Effect of Heat Treatment on Corrosion Behavior of Al-4Ti/MgO-SiC Composite

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ABSTRACT

This work focuses on the effect of annealing, normalizing and tempering on corrosion behavior of Al-4Ti/1 wt% MgO-2 wt% SiC composite fabricated by stir casting method. The XRD analysis and optical examination indicate that the heat treatments lead to breaking up the main phase (Al_3Ti) in Al-4Ti alloy and form many oxides that cover the composite surface.

Linear and cyclic polarizations have been investigated in seawater at room temperature by Potentiostat. The corrosion data showed that the corrosion potential became more negative for heat treated composites compared with untreated once. Corrosion current density decreased after heat treatments. The normalized composite has lowest corrosion rate due to expose the specimen to atmosphere for quenching which leads to form SiO_2 in addition to MgO and Al_2O_3. The breakdown of passive layer in composite decreased by heat treatments which assessed by cyclic polarization test.

Keywords: Corrosion of composite; SiC; MgO; Ceramic reinforcements.

INTRODUCTION

To obtain the best properties of materials, we can manufacture a composite material which captures a specific property of each material that is better in the composite. Appropriate selection of alloy composition and thermo mechanical processing method give controllable properties of metallic material. These properties reflect not only the strength and toughness of materials but also the relative ease and low cost of fabrication with wide range of manufacturing processes. The most common composites are metal matrix composites (MMCs) which are tailored composites resulting from the addition of reinforcements to a metal to enhancing specific stiffness coupled with improved fatigue and wear resistance, or perhaps increased specific strength combined with desired thermal properties.

Corrosion resistance is the main obstacles in MMCs. But in aluminum matrix composite, this problem is reduced due to a protective oxide film which improves corrosion resistance. The acceleration in corrosion may originate from electrochemical and chemical interaction between reinforcements and matrix [1].

There are many researches discussed the corrosion behavior of aluminum and its alloys in different media [2-7]. Other researches focus upon the corrosion behavior of aluminum matrix composites [8-16].

The current work related to investigate the corrosion behavior of Al-4Ti/1wt% MgO- 2wt% SiC in seawater at room temperature to show the role of MgO and SiC as reinforcements. Heat treatments include annealing; normalizing and tempering have been achieved to investigate the role of these treatments on corrosion behavior.

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Materials and Procedure

Preparation of Specimens

Al wires and powders of Ti, MgO and SiC were used as matrix and reinforcement elements in the production of composite specimens. The particle size of Ti was 165 μm, while was 53 and 20 μm for MgO and SiC respectively.

For the production of composite specimens, matrix material Al was put in the crucible and the melting process was started and continued until the temperature of the liquid matrix reached 700 °C using furnace (carbolite type) with thermocouple (K type). Electrical stirrer (Arrow, Model 850, 1000 rpm max, 120Vand 60Hz) was immersed in the liquid metal and stirring was started. The appropriate amount of Ti and then 1 wt% of MgO and 2 wt% of SiC were added in the liquid metal by a funnel during the stirring process. After the addition of reinforcements to liquid matrix, the mixture was stirred for about 7 min at 500 rpm in order to allow homogeneous distribution of MgO and SiC particles in the mixture. When stirring was completed, the crucible was taken out of the furnace; the liquid melt was poured in to steel mold of 20 mm diameter and 170 mm height and was allowed to cool down in air to room temperature within mould.

The specimens were cut as cylindrical shapes for characterization and corrosion test with dimensions of 20 mm diameter and 4 mm thickness. Grinding and polishing was done with emery papers 220, 400, 500, 800, and 1000 mesh grit and then rinsed with acetone.

Heat Treatment

The specimens were subjected to annealing, normalizing, and tempering processes. During annealing, the specimen was heated to 500^{o}C, held for one hour, and allowed to cool in the furnace. For the normalized, the specimen was heated to 500^{o}C, held for one hour, and allowed to cool in air. The tempered specimen was heated to 500^{o}C, held for one hour, quenched rapidly in water, reheated to 100^{o}C, held at this temperature for one hour, and then allowed to cool in air.

X-ray Diffraction and Optical Microscopy

XRD was carried out by X-Ray Diffractometer, Model: XRD-6000 with Cu as target at voltage = 40.0 (kV) and current = 30.0 (mA). The microstructure evolution was investigated by means of optical microscope using (BEL photonics) microscope which was connected to computer. The specimens were etched by Killers solution (2 ml HF +3 ml HCl + 5 ml HNO_3 + 190 ml H_2O) as etchant for 10-30 sec. for optical examination.

