STUDY THE EFFECT OF ZINC ADDITION ON DRY SLIDING WEAR RATE OF PURE ALUMINUM

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ABSTRACT

In this research, the effect of Zinc addition to pure Aluminum to resist dry sliding wear had been studied using the pin-on-disc technique, to calculate the wear rate for pure Aluminum samples, and others with the addition of Zinc at different rates (1%, 3%, 5%), during sliding the test samples under dry sliding conditions on a disk of carbonic steel at different loads, variable slide speeds, and variable slide periods.

The results showed that the wear rate decreases with increasing the Zinc proportion for the test samples. It has been noted that the increasing the applied vertical load leads to increasing the rate of wear and the rate of wear at 5% Zinc is less than the other rates. The results also showed that the rate of wear decreases with the increase of sliding speed for all the above added ratios. The results of X-ray diffraction for the samples of the test also showed the occurrence of the main phase ($Al_{0.71}Zn_{0.29}$) which has a great effect on reducing the rate of wear, as it increased with the increase of the proportion of zinc and for all the added percentages.

Keywords: Aluminum, Aluminum-Zinc, Resistance of wear

INTRODUCTION

Zinc is the main founding element in Aluminum alloys chain (7xxx) with a rate ranging (1-8%) when associated with small rates of Magnesium, that produces heat treated and high tensile strength average alloys. Small rates of Copper and Chromium elements may be added as well.

Aluminum and its alloys are attractive or effective in many chemical applications, cars, and aerospace industries, because of its high tensile strength due to weight; thermal and electrical conductivity; and its good resistance to enter some corrosive media. Aluminum usually strengthens by formation or deposition of the second phase and fixes it as strengthen molecules. The high performance of many strengthen molecules, that led to strengthening Aluminum alloys, has a significant and important role in improving the mechanical and tri-biological properties, which consequently led to a wide range of applications. Anyhow, Aluminum, as a basic material, often suffers from severe dangers when it comes under supportive attack of wear and tear in some aggressive media, regardless its good resistance to corrosion. This occurs due to the mechanical strength that could damage or hurt the layer of protection negatively that leads to failure. Therefore, any improvements in minimizing the damage of the protection layer under the effect of wear and tear attack will help in prolong the life of the material, and consequently improving the performance of Aluminum. Therefore, the presence of some additions, which some are called (the ground elements) like Elytrum and Cerium, are used as founding elements to improve the oxidations resistance of Aluminum. There are previous studies demonstrated that the best effect of the ground elements on corrosive wear is represented by improving the passive film. These studies also demonstrated that the addition of Cerium and Elytrum to (Al-Zn-Mg) alloy led to improve the resistance of stress wear excitingly.

D.P. Mondal, S. Das, V. Rajput in 2005 studied the effect of Zinc concentration and experimental parameters on the behavior of high stress wear rubbing of Aluminum-Zinc alloys. They studied Aluminum-Zinc Alloys of high Zinc concentration, with changing the applied convection and the rubbing volume during two close levels of design. They found that the applied convection effect is harsher on the behavior of rubbing wear of alloys, and that the rubbing volume and Zinc concentration has less effect on the rate of wear. They also found that active effect of the applied convection and rubbing volume is higher than the effect of Zinc concentration with the applied convection and rubbing volume. On the other hand, the effect of Zinc concentration- rubbing volume is more than the effect of Zinc concentration- applied convection.

In 2009, Temel Savaskan and others studied the development of (Aluminum-Zinc) alloys with new base for the tribiological applications. They studied six bilateral alloys of (Al-Zn) and seven triple alloys by adding Copper Al-xZn-(1-5)Cu. These researchers reached to that the best addition of Zinc in alloys was (Al-25Zn), as it gave the best hardness and tensile strength. The resistance of wear for these alloys depends on the tensile strength and pressing as well as hardness. In addition, the tensile strength and pressing Al25Zn-(1-5)Cu increase with the increase of the Copper content up to (3%), and the best resistance of wear achieved with Al-25Zn-3Cu alloy.

