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Corrosion Behavior of Al alloys 6061-T6 Shot Peening in Different Aqueous Solution

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Abstract*— This work are studying the effects of shot peening time on corrosion behaviors of AA 6061-T6 in aqueous solutions. Many specimens prepared for Corrosion test with the dimensions of (15*15*3) mm according to ASTM G71-31. The shot peening process using steel ball have diameter 2.75 mm and shot peening time at (15, 30, 45) min. The series of experimental techniques have been conducted to evaluate shot peen properties of the alloys by carrying out hardness, surface residual stresses, microstructure and surface roughness. Corrosion test by tafel extrapolation method was carried out on shot and un shot corrosion specimens in different media as 3 .5% NaCl solution and tap water. Corrosion rate was calculated using tafel equation. The obtained results shows a favorable influence of shot peening (SP) treatment on corrosion resistance as induced compressive residual stresses lead to increase hardening of layer surface and decreasing in corrosion rate.

Index Terms— **shot-peening, Al alloys 6061T6, corrosion behavior, residual stress.**

I. INTRODUCTION

Corrosion by sea water (aqueous corrosion), is an electrochemical process, and all metals and alloys when in contact with sea water have a specific electrical potential (corrosion potential) at a specific level of sea water acidity or alkalinity. Most corrosion resistant of metals rely on an oxide film to provide protection against corrosion. If the film is loose, powdery, easily damaged and non-self-repairing, such as rust on steel, then corrosion will continue unchecked. Even so, the most stable oxides may be attacked when aggressive concentrations of hydrochloric acid are formed in chloride environments. Many different types of destructive attack can occur to structures, ships and other equipment used in sea water service [1]. The term 'aqueous corrosion' describes the majority of the most troublesome problems encountered in contact with sea water, but atmospheric corrosion of metals exposed on or near coastlines, and hot salt corrosion in engines operating at sea or taking in salt-laden air are equally[2]. Corrosion is one of the main factor which causes structural degradation in aging aircrafts. Corrosion also leads to crack propagation and damage of the structural components. The corrosion resistance of these alloys is related to the formation of an oxide (passive) film, which naturally develops on the alloy surface under normal atmospheric conditions the oxide film formed on the aluminum alloy surface is non-uniform, thin and non-coherent. When exposed to environments containing halide ions, of which the chloride (Cl^-) is the most frequently encountered in service, the oxide film breaks down at specific points leading to the formation of pits on the aluminum surface.

Corrosion of aluminum alloy takes place when it is exposed to the presence of electrolyte having pH between 4.5 to 8.5 [3]. All mechanical surfaces treatments lead to a characteristic surface roughness increased near surface dislocation density (cold work) and development of microscopic residual stresses. Shot peened surfaces are compressive residual stresses and extremely high dislocation densities in near surface layers resulting from inhomogeneous plastic deformations, leading to additional surface hardening [4].

Shot peening is a cold working process in which small spherical shots with velocities of 20-100 m/s are fired against a target surface. Shot peening is commonly used to produce layer of compressive residual stress at the surface of components subject to fatigue or stress corrosion failure. The stress distribution produced by shot peening depends upon the properties of the material being shot peened, prior processing, and the specific peening parameters used [5]. The aim of this study was to attain better understanding of surface study on electro chemical corrosion behavior of aluminum alloy 6061-T6 in different solution as tap water and sea water after treated and un treated with different shot penning time.

II. EXPERIMENTAL WORK

A. *Materials*

Materials used in this study was Aluminum alloy 6061-T6. The chemical composition of the alloy as shown in Table (1), which was conducted by using ARL spectrometer. Then many specimens for Corrosion test were prepared by the dimensions of (15*15*3) mm according to ASTM (G71-31).

Table (1): Chemical Analysis of the metal 6061- T6.

Elements w%	Si	Fe	Cu	Mn	Mg	Cr	Al
Measured value	0.6	0.4	0.3	0.12	1.0	0.2	Rem
Slandered value[9]	0.4 - 0.8	Max 0.7	0.1 - 0.4	Max 0.15	0.8 - 1.2	0.04-0.35	Rem

B. *Categorizing of specimens*

After completing preparing specimens they were categorized to groups as shown in Table (2).

