Effect of Surface Roughness on Corrosion behavior of Aluminum Alloy 6061 in Salt Solution (3.5%NaCl)

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Abstract: *The corrosion of AA6061 after changing the roughness at different degrees was investigated. The aim of this work was to determine the effect of roughness on corrosion behavior of AA6061.*

The roughness of samples were (Ra= 0.64, 1.83, 3.48, 7.04 µm). The mechanical properties were investigated by hardness tests and tension tests. The corrosion behavior was investigated by immersion tests in 3.5% NaCl salt solutions. The microstructure was investigated by optical microscope.

The results showed that the corrosion rate deceased gradually in alkaline salt solution with decreasing the roughness. However in acidic and neutral salt solutions, with decreasing roughness the corrosion rates decreased gradually with the existence of a sharp steps in decreasing.

Keywords: *Aluminum Alloys, AA6061, Corrosion of Aluminum, Surface Roughness.*

1. Introduction

Corrosion is the transformation of a metal through a chemical or electrochemical reactions, starting at its surface. Although all metals have a tendency to be oxidized, some will oxidize more easily than others. That will be done as a result of contact with an electrolyte like water or moist air. Aluminum is one of these metals, aluminum surface will react spontaneously to form aluminum oxide. This oxide layer is tightly bonded with surface of metal and doesn't have defects.This natural, stable oxide layer is an integral part of the aluminum surface, thus protecting it from further oxidation [1].

There are two factors affecting the corrosion resistance of wrought aluminum alloys, related with surface, the first is the near surface that will be full of dislocation and deformations, and this will induce the corrosion. In addition the boundaries of grains will be active, and any pre-heating will cause precipitate of secondary phases that affect corrosion, so a subsequent high shear finishing processes like grinding are applied to remove these layers.
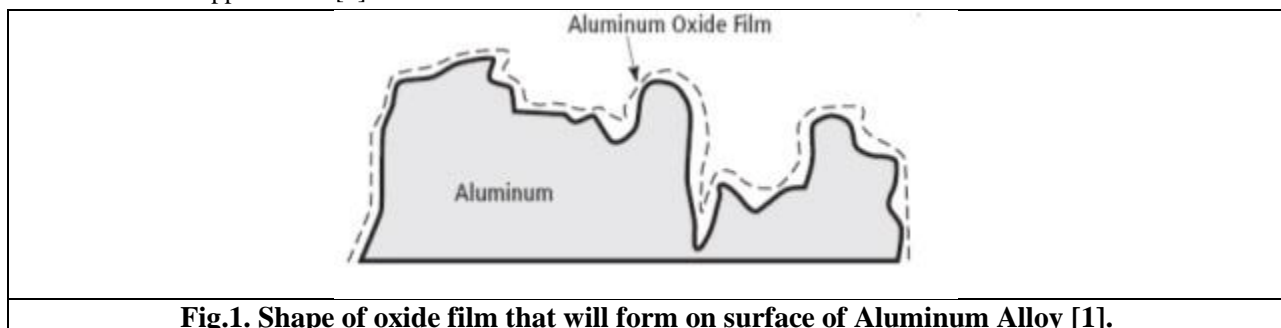
This is can be noted in automotive applications, where alloys of the Al-Mg-Si-(Cu) family (AA6xxx) are used for external closure panels. Materials of these sheet are generally supplied in a cleaned state, and therefore resist corrosion. However, mechanical grinding is frequently applied as process prior to final cleaning, pre-treatment

and painting at the automotive manufacturer and this process typically produces fine surface layers of several micrometers thickness. The relatively thick layers were not removed by cleaning and pre-treatment [2].

Studies had been achieved in Innoval Technology about shear processing of aluminum alloy surfaces and its influence on corrosion. The mechanical processes were hot or cold rolling, grinding, machining or cutting and these process will change the surface structure. The surface microstructure is locally transformed and if the surface shear is high enough, a fine grain size layer will result. This layer has very different optical, mechanical and electrochemical properties differ of bulk microstructure. These properties can be used to understand why and how aluminum alloys corrode either as a result of mechanical abrasion, or during preparing samples for electrochemical testing, or in service [3].