In 2009**,** Yassin Alemdag & Temel Savaskan studied the mechanical and tribiological properties for (Al-40Zn-Cu) alloys. They studied the properties of bilateral alloy (Al-40Zn) comparing it with five alloys of (Al-40Zn-Cu) and changing the ratios of Copper, compared with Bronze bearings alloy (SAE 65). They reached that the microscopic construction (Al-40Zn-Cu) contains Aluminum rich with Alpha bushes surrounded by (Alpha+ Gamma) phase, and (Theta) phase which represents ($CuAl_2$) molecules. Also, the hardness of the triple alloys increases with the continued increase in Copper content, while the tensile resistance decreases when the rate of Copper is more than (3%). They also found that wear resistance of (Al-40Zn-Cu) alloys surpasses Bronze bearings alloys (SAE 65), and that the best properties of wear resistance and high tensile strength occurred to (Al-40Zn-3Cu) alloy.

In 2009**,** Majid H. Abdulmageed studied the effect of different media on the behavior of wear and some mechanical properties of (Al-Zn-Mg) alloy. This researcher studied some mechanical properties such as hardness and wear, and the results of wear measuring at different sliding speeds showed that the wear rate of samples treated in alkaline solution is higher than those treated in acidic or saline solutions. The same results have been shown in measuring the wear rate when imposing different convections.

THE PRACTICAL PART

Preparation of Samples

1. Wires of pure Aluminum of (98, 98%) purity was used. These wires were cut, and then put them in the oven for melting process after it has been heated to a temperature of (750C^o) to ensure the full fusion, then adding a malice remover and gases repellent material of the structure ($KAlF_4$) in order to obtain a fusible free of defects.
2. Add Zinc powder to the molten Aluminum and stimulate it well for the purpose of full consistency, and then the casting process in a metal mold.
3. The casting process has been conducted three times for the alloy in different percentages of Zinc: (1%, 3%, and 5%).as shown in table (1).

Table 1. The prepared alloys

Percentage of Zinc	*Weight of the dissolved Aluminum/gm*	*Weight of the added Zinc / gm*	*Total weight of alloys/ gm*	*Symbol of alloy*
1%	200	2	202	Al-1%Zn
3%	200	7.0	207	Al-3%Zn
5%	200	10	210	Al-5%Zn

4. Cast rods have been obtained with a diameter (3cm) and length (25cm). These rods have been run on the turning machine with the existence of a coolant, and cut into several samples with a diameter (2.5cm), and thickness (6mm). And then conducted the chemical analysis of samples prepared as shown in table (2).

Table 2. The chemical composition of pure Aluminum and prepared alloys

Elements (Wt. %)	*Al*	*Pb*	*Ni*	*Cr*	*Ti*	*Zn*	*Mg*	*Mn*	*Cu*	*Fe*	*Si*
Pure Aluminum	98.83	-	-	0.0008	0.006	0.002	0.542	0.002	0.001	0.167	0.456
Al-1% Zn	Rem.	-	-	0.005	0.006	2.524	0.560	0.002	0.008	0.1620	0.445
Al-3% Zn	Rem.	-	-	0.009	0.007	3.535	0.560	0.012	0.007	0.170	0.465
Al-5% Zn	Rem.	-	-	0.010	0.008	4.489	0.560	0.009	0.007	0.1690	0.455

5. Polishing and smoothing processes were conducted for models of regular shapes and smooth surfaces. Samples were prepared for the microscopic examination by performing the smoothing process using silicon carbide papers of different sizes (180-2000) with water to prevent overheating. Then making the polishing process by using a polishing cloth with Alumina powder in its two coarse and fine types in two stages, with diamonds paste. Then clean it with water and alcohol, and dry it for the purpose of microscopic structure test. A manifesting solution related to Aluminum castings of the structure (HF, 1.5ml-HCL, 1.0ml-, 95ml- water 2.5ml-HNo3) was used. The samples were dipping for (20) seconds. The scanning was conducted by using the optical microscope (Olympus) type, which is camera- equipped and computer connected.
6. Samples to examine the wear were prepared from pure Aluminum and Aluminum-Zinc alloys with the weight rates (1,3,5)% in a cylindrical shape, with diameter (10mm), length (20mm), using a CNC machine programmed. The samples of test were cleaned by using water current, smoothing and dried them with hot air, then refined them for the purpose of getting a surface free from defects (scratching), which may increase the rate of wear between the surfaces in contact before beginning the process of testing samples.

