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Study of Corrosion Behavior of Metal Matrix Composite Based on Al-Alloy (7020) Prepared by Atomization

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Abstract

An experimental procedure has been fully formulated and carried out to prepare composite material of an aluminum (alloy 7020) matrix reinforced by Al_2O_3 particles with weight percentages of 5%, 7% and 10% and its particle size of (+53-75)µm using molten metal atomization technique.

These experiments involve the preparation of aluminum matrix composite (AMC_S) materials and study their Corrosion resistance in 3.5% solution of NaCl at temperature degrees 30°C, 38°C and 45°C using various testing techniques. These include electrochemical corrosion and optical microscopy.

The corrosion rate was found to increase as the temperature was nominally raised from 30°C to 38°C and 45°C for the 10%wt of alumina in atomized AMC_S samples in 3.5% NaCl solution. At a temperature of 30°C the corrosion rate was found to rise with increasing percentages of Al_2O_3 particles for 5%, 7% and 10% atomized samples. This is due to galvanic corrosion between the matrix and the second phases ($MgAl_2O_4$) and (MgO) in microstructure of AMC_S.

Optical microscope showed a profound appearance of general corrosion in all microstructural area and grain boundaries.

Keywords: Metal Matrix Composite, Atomization, Al-Alloys, Corrosion.

دراسة سلوك التأكل لمادة متراكبة معدنية ذات اساس سبيكة المنيوم 7020محضرة بطريقة التذرية.

الخلاصة

تم وضع طريقة عمل مناسبة لتحضير مواد متراكبة ذات أساس سبيكة المنيوم نوع 7020 مقواة بدقائق من الألومينا Al_2O_3 بنسب وزنية (5% ,7% ,10%) وذات حجوم دقائق تتراوح بين (53- 75) مايكرون بأستخدام تقنية التذرية لمنصهر السبيكة بعد تصنيع وتشغيل منظومة لهذا الغرض .شملت التجارب التي تضمنها البحث الحالي على تحضير هذه المواد ودراسة مقاومتها للتاكل الكهروكمياوي في محلول ذو تركيز 3.5% من كلوريد الصوديوم عند درجات حرارية مختلفة (30°C, 38°C, 45°C) باستخدام طرق الفحص والقياس والتي تضمنت اختبارات التآكل الكهروكيمياوي والمجهر الضوئي.

اثبتت تجارب التاكل الكهروكمياوي ان معدل التآكل للعينات المحضرة بنسبة 10% من الآلومينا يزداد بازدياد درجات الحرارة من30°C الى 38°C و 45°C في محلول 3.5% كلوريد الصوديوم بسبب التغير الحاصل في حركية التفاعل ومعدلات الانتشار العالي. ان زيادة نسبة مادة التقوية من 5% الى 7% و10% في درجة حرارة 30°C يزيد معدل التاكل وهذا يعود الى نشوء التاكل الكلفاني بين الاطوار الثانوية مثل ($MgAl_2O_4$) و (MgO) الناتجة من تفاعل مادة التقوية مع المغنيسيوم , والمادة الاساس.
يلاحظ من مشاهدة صور المجهر الضوئي ان التاكل يحدث في جميع مناطق التركيب المجهري وكذلك الحدود الحبيبية وهذا يدل على ان التاكل هو نوع التاكل العام (general corrosion).

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Introduction

Aluminum metal matrix composites AMC's are attractive for a wide variety of aerospace and defense applications because of their low density and their improved mechanical properties as compared to the alloys.

The corrosion behavior of this class of materials during exposure to chloride containing environments has been studied by a variety of researchers [1]. Matrix materials of these composites can be comprised of either commercially pure aluminum or aluminum alloy, and the reinforcements are typically SiC, Al_2O_3, or graphite [2, 3]. The AMC's that have been subjected to electrochemical testing have been produced in a wide variety of manners including hot pressing, infiltration, atomization, and casting [4, 5, 6].

Although the incorporation of a second reinforcing phase into a metal matrix can enhance the physical and mechanical properties of a material, it can also alter the corrosion behavior of materials. The presence of the reinforcement may or may not increase the materials susceptibility to corrosion, depending on the metal-reinforcement combination as well as the processing parameters involved [7].

The corrosion problems that are likely to occur in AMC's are as follows:

- Galvanic coupling between the reinforcing phase and matrix.
- Selective corrosion at the reinforcement / matrix interface.
- Corrosion of matrix defects arising from composite manufacture.

If the reinforcement were an electrical insulator, such as alumina, boron and silicon carbide, little or no galvanic reaction between it and the aluminum matrix would be expected.

However, on the other hand investigations of the composite materials with the aluminum matrix reinforced with Al_2O_3 have proven the possibility of occurs the selective corrosion on the boundary of the ceramic and matrix material phases. It has been presented in literature [3] that the Al_2O_3 ceramic particles with the sizes of 30 and 50µm cause the decrease of the corrosion resistance of the AMC's. Durai et al [8] analyzed the corrosion behavior of Al-Zn/Al_2O_3 AMC's with minor alloying additions of Cu and Mn. The results of the corrosion tests evaluated using the potentiodynamic method indicates that the corrosion of the investigated composites materials depends on the weight percent of the reinforcing particles.

The aim of this work

The aim of the present work is to study the electrochemical behavior of AMC_S reinforcing with Al_2O_3 particles prepared by molten metal atomization.

Experimental procedure

In this study, a plate of aluminum alloy 7020 with the theoretical density of 2.78 g/cm^3 was used as the matrix material while α-Al_2O_3 alumina particles with various particles sizes ranged from (53-75)µm, and a bulk density of 3.97 g/cm^3 were used as the reinforcement, as shown in Figure

(1). The chemical composition analysis of the 7020 aluminum alloy which carried out by using X-ray fluorescence (XRF) apparatus are presented in Table (1). For manufacturing of the AMCs, 5, 7 and 10wt% Al_2O_3 particles were used. The Al_2O_3 particle reinforced 7020 aluminum alloy metal matrix composites have been produced by using molten metal atomization method. The preparation procedure of the composite material by atomization is shown in Figure (2). The atomization apparatus includes a gas feeding unit, nozzle, melting unit, control unit and mixing unit. As shown in Figure (3).

The N_2 gas is delivered to both an atomizer to achieve atomization, and to the melting unit to prevent oxidation. At this stage the temperature of the N_2 gas to the atomizer unit should be at 700°C to avoid the freezing of molten metal and the blockage of the atomizer to achieve such temperature level.

The gas to metal mass flow ratios used is estimated in the range (0.1-0.3) with metal flow rate estimated above (0.01-0.03) kg/s.

Preparation of Base Alloy 7020 by Atomization Method

The base alloy 7020 has been prepared by molten metal atomization method, according to the following steps:

1. Heating

The movable assembly, which is composed of the atomizer, crucible and N_2 gas heating coil, was placed inside the furnace, as illustrated in Figure (3). Subsequently the temperature of the furnace was increased up to the preset temperature, 750°C, by means of the temperature controller.

2. Melting

When the alloy melting had been observed the mixer at speed 350 revolutions per minute (rpm) was operated.

3. Atomization

The atomization process, which is a continuous process, was conducted through the pre-adjusted gas flow by means of valve (V-13), and according to the flow meter readings. Subsequently, the crucible orifice was opened in order to flow and accumulate the atomized molten metal on a rotating base measuring 250 mm in diameter, for testing and measurement.

Finally, the system was turned off.

Preparation of AMC$_S$ by Atomization

The aluminum alloy (7020) matrix composite has been prepared by molten metal atomization method, according to the following steps:

1. Heