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Corrosion Behaviour of Aluminium Alloy 6061 after Cold Deformation and Annealing in Low NaCl Concentration

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Abstract- The alloy 6061 is used as cladding material in research reactors. During fabrication the alloy undergoes deformation and heat treatment process. In the research reactors harm elements should not be present, if any is present is cause bad effect on the performance of the alloy. In the present work alloy 6061 was deformed by different degrees from 15% to 70%. The effect of presence of 10 ppm NaCl in corrosion behavior of the alloy. A second condition was annealing the deformed samples at 300oC for 60 min .the corrosion behavior of these annealed samples was also studied in presence of 10 ppm NaCl. The result shows that there is no protection of samples surface even at the low concentration of NaCl and the corrosion form of the samples is uniform corrosion.

I. INTRODUCTION

Aluminium and its alloys have a wide range of properties that can be applied for specific application [1]. Some of aluminum alloys are employed as cladding materials for research reactor. This is due to its small cross section of neutron adsorption, good corrosion resistance against cooling water, good toughness after long term exposure in neutron field, and short life time of the radioactive nuclei produced by nuclear reactions [2]. The water quality affects the corrosion suscepility of metals. In many of commercial power and research reactors, water is considered as source for cooling components by removing heat from fission products and for neutron moderation [3]. Water quality is defined as group of parameters which are used for characterization water physical and chemical conditions. These parameters include pH, dissolved impurity species, conductivity, and many other parameters which affect water quality [4, 5].

The pH and conductivity are the two foremost parameters used in characterization of water quality conductivity of water is affected by impurity species as Na and Cl. Alloy 6061 as cladding is highly affected by the presence of Na and Cl. The presence of chloride ions at low concentrations is a strong parameter of corrosion of the aluminium fuel clad alloy [6, 7]. Also it is well known that corrosion rate increase with the increase in deformation degree. The values of corrosion rate are low in neutral solution [8].

The aim of the present work is to study the effect of presence of low concentration of NaCl 10ppm which is the accepted concentration in reactor cooling water on the corrosion characterization of deformed alloy 6061.

II. EXPERIMENTAL WORK:

Electrochemical tests were conductor to investigate the effects of exposure of aluminium cladding alloy AA6061 to low concentration of NaCl 10ppm representing the alloy able concentration of these ions in research reactor water.

Electrochemical measurements were carried out in a conventional three- electrodes glass cell with graphite counter electrode and a saturated calomel electrode SCE as reference electrode. The salt solution 10ppm NaCl was prepared by adding high purity NaCl to distilled water.

The polarization curves in cyclic potentiodynamic test were recorded by changing the electrode potential automatically with electrochemical. Impedance analyzer model 6310, manufactured by EG&G instruments, Princeton applied research equipped with computer. Tests were performed at room temperature.

Alloy 6061 samples were immersed in the solution and the delay time was 300 min was applied before starting polarization scan. After delay time the cyclic potentiodynamic polarization curves were plotted by starting scanning electrode potential at a scanning rate 0.5mv/sec, the initial potential -250 mv below the open circuit potential to 200mv, the vertex was at 100mv against open circuit potential. The nominal composition alloy AA6061 as given in Table (1)

Table (1) Nominal Composition of Alloy AA6061

element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt %	0.6	0.7	0.3	0.15	0.99	0.2	0.25	0.15	balance

The nuclear grad aluminum 6061 was received in the form of extruded plates with 6mm thick and 110 mm wide, it was in the annealing condition, the material was supplied by the Cressona aluminum company, Germany.

III. RESULTS AND DISCUSSION

3.1. The Microstructure of the Received Specimens

The microstructure of the received specimens is shown in Fig .1 (i.e. zero state)

Fig .1 Microstructure AA6061 as Received (x 1000)

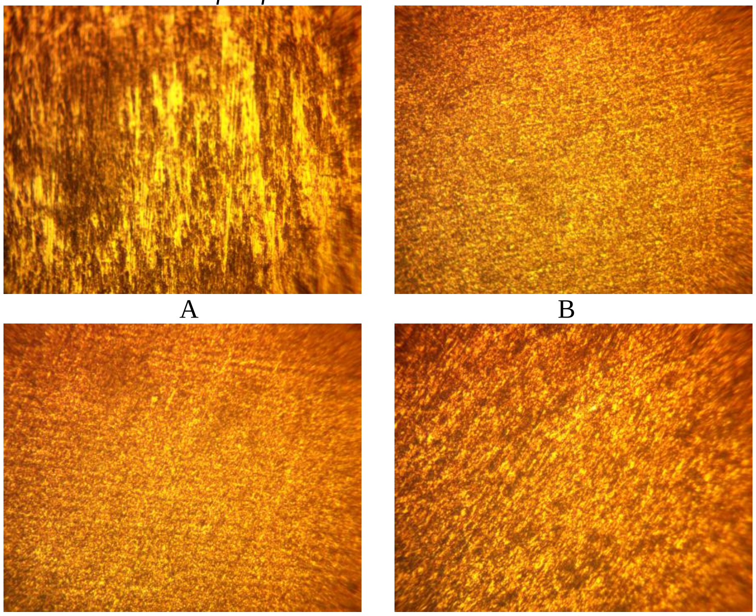
The specimens were reduced by 0, 15 %, 30% and 70% cold rolling, and the micro hardness measurements and corrosion rate are record as show in Table.2

The effect of deformation on hardness is shown in Table.2, the increase in percent deformation leads to an increase in micro hardness. Deformation leads to energy storage for the period of lattice defect creation, i.e. dislocations [9, 10].

Table (2) The Effect of Cold Rolling Degree on Hardness of AA6061

Cold Rolling%	0	15	30	70
Hardness Inc %	0	11.4	26.1	65.9
Corrosion current density	2x10-6	2x10-7	4x10-7	5x10-7

3.2. Electrochemical Corrosion Behavior of Deformed and Annealed AA 6061



A B

C D

Fig. 2 Corrosion Behavior of Deformed AA 6061- (a) as Received 0% (b) as 15% (c) as 30% and (d) as 70% Cold Rolling.

Fig.2 show the surface of the samples presents a contrast likely due to presence of the cold deformation at different reduction ratios. The surface of sample in (Fig.2a) presents broad holes here. However another samples (b, c and d) present the deposition of the corrosion products on continuum substrate, this may explain the good corrosion resistance of this alloy [11, 12].

Cyclic potentiodynamic curve of deformed and annealed AA 6061 in 10ppm NaCl solution are show in (Figs.3-5). A general feature of the potential – current density curves for undeformed and deformed specimens is a contentious increase in corrosion current densities, the extent of the current densities increase changed with the degree of deformation. In case of undeformed condition no break in the curve and current density increase till the vertex potion - 0.440 mv then, there is curve shows a negative values in the reverse curve. It is well know the presence of NaCl even in low concentration increase the corrosion rate. The corrosion potential of the undeformed specimen is -750 mv and corrosion current density is 2x10-6 A/cm2 (Fig. 3).

Figs.4-5 show the corrosion behavior of deformed specimens, Fig.4 shows the behavior of the alloy deformed by 15%, there is an increase in corrosion current density, but a break in current density is shown at - 430 mv and the vortex is at -320 mv. The corrosion current density curves show negative values in the reverse curve, which is a general feature for the corrosion curves of all specimens. The corrosion potential is -760 mv and corrosion current density is 2x10-7 A/cm2.

Fig.5 shows the corrosion behavior of alloy 6061 deformed by 30 %, the curve have a negative values in the reverse direction and a break at -420mv and the vortex is at -370mv, which mean no curing of the film in alloy for all specimens.

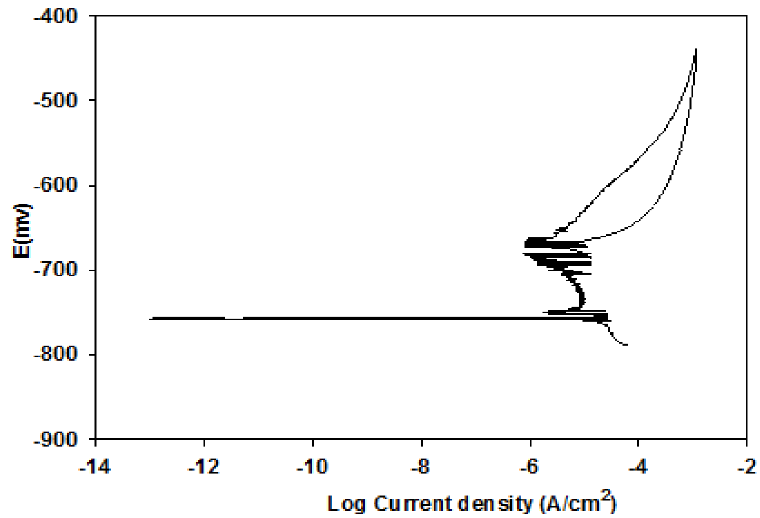


Fig. 3 Cyclic Potentiodynamic Polarization of as Received AA6061 0% Deformation, in 10ppm NaCl Solution

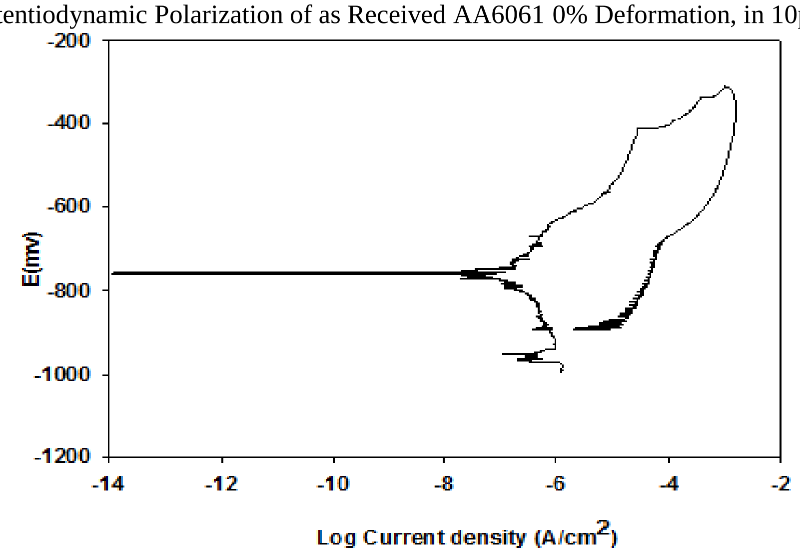


Fig. 4 Cyclic Potentiodynamic Polarization of as Received AA6061 15% Deformation, in 10ppm NaCl Solution

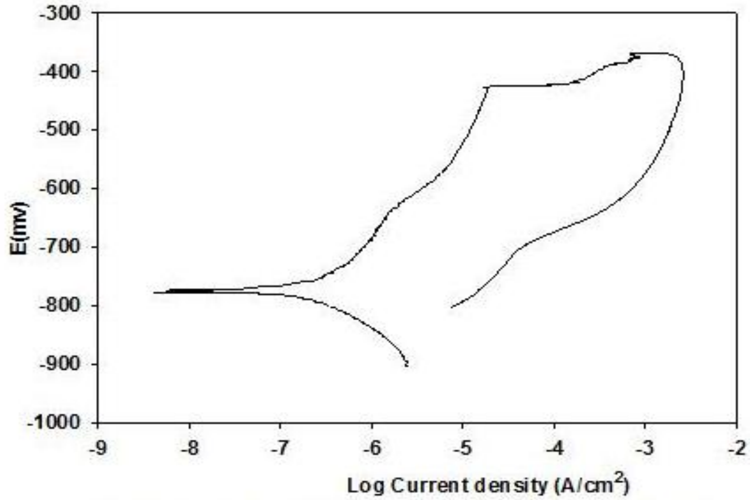


Fig. 5 Cyclic Potentiodynamic Polarization of as Received AA6061 30% Deformation, in 10ppm NaCl Solution

The corrosion potential for alloy deformed by 30% - 780 mv and corrosion current density is 4x10-7 A/cm2. Fig.6 show the corrosion behavior of alloy deformed at 70%. Fig. 6 shows a negative value in the reversed direction which means increasing values of corrosion current density. The corrosion potential 1050 mv and corrosion current density is 4x10-7A/cm2 the curves show a break at -440 mv and the vortex is at 380mv.

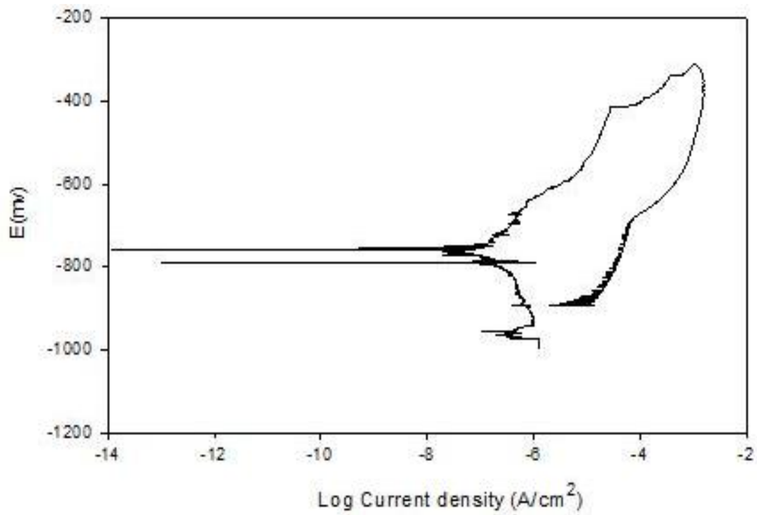


Fig.6 Anodic and Cathodic Polarization Curve of AA6061 as Received 70% Deformation, in 10ppm NaCl Solution

Fig.7 show the surface of the samples presents a contrast likely due to presence of the cold deformation and annealing at 300oC for 1hr at different reduction ratios. The annealing process after cold deformation leads to recrystallization of grains and increase the good corrosion resistance of alloy.

The second groups of specimens were annealed for 60 min at 300oC, the alloy AA6061 is a type of aluminium alloy which is age hardenable and usually heat treated to both T4 (solution heat treated and aged naturally) and T6 (solution heat treated and artificially aged) . The cyclic potentiodynamic polarization of the annealed specimens, curves are shown in (Figs.8-11). Fig. 8 shows the cyclic polarization of undeformed alloy AA6061 aged for 60 min at 300oC in 10ppm NaCl solution. The corrosion potential of the alloy is 560 mv and corrosion current density is 3x10-3 A/cm2. the behavior of the curve shows no pitting corrosion and the vortex potential is 1300 mv , the reverse curve shows a negative potential values.

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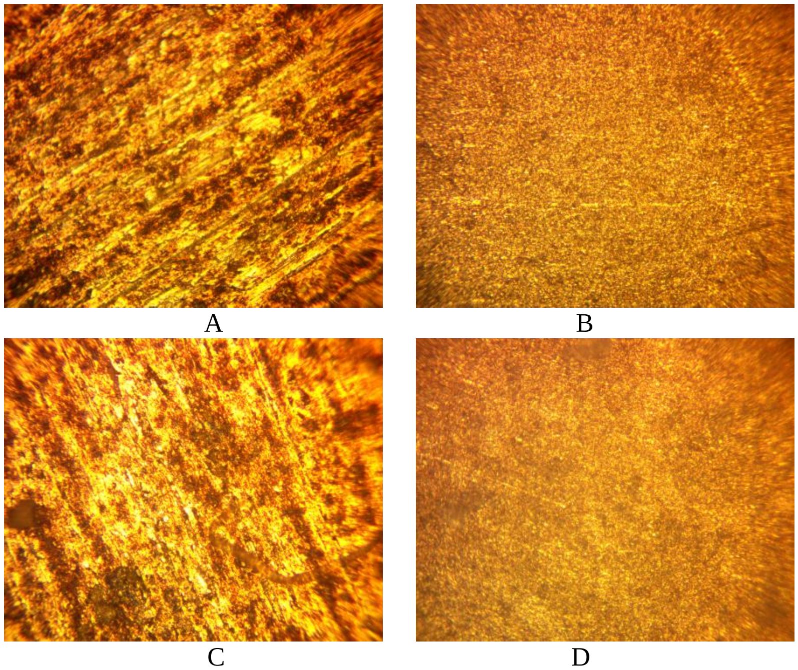