Corrosion

Corrosion test was achieved by a potentiostat with SCI electrochemical software at a scan rate 5 mV.sec^{-1}. The voltages were applied when the rate at which open circuit potential (E_{oc}) changed $\pm$200mV. The main results obtained were expressed in terms of the corrosion potentials (E_{corr}) and corrosion current density (i_{corr}) by Tafel extrapolation method. The corrosive medium which used is 3.5wt% NaCl solution.

Results and Discussion

XRD analysis of Al-4Ti/1%MgO-2%SiC composite is presented in Fig. (1) for untreated and heat treated specimens. The most intensive peak in the XRD spectrum for the Al matrix was good agreement with JCPDS card (04-0787). The peaks of Al were overlapped with the peak of Al_3Ti phase according to JCPDS card (37-1449).

The peaks of MgO and SiC also overlapped with the peaks of matrix according to JCPDS cards (30-0794) and (39-1196) respectively.

The heat treatments led to decreasing the formation of Al_3Ti phase and increasing the segregation of MgO at grain boundaries as illustrated in the peak of MgO at $2\theta = 64.527^{o}$. The strongest peaks with (khl) value are listed in Table (1). The normalizing and tempering led to breaking up Al_3Ti phase as illustrated in optical microscopies in Figure (2).

Optical examination of structure before and after heat treatments indicates the presence Al_3Ti phase and uniformly distribution of MgO and SiC particles in Al matrix.

In Al/SiC composites, the liquid aluminum (***l***) tends to attack SiC (as solid ***s***) to produce solid Al_4C_3 and silicon within liquid aluminum, i.e., Si in $Al_{(l)}$, according to the following reaction [17]:

$$4Al_{(l)} + 3SiC_{(s)} \leftrightarrow Al_4C_{3(s)} + 3Si_{(in\ l\ Al)} \quad ....(1)$$

The Al_4C_3 compound has deleterious effects within the composite because, firstly, as a brittle phase degrades the mechanical properties, and secondly, it reacts with liquid water or with moisture in the ambient, debilitating even more the composite, according to the following reactions [18]:

$$Al_4C_{3(s)} + 18H_2O_{(l)} \rightarrow 4Al(OH)_{3(s)} + 3CO_{2(g)} + 12H_{2(g)} \quad .....(2)$$

During the casting, some aluminum may be converting to Al_2O_3. At the same time, the aluminum content oxidizes and then reacts with MgO to form a nonstoichiometric spinel [18]:

$$MgO_{(s)} + Al_2O_{3(s)} \rightarrow MgO.Al_2O_{3(s)} \quad .....(3)$$

Some SiC particles in the composites might oxidize during heating, and, then, SiO_2 film forms around the particle surface [19]. After that, $2MgO.SiO_2$ forms on the boundary between MgO and SiC particles, and its amount increases in the matrix with heating temperature and time.

The molten base alloy damaged the integrity of MgO–SiC composites under high temperature. SiC particles can be directly dissolved into molten alloy. The interspace that remains after SiC decomposition acts as the route for Al-4Ti penetration. MgO particles become isolated and dissolve into the molten alloy [20].

Corrosion behavior of Al-4Ti/1% MgO-2% SiC composite is shown in Fig. (3) for untreated and heat treated specimens in 3.5% NaCl solution at room temperature. Aluminum matrix composite undergoes the corrosion according to the following reactions [3]:

$$Al \rightarrow Al^{3+} + 3e \quad \text{(At Anode)} \quad ......(4)$$

$$O_2 + 2H_2O + 4e \rightarrow 4OH^- \quad \text{(At Cathode)} \quad .....(5)$$

Generally, in the presence of chloride ions, the dissolution of metals enhanced because of chloride ion is bonded chemically in the interface as an initial step of the formation of different mixed oxohydroxo – and chloro complexes to produce finally the $[AlCl_6]^{3-}$ complex [21].

The heat treatments led to shift corrosion potential (E_{corr}) to active direction due to increasing in cathodic sites which suggest increasing in reduction reactions. While corrosion current density (i_{corr}) shifted to lower values especially for normalized specimen and then corrosion rate was decreased due to cover the most surface by oxide layers of Al, Mg, Si and Ti. Cathodic and anodic Tafel slopes are also influenced by the heat treatments. The data of corrosion are listed in Table (2).