In 2006, a research about precipitation and corrosion behavior of Nano-Structured Near-Surface Layers on an AA6111 Aluminium Alloy was performed. This alloy 6061-T6 with magnesium and silicon has high strength, excellent formability, good weldability and good corrosion resistance. The most application of this alloy application is in the ship building and transport industries where welding often forms part of the manufacturing process. Al6061-T651 is, however, prone to corrosion in chloride-containing environments. A nano-structured, near-surface layer has been generated by mechanically grinding an AA6111 alloy. After heat treatment at 180°C for 30 minutes, Q phase particles, ~20 nm diameter, were precipitated preferentially at grain boundaries within the nano-structured near surface layer. Other precipitates were not observed in the bulk alloy after this heat treatment. This preferential precipitation results in the near-surface layers having increased corrosion susceptibility than the whole microstructure, due to the micro-galvanic coupling between the precipitates at grain boundary and the grain matrix. It is expected that localized attack is intergranular [4].

The second factor is the shape of this layer that will be the same of shape base metal, curvatures, meanders…etc. and this presents important role in corrosion resistance, where some sites will be weak and may deteriorate and initiate local corrosion attacks. Especially for aluminum used in exterior architectural applications, aggressive elements such as chloride ions (Cl^-), sulphates ($SO4^{--}$) or others, may be potential causes of corrosion depending on the local environment. For this reason, an effective lifetime protective surface treatment is essential for architectural applications [1].

Fig.1. Shape of oxide film that will form on surface of Aluminum Alloy [1].

By grinding and polishing process it is possible to remove the deformed layer and get finer surface, and this will reflect on corrosion behavior, so in this research we will study the effect of surface roughness on corrosion behavior of wrought aluminum alloy 6061.

It is obvious that research on the relationship between surface roughness and corrosion rate is not taking much concern from scientists. The present work is a contribution to this field to shed the light on the importance of surface roughness and its influence on corrosion rate.

2. Experimental procedure

2.1. Sample Preparation

AA6061 with base composition by weight % is 1Mg, 0.56Si, 0.28Fe, 0.08Cu, 0.23Mn, 0.61Mg, 0.05Zi, 0.02Cr, and 0.04Ti was used in this study. The composition was measured by spectrometer XMF 104 that manufactured by Unsisantis Europe company in Germany. The condition of alloy was as received from manufacturing operation "hot rolled" and thus the specimens was full of dislocations.

Specimens with dimensions 19×15×7 mm were used. The emery papers and Al_2O_3 powder and diamond powder were used to obtain specimens with different surface roughness. The degree of roughness was measured by roughness machine tester TR110, produced by TIME HOLLND Company, China. Table 1 shows the different samples related with roughness.

Table 1. Samples of Specimens related with Roughness	
Samples	**Ra (μm)**
1	0.64
2	1.83
3	2.06
4	3.48
5	7.04

2.2. Mechanical tests

2.2.1. Hardness test

Brinell test was applied to determine the hardness with ERNSL apparatus provided from ERNST Company, Italy. The ball steel diameter was 5 mm, the applied force was 125 kg.

2.3. Optical Microscopy Observation

The samples of alloy AA6061 were examined using an optical microscope B-353 provided by Optica Company, Germany.

2.4. Corrosion test

The corrosion tests were carried out in salt solutions 3.5wt% NaCl with different values of PH(2,7,12) which was prepared using standard procedures, by adding highly pure NaCl to reagent water (3.5% NaCl with 96.5% H_2O), 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 dissolute Oxygen and ion conductivity at higher values. This solution was divided into three groups. HCl was added to the first group to obtain acidic solution, NaOH was added to the second group to obtain alkaline solution, and the third group was left without additions to keep neutral solution. The value of PH for three groups were controlled by PH Meter P11, manufactured by Sartorius Company, Germany.

