IJASR International Journal of Academic Scientific Research
ISSN: 2272-6446 Volume 3, Issue 1 (February - March), PP 24-33
www.ijasrjournal.org

Effect of artificial aging on Structure, Mechanical properties and Corrosion behavior of Aluminum Alloy 6061

Ahmad Almansour[1], Mazen Azizi[2], Abdul Munem Jesri[3], Sami Entakly[4]
[1,2]*(Department of Material Engineering, Aleppo University)*
[3]*(Department of Production Engineering Aleppo University)*
[4]*(Department of Production Engineering Aleppo University ,PhD Candidate)*

ABSTRACT: *The corrosion of AA6061 after natural aging at different temperatures and different medium was investigated. The aim of this work was to determine the effect of quenching mediums and temperature on the microstructure and the corrosion behavior of AA6061.The samples conditions were; As received, natural aged (490, 530,570°C mediums of quenching water, oil).The microstructure was investigated by optical microscope. The mechanical properties were investigated by hardness test. The corrosion behavior was investigated by immersion test 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 (0.013925865mm/y) for as received AA6061 and (0.011938369, 0.012006523mm/y) for solution temperature 490°C and quenching medium (water, oil) respectively, (0.011127151, 0.012188457mm/y) for solution temperature 530°C and quenching medium (water, oil) respectively, (0.0117488, 0.011751153mm/y) for solution temperature 570°C and quenching medium (water, oil) respectively in acidic salt solution.In neutral salt solution the corrosion rate was (0.002266478 mm/y) for as received AA6061 and (0.002597958, 0.002677378 mm/y) for solution temperature 490°C and quenching medium (water, oil) respectively, (0.002415756, 0.002819388mm/y) for solution temperature 530°C and quenching medium (water, oil) respectively, (0.002952099, 0.003644528mm/y) for solution temperature 570°C and quenching medium (water, oil) respectively.In alkaline salt solution the corrosion rate was (0.029565995mm/y) for as received AA6061 and (0.022907954, 0.025419624mm/y) for solution temperature 490°C and quenching medium (water, oil) respectively, (0.03025972, 0.031595412mm/y) for solution temperature 530°C and quenching medium (water, oil) respectively, (0.027642156, 0.032702518mm/y) for solution temperature 570°C and quenching medium (water, oil) respectively.*

Keywords: *Aluminum Alloys, AA6061, Corrosion of Aluminum, Heat treatment of Aluminum.*

1. INTRODUCTION

Present tendencies of the development of different groups of materials evidence the fact, that the mass-participation of modern products such as products of the aircraft industry, aerospace industry or biomaterials is constantly increasing. Prevailing are still metal materials, because nowadays it is not yet possible using everywhere for example polymers, because of their small abrasion resistance, resistant to corrosion, and also for temperature range of the usage, not exceed the temperature range 300-400ºC. By the reason of this the basic materials in the mechanical engineering, automotive industry, shipbuilding industry, metal industry, the household, and building industry there are so still metals and their alloys.

Nowadays the technology makes many requirements to construction materials in the range of their low production costs, availability and good mechanical properties, great heat resistance, the resistance on corrosions and the not large specific gravity.

Application of aluminum alloys meet above requirement in many branches of industry as [1]. The combination of acceptable cost, low component mass derived from its low density, appropriate mechanical properties, structural integrity and ease of fabrication are also attractive in other areas of transport. Aluminum is used in buildings for a wide spectrum of applications. These include roofing for factories which incorporate foil vapor barriers, windows and pre-formed sheet cladding features, doors, canopies and fronts for shops and prestigious buildings, architectural hardware and fittings, rainwater goods and replacement windows [2].

The successful use of aluminum alloys as foil for food wrapping and for containers utilizes their good corrosion resistance and barrier properties against UV light, moisture and odor. Foil can be readily formed, attractively decorated and can be usefully combined with paper and plastic if required.Among all aluminum alloys are use alloys on the groundmass Al-Mg-Si such as AA6061. They have good mechanical properties, good corrosion resistance in many environments. There is also possibility to improve their mechanical properties by precipitation strengthening, with precipitation some phases, in this case Mg_2Si precipitations [3].Solution heat treatment of aluminum alloys allows the maximum concentration of a hardening solute to dissolve into solution. This procedure is typically carried out by heating the alloy to a temperature at which one single solid phase exists. By doing so, the solute atoms that were originally part of a two phase solid solution dissolve into solution and create one single phase. Once the alloy has been heated to the recommended solutionizing temperature, it is quenched at a rapid rate such that the solute atoms do not have enough time to precipitate out of the solution. As a result of the quench, a super saturated solution now exists between solute and aluminum matrix [4-5].

