Eng. & Tech. Journal ,Vol. 28, No.3,2010

Effect of Different Media on the Corrosion Behavior and Some Mechanical Properties of Al-Zn-Mg Alloy

Majid Hameed Abdulmageed*

Received on:5/5/2009
Accepted on:5/11/2009

Abstract

This work investigates the effect of different media (0.1N of NaOH, H_2SO_4 and NaCl solution) on the polarization behavior of Al-Zn-Mg alloy and calculates some of the corrosion parameters such as corrosion potential (E_{corr}) and current density (i_{corr}), cathodic and anodic Tafel slopes (b_c & b_a), and the polarization resistance (R_p) .

The results of the polarization resistance indicates that Al-Zn-Mg alloy have resistance in slat solution higher than that observed in acidic and basic solution respectively .

Also some of the mechanical properties like the hardness and wear were measured. The results for hardness showed that the untreated alloy in the experimental solutions had higher hardness than those which are treated in salt, acidic , and basic solutions respectively .

While the results for the rate of wear at different sliding speeds showed that the rate of wear for the samples that treated in basic solution higher than those for samples which are treated in the acidic and salt solutions . Also the same results were get when measure the rate of wear with different applying loads.

Keywords: Corrosion of Al-Zn-Mg alloy, Hardness, wear.

تأثير أوساط مختلفة على سلوك التأكل وبعض الخواص الميكانيكية لسبيكة المنيوم – زنك - مغنيسيوم

الخلاصة

يتضمن البحث دراسة تأثير أوساط مختلفة (0.1 مولالي من هيدروكسيد الصوديوم وحامض الكبريتيك وكلوريد الصوديوم) على السلوك الاستقطابي لسبيكة (Al-Zn-Mg) حيث تم حساب العديد من متغيرات التأكل كجهد وكثافة تيار التأكل وميول تافل الكاثودية والانودية ومقاومة الاستقطاب. وقد اظهرت نتائج قياس المقاومة بان سبيكة المنيوم- زنك –مغنيسيوم تمتلك مقاومة استقطابية في المحلول الملحي NaCl اعلى مما في المحلول الحامضي H_2SO_4 والقاعدي NaOH. كما تم قياس بعض الخواص الميكانيكيه مثل الصلادة والبلى وبينت نتائج قياس الصلادة بأن السبيكة غير المعاملة بالمحاليل التجريبيه تمتلك صلادة اعلى مما للعينات المعاملة في المحلول الملحي والحامضي والقاعدي على التوالي .

كما اظهرت نتائج قياس معدل البلى عند سرع انزلاق مختلفة بأن معدل البلى للعينات المعاملة في المحلول القاعدي اعلى من تلك العينات المعاملة في المحاليل الحامضية والملحية , كما اظهرت نفس النتائج لقياس معدل البلى عند تسليط احمال مختلفة .

* Materials Engineering Department, University of Technology / Baghdad

1-Introduction

Zinc, in amounts of 1 to 8%, is the major alloying element in 7xxx series alloys of aluminum, when coupled with a small percentage of magnesium results in heat-treatable alloys of moderate to very high strength. Usually other elements, such as copper and chromium, are added in small quantities [1].

Higher strength 7xxx alloys exhibit reduced resistance to stress corrosion cracking and are often utilized in a slightly overage temper to provide better combinations of strength, corrosion resistance, and fracture toughness. There are many investigations about behavior of Al-Zn alloy, Lunarska and Szklarska studied the changes in morphology and chemical composition of corrosion on the surface of three powder metallurgy Al-Zn-Mg alloys containing 8.8 to 12.5% Zn, 2.4 to 2.5% Mg and 1.2 to 1.5%Al after their exposure to deaerated 3.5% NaCl solutions of pH 1 , 7 and 13 at room temperature in a wide range of applied potentials, using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) techniques [2].

Also they studied the stress corrosion cracking (SCC) of three wrought powder metallurgy (P/M) Al-Zn-Mg alloys differing in Zn content and heat – treatment in deaerated 3.5% NaCl solution over a wide range of applied potentials, using the slow strain rate tensile technique (SSRT)[3]. Hong–pyo Kim and Co–workers studied stress corrosion cracking (SCC) and corrosion behavior of Al–Zn–Mg alloys in deaerated 3.5wt% NaCl solution at pH=3.5 with and without the hydrogen recombination poisons (HRPs) $Na_2S.9H_2O$ or Ca_3P_2 [4].