Fig .7 Corrosion Behavior of Deformed and Annealed at 300oC for 1hr of AA 6061- (a) as Received 0% (b) as 15% (c) as 30% and (d) as 70% Cold Rolling

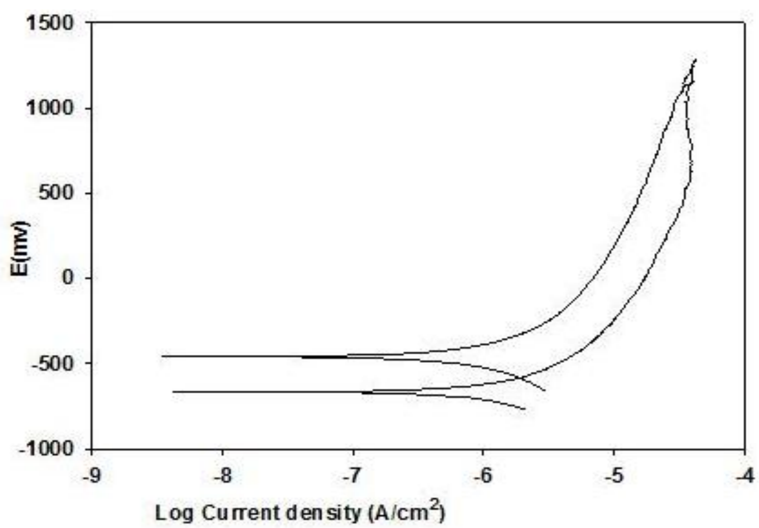

Fig. 8 Cyclic Potentiodynamic Polarization of AA6061, as Received and Aged at 300oC, in 10ppm NaCl Solution

The corrosion potential is less negative value and corrosion current density also less than of unheat treated alloy [13, 14]. (Fig 9) shows the cyclic potentiodynamic polarization curve for alloy AA6061 deformed by 15% and aged at 300oC for 60 min in 10ppm NaCl solution. The corrosion current density increases with the potential, the corrosion potential is 960 mv and corrosion current density is 4x10-7 A/cm2. Also; there is a break in the curve at -420 mv and the vortex is at -430 mv. (Fig. 8) shows the cyclic polarization potential of AA6061 deformed 30% and aged at 300oC for 60 min, in 10 ppm NaCl the corrosion potential is -790 mv and corrosion current density is 5x10-7 A/cm2. The corrosion current density increases and a break in the curve are observed at -480 mv and the vortex is at 320mv.

Fig. 11 shows the corrosion behavior of alloy AA6061, deformed by 70 % and aged at 300oC for 60 min in 10 ppm NaCl. The corrosion potential is -520 mv and corrosion current density 5x10-7 A/cm2 .the behavior show two breaks at -320 mv and 220mv, the vortex at 230 m A.