The cooling rate associated with the quench can be controlled through the variation of quenching parameters such as bath temperature and degree of agitation. The variation of this parameter allows the heat transfer, the ability to increase or decrease the cooling rate to achieve certain mechanical properties and corrosion resistance as well as eliminate distortion and the possibility of cracking [6].After that natural aging is achieved, and the increase in properties occurs by the rapid formation of GP (Guinier-Preston) zones from the supersaturated solid solution and from quenched-in vacancies. Strength increases rapidly, with properties becoming stable after approximately 4-5 days [7].The Al-Zn-Mg-Cu and Al-Mg-Cu alloys (7XXX & 6XXX), harden by the same mechanism of GP Zone formation. However, the properties from natural aging are less stable. These alloys still exhibit significant changes in properties even after many years [7].

One of the factors that affect corrosion of AA6061 the nature of media. In 2010 Muhamad Zulkarnin Bin Zulkifli investigated the corrosion inhibition of AA6061 in marine environments by milk. This study examined the use of milk for improvement of corrosion resistance of AA6061 in sodium chloride. Weight loss method and potentiodynamic polarization measurement were employed to study the corrosion behavior of AA6061 in sodium chloride. The weight loss method showed that the presence of milk significantly decreases the corrosion rates of AA6061 in the test solutions. The electrochemical measurements also showed the similar finding that the presence of milk reduces the corrosion rates, and that corrosion current densities i_{corr} simultaneously increases the values of polarization resistance R_p [8]. 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 [9].

Another factor effect corrosion of AA6061 nature of alloying elements in structure. Kalenda Mutombo studied effect of Intermetallic Particles-Induced Pitting Corrosion in AA 6061-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[10].

Mohammed A. Amin has studied Influence of the alloying elements on uniform and pitting corrosion events induced by SCN^- anions on AA6061 and Al-Cu alloys surfaces. As a result, AA 6061 alloys presented the highest corrosion resistance towards uniform and pitting corrosion processes in KSCN solutions [11]. Also the heat treatments of AA6061 will change the microstructure according to the parameters of process, and this will reflect on properties such as mechanical properties in addition to corrosion resistance, so the primary objective of this work is to experimentally determine the effect of temperature of solution heat treatment in addition to oil and water as mediums for quenching on the mechanical properties of AA6061 aluminum alloy. The properties of interest include: hardness and the microstructural changes, and corrosion behavior.

2. EXPERIMENTAL PROCEDURE

2.1. Sample Preparation

AA6061 with base composition % by weight is 1% Mg, 0.56Si, 0.28Fe, 0.08Cu, 0.23Mn, 0.61Mg, 0.05Zi, 0.02Cr, and 0.04Ti was used in this study, these percentages were measured by spectrometer XMF 104 that manufactured by Unsisantis Europe company in Germany. It depends 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 specimen. The specimens with dimensions 150×19×4.5mm were solution heat treated at different temperatures and the quenched, after that aged naturally. Table 1 showed parameters of heat treatments, this processes were done by air furnace, TOUCH, produced by Kelvin company, Germany.

Table 1. parameters of heat treatments

Samples	Temperature of Solution heat treatment °C	Medium of quenching
1	490	Water
2	490	Oil
3	530	Water
4	530	Oil
5	570	Water
6	570	Oil

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 5mm, the applied force was 125 kgr.

2.3.Optical Microscopy Observation

The samples of alloy AA6061 were examined using an optical microscope B-353 provided by Optica Company, Germany. The etching solution was 2ml HF,3ml HCl, 2mlHNO_3, 190ml H_2O.

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 high pure NaCl to reagent water (3.5%gr 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 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 specimens for the test were cut to rectangular shape L=19 mm, W=15 mm t=4.5 mm , after which the sample surface were mechanically polished with emery papers starting from 320 grit up to 1000 grit.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 and corrosion rate For this purpose weighting apparatus, M-power, produced by Satorius company, Germany.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.
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. Results Of Hardness Test:

Fig.1 shows results of hardness tests, the basic specimen (as received) has the highest hardness, this because of exist the stresses and dislocation in the microstructure that resulted from formation process during manufacturing.For the samples that aged, with the increasing in quenching solution temperature the hardness increased, but in the case of oil as quenching medium the hardness was lower than water.