Jong[5] studied the influence of loading direction on the (SCC) susceptibility of aluminium alloy (7075-T651) and the specimens having been tested by the constant strain rate method. The influence of the strain rate on the mechanical properties of the material was also investigated. Yong-Seog and Pyun[6] studied the stress corrosion cracking (SCC) of Al-Zn-Mg welds in an aqueous solution of 3.5wt% NaCl (pH=1) at $15^o \underline{+} 2^oC$ under constant load as a function of the applied anodic potential and the post weld heat treatment. Various theories of SCC in high strength aluminium-based alloys are reviewed. Also Hong–pyo and Pyun described the (SCC) processes in a high purity Al-Zn-Mg alloy under constant strain-rate in terms of the stress-corrosion (SC) crack growth rate and the SCC fracture mode [7].

2- The Aim of work

The aim of this work was studied the electrochemical behavior of Al-Zn-Mg alloy in different media and measured some mechanical properties so that compare the corrosion behavior and mechanical properties.

3-Experimental Part

3-1Materials and Chemicals

Al-Zn-Mg Alloy was used in this work and the analytical composition of alloy was shown in Table (1).

The basic solutions were 0.1N of each NaOH (M.wt 40 gm/mol), H_2SO_4 (Sp.gr 1.84 gm) and NaCl (M.wt 58.44 gm/mol) for study the corrosion behavior. While the solutions which used to measure the mechanical properties were (1N of each NaOH (M.wt 40 gm/mol),

H_2SO_4 (Sp.gr 1.84 gm) and NaCl (M.wt 58.44 gm/mol).

3-2 Corrosion Test

Al–Zn–Mg alloy was cut into cylinder shape with (1.2 cm) diameter, and made into electrode by pressing a copper wire into a hole on one side and then insulating all but one side with an epoxy resin. The open side was polished mechanically to a mirror finish, rinsed in distilled water and stored in a desiccator.

The electrochemical glass cell was of the usual type with provision for working electrode (Al-Zn-Mg alloy), auxiliary electrode (Pt electrode), and a Luggin capillary for connection with an saturated calomel electrode (reference electrode SCE).

Electrochemical measurements were performed with WINKING M Lab Potentiostat from Bank-Elektronik at a scan rate 2 $mV.sec^{-1}$.

3-3 Polarization Resistance (R_p)

From the study of polarization behavior of samples can be get the corrosion potential (E_{corr}) and corrosion current density (i_{corr}) by extrapolation method. Another parameter can be calculated from corrosion measurement is the polarization resistance (R_p) which represent the measure of the resistance of the metal to corrosion in the solution in which the metal is immersed.

The polarization resistance (R_p) can be determined from Stern- Geary equation:

$$R_p = \left(\frac{dE}{di}\right)_{i=0} = \frac{b_a b_c}{2.303(b_a + b_c) i_{corr}} \quad \ldots(1)$$

Where E is the applied potential (Volt) , i is the current density ($A\ .cm^{-2}$) and b_c, b_a are cathodic and anodic Tafel slops respectively.

3- 4 Mechanical Properties Measurement

3- 4 -1 Hardness

Hardness is commonly defined as the resistance of a material to indentation by a harder material with applied load. Hardness can be quantified by depth of indentation of a hard indenter, usually diamond, and loaded perpendicular to planer surface of the material under test.

The penetration depth is related to the contact area over which the load is transferred between the indenter and the sample. The hardness is equal to the load divided by the area of plastic contact.

The measured hardness of any material depends on parameters associated with the test method, indenter geometry and load, Brinell, Vickers, Rockwell, etc., so that hardness is hot an intrinsic bulk property, comparable to elastic modulus, yield strength or fracture toughness. In general, the measured hardness varies with applied load and the indenter shape and dimensions, but also with the microstructure and prior history of the material, the environment, and the test temperature [10, 11].

Brinell hardness can be calculated by using the following equation :

$$H_{Br} = \frac{2f}{pD_b(D_b - \sqrt{D_b^2 - d_i^2})} \quad \ldots..(2)$$

-----(1)

where H_{Br} is Brinell hardness, d_i is the diameter of the circular indentation (mm), D_b is the diameter of the Steel ball (mm), and f is force applied (N).

3- 4 -2 Wear Test Equipment

Pin-on-disc machine which belong to melts laboratory, department of materials engineering was used to carry out the wear test experiment.