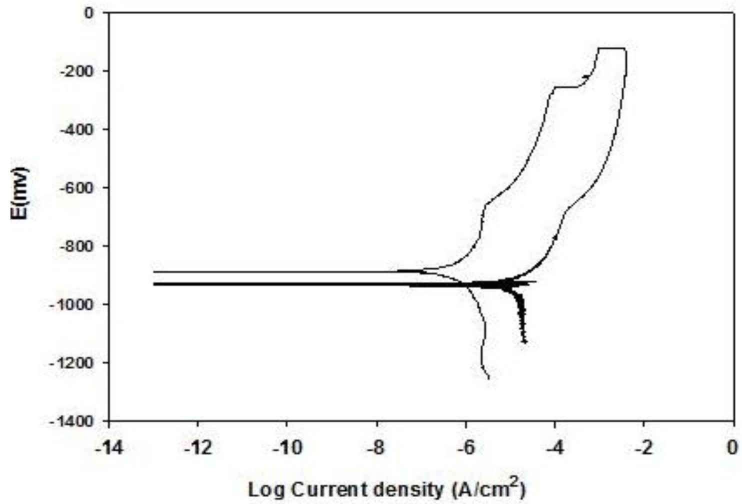

Fig. 9 Cyclic Potentiodynamic Polarization of AA6061,15% and Aged at 300oC for 60min, in 10ppm NaCl Solution

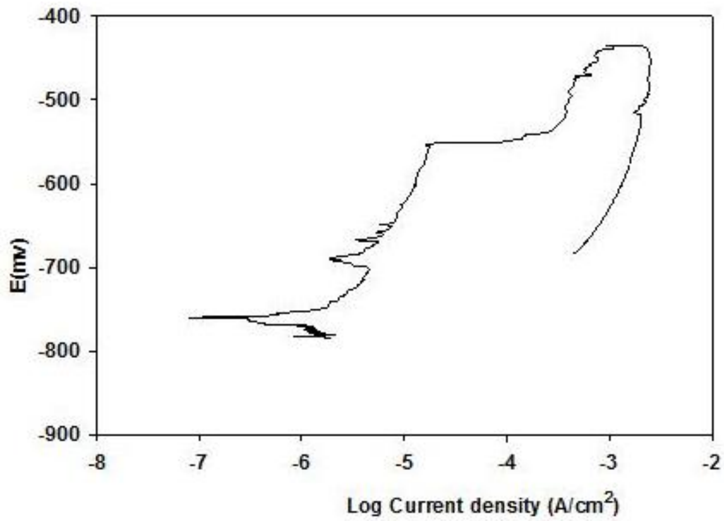

Fig. 10 Cyclic Potentiodynamic Polarization of AA6061, 30% and Aged at 300oC for 60min, in 10ppm NaCl Solution

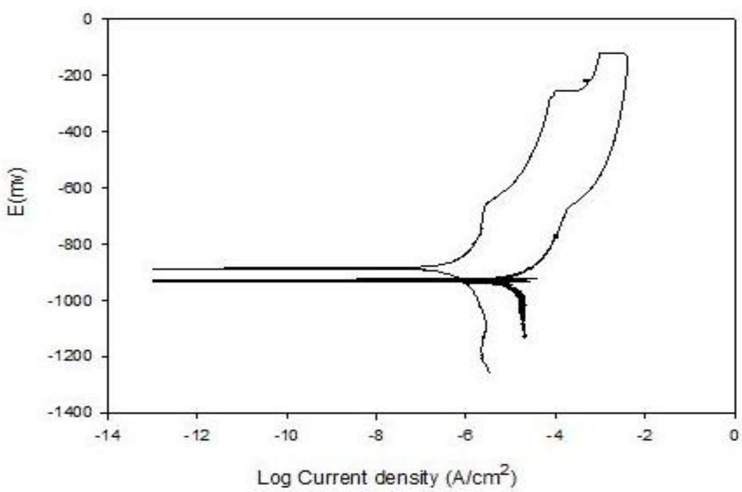

Fig. 11 Anodic and Cathodic Polarization Curve of AA6061 as Received 70% Deformation at Annealing 300oC for 60min, in 10ppm NaCl Solution

The corrosion behavior of all deformed and aged specimens show a negative corrosion density in the reverse direction.

IV. CONCLUSION

From the experimental work the following conclusion can be adapted:

1-Even in case of low concentration of NaCl (10ppm) the reverse curve in the cyclic potentiodynamic is in the right side, which means that there is no protection.