The samples were degreased with acetone and then rinsed in distilled water before immersion in test solutions. The electro-chemical experiment was monitored for 8 days. The corrosion test results were evaluated using weight loss. The weight loss (mg) for each sample was evaluated by finding the difference in weight "final weight initial weight" considering the total surface area of the specimen in accordance with ASTM G311 standard

recommended practice ASTM, 1994. For this purpose weighting apparatus, M-power, produced by Satorius company, Germany was used.

Corrosion rate for each specimen was evaluated from the weight loss measurement following standard procedures as relation down.

$$C_R = \frac{W \times 365 \times 1000}{A \times T \times D}$$

CR: corrosion rate (mm/year).
W: reduction in weight (gr).
A: area (mm^2).
T: time of immersion (hours).
D: density of AA6061 (gr/cm^3)

3. Results

3.1. Mechanical Properties:

3.1.1. Hardness Test:
The average value of hardness was 275 BHN. This high value was a result of dislocations and defects during manufacturing process.

3.1.2. Tension Test:
Table.2 shows the average values that results from tension test, the strength of specimen in addition to elongation. The value of elongation was low because of defects in specimen.

Table.2 Results of tension test		
Strength (Mpa)	**Yield Strength (Mpa)**	**Elongation ΔL/L%**
242	195	9

3.2. Optical Microscopy observation:
Figure.2 shows the microstructure of the Specimens, the microstructure is consist of aluminum matrix and precipitates of Mg2Si dispread on it.
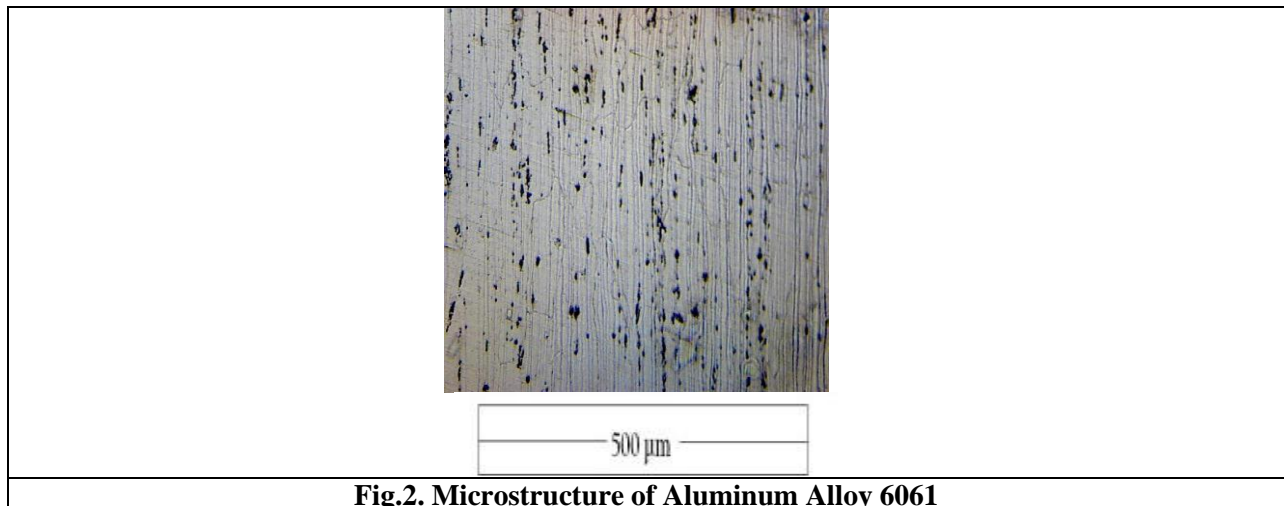

500 μm

Fig.2. Microstructure of Aluminum Alloy 6061

3.3. Corrosion Test:
3.3.1. Corrosion Rate:

Table 2 shows results of immersion test in acidic salt solution, the corrosion rate of as received sample of AA6061 is gradually decreasing with decreasing of Ra and the sharp decreasing get when the Ra has the value (0.64μm).