The heat treatments led to form $MgO.Al_2O_3$ and $2MgO.SiO_2$. Also the chemical reaction between molten aluminum and SiO_2 is also thermodynamically possible according to the following reaction [22]:

$$2/3\ SiO_{2(s)} + 2Al_{(l)} \rightarrow 2Al_2O_{3(s)} + 2/3\ Si_{(in\ l\ Al)} \quad .....(6)$$

This means that the heat treatment form many oxides in Al matrix, these oxides enhance the corrosion resistance of experimental composite.

Cyclic polarization test is used to assess pitting corrosion resistance by determining the initiation and propagation of pits. Figure (3) shows the cyclic polarization of untreated and heat treated of Al-4Ti/1%MgO-2%SiC composite. The polarization behavior shows that the breakdown potential became nobler for treated specimens compared with untreated composite especially for normalized composite.

Table (1) XRD data for fabricated Al-4Ti/1%MgO-2%SiC composite.

Condition	2θ	Intensity	khl
Untreated	38.473° 44.739° 78.229°	100 45 20	111 200 311
Annealed	38.6791 44.9323 65.2615	100 46 42	111 002 202
Normalized	39.1049 45.2639 78.7296	100 36 32	101 012 021
Tempered	38.5902 44.8293 65.1959	100 71 54	111 002 202

Table (2) Corrosion parameters of untreated Al-4Ti/1%MgO-1%SiC composite in seawater at room temperature.

Treatment	E_{corr} mV	i_{corr} $\mu A/cm^2$	$-b_c$	$+b_a$	C_R mpy	E_b mV
			mV/dec^{-1}			
Untreated	-756	0.7548	63.2	44.7	0.327	-223
Annealed	-799	0.6352	157.4	114.6	0.275	-107
Normalized	-922	0.0122	110.7	55.3	0.005	-75
Tempered	-806	0.1618	54.2	22.7	0.070	-84

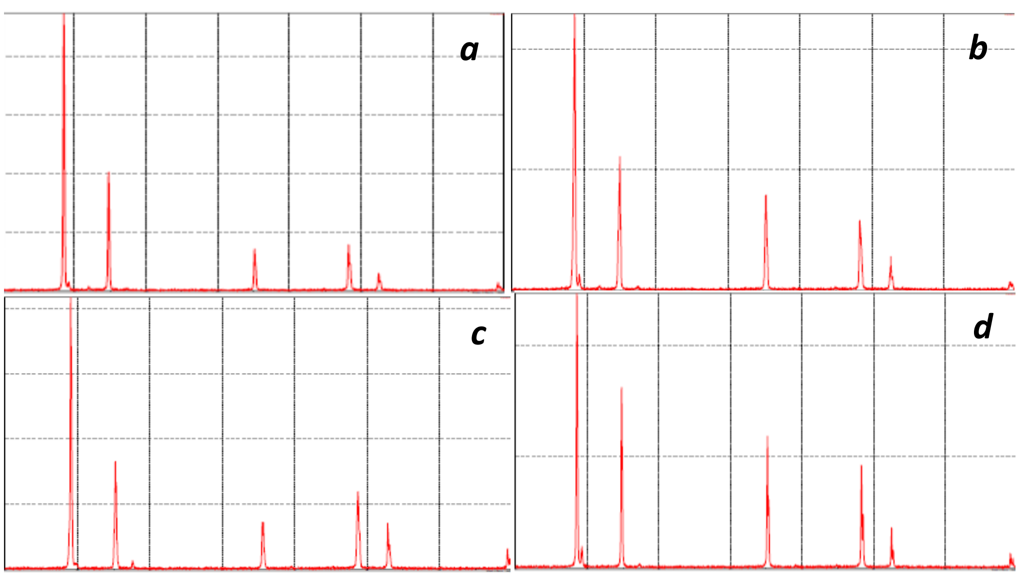

Figure. (1) XRD analysis of untreated (a), annealed (b), normalized (c) and tempered composite (d).

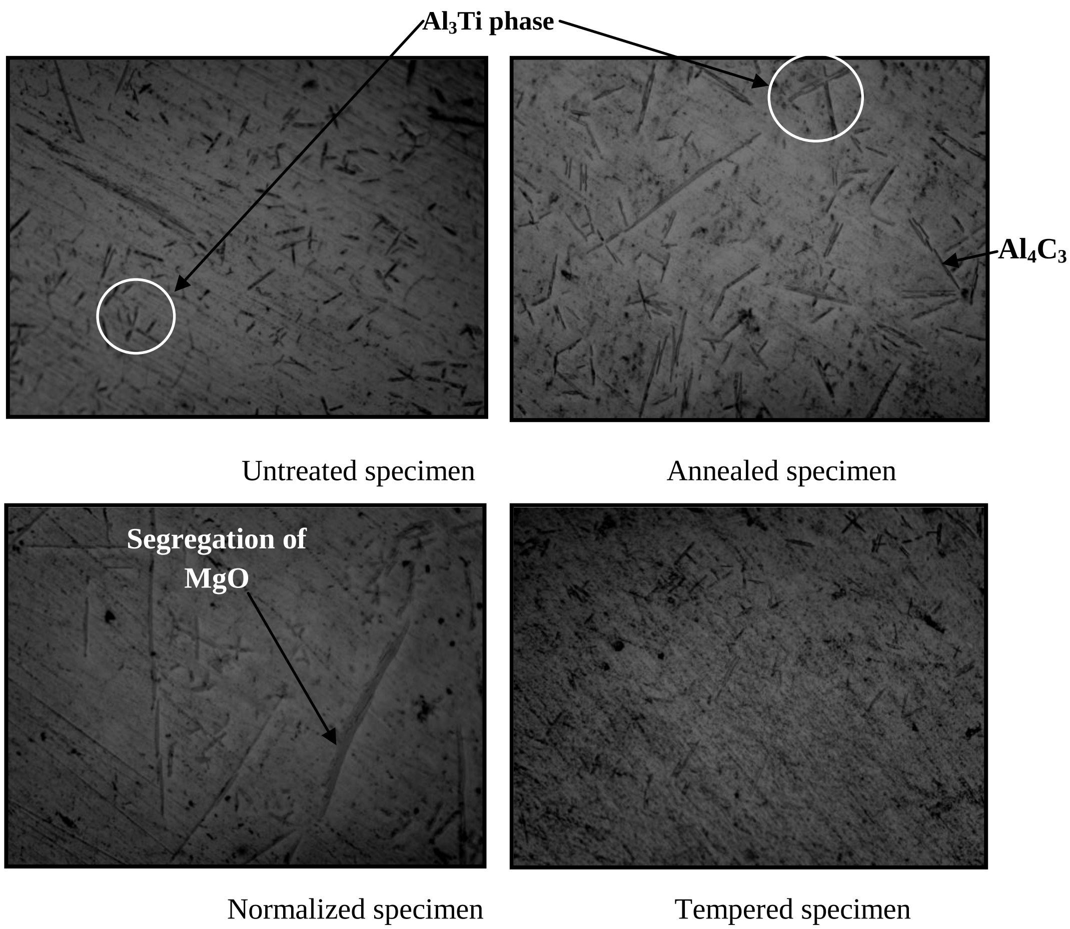

Figure. (2) Optical microscopy of untreated and treated Al-4Ti/1%MgO-2%SiC.

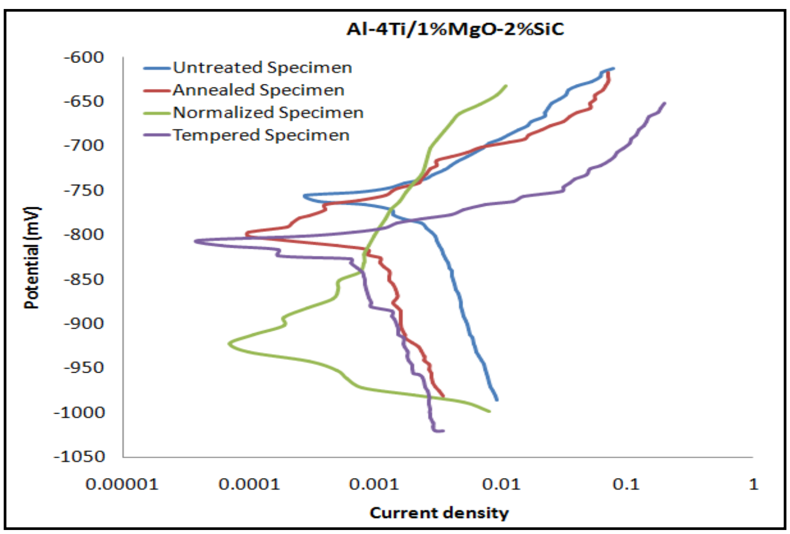

Figure. (3) Tafel plot of untreated and heat Cyclic polarization of untreated and treated composite.