THE USED DEVICES

Device for Measuring the Wear

In this research, we study the impact of slide speed, vertical bearing, and sliding time on the properties and behavior of dry sliding wear for samples of Aluminum-Zinc alloys (1wt.%-

3wt%Zn) by using the dry sliding wear measuring device (Pin-on-disc) in order to get the status of contact between the sample and turntable made of steel (45HRC).

The device consists of an electric motor of electric rotational speed capacity (1.5) hp, and an arm of a rectangle section in order to fix the sample in it by a holder of (10mm) diameter. A strain gauge has been fixed on the arm to measure the power of friction. Five different loads have been used (5,10,15,20,25)N under the impact of changing the linear sliding speed (0.94, 1.88, 2.82, 3.76, 4.9) m/s , where the turntable speed will be controlled by transmission belts from the electric motor as shown in figure (1). All the examinations for testing the samples were conducted in the normal atmosphere at room temperature.

Figure 1. Device of wear test

Testing the Wear

Testing the wear for the prepared samples was conducted by using (Pin-on-disc) device. The rate of wear has been calculated by following the weighted method, which includes calculating the weight loss from the sample. The samples weight was calculated before and after the test by an electric scale of (0.0001) gm precision. The rate of wear was calculated according the following equation:

$$\text{Wear Rate: } (W_R) = \frac{\Delta W}{2\pi rnt}$$

$$= \frac{W1-W2}{2\pi rnt} \text{ (g/cm)}$$

Where:

Δm: The lost weight (gm), which is the difference in weight for the two samples before and after the test, that is, any loss in weight could be calculated as follows:

Δw (weight loss) : w1-w2

W1: weight of the sample before the test (gm).

W2: weight of the sample after the test (gm).

t: time of test (min).

r: radius of the rotation center from the center of the sample to the center of the disc.

n: speed of the disc rotation (540 RPM).

RESULTS AND DISCUSSION

Effect of the applied Load on the Wear Rate

During this stage of the research, effect of the applied load on the rate of the dry sliding wear for Aluminum has been studied. Different loads value (5, 10, 15, 20 and 25) N had been adopted respectively, with sliding time (20min) for the test samples while they are running on a steel disc with (45HRC) hardness. In figure (2) we find that the increase in the applied vertical load leads to an increase in the rate of wear due to an increase in the force of friction, as the friction force commensurate with the pressing force between surfaces in contact (N) as shown in figure (3). Thus the friction force is commensurable directly with the vertical load and the friction coefficient ($F=\mu N$), which leads to an increase in the temperature of surfaces (the sample and disc). Since the surface of both of the sample and turntable disc consists of protrusions and grooves, so beginning of the contact occurs in the sharp aspirates. When the applied vertical load increases, the stress concentrates on the sharp aspirates area, which in turns leads to soft distortion in this aspirates and the region near the surface, so the holes increase as a result of influencing the smalls that resulting from breaking the contacted surfaces peel. Thus, the small cracks will coalesce together leading to remove the surface layer as thin smalls, therefore, the soft distortion increases with the increase in the vertical load amount, which in turn, the latter leads to an increase in the rate of wear for the test samples. Also, increasing the vertical load leads to increasing the overlap between the aspirates, thereby increasing the coefficient of friction, since that increasing the overlap makes the force needed to disengage large. This requires a high shear force, and thus the static coefficient of friction increases more than the dynamic coefficient friction.