Table 2: Corrosion rates of samples of AA6061 in acidic salt solutions, immersion time was eight days		
Sample	Ra (μm)	Corrosion rate (mm/y)
1	0.64	0.002223639
2	1.83	0.007792235
3	2.06	0.00845617
4	3.48	0.008821884
5	7.04	0.008911285

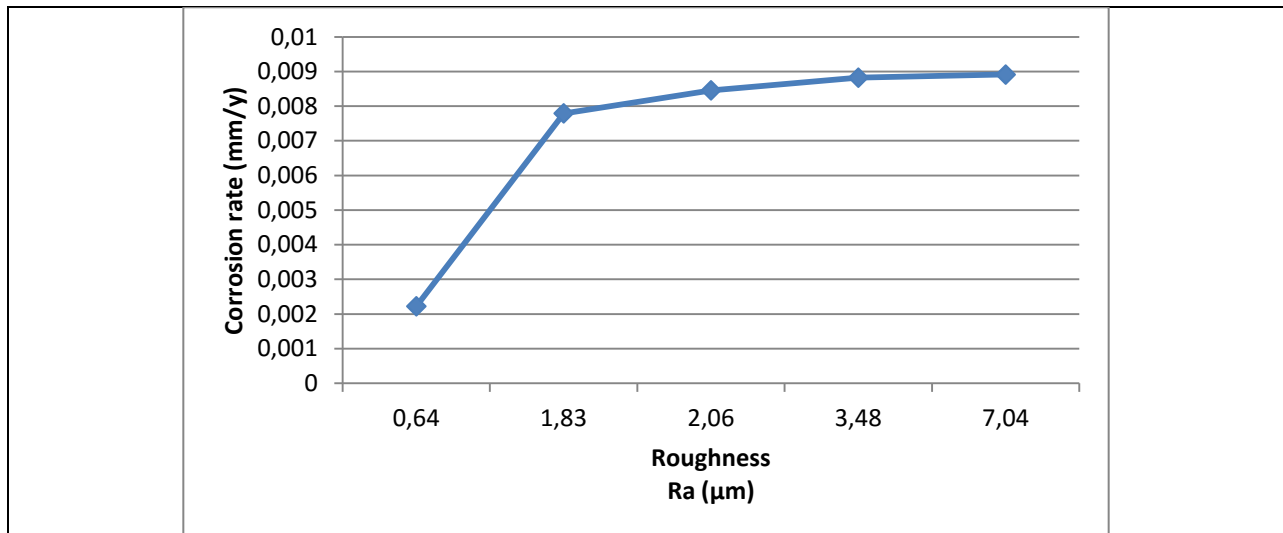The results showed in table 2 was represented in Fig 3.

Fig 3. Corrosion rates of AA6061 samples in acidic salt solution.

Table 3 shows results of immersion test in neutral salt solution, the corrosion rate of as received sample of AA6061 is sharply decreasing with decreasing of Ra between values (2.06-7.04 μm), then decreasing gradually up to value (0.64μm).

Table 3: Corrosion rates of samples of AA6061 in neutral salt solutions, immersion time was eight days		
Sample	Ra (μm)	Corrosion rate (mm/y)
1	0.64	0.001067847
2	1.83	0.00115001
3	2.06	0.001337646
4	3.48	0.001749653
5	7.04	0.002265203