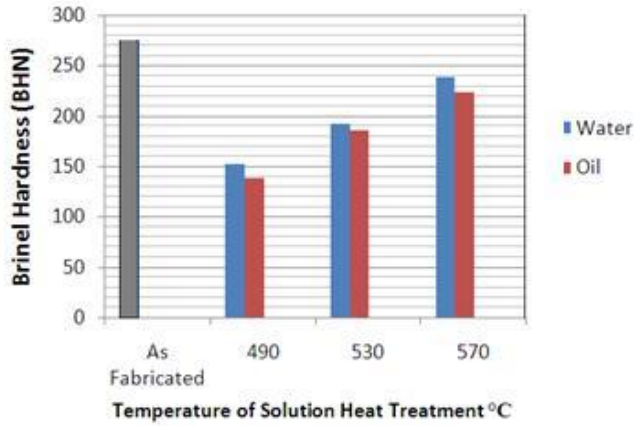


Fig.1. values of hardness for AA6061 specimens

3-2- Optical Microscopy observation:

Fig 2 showed the microstructures of AA6061 specimens, as received specimen and heat treated AA6061 specimens. With increase of temperature the quantity of precipitate increase in addition to the size of precipitates.

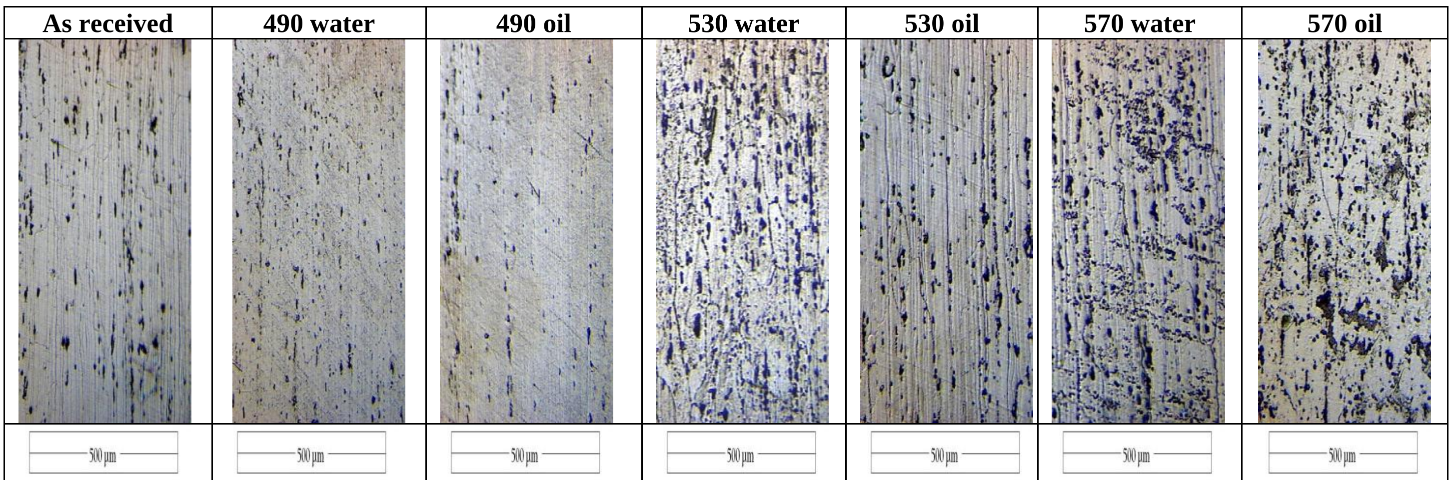


Fig.2. Microstructures of AA6061 specimens.

3-3- Results Of Corrosion Test:

3-3-1- Corrosion Rate:

Table 2 shows results of immersion test in acidic salt solution, the as received sample of AA6061 has the highest corrosion rate, for the heat treated samples of AA6061 in the same degree of solution heat treatment the corrosion rate was bigger when the medium of quenching was oil. Also the sample of AA6061 that heat treated at 530°C and quenched in oil had the highest corrosion rate between heat treated samples. The results showed in table 2 was represented in Fig 3.

Table 2. Corrosion rates of samples of AA6061 in acidic salt solutions, immersion time was eight days,			
Samples	**Temperature of Solution heat treatment °C**	**Medium of quenching**	**Corrosion rate in mm/y**
1	As received		0.013925865
2	490	Water	0.011938369
3	490	Oil	0.012006523
4	530	Water	0.011127151
5	530	Oil	0.012188457
6	570	Water	0.0117488
7	570	Oil	0.011751153

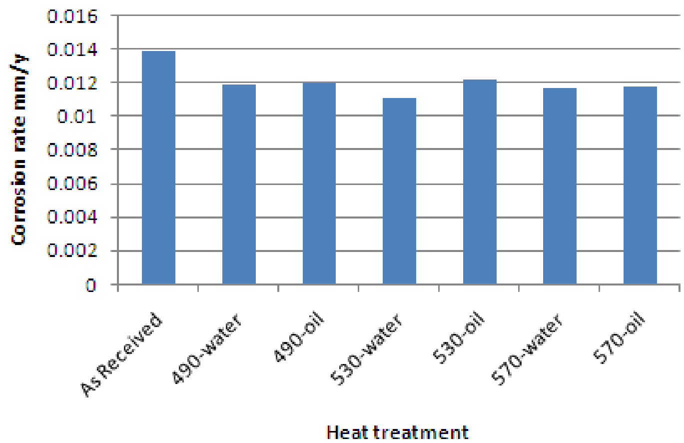


Fig.3. Corrosion rates of AA6061 samples in acidic salt solution.

Table 3 shows results of immersion test in neutral salt solution, for the heat treated samples of AA6061 in the same degree of solution heat treatment the corrosion rate was bigger when the medium of quenching was oil. Also the sample of AA6061 that heat treated at 570°C and quenched in oil had the highest corrosion rate between heat treated samples. The results showed in table 3 was represented in Fig 4.

Table 3. Corrosion rates of samples of AA6061 in neutral salt solutions, immersion time was eight days			
Samples	**Temperature of Solution heat treatment °C**	**Medium of quenching**	**Corrosion rate in mm/y**
1	**As received**		0.002266478
2	490	Water	0.002597958
3	490	Oil	0.002677378
4	530	Water	0.002415756
5	530	Oil	0.002819388
6	570	Water	0.002952099
7	570	Oil	0.003644528

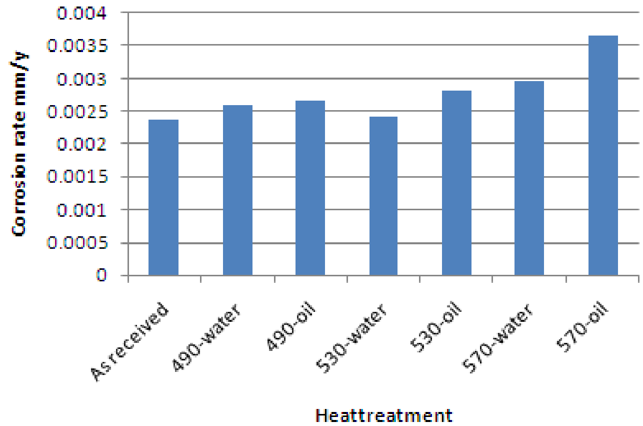


Fig.4. Corrosion rates of AA6061 samples in neutral salt solution.

Table 4 shows results of immersion test in alkaline salt solution, for the heat treated samples of AA6061 in the same degree of solution heat treatment the corrosion rate was bigger when the medium of quenching was oil. Also the sample of AA6061 that heat treated at 570°C and quenched in oil had the highest corrosion rate between heat treated samples. The results showed in table 4 was represented in Fig 5.

Table 4. Corrosion rates of samples of AA6061 in alkaline salt solutions, immersion time was eight days

Samples	Temperature of Solution heat treatment °C	Medium of quenching	Corrosion rate in mm/y
As received			0.029565995
1	490	Water	0.022907954
2	490	Oil	0.025419624
3	530	Water	0.03025972
4	530	Oil	0.031595412
5	570	Water	0.027642156
6	570	Oil	0.032702518

