

## Effect of deformation Processes on Corrosion Behavior of AA6061 in Salt Solution (3.5% NaCl)

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**Abstract:** The corrosion of AA6061 after deformation at different degrees was investigated. The aim of this work was to determine the effect of deformation on the microstructure and on the corrosion behavior of AA6061. The samples conditions were; annealed (O), tensed ( $Ten_1=14\%$ ,  $Ten_2=22\%$ ,  $Ten_3=30\%$ ). The microstructure was investigated by optical microscope. The mechanical properties were investigated by hardness tests. The corrosion behavior was investigated by measuring linear polarisation, combined with open circuit potential using Potential State in acidic pH = 2 and alkaline pH = 12 and neutral PH = 7 chloride solutions. The result showed that the corrosion rate of the alloy was (500,100,1000  $\mu\text{m}/\text{y}$ ) for annealed material in PH(2,7,12) respectively, and for  $Ten_1$  (728,506,1800  $\mu\text{m}/\text{y}$ ) in PH(2,7,12) respectively, and for  $Ten_2$  (1500,783,2678  $\mu\text{m}/\text{y}$ ) in PH(2,7,12) respectively, and for  $Ten_3$  (2300,212,3160  $\mu\text{m}/\text{y}$ ) in PH(2,7,12) respectively. That means the alkaline medium has the greatest influence on corrosion resistance for all structures, also the increase in rate of deformation causes decrease in corrosion resistance in all mediums.

**Keywords :** Aluminum Alloys, AA6061, Corrosion of Aluminum, Deformation of Aluminum.

### 1. Introduction:

The importance of selection and use of engineering materials for design and subsequent manufacturing of component parts cannot be over emphasized [1]. Most of engineering applications that meet service requirements need to investigate their properties before putting them to use [2].

The case of aluminum and AA6061 are not exception. Aluminum is one of the most abundant metals on earth which is silvery-whitish in appearance [3]. Aluminum, as indicated by its position in the electrochemical series, is a thermodynamically reactive metal; among structural metals, only beryllium and magnesium are more reactive [4]. Aluminum owes its excellent corrosion resistance and its use as one of the primary metals of commerce to the barrier oxide film that is bonded strongly to its surface and that, if damaged, re-forms immediately in most environments [1].

One of reasons that cause corrosion of AA6061 is the nature of medium. In 2008 a work about effects of pH and chloride concentration NaCl on pitting corrosion of AA6061 has been achieved by B. Zaidet et al. The results showed that the corrosion behavior of the AA6061 was found to be dependent on the pH and chloride concentration in the solution [5]. In 2011 Solhan Yahya et al studied the inhibitive behavior of corrosion of AA6061 in NaCl by Mangrove Tannin. The results showed that the inhibition efficiency increased with increasing tannins concentration in chloride solution at pH=6. Treatment of AA 6061 with all concentrations of mangrove tannins reduced the current density, thus decreased the corrosion rate. Tannins behaved as mixed inhibitors at pH = 6 and reduction in current density predominantly affected in cathodic reaction. Meanwhile, at pH = 12, addition of tannins

shifted the corrosion potential to more cathodic potentials and a passivating effect was observed in anodic potentials. SEM studies have shown that the addition of tannins in chloride solution at pH = 12 reduced the surface degradation and the formation of pits [6].

Another thing that is considered reason of corrosion is alloying elements. The presence of alloying elements will change the microstructure and as a result changing in corrosion behavior. Kalenda Mutombo studied effect of Intermetallic Particles-Induced Pitting Corrosion in AA6061-T651. The results showed that Al-Fe-Si containing rich-particles acted as cathodes and promoted the dissolution of the aluminum surrounding the matrix. The cathodic behavior of Al-Fe-Si intermetallics depended on the pH of the solution and chloride-containing environment. Pitting associated with constituent-particles was attenuated in acidic and alkaline solution [7].

Mohammed A. Amin has studied Influence of the alloying elements on uniform and pitting corrosion events induced by SCN<sup>-</sup> anions on AA6061 and Al-Cu alloys surfaces. As a result, AA6061 alloys presented the highest corrosion resistance towards uniform and pitting corrosion processes in KSCN solutions [8]. Also the microstructure can be change by formation processes such as stretching, compressing, bending or drawing, and this will has its effect on corrosion behavior [1]. In this respect, the present work is aimed to study the effect of the degree of deformation on corrosion behavior of the AA6061 in chloride solutions and the effect of the pH of the solutions by use potentiodynamic measurements.

## 2. Experimental Procedures

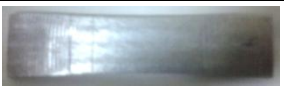


### 2.1. Sample Preparation

The chemical composition of AA6061 alloy used in this study is shown in Table 1. These percentages were measured by spectrometer XMF 104 manufactured by Unsisantis Europe company, Germany. it depend on releasing high Speed Micro ED X Ray, during igniting of electrons the atom absorb specified energy and release photon from lower energy, this different in the levels of energy appear as X ray that through it detecting of chemical element is done according to significant wave length of every element that exist in the specimens. The specimens with dimensions 150×19×4.5mm were annealed at temperature 404°C and staying at this degree for 160 min, then cooled to 260°C at rate 50°/h and then cooling to room temperature by air, these specimens were considered as reference.

Table1 AA 6061 alloy composition% by weight							
Mg	Si	Cu	Cr	Fe	Mn	Zn	Ti
1	0.56	0.33	0.24	0.52	0.023	0.012	0.017

### 2.2. Deformation Process

The specimens were divided into three groups, each one was tensed at determined rates by H50KS tension machine, manufactured by Tinuis Olsen company, England. The working surfaces of samples were wet grounded with emery paper up to 1000 grit and then degreased with ethanol, cleaned with distilled water, and finally dried in air. Table 2 shows the deformed samples.

Table2 Three groups with different tensing rates			
Group	Ten <sub>1</sub>	Ten <sub>2</sub>	Ten <sub>3</sub>
Tensing Rate ΔL/L%	14	22	30
			

### 2.3. Hardness Test

Brinell test was applied to determine the hardness with ERNSL apparatus, manufactured by ERNST company, Italy, the steel ball diameter was 5 mm, the applied force was 125 kg [9].

### 2.4. Optical Microscopy Observation

The samples of alloy AA6061 were examined using an optical microscope B353, manufactured by Optika company, Italy. The etching solution was “2 ml HF, 3 ml HCl, 2 ml HNO<sub>3</sub>, 190 ml H<sub>2</sub>O” [10].

### 2.5. Electrochemical Measurements

Electrochemical measurements were carried out in a conventional three-electrode electrochemical glass cell with a platinum counter electrode and a saturated calomel electrode SCE as reference. All the potentials in this paper are reported in the SCE scale [11]. The salt solution 3.5%NaCl was prepared by adding high pure NaCl to reagent water (3.5%gr NaCl with 96.5% H<sub>2</sub>O), and the salt was dissolved in the water by using the magnetic mixer GD503, manufactured by Sartorius company, Germany. this concentration is approximate to salts concentrations in sea water and this percentage causes the higher corrosion of aluminum because of the quantity of dissolution Oxygen and ion conductivity at higher values. This solution was divided into three groups, HCl was added to the first group to obtain on acidic solution, and NaOH added to the second group to obtain on alkaline solution, and the third group was without adding to obtain on neutral solution. The value of PH for three groups were controlled by PH Meter P11, manufactured by Sartorius company, Germany.

The polarisation curves were recorded by changing the electrode potential automatically with a potentiostat type Volta Lab 10 controlled by the Software Master 4, manufactured by Volta company, Germany, at a scan rate of 0.166 mV/s. All tests were performed under ambient temperature [11]. Alloy AA6061 samples were immersed in solution and allowed to attain a stable open circuit potential (OCP) before starting the polarisation scan. OCP measurements indicated that the OCP of the alloy AA6061 at 3 hours of immersion was nearly identical ( $\pm 20$  mv) to that measured at several hours. Hence, this time (t=3h) was adopted as the time required to get a stabilization for all the electrochemical measurements [11]. After the period of a stabilisation (t=3h) the potentiodynamic polarisation curves were plotted by starting scanning electrode potential from an initial potential of 250 mV below the OCP up to 0 V. A vertex current density of 0.001 A/cm<sup>2</sup> was used [11].