A carbon steel disc was used as a counter face with a hardness and surface roughness values of 428 Hv. Dry and wet sliding wear test were conducted for wet wear tests the specimens were immersed 24hrs in Babel motor oil.

Sliding speed: the disc rotational speed was 420 rpm, with a linear sliding of (1.65,3.2,4.7gm/sec). The linear speed was calculated as follows:

$$V = pD_s N / 1000 \times 60 \quad \text{……(3)}$$

where V is a linear sliding speed (m/sec), D_s is sliding circle diameter (mm), and N is disc rotational speed (420 rpm).

Applied load: loading was carried out normally by putting suitable weight on the specimen holder weighting (5, 10, and 15 N).

Wear rate calculated from weight loss measurement by using sensitive balance with an accuracy of $\pm$ 0.0001 gm. Mettle type AE 200, the formula used to convert, the weight loss into rate is:

$$\text{Wear rate (weight loss)} = \Delta w/s \quad \text{….(4)}$$

$$\Delta w = w_1 - w_2 \quad \text{…..(5)}$$

where Δw: weight loss of the sample (gm), w_1: sample weight before the wear test, and w_2: sample weight after the wear test.

The total sliding distance S (cm) was calculated as:

$$S = V \times t \quad \text{…….(6)}$$

where t: running time (30 min) at each test.

4- Results and Discussion

4 -1 Corrosion behavior

Polarization experiments were started when the rate at which open circuit potential (E_{oc}) changed was less and more 200mV. The variation of potential with time to measure the open circuits potential were shown in Figure (1) to (3) for Al-Zn-Mg alloy in NaOH, H_2SO_4 and NaCl solution respectively.

Figures (4) to (6) show the polarization behavior of this alloy in experimental solution. This behavior indicates appear two regions in the polarization curve the cathodic and anodic zone.

The cathodic region represents the reduction reaction which occur on the surface of alloy according to the medium of corrosion.

In the acidic medium:

$$2H^{+n} + 2e \rightarrow H_2 \quad \text{……(7)}$$

In the neutral and basic solution:

$$\tfrac{1}{2}O_2 + H_2O + 2e \rightarrow 2OH^- \quad \text{…… (8)}$$

While the anodic region represent the dissolution of metal or metals in alloy to ions according to the following reactions:

$$Al + NaOH + H_2O \rightarrow NaAlO_2 + 3/2H_2 \text{ …..(in NaOH solution) …….(9)}$$

$$2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2 \text{ (in } H_2SO_4 \text{ solution) ……(10)}$$

$$Al + 3NaC + H_2O \rightarrow AlCl_3 + 3Na^+ + H_2 \text{ (in NaCl solution) …..(11)}$$

The corrosion parameters were shown in table (2) includes corrosion potentials (E_{corr}) and the corrosion current density (i_{corr}). The different in the corrosion parameters with different medium shows in Figs.(7) and (8).

The values of R_p are presented in table (2) which indicates that the corrosion in the NaCl solution more resists than the other solutions, as shown in Fig. (9).

4-2 Mechanical Properties

***4 -2 -1 Hardness* Property**

The Brinell hardness test were chosen to characterize hardness of the alloy. The effect of corrosion surface layar on the hardness properties has been investigated on pitting specimens to concentrate the applied load in a certain point.

Table (3) shows the Brinell hardness test as a function of Medium chemical treatment.

4 -2 -2 Wear Property

-Effect of Sliding Speed

The results of wear test of Al-Zn-Mg alloy before and after chemical treatment at different sliding speeds and constant applied load(10gm) were shown in the Figure(10) which indicates that the chemical treatment (with (0.1N of NaOH, H_2SO_4 and NaCl solution) increases the rate of wear.

The increasing of sliding speed leads to decrease rate of wear because of increase the smoothness of surfaces which due to increases friction between surfaces and leads to instantly produced temperature .This lead to partial contact between the bulges for two sliding surface, and increase the required force to cut the points contact, This increased force is more than the adherence of atoms in metals it self.

The samples of Al-Zn-Mg alloy which immersed in the acidic and salt solutions gives more resistance for wear than that which immersed in the basic solution .

-Effect of Applied Load

The increasing of applied loads lead to increases the rate of wear because of plastic deformation of the protrusions which presence in the touching surfaces and then lead to removing the particular top of protrusions.