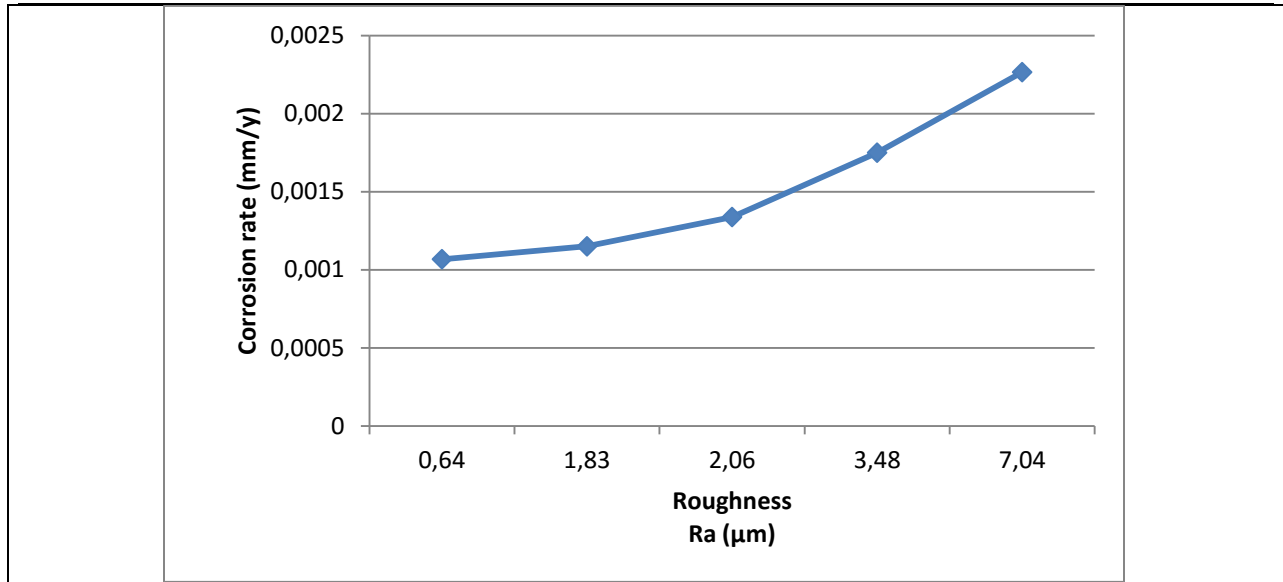The results showed in table 3 was represented in Fig 4.

Fig 4. Corrosion rates of AA6061 samples in neutral salt solution.

Table 4 shows results of immersion test in alkaline salt solution, the corrosion rate of as received sample of AA6061 is gradually decreasing with decreasing of Ra between values.

Table 4: Corrosion rates of samples of AA6061 in alkaline salt solutions, immersion time was eight days		
Sample	Ra (µm)	Corrosion rate (mm/y)
1	0.64	0.016949
2	1.83	0.019374
3	2.06	0.020567
4	3.48	0.021979
5	7.04	0.022121

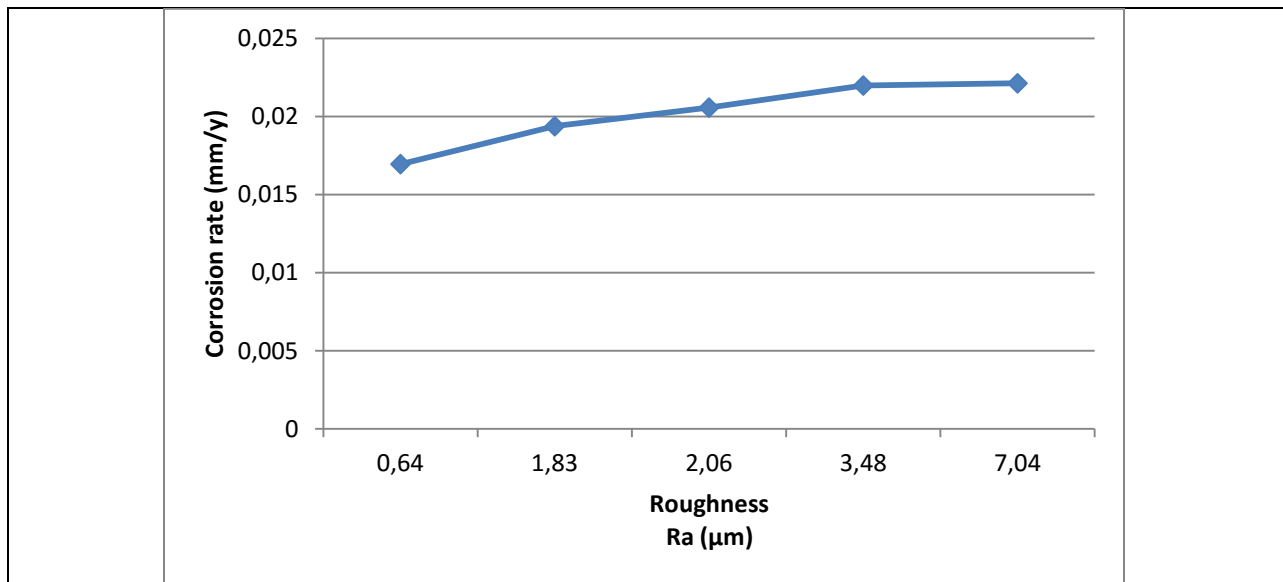The results showed in table 4 was represented in Fig 5.