## 3. Results and Discussion

### 3.1. Hardness Test

The hardness increased with increasing of tensing rates, this because of increase in number of dislocations and refining of precipitates, Table 3 shows the average values of hardness, number of readings for every specimen is ten.

Table3 Hardness values after tension				
Groups	Ten <sub>1</sub>	Ten <sub>2</sub>	Ten <sub>3</sub>	Reference Sample
Brinell Hardness	170	185	200	125

### 3.2. Microstructure:

Fig.1 shows the microstructure of annealed specimen. The matrix is aluminum containing a precipitates of Mg<sub>2</sub>Si.

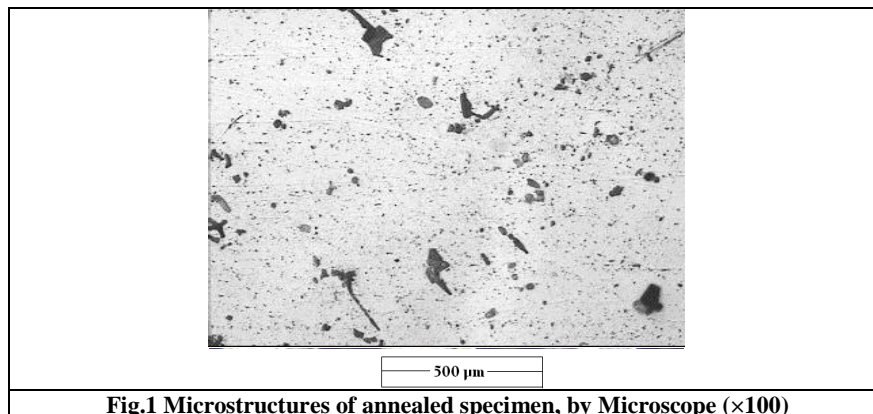
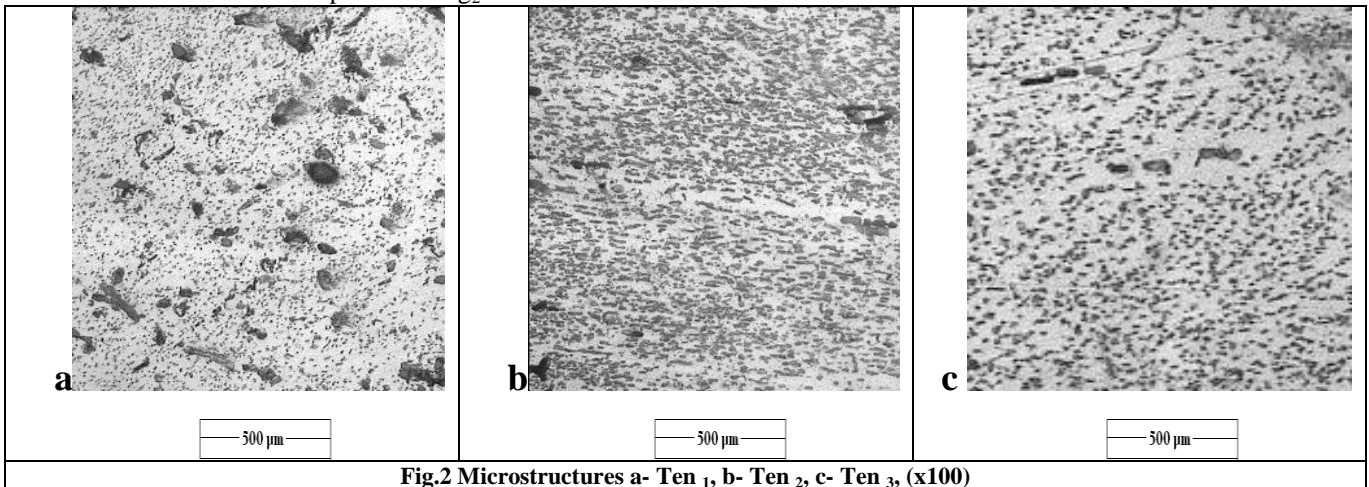