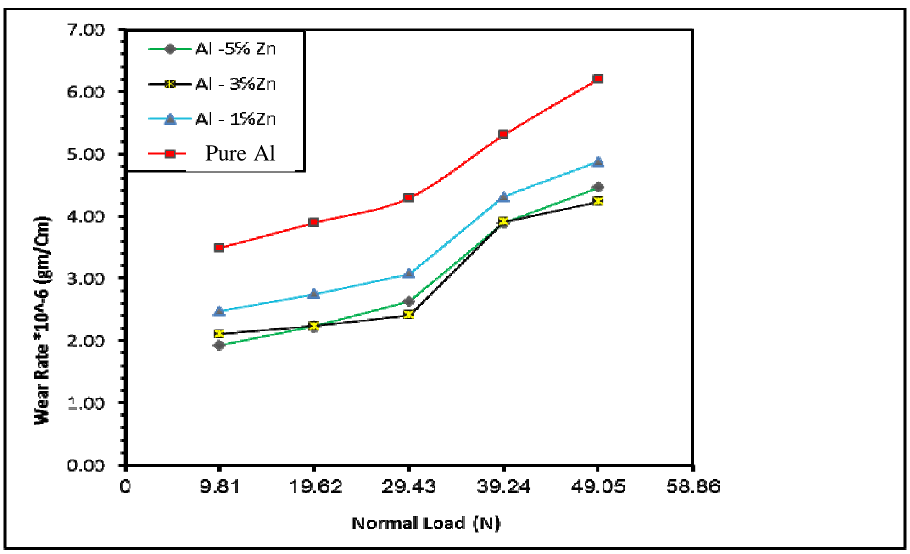

Figure 2. Represents the Effect of applied load on wear rate for Aluminum-Zinc and pure Aluminum alloys under the conditions of Sliding Speed (1.87 m/s), sliding time (30min), and temperature of (25C^{o})

As for the effect of adding Zinc to Aluminum, which represents finding the effect of the vertical load on the wear rate for the test samples of Aluminum-Zinc alloy with proportions (Al-1wt%Zn, Al-3wt%Zn and Al-5wt%Zn), it can be noticed that the behavior of wear for the pure Aluminum is similar to its behavior after the addition of Zinc, where the transmission of wear from mild wear when loads are few to the transitional wear, and then to severe metallic wear. But the wear rate of the alloy itself after the addition of Zinc was lower than it is in the case of pure Aluminum, at all applied loads values and under the same test conditions (steady speed and sliding time, and as shown in all figures.

Effect of the Sliding Speed on the Wear Rate

In this study, effect of the sliding speed on the rate of wear for the test samples before and after the addition of Zinc, had been shown. The sliding speeds used were (0.94, 188, 2.82, 3.76 and 4,9) m/s respectively, while time of the test was (20min) for each test under the influence of a steady vertical load (19.62)N when the test samples slide on a steel disc with (35HRC) hardness. Scheme (3) shows that the speed of sliding causes substantial changes in the process of wear with the applied load and ambient temperature, as these factors can change the temperatures resulting from the speed of sliding. From figure (3), we can notice that the rate of wear for alloys decreases with increasing the speed of sliding, and this attributed to that leakage of heat through the metal of sample and disc, at high sliding speed, is less than it is at low sliding speed, which results in a high temperature of the contact surface at velocities, and increasing the ability of the sliding surfaces to interact with humidity and air. A layer of oxide is formed on the surface of contact, works on reducing the direct metal contact between the two sliding surfaces, leading to lower and reduce the rates of wear. We can also notice that the rate of wear increases to its maximum value at the speed (0.94 m/s), and this attributed to that the instantaneous temperatures is high at this low sliding speed, as well as, at low sliding speed, the possibility of occurring the oxidation process would be little, resulting high wear rates due to the direct metal contact between the sample surface and the turntable disc, and producing the metallic wear debris.