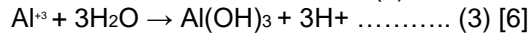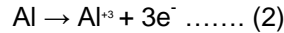**Fig 5. Corrosion rates of AA6061 samples in alkaline salt solution.**

In case of alkaline solutions PH=12, the values of Corrosion rates were observed to be more than acidic and neutral solution.

One of the main corrosive reactions is:
$$NaOH+Al+H_2O \rightarrow NaAlO_3+H_2O \quad \ldots\ldots\ldots(1) \; [5].$$
With decreasing the roughness, the contact surface with solution is reducing, and as a result the quantity of reaction is reduced, consequently the corrosion rate is reduced.
However, the mechanism of corrosion of the Al matrix in neutral media is related with the formation of protective layer of aluminum hydroxides $Al(OH)_3$.
$$Al \rightarrow Al^{+3} + 3e^- \quad \ldots\ldots (2)$$
$$Al^{+3} + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \quad \ldots\ldots\ldots.. (3) \; [6]$$
The $Al(OH)_3$ layer becomes more protector with decreasing the roughness, because the defects is lowered.

In acidic solution, the solubility of Al^{3+} facilitates the dissolution of the Al matrix and further accelerates the chloride attack.

The cl^- ions will initiate at weak sites in the oxide film by chloride attack, The resulting HCl formation inside the pit causes accelerated pit propagation, This product was considered to be $AlCl_3$ or $Al(OH)_2Cl$ [7].The decreasing of roughness reduce the weak sites on surface and consequently reduce the corrosion rate.

3.3.2. Shape of Corrosion:

Fig.6 shows the optical micrograph of AA6061 surfaces after removing from immersion solutions. In the alkaline solutions, the surfaces of specimens for different roughness are covered with Al(OH)3 and the general corrosion is controlled. In acidic and neutral solutions, pits were observed on surfaces and with increasing in roughness the pits increased.

4. Conclusions

This paper studied effect of degree of roughness on corrosion behavior of aluminum alloy AA6061. The roughness was achieved on specimens by grinding in different emery paper in addition to use Al_2O_3 powder, and diamond powder, to obtain on five surfaces.

The immersion corrosion tests in 3.5% salt solutions with different values of PH were applied. With the decrease in the roughness, the corrosion rate decrease, because of, in alkaline solution, the contact surface between solution and specimen was reduced and by this the corrosion reactions became less.

In neutral solution, the corrosion depend on $Al(OH)_3$ layer that formed, and with decreasing the roughness this layer became more protecting.

In acidic solution, with decreasing the roughness, the sites of collection the HCl were reduced, and by this the chloride aggressive became less.

Roughness Ra (µm)	PH =2	PH =7	PH=12
0.64			
1.83			
2.06			
3.48			
7.04			
Scale	500 µm	500 µm	500 µm
Fig.6. Shape of corroded specimens			

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