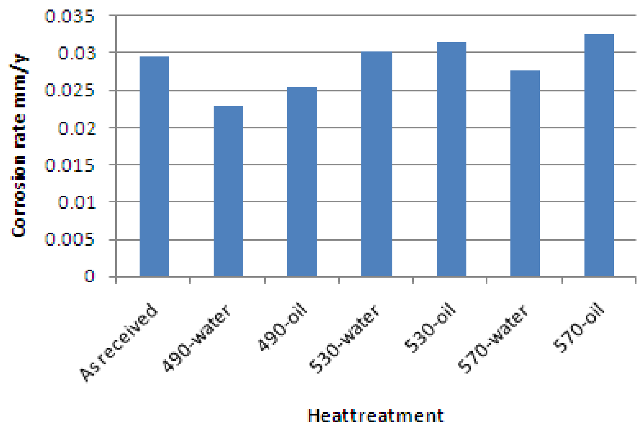


Fig.5. Corrosion rates of AA6061 samples in alkaline salt solution.

3-3-2- Shape Of Corrosion:

Fig. 6, presented the optical micrograph for the as-received sample and heat treated samples of AA6061 aluminum alloy, This micrograph is presented here for comparison corroded samples. From the optical micrograph of the film formed upon the surface of the sample after eight days immersion in 3.5%NaCl solutions at slightly neutral (pH = 7) and acidic pH (pH = 2) respectively. Hemispherical pits with different size were grown throughout the surfaces of the samples and around each pit a white corrosion product (CP) was accumulated as the result of the corrosion of the aluminum alloy matrix in the vicinity of the precipitates.

These micrographs clearly show that the damage caused by this type of corrosion is accentuated in solutions of acidic pH comparing to slightly neutral solution, suggesting that the anodic activity of the system became intense with this acid range of PH.

Exposure to solution of alkaline pH results in more intense corrosion attack. Fig. 6 shows the morphology of the sample surface immersed in 3.5 wt% NaCl solution at pH = 12 for eight days. As consequence of this treatment, a film of oxide is formed over the surface of the sample, which is covered with white gelatinous mass (CP), normally called alumina.

4. CONCLUSION

This paper studied effect of temperature of solution heat treatment and medium of quenching and natural age on corrosion behavior of aluminum alloy AA6061.

The artificial age was achieved on as received specimens, to obtain on six structures.

The hardness of all structures was less than hardness of as received specimen, because this specimen was full in dislocation, and with increasing in temperature of heat treatment the hardness was increased. The quenching in oil gave hardness less than quenching in water.

In acidic salt solution the as received sample had the higher corrosion rate than the natural aged specimens, and the heat treated specimen (530°C solution temperature, medium of quenching oil) had the highest the corrosion rate between heat treated specimens.

In neutral salt solution the specimen (570°C solution temperature, medium of quenching oil) had the highest corrosion rate, also in alkaline solution.