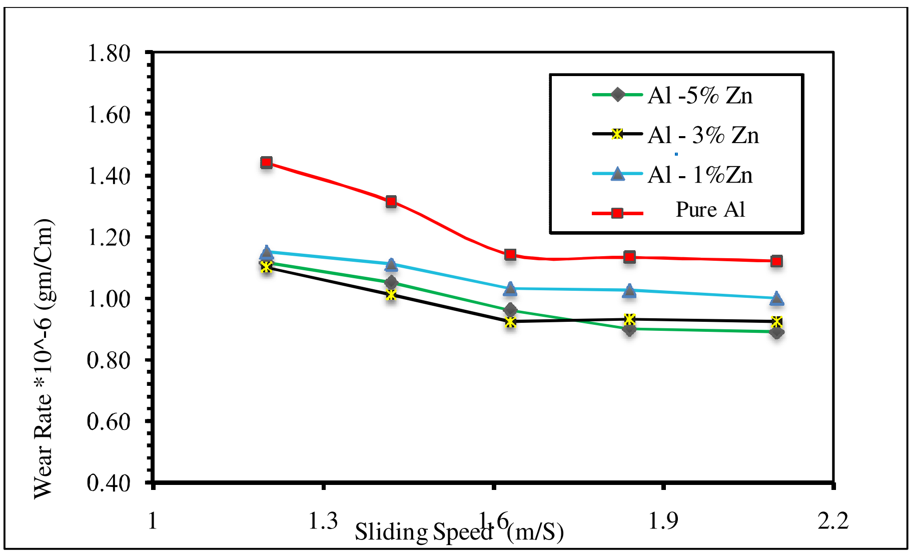

Figure 3. Represents the Effect of sliding speed on the wear rate of Aluminum-Zinc and pure Aluminum alloys under the conditions of applied load (19.62N), sliding time (30min), and temperature of (25C^{o})

Effect of the Sliding Time on the Wear Rate

Figure (3) represents the relationship between the periods of sliding and dry sliding wear rates for Aluminum - Zinc alloys when imposing load (19.62N), at sliding speed (186m/s), and turntable hardness (35HRC). It can be noticed that the rate of wear increases continuously with increasing time of sliding, but the rate of wear for Zinc-Aluminum alloys is less than the pure Aluminum. This can be attributed to that the addition led to increasing the hardness of the test samples, which leads to reducing the contact of the surface separating the sample and the turntable disc, that is, reducing metal to metal contact zone, which in turns leads to expansion of the soft wear area and reducing the severe wear area, i.e., making the behavior of the soft wear, between the samples during sliding on the turntable disc, is the prevailed one. From figure (4), it can be noticed that the rate of wear increases abruptly after (120)min, and vertical load (19.6N) for pure Aluminum, due to the occurrence of the Walden formation and excitable hunt phenomenon in the surface layers, and this in turn leads to the occurrence of longitudinal and transverse cracks. In addition to that, deep holes; wear lines; and longitudinal and transverse grooves have been formed, resulting in a significant loss in the metal, and this in turn increases the rate of wear.

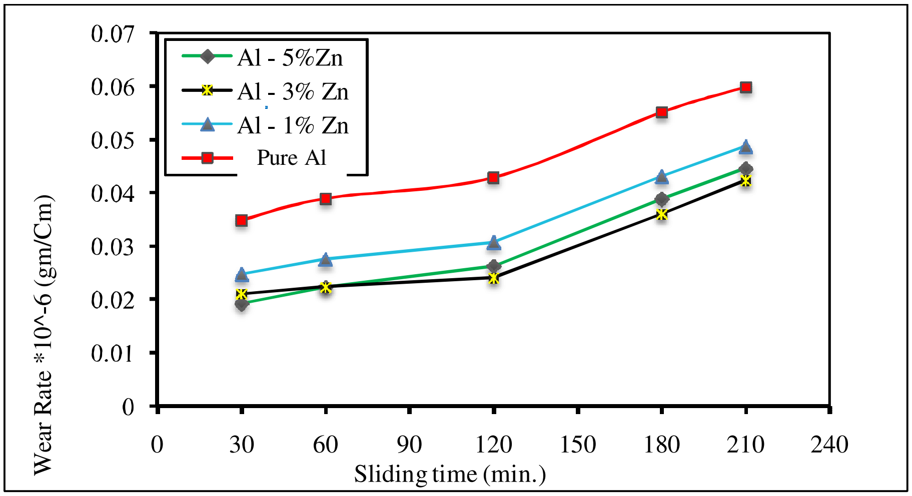

Figure 4. Represents the Effect of sliding time on the wear rate of Aluminum-Zinc and pure Aluminum alloys under the conditions of applied load (19.62N), sliding speed (1.86m/s), and temperature of (25C°)

The results of the same stage for this research, which includes the study of the effect of periods of sliding on the rates of wear for alloys, are: the increase in the rate of wear with the sliding time is gradual and much less when compared with the pure Aluminum, and this is shown in figure (4). Figure (5) shows that the addition of Zinc led to reducing the rate of wear for the alloys, but in proportions depend on the rate of Zinc added to pure Aluminum. The results showed that the addition of (1%) Zinc did not affect much on the rate of wear, so it almost remained constant with the change of speed and time of sliding.