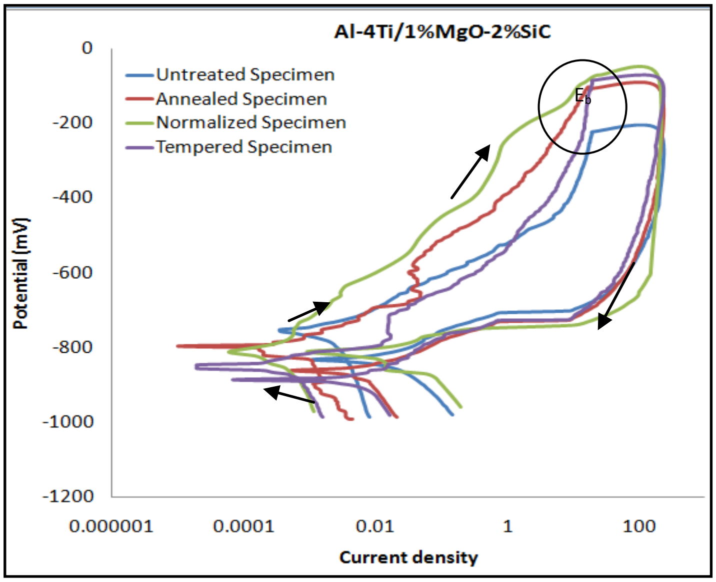

Figure. (4) Cyclic polarization of untreated and heat treated composite

CONCLUSIONS

Composites sometimes undergo dissolution in corrosive medium because of poor interaction between matrix and reinforcement. Therefore, heat treatments were achieved to estimate the effect of them on corrosion behavior of fabricated composite (Al-4Ti/1%MgO-2%SiC). The XRD and optical examination showed that heat treatment improved the resistance of composite in spite of break up the Al_3Ti phase. This improvement occurs by formation many metal oxides on the surface of composite which led to decreasing the corrosion rate and increasing pitting potential for treated specimens in seawater at room temperature.

REFERENCES

[1]- L.H. Hihara, "Corrosion of Metal-Matrix Composites" in ASM Handbook Vol. 13 B, Corrosion: Materials, S.D. Cramer and B.S Covino, Jr., Ed., ASM International, Materials Park, OH, 2005, p. 526-542

[2]-R. A. M. Anaee, H. Al-Kaisy and H. Al-Atrakchy, "Effect of chloride ions on the corrosion behavior of Al-Zn alloy in NaOH solution at four different temperatures", Al-Khawarizmi Engineering Journal, Vol.4, No.4, 2008, 26-36.

[3]- N. A. Hikmat, A. M. Farhan and R. A. M. Anaee, "Effect of chloride ions on the passive layer for three Al alloys at pH=9" Al-Nahrin University Journal for Science, Vol.12, No.3, 2009, 23-32.

[4]- N. A. Hikmat, A. M. Farhan and R. A. M. Anaee , "Effect of deareation on the corrosion of pure Aluminium and its three alloys in NaOH solution at pH=11", Eng. & Techn. Journal, Vol. 27, No. 8, 2009, 1532-1543.

[5]- R. A. M. Anaee, M. H. Abdulmajeed, S. I. Ibrahem and H. Deaa Al-Deen, "Effect of oxygenated additives on the corrosion behavior of Al-Si-Cu alloy in a synthetic condensed automotive solution", Journal of King of Abdulaziz University – Engineering science, JKAU: Eng. Sci., Vol.23, No.2, 2012, 3-18.

[6]- R. A. Anaee, M. Mahdi, H. A. Al-Kaisy and S. A. Abdul Maged, "Corrosion Behavior for Al-Cu-Mg Alloy by Addition of SiO_2 Particles in Seawater", Eng. and Techn. Journal, Vol. 32, Part (A), No. 2, 2014, 354-364.

[7]- R. A. M. Anaee, M. H. Abdulmajeed, S. I. Ibrahem, S. A. Abdul Maged and Z. Al-Saffar, "Effect of (50%Isopropanol – 30%Methanol – 17%Xylene) Mixture on Corrosion Behavior of Pure Al and its Alloys in Simulated Fuel", Eng. & Techn. Journal, Vol.32 Part A, No.6, 1380-1389, 2014.