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Table (2): Categorization of corrosion test specimens

Symbol	Corrosion media	Shot time (minute)
A	As received	
B	sea water	15
C	sea water	30
D	sea water	45
E	tab water	15
F	tab water	30
G	tab water	45

C. Shot peening process

The corrosion test specimens subjected to the shot peening processes by using ball steel with a hardness of 55 HRC and a nominal diameter of 2.75 mm to shot the specimens at different time 15, 30 and 45 min. In order to avoid medium collision, the angle of nozzle inclination was shifted by 10° with regard to the vertical axis [6]. A constant specimen distance from the nozzle of around 120 mm was maintained. The shot peening device used was shot tumbles control model STB – OB machine No. 03008 05 type. **Fig. 1** shows the shot peening device with shot balls used.

Fig (1): Shot peening machine with shot balls.

D. Specimen preparation for microstructure

Samples base alloy were prepared including: ground, polished and etched and observed under optical microscope in sequences steps. Wet grinding operation with water was done by using emery paper of SiC with the different grits of (220,320,500, and 1000). Polishing process was done to the samples by using diamond paste of size (1µm) with special polishing cloth. They were cleaned with water and alcohol and dried with hot air. Etching process was done to the samples by using etching solution (Keller's reagent) consisting of 95 ml distill water, 2.5 ml HNO3, 1.5 ml HCl and 1 ml HF washed after that with water and alcohol and dried in oven. The samples were examined by Nikon ME-600 optical microscope provided with a NIKON camera, DXM-1200F.

E. Corrosion test

Cell current readings were taken during a short, slow sweep of the potential. The sweep was taken from (-100 to + 100) mV relative to (OCP). Scan rate defines the speed of the potential sweep in mV/sec and it was taken (10) mv .The tests were performed by using a WENKING Mlab multi channels potentiostat and SCI-Mlab corrosion measuring system from Bank Electroniks-Intelligent control GmbH, Germany 2007, as shown in **Fig. 2.** In this test, aluminum alloy (6061-T6) samples were used as working electrode (WE), a saturated calomel electrode immersed in the salt solution was used as reference. Electrochemical corrosion test by Tafel extrapolation method was carried out on all samples of shot peening and as received in sodium chloride solution of 3.5% NaCl with Ph of 6.8 and tap water has PH 8.2 to determine corrosion Parameters, such as corrosion potential (Ecorr) and corrosion current (Icorr) at each shot time. These parameters will lead to calculate the corrosion rate according to the equation below [8], [9].

$$C.R\ (m.p.y) = 0.13 * Icorr * eq.wt / \rho \qquad (1)$$

Where:
m.p.y= mille-inches per year
Icorr=corrosion current density (µA/cm2)
E.W=equivalent weight of the corroding species,
ρ= density of the corroding specimens, (g/cm3).

Fig (2): the electrochemical corrosion unit.

III. RESULTS AND DISCUSSION

Fig. 3, show the microstructure base metal revealed a coarse, elongated grain structure in the 6061-T6 base metal due to presence of alloying elements such as silicon and magnesium precipitation as shown by darken particles Mg_2Si. The average surface roughness of base material (USP) sample (A) was 0. 15µm. It was found to be less roughness compared with the shot peened samples B, C and D, as shown in **Table (3))**, which was measured using (pertho meter) type (s6p) at the surface area of specimens(A) and peened area for specimens (B,C and D) indicated by the parameter Ra which is the center-line average of adjacent peaks results are shown

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in **Fig. 4**, which gives the relation between 2 Theta (deg) and Psi (deg). The relation between surface roughness and hardness when surface roughness was increase hardness increase due to increase shot time left over comparative residual stresses subsequently effected on corrosion behavior in the residual compressive stress from the on-side were measured by using Lab XRD-6000 shimadzu x-ray diffraction meter, the residual stress results are shown in Table(3)**.** This result was good agreement with result of [7].