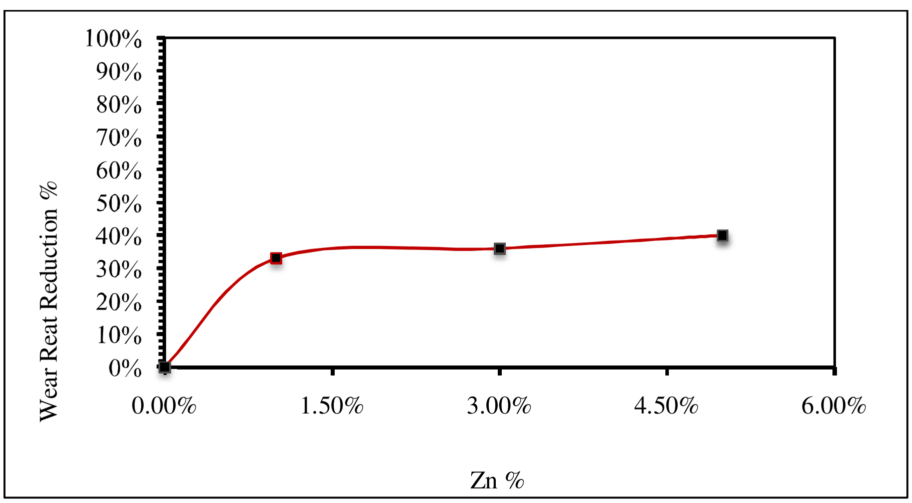

Figure 5. Represents the impact of the rate of Zinc on reduction the rate of wear of Aluminum- Zinc alloys

Figure (6) shown X Ray diffraction for all samples of Aluminum-Zinc Alloys And that showed us the presence phases have had a major role in minimizing the wear rate for all samples.

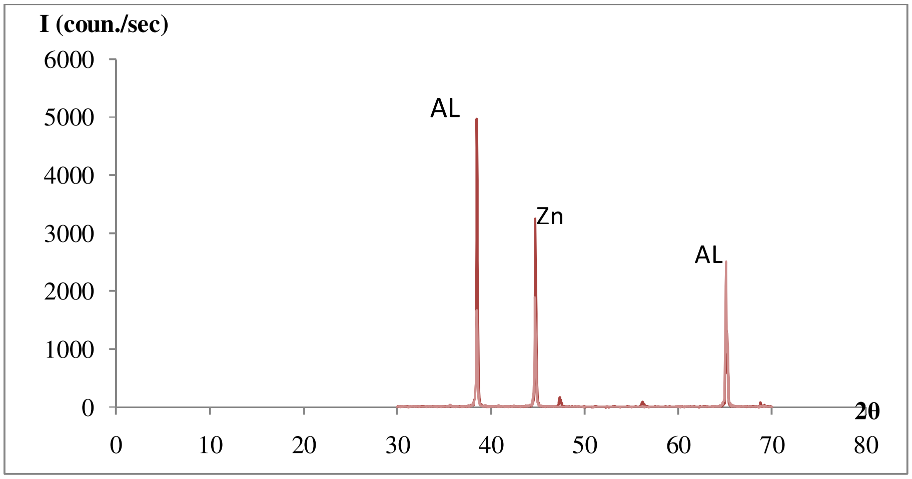

Figure 6-A. Represents the diffraction of X-rays with changing the rates of Zinc Al-5% Zn

