing the applied load.
- The wear rate decreased by (54%) under conditions of 0.20 %wt. % Zr addition to α-brass Cu-Zn30 alloy.
- The corrosion rate in 3.5%NaCl was reduced by (99%) under addition of 0.20 %wt.% Zr to α- brass Cu-Zn30 alloy.

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