[8]- S.B. Jamaludin, Z. Yusoff, K.R. Ahmad, "Comparative Study of Corrosion Behavior of AA2014/15 Vol%Al_2O_3p and AA2009/20 Vol% SiC_w", Portugaliae Electrochimica Acta, Vol. 26, 2008, 291-301.

[9]-B. Bobic, S. Mitrovic, M. Babic and I. Bobic, "Corrosion of Metal-Matrix Composites with Aluminium Alloy Substrate", Tribology in industry, Vol. 32, No. 1, 2010, 3-11.

[10]- El-Sayed M. Sherif, A. A. Almajid, Fahamsyah Hamdan Latif and Harri Junaedi, "Effects of Graphite on the Corrosion Behavior of Aluminum-Graphite Composite in Sodium Chloride Solutions", Int. J. Electrochem. Sci., Vol. 6, 2011, 1085-1099.

[11]- Ahmad T. Mayyas, Mohammad M. Hamasha, Abdalla Alrashdan, Adel M. Hassan and Mohammed T. Hayajneh, "Effect of Copper and Silicon Carbide Content on the Corrosion Resistance of Al-Mg Alloys in Acidic and Alkaline Solutions", Journal of Minerals & Materials Characterization & Engineering, Vol. 11, No. 4, 2012, 435-452.

[12]- H.M. Zakaria, "Microstructural and corrosion behavior of Al/SiC metal matrix composites", Ain Shams Engineering Journal, Vol. 5, 2014, 831-838.

[13]- C. Muthazhagan, A. Gnanavelbabu, K. Rajkumar, and G.B. Bhaskar, "Corrosion behavior of Aluminium-Boron carbide-Graphite composites", Applied Mechanics and Materials, Vol. 591, 2014, 51-54.

[14]- Muna K. Abbass, Khairia S. Hassan, and Abbas S. Alwan, "Study of Corrosion Resistance of Aluminum Alloy 6061/SiC Composites in 3.5% NaCl Solution", International Journal of Materials, Mechanics and Manufacturing, Vol. 3, No. 1, 2015.

[15]- R. A. M. Anaee, "Thermodynamic and Kinetic Study for Corrosion of Al-Si-Cu/Y_2O_3 Composites", Asian Journal of Chemistry, Vol. 26, Issue 14, 2014, 4469-4474.

[16]- R. A. M. Anaee, "Study of Corrosion Behavior of Al-Si-Cu/WC Composites in 0.1 N NaOH Solution", Journal of King of Abdulaziz University – Engineering science, JKAU: Eng. Sci. Vol. 26 No. 1, 2015, 55- 65.

[17]- Luo Z.P., "Crystallography of SiC/$MgAl_4C_3$/Al Interfaces in Pre-oxidized SiC Reinforced Al/SiC Composite", Acta Materialia, Vol. 54, Issue I, 2006.

[18]- Bowen Xiong, Qingsong Yan, Baiping Lu, Changchun Cai, "Effects of SiC Volume Fraction and Aluminum Particulate Size on Interfacial Reactions in SiC Nano-Particulate Reinforced Aluminum Matrix Composites", Journal of Alloys and Compounds, Vol. 509, 2011, 1187-1191

[19]- Z. Chen, Chemical Thermodynamics of Refractories; p. 565. Metallurgical Industrial Publishing, Beijing, 2005.

[20]- W. Yaowu, L. Nan and K. Changming, "Effect of Silicon Carbide on Reactions between Molten Steel and Fused Magnesia–Silicon Carbide Composite Refractory", American Ceramic Society Bulletin, Vol. 86, No. 9, 2007, 9201-9205.

[21]- L. Tomesanyi, K. Varga, I. Bartik, H. Horanyi and E. Maleczki, "Electrochemical study of the pitting corrosion of aluminium and its alloys–II. Study of the interaction of chloride ions with a passive film on aluminium and initiation of pitting corrosion", Electrochimica Acta, Vol. 34, No. 6, 1989, 855-859.

[22]- Liu ZS, Huang GS, Gua MY., "Effect of hydrolysis of AlN particulates on the corrosion behavior of Al/AlNp composites", Materials Chemistry and Physics, Vol. 99, 2006, 75–79.