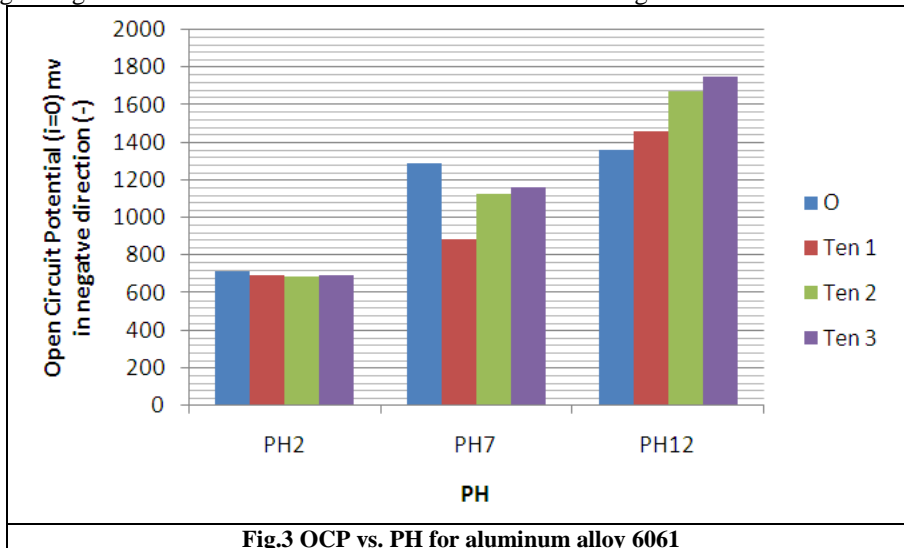
Fig.2 shows the three microstructures of the Specimens, with increase in degree of tension the structure become finer. Note how the Precipitates of  $Mg_2Si$  was broken.