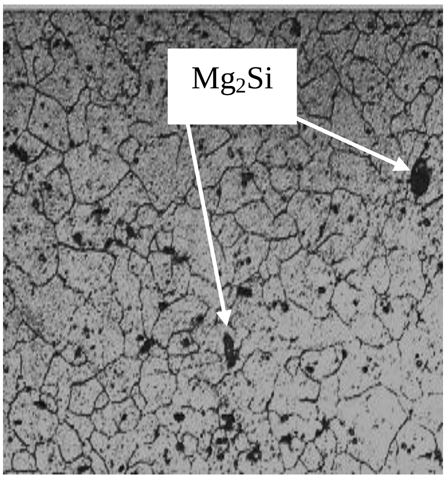
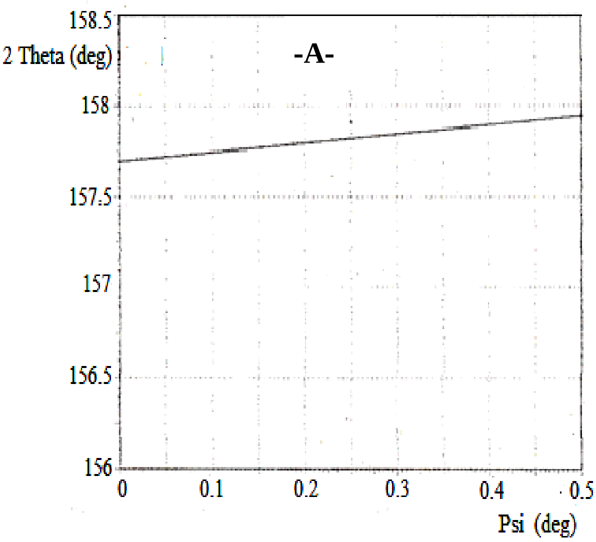
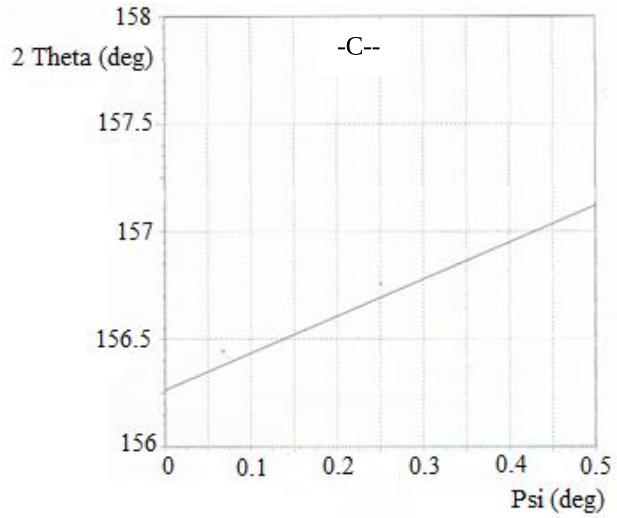


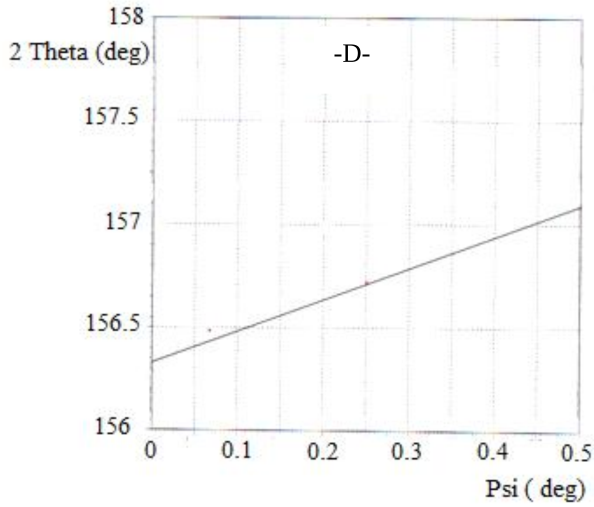
Fig (3): Show the microstructure of metal, 500X.

Table (3): The results of Vickers Hardness, Surface roughness &Residual stress.

symbol	Hardness (Kg/mm^2)	Surface roughness (μm)	Residual stress (Mpa)
A	125	0.15	-18
B	133	2.1	-140
C	135	2.23	-148
D	138	2.6	-158







Fig(4): Photo graph of residual stress for specimens with different time .