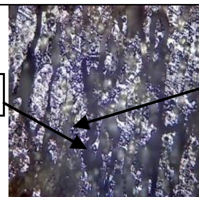
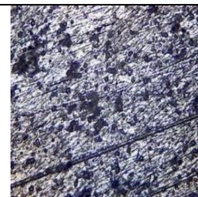
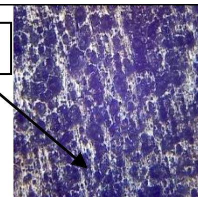
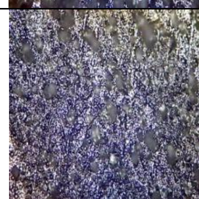
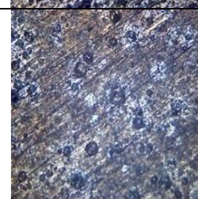
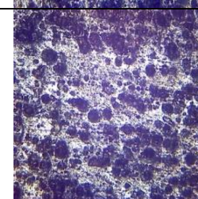
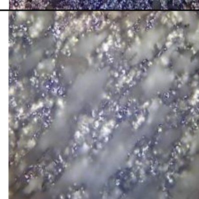
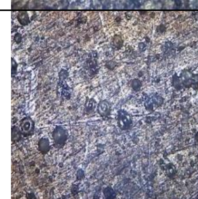
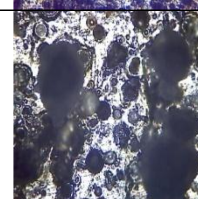
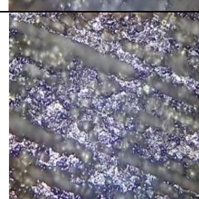
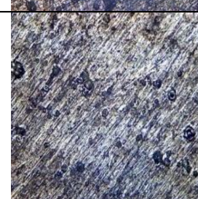
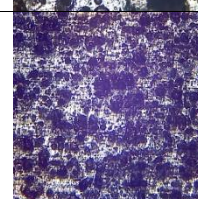
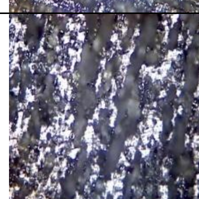
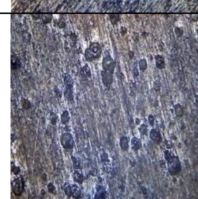
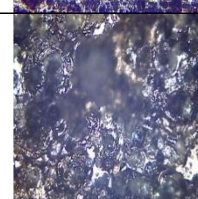
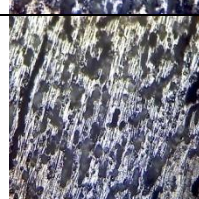
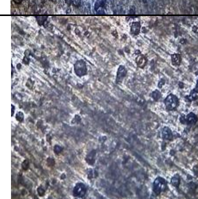
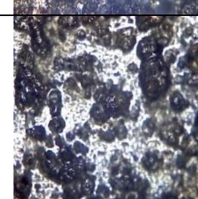
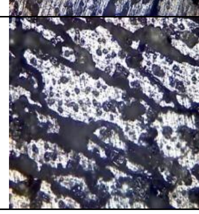
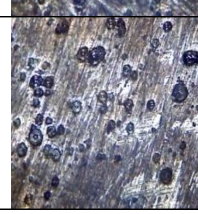
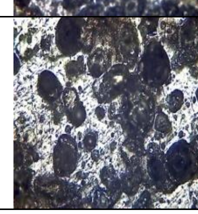
	PH2	PH7	PH12
As Fabricated			
Temperature of Solution heat treatment 490 ºC, Medium of quenching water			
Temperature of Solution heat treatment 490 ºC, Medium of quenching Oil			
Temperature of Solution heat treatment 530 ºC, Medium of quenching water			
Temperature of Solution heat treatment 530 ºC, Medium of quenching oil			
Temperature of Solution heat treatment 570 ºC, Medium of quenching water			
Temperature of Solution heat treatment 570 ºC, Medium of quenching oil			
			

Fig.6. shapes of corroded specimens

REFERENCES:

[1] .Z. mieszek, T. Biegaj, Tendencies in the European industry of non-ferrous metals, Rudy iMetaleNieelazne, Nr 4, 2000 (in Polish).
[2] .J. Michaek, The full world of aluminum, aluminum plenty of in the world, wiataluminium, Nr 1, 1999 (in Polish).
[3]. G. Svenningsen, K. Nisancioglu, M.H. Larsen, J.H. Nordlien, Corrosion Science 48 (2006) 258-272.
[4]. Davis J. R., 1993, *Aluminum and Aluminum Alloys*, in ASM Specially Handbook, ASM International, Metal Park, Ohio.
[5]. Callister, W. D., 1997, *Material Science and Engineering*, John Wiley and Sons, New York.
[6]. Boyer,H. E., 1998, *Quenching and Distortion Control*, ASM International, Metal Park, Ohio.
[7].George E. Totten, *Handbook of AluminumVolume 7 Physical Metallurgy and Processes*, (Printed in the USA, Library of Congress Cataloging,2003).
[8]. MohdZulkarn ain bin Zulkifli , Corrosion *inhibition of 6061 aluminum alloy in marine environments by milk*, University Malaysia Pahang 2010, ID Number: MA07067.
[9].SolhanYhya, Afidah Abdul Rahim, AffaizzaMohd Shah, Ohana Adnan, *Inhibitive Behaviour of Corrosion of Aluminium Alloy in NaCl by Mangrove Tannin*,(SainsMalaysiana,2011, 40(9)953–957).
[10].KalendaMutombo, *Intermetallic Particles-Induced Pitting corrosion in 6061-T651 Aluminium Alloy*, (Council for Scientific and Industrial Research CSIR, South Africa kmutombo@csir.co.za)..
[11].Mohammed.A. Amin, *Influence of the Alloying Elements on Uniform and Pitting Corrosion Events Induced by SCN- Anions on Al-6061 and Al-Cu Alloys Surfaces*,(2010, *Jordan Journal of Chemistry* Vol. 6 No.1, 2011, pp. 91-105).