**Fig.2 Microstructures a- Ten<sub>1</sub>, b- Ten<sub>2</sub>, c- Ten<sub>3</sub>, (x100)**

**3.3.3. Electrochemical Test Results**  
**3.3.3.1. Open Circuit Potential OCP**

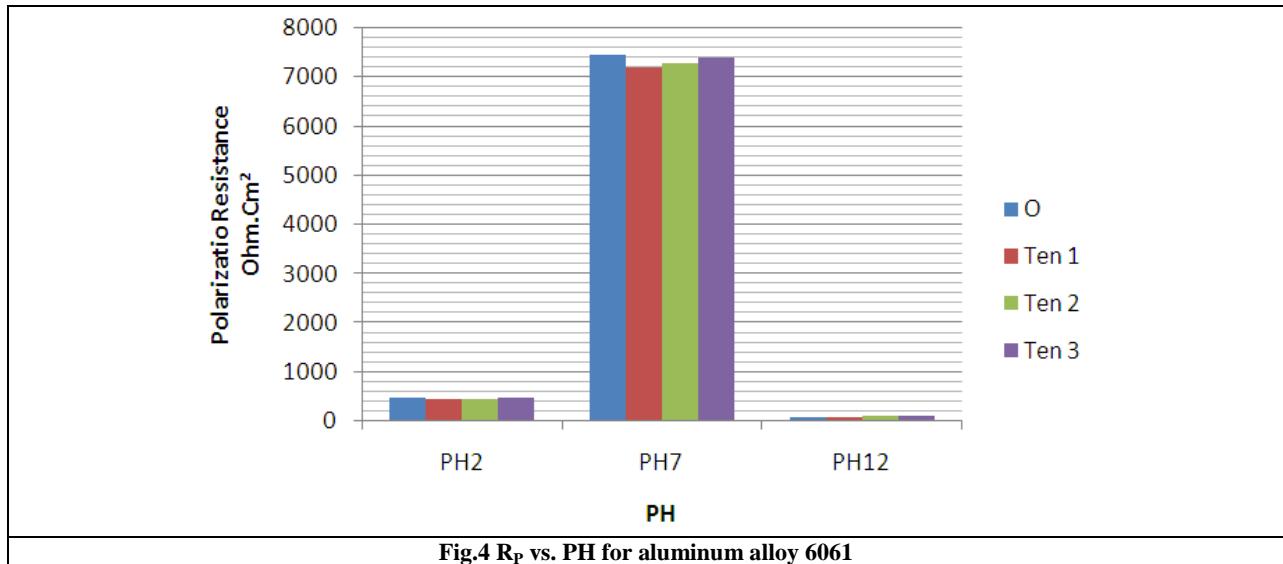
Fig.3 shows the OCP vs. PH curves obtained with samples of AA6061 immersed in 3.5 wt% NaCl solution of different PH. It can be seen that, exposure to NaCl solution with pH varying from 2 to 12, caused change of the OCP of the samples of aluminum alloy. Increases of PH value caused increasing of value of OCP in negative direction and decreasing the stable for all specimens. In acidic solution the values were between (-715 mv) for annealed specimen “reference” and -695 mv for Ten<sub>3</sub> specimen. In neutral solution the OCP of annealed specimen -1290 mv is more negative than OCP of three groups (-890, -1125, -1165 mv respectively). In alkaline solution, the values shifted towards negative direction -1360 mv for annealed specimen up to -1750 mv for Ten<sub>3</sub> specimen. With increasing in degree of tension the values of OCP shifted towards negative direction.



**Fig.3 OCP vs. PH for aluminum alloy 6061**

### 3.3.3.2. Polarization Resistance $R_p$ :

The values of polarisation resistance ( $R_p$ ) calculated from the corresponding curves of linear polarisation recorded for samples of AA6061 exposed to 3.5% NaCl solutions at different PH and at different tension rates are shown in Fig.4. The results from this figure clearly demonstrated that the polarization resistance of the AA6061 was found to be a maximum in the neutral solutions about  $7.45 \times 10^{-3} \text{ Aohm.cm}^2$ . Furthermore, in this figure it can be noticed how there is a fall in the  $R_p$  values, and accordingly an increase in the dissolution activity of the system when the pH of solution was displaced in basic or in acidic values.