Figure(11) show the effect of different applied loads in the wear test for Al-Zn-Mg alloy before and after the chemical treatment which indicates that the rate of wear after treatment by salt, acidic and basic medium more than that of as received (the original sample without treatment by chemical solutions).

It was observed that within the first few minutes of running a dark-coloured band appeared on the disc, consisting of loose particles which did not stick to the disk.

At higher loads, increasing fraction of the particles and increase the plastic deformation of bulges which presence on the interaction surfaces lead to partial remove of peaks the bulges which affect on the weight of sample. The increasing of loads and continuoued sliding and remove the oxide layer from the surface and caused stronger metallic adhesive which required more force to cut the metallic boundaries for alloy and lead to increase rate of wear.

The samples which immersed in the basic solution gives rate of wear more than that the samples which immersed in the acidic and salt solution and the results of wear testing.

5- Conclusions

All the results can be concluded as follow:-

1- The corrosion potential (E_{corr}) which take the following sequence with the different of the medium:-

$-E_{corr}$ (mV) H_2SO_4 solution < NaCl solution < NaOH solution

2- The corrosion current density (i_{corr}) take the following sequence :-

i_{corr} ($\mu A.Cm^{-2}$) NaOH solution > H_2SO_4 solution > NaCl solution

3- The polarization resistance (R_p) showed that the corrosion in NaCl solution more resist than other solutions and the (R_p) take the following sequence :-

R_p ($\mu.Cm^{-2}$) NaOH solution < H_2SO_4 solution < NaCl solution

6- References

[1] Davis J. R., "Metal Handbook", second edition, pp.443, 1998.

[2] Lunarska E., and Szklarska–Smialowska Z.,"Surface degradation of powder metallurgy Al-Zn-Mg alloys in NaCl solutions at different applied potentials" *Corrosion–nace*, vol.43, No.6, pp.353-359, June 1987.

[3] Lunarska E., and Szklarska–Smialowska. Z.,"Stress corrosion cracking of powder metallurgy (P/M) Al-Zn-Mg alloys in deaerated 3.5%NaCl" *Corrosion-nace*, vol.43, No.7, pp.414-424, July 1987.

[4]Hung-Pyo Kim, Rak-Hyun Song, and Su-Il Pyun, "Effects of hydrogen recombination poisons on stress corrosion crack initiation and propagation in Al-Zn-Mg alloys", *Br. Corrosion J.*, vol.23, No.4, pp. 254-258, 1988.

[5] Jong H.F. "Influence of loading direction and environment on the SCC susceptibility of aluminium 7075-T651", *Br. Corrosion J.*, vol.15, No.3, pp. 118-122, 1980.

[6] Yong-Seog Kim and Su-II Pyun, "Contribution to mechanism of stress corrosion cracking in a welded Al-Zn-Mg alloy", *Br. Corrosion J.*, vol.18, No.2, pp.71-75, 1983.

[7] Su-II Pyun and Hong-Pyo Kim, "Contribution to stress-corrosion crack propagation process in a high purity Al-Zn-Mg alloy", *Br. Corrosion J.*, vol.19, No.4, pp. 189-191, 1984.

[8] ASTM. Standards *"Metals Test, Methods and Ayalytical Procedures"*Vol. 03.01, Americans Society for Testing and Materials, (1988).

[9]W.D. Callister "Materials Science and Engineering an Introduction", six edition .,john Wiley and Sons,Inc,2003.

Table (1) The analytical compositions of Al-Zn-Mg alloy which useful in this search

Metal	*Zn*	*Mg*	*Cu*	*Cr*	*Ni*	*Ti*	*Mn*	*Al*
Wt%	5.70	2.50	1.330	0.22	0.01	0.08	0.06	Bal.

Table (2) Values of corrosion potentials E_{corr} ,corrosion current densities i_{corr}, cathodic and anodic Tafel slopes b_c and b_a, cathodic and polarization resistances R_p for the polarization of Al-Zn-Mg in different media at room temperatures.

Medium	*Corrosion*		*b (mV.decade^{-1})*		*R_px10^{+2} Ωcm^{-2}*
	-E_{corr} (mV)	*i_{corr} (μA.cm^{-2})*	*-b_c*	*+b_a*	
0.1N NaOH	1416.6	280.89	35.2	49.5	0.31801
0.1N H_2SO_4	512.5	130.43	104.7	55.9	1.21323
0.1N NaCl	735.9	8.90	71.6	57.7	15.5886

Tables (3) The results of ampact testing for Al-Zn-Mg alloy at different medium.