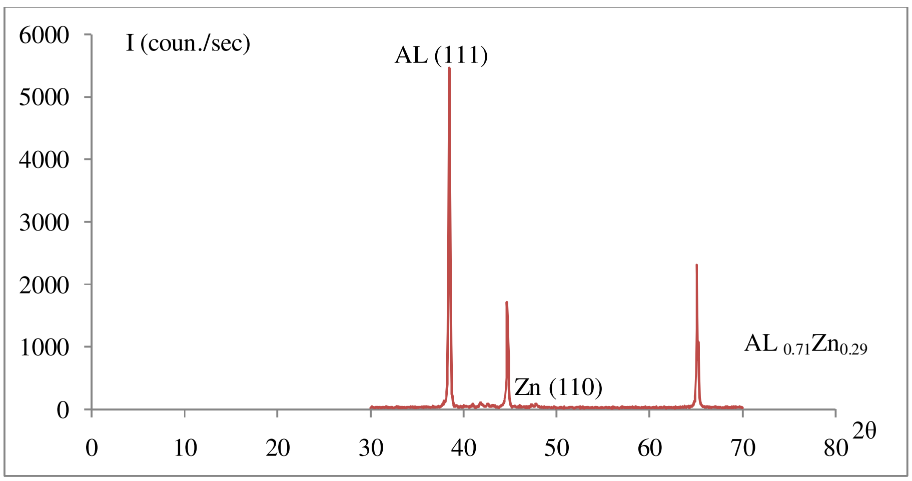

Figure 6-B. Represents the diffraction of X-rays with changing the rates of Zinc Al-3% Zn

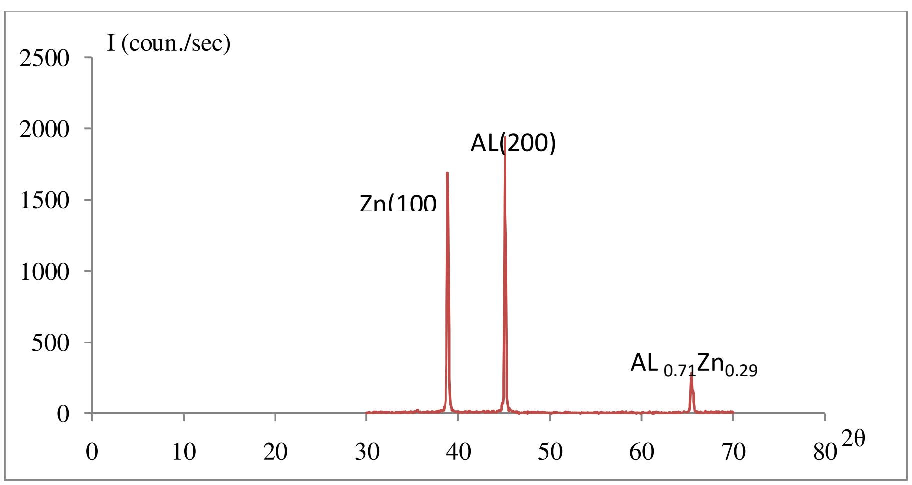

Figure 6-C. Represents the diffraction of X-rays with changing the rates of Zinc Al-1% Zn

Figure (7, 8, 9) shown the effect of wear occurring on the test samples under the influence of a applied load 36.92 N, sliding speed of 2.88 m/s and periods of sliding 20 (min) for the alloys Al-5% Zn, Al-3% Zn and Al-1% Zn respectively.

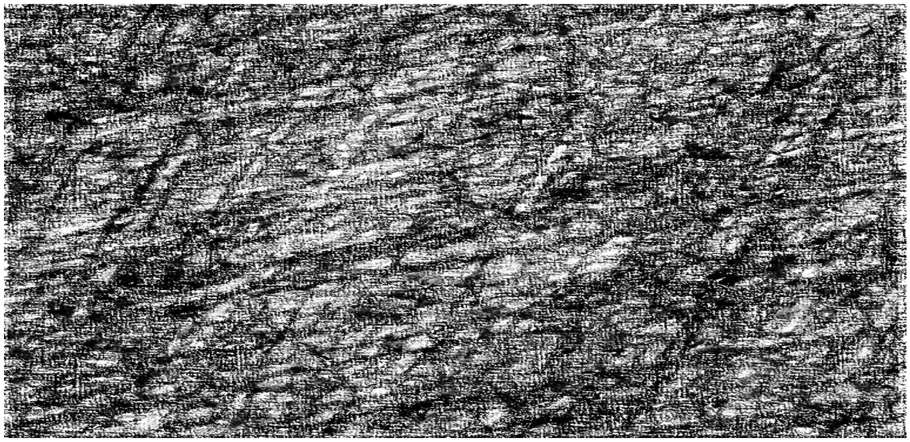

Figure 7. Impact of wear occurring on the test samples under the influence of a vertical load 36.92 N, sliding speed of 2.88 m/s and periods of sliding 20 (min) for the alloy Al-5% Zn (20 X)