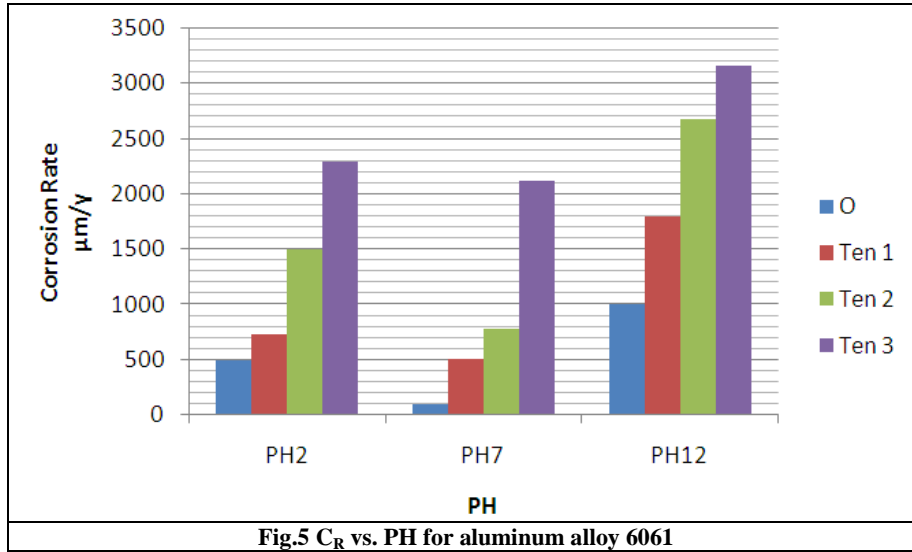


**Fig.4  $R_p$  vs. PH for aluminum alloy 6061**

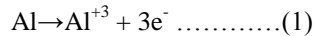
In acidic solution the value of  $R_p$  for annealed specimen was  $470 \text{ ohm.cm}^{-2}$  and then decrease to  $450 \text{ ohm.cm}^{-2}$  for specimen Ten<sub>1</sub> and then increased to  $460, 470 \text{ ohm.cm}^{-2}$  for Ten<sub>2</sub>, Ten<sub>3</sub> respectively. The same for neutral solution, the value of  $R_p$  for annealed specimen was  $7450 \text{ ohm.cm}^{-2}$  and then decrease to  $7200 \text{ ohm.cm}^{-2}$  for specimen Ten<sub>1</sub> and then increased to  $7300, 7400 \text{ ohm.cm}^{-2}$  for Ten<sub>2</sub>, Ten<sub>3</sub> respectively. In alkaline solution, the values were between  $97, 100 \text{ ohm.cm}^{-2}$ .

### 3.3.3.3- Corrosion Rate $C_R$

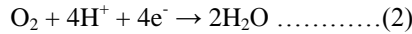
The values of corrosion rates  $C_R$  calculated from the corresponding curves of linear polarisation recorded for samples of AA6061 aluminum alloy exposed to 3.5% NaCl solutions at different PH at different tension rates are shown in Fig.5.



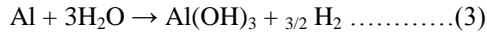
With increase in degree of deformation the corrosion rate will increase, because of refining the structure (see Fig.2) and broken of strengthening precipitates that disperses in uniform shape and form cathodic sites and the matrix of aluminum will be anodic areas. In case of alkaline solutions PH=12, the values of  $C_R$  were observed to be higher than acidic and neutral solution. Further, the increase in the corrosion potential  $E_{cor}$  values, compared to those of acidic and neutral pH, indicate to the loss of passivity of AA6061 due either to thinning of surface oxide layer by hydroxide ion  $OH^-$  attack “alkaline chemical dissolution” or to the absence of the primary oxide film. In acidic solution, the solubility of aluminum ions  $Al^{3+}$  facilitates the dissolution of the Al matrix and further accelerates the chloride attack as shown in formula 1 [5].



The oxygen is reduced to form the water as shown in formula 2 [5].



However, the mechanism of corrosion of the Al matrix in neutral and alkaline media is related with the formation of protective layer of aluminum hydroxides  $Al(OH)_3$  [5].



The results obtained above can be interpreted by considering the fact that the chemical reactions of aluminum and its alloys are unusual in the sense that these materials are amphoteric, i.e., soluble in acid as well as in alkali solutions [5]. The oxide film is uniformly thinned by the chemical dissolution, which is facilitated by the presence of high  $OH^-$  concentration in alkaline solution. Whereas in neutral pH solutions, the passive film of aluminum hydroxides  $Al(OH)_3$  formed on AA6061 surface is remarkably stable due to its low solubility, acts as protector for this alloy against corrosive agents [5].

#### 4. CONCLUSION

This paper studied effect of degree of deformation on corrosion behavior of aluminum alloy AA6061.

The deformation was achieved on annealed specimens by tensing operation, to obtain on three structures. With the increase in the degree of deformation, the hardness increased because of dislocations that formed and the structure became fine because of participates that broke. This may have increased the free energy and created a potential energy for corrosion. The corrosion was studied by electrochemical method in 3.5 NaCl % solution with different PH values. Corrosion rate increased with the increase in deformation degree in all solutions. However, the highest values were in alkaline solution. In neutral solution the values was the lowest. The acidic and alkaline solutions have the ability to solve the protective layer and with high energy free the corrosion rate will be high.

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