Hardnass (Kg/mm^2)	Concentration (Normality)	Medium	No.
74.5	-	Without treatment	1
68.3	0.1	Immersed in salt medium	2
52.8	0.1	Immersed in acidic medium	3
50.3	0.1	Immersed in basic medium	4

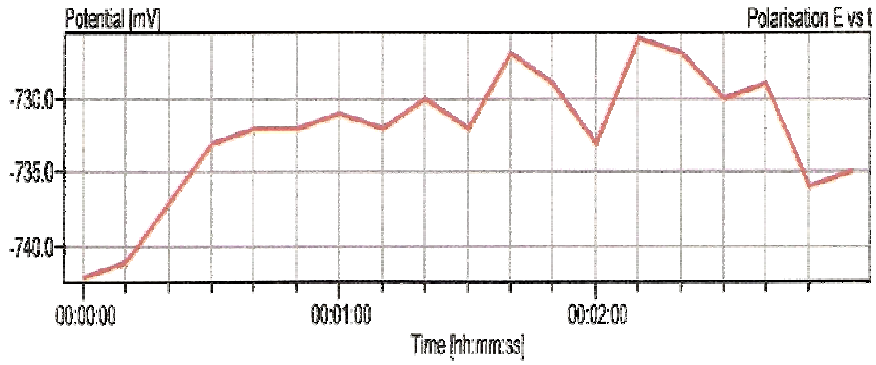

Figure (1) The variation of potential (mV) versus time (sec.) for Al-Zn-Mg alloy in 0.1N NaOH solution at room temperature.

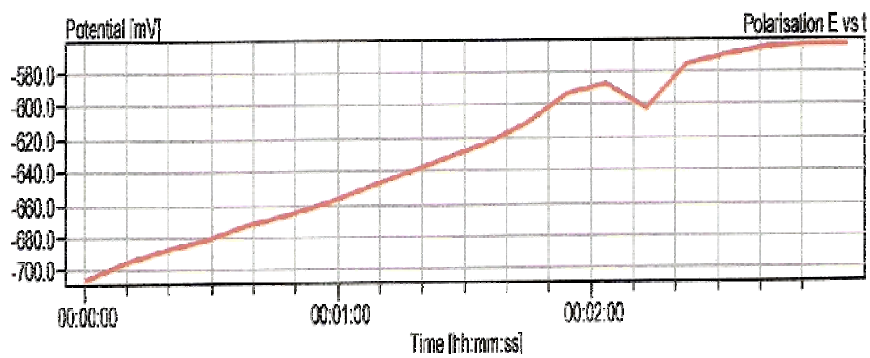

Figure (2) The variation of potential (mV) versus time (sec.) for Al-Zn-Mg alloy in 0.1N H_2SO_4 solution at room temperature.

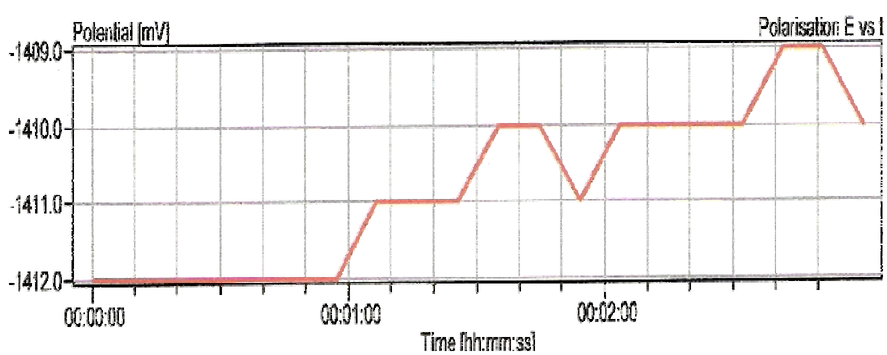

Figure (3) The variation of potential (mV) versus time (sec.) for Al-Zn-Mg alloy in 0.1N NaCl solution at room temperature.