2-The corrosion current density increases as the degree of deformed increase is 2x10-7 A/cm2 for unreformed samples, as for samples deformed 15% the corrosion current density is 3x10-7 A/cm2 and the corrosion current density for deformed samples by 70% is 6x10-7 A/cm2

3- As for in case of annealed samples of 300 for 60 min the corrosion current density for unreformed samples is 3x10-7 A/cm2 , which that of the annealed samples after 70% deformed , the current density is 5x10-7 A/cm2.

4- From the photos of the corrosion samples, it is observed that the form of corrosion is uniform and pitting corrosion.

V. REFERENCES

[1] E Mostaed, M. Vedani and Massimiliano Bestetti," Influence of ECAP Process on Mechanical and Corrosion Properties of Pure Mg and ZK60 Magnesium Alloy for Biodegradable Stent Application", Biomatter ,vol.5 ,2014, pp.80-83.

[2] L. Wang, X. Li, Chao Wan, and Z. Cao, "Effect of Cooling Rate on Bio-Corrosion Resistance and Mechanical Properties of Mg-1Zn-0.5Ca Casting Alloy" Trans. Nonferrous Met". Soc. China 26, 2016, pp.704-711

[3] A Desola, O. Deshi, L. Anke " The Effects of Aging Treatment and Strain Rates on Damage Evolution in AA 6061 Aluminum Alloy in Compression", Materials and Design, 2013, 45, pp. 212-221.

[4] D. Xiang ‘‘Comparative Study of the Dynamic Mechanical Behavior of Aluminum Alloy 2519A and 7039. Materials Science and Engineering" 2015, A 640, pp. 165-170.

[5] N. Birbilis, M. Cavanaugh ,R. Buchheit" Electrochemical Behavior and Localized Corrosion Associated with Al7Cu2Fe Particles in Aluminum Alloy 7075-T651. Corrosion Science, 2006, 48(12), pp. 4202-4215.

[6] T. Shailesh " Evolution of Texture and Microstructure During High Strain Rate Torsion of Aluminium Zinc Magnesium Copper Alloy. Materials Science and Engineering" 2017, A 683, pp. 94-102.

[7] A Ghosh" Effect of Tempering Conditions on Dynamic Deformation Behaviour of an Aluminium-Lithium Alloy. Materials and Design, 2015, 81, pp. 1-10.

[8] Y.Gan, D. Zhang, W. Zhang , et al. " Effect of Cooling Rate on Microstructure and Mechanical Properties of Squeeze Cast Al-Cu-Mg alloy". International Journal of Cast Metals Research, 2015, 28(1), pp. 50-58.

[9] H. Yang, S. Ji, Z. Fan" Effect of Heat Treatment and Fe Content on the Microstructure and Mechanical Properties of Die-Cast Al–Si–Cu Alloys". Materials and Design, 2015, pp. 25-31.

[10] M. Larsen, et al. "Intergranular Corrosion of Copper-Containing AA6xxx Al Mg Si Aluminum Alloys" J. Electrochemistry. Soc. 155, 2008, pp.550-556.

[11] M. Larsen, et al, ‘‘Effect of Excess Silicon and Small Copper Content on Intergranular Corrosion of 6000-Series Aluminum Alloys" Journal of Electrochemistry. Soc. 157, 2010, pp. 61-68.

[12] E Dwarakadasa, "Studies on the Influence of Chloride Ion and pH on the Electrochemical Behavior of Aluminum Alloys 8090 and 2014" Journal of Applied Electrochemistry 24 ,1994, pp. 911-916.

[13] M. El-Bedawy, M.Sc. " Effect of Aging on the Corrosion of Aluminum Alloy 6061, Faculty of Engineering" Cairo University, 2010.

[14] H. Greene and F. Mansfeld, " Corrosion Protection of Aluminum Metal-Matrix Composites",Corrosion Science 53 ,1997, pp. 920-927.