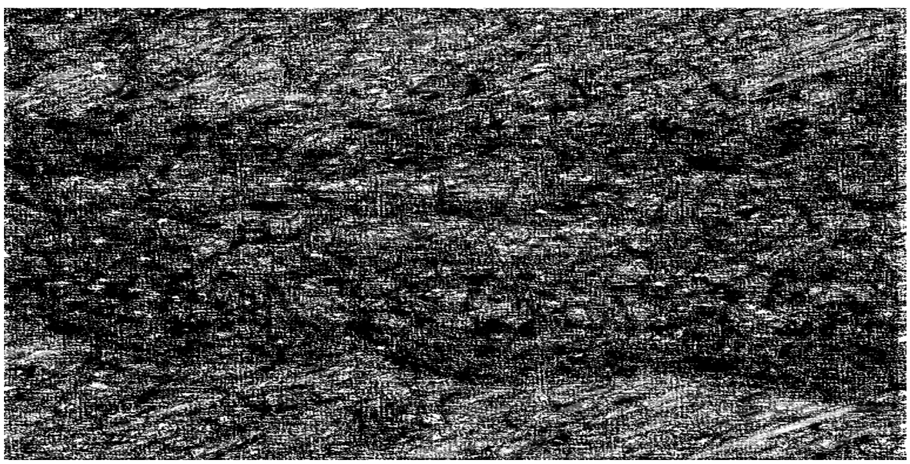

Figure 8. Impact of wear occurring on the test samples under the influence of a vertical load 36.92 N, sliding speed of 2.88 m/s and periods of sliding 20 (min) for the alloy Al-3% Zn (20 X)

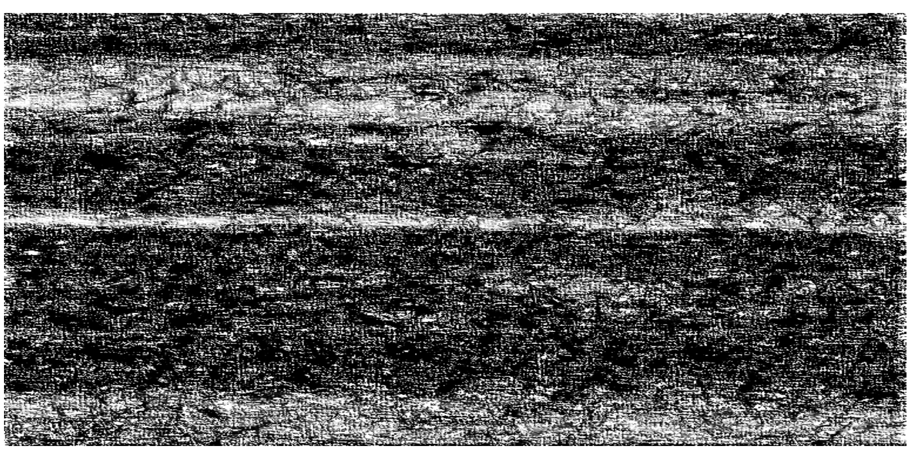

Figure 9. Impact of wear occurring on the test samples under the influence of a vertical load 36.92 N, sliding speed of 2.88 m/s and periods of sliding 20 (min) for the alloy Al-1% Zn (20 X)

CONCLUSIONS

1. Increasing of Zinc percentages causes decreasing the wear rate.
2. Wear rate at 5% Zinc was less than the other rates.
3. Increasing of sliding speed causes decreasing in wear rate.
4. An increasing of applied leads to increasing in wear rate.
5. The main phase is ($Al_{0.71}Zn_{0.29}$) has effect on reducing the wear rate**.**

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