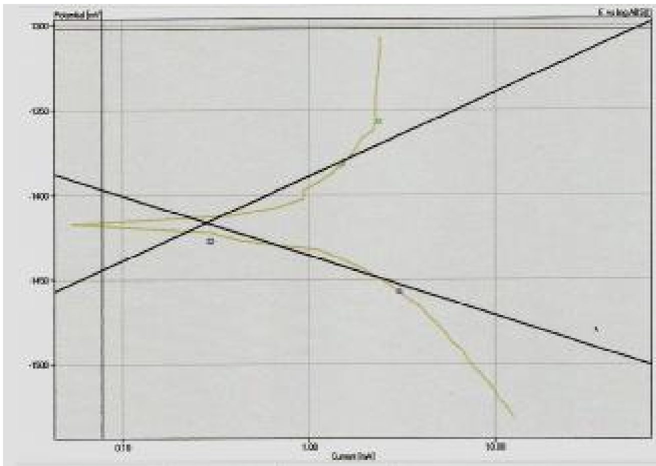

Figure (4) The polarization curve of Al-Zn-Mg alloy in 0.1N NaOH solution at room temperature.

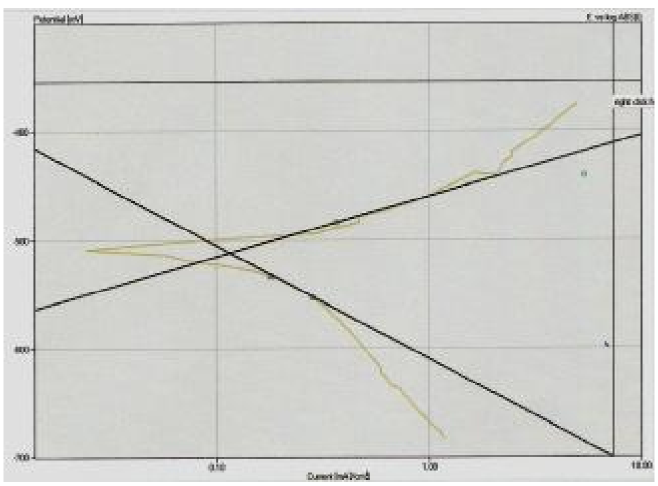

Figure (5) The polarization curve of Al-Zn-Mg alloy in 0.1N H_2SO_4 solution at room temperature.

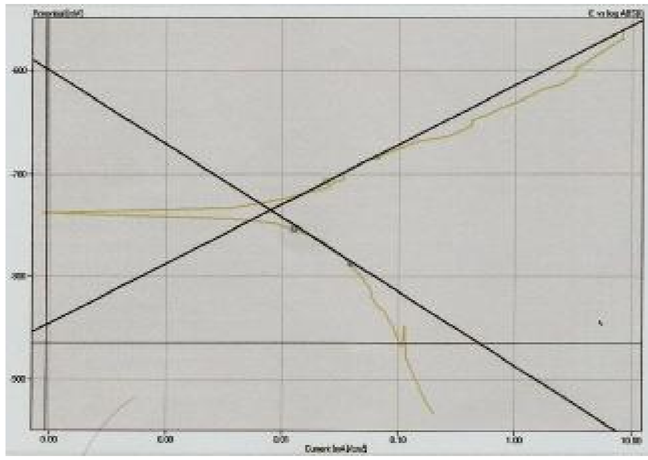

Figure (6) The polarization curve of Al-Zn-Mg alloy in 0.1N NaCl solution at room temperature.

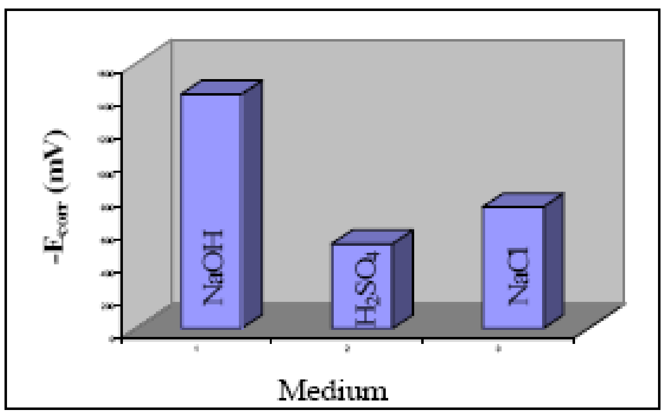

Figure (7) The variation of corrosion potentials for treated samples of Al-Zn-Mg alloy in different media.