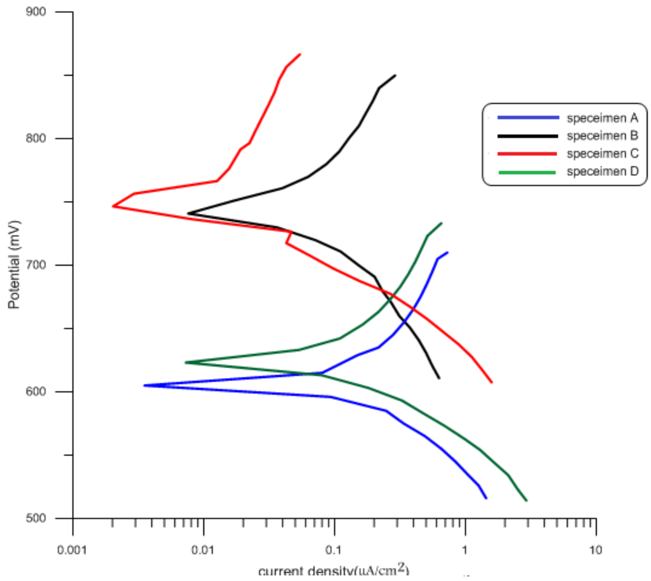


Fig (5) :Polarization curves for specimens in sea water media.

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The parameters of shot time in corrosion phenomena are important since the major physical damage during pitting corrosion occurs during late stages. The results of corrosion parameters, such as corrosion potential (Ecorr) and corrosion current (Icorr) at each shot time. These parameters will leads to calculate the corrosion rate for all specimens according to the equation (1).

Main electrochemical characteristics obtained from measured curves by analysis are in **Table 4**. Total polarization resistance of the specimen's surface as shown in **Fig. 5** and **Fig. 6, were** explain the polarization curves of the all specimen which depends on the electrochemical behavior of the microstructure and this is directly dependent on the quantity of the present phases for example, specimen (A) has a corrosion potential of -0.707V and a corrosion current of 50.57 µA/cm^2 and the corrosion rate is 21.751 m.p.y. Sea water is a complex natural electrolyte.

The corrosion is severe due to the presence of chloride ions which combine with dissolved hydrogen to formed hydraulic acid which increases corrosion rate. A decreasing in corrosion rate for (B, C, D) specimens, this is because of the comparative residual stress which formed by shot peened process cases in reduce the corrosion properties. and as the shot peen 15 min there is a decreasing in corrosion rate in small values, this is because of the comparative residual stress which formed by shot peened process cases in reduce the corrosion properties.

A decreasing in Icor value bounce for specimens C and D lead to decrease corrosion rate in specimen C and D but lower than it in specimen A inducing favorable compressive residual stresses layer which was increasing in depth with increasing in shot time this is because this layer act as oxide film productive in aluminum and its alloys when aluminum react with dissolve oxygen to form it. Reducing corrosion rate in specimens E, F, G as shown in **Fig. (6)** Because of same reason above. These results are a good agreement with results of [10], [11].

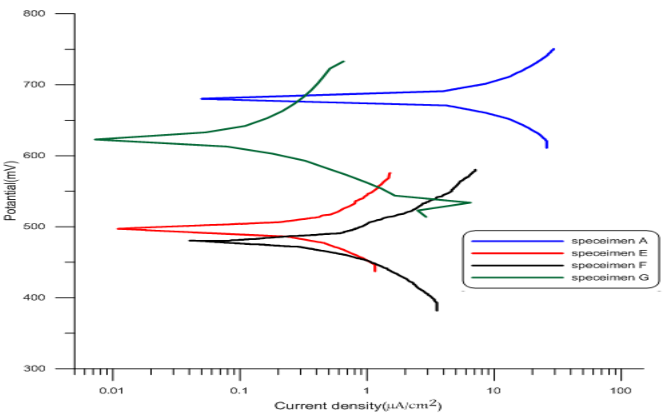

Fig (6): Polarization curves for specimens in tap water media.

Table (4): Corrosion result for all specimens

symbol	I_{corr}[µA/cm^2]	E_{corr}[mV]	Corrosion rate (M.p.y) =0.43 i_{corr}
A	50.57	-707	21.751
B	5.08	-671.3	2.182
C	3.3	-671.3	1.419
D	16.8	--509.5	1.224
E	7.1	-500.5	3.053
F	2.4	-423.1	1.032
G	4.1	-597.4	1.7

Fig. 7, shows the images observed of optical Surface morphology of Al- Alloy 6061-T6, and the surface specimens totally different from the corrosion media.