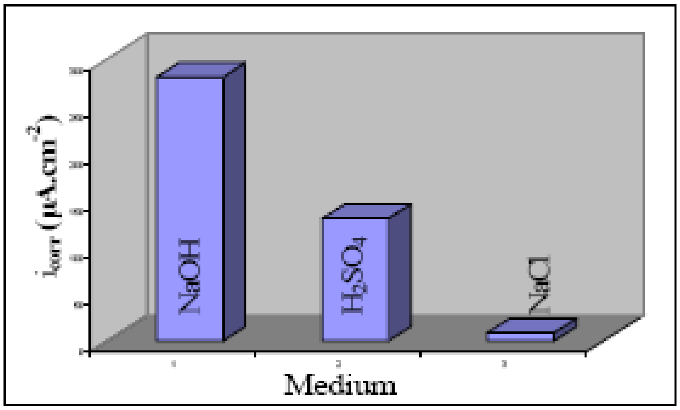

Figure (8) The variation of corrosion current density for treated samples of Al-Zn-Mg alloy in different media.

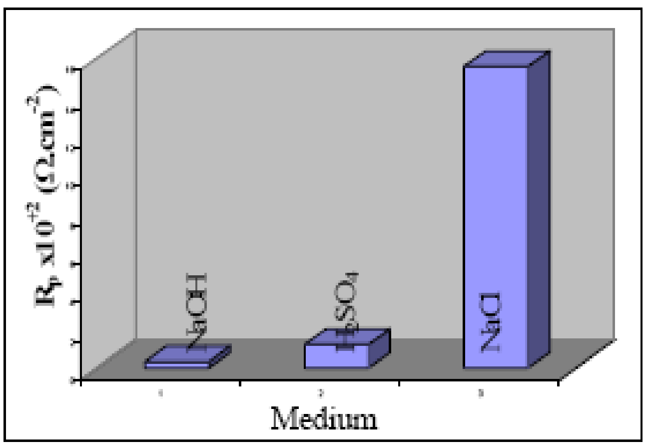

Figure (9) The variation of polarization resistance for treated samples of Al-Zn-Mg alloy in different media.

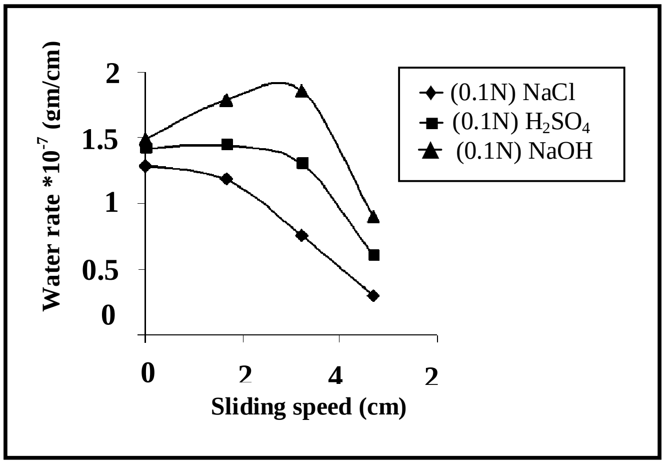

Figure (10) Effect of sliding speed in the wear test of Al-Zn-Mg alloy in the acidic ,salt and basic medium.

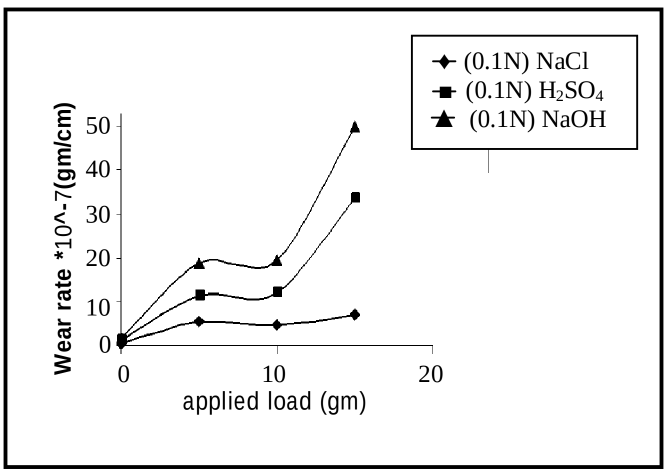

Figure (11) Effect of applied load in the wear test of Al-Zn-Mg alloy in the acidic ,salt and basic medium.