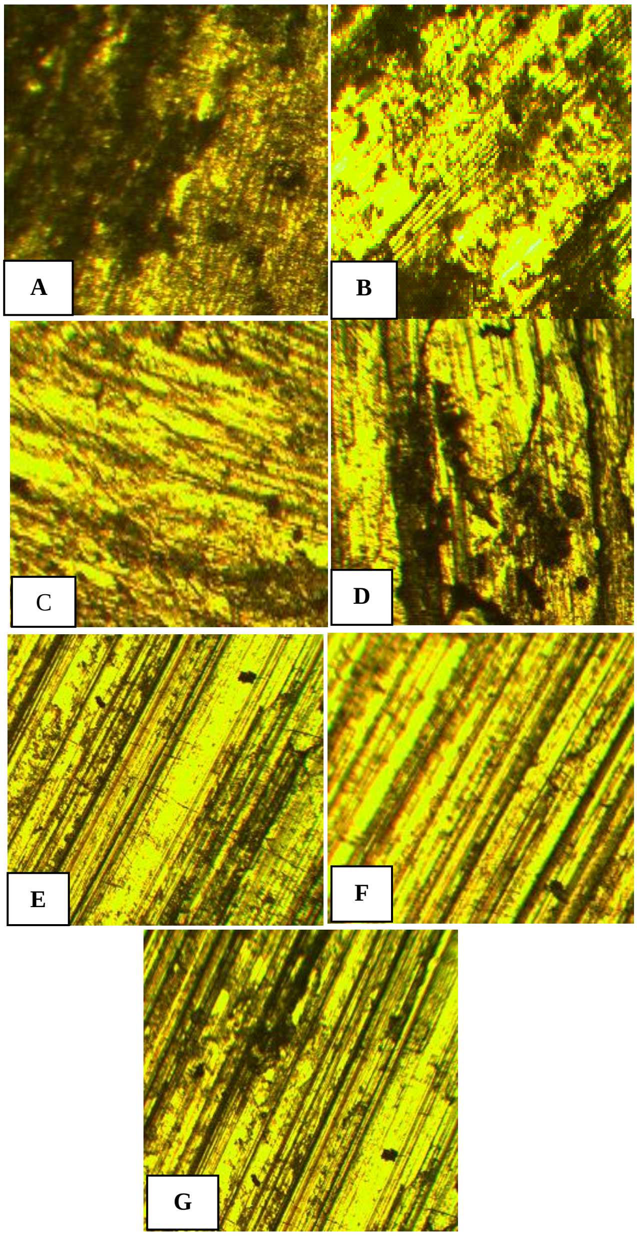

Fig (7): Optical Surface morphology of Al- Alloy 6061-T6 specimens (500X), A: as received and B, C and D corrosion in sea water. E, F and G corrosion in tap water.

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Fig. 7 a, it was noticed that the surface become rough compared with another sample. This shows that the corrosion reaction has occurred in this sample. Thus, caused almost sample surface covered by the corrosion product. On the other hand, **Fig. 7 b, c** and **d**, shows the specimen immersed in sea water solution, the corrosion rate are increases when increase the shot peening time. In comparison between **Fig. 7 b** and **c**, the morphological analysis showed that there were two regions; base Al 6061-T6 and corrosion product. The corrosion product obtained in **Fig. 7d**, grown throughout the surface of Al 6061-T6 Compared with **Fig. 7b** and **c**. It also clearly stated that less damage caused by this corrosion attack by solutions water tap as shown in F**ig. 7 e**, **f** and **g**)

IV. CONCLUSIONS

A given level of surface compressive residual stress is a necessary condition to indicate that shot peening was performed property. The shot peening improves corrosion resistance of the Al- Alloy 6061-T6due to the homogenous cold worked surface layer and the compressive residual stresses produced during shot peening. Also increasing the pressure of peening can increase the corrosion resistance.'

Surface treatments by shot penning produce similar levels of surface compression are effected as the residual stress distributions produced by shot peening are effect to increase surface roughness and hardness with increase the shot peening time. That's effects to decrease corrosion rate in tap water and sea water. The comparisons of results refer to that the corrosion rate in tap water was less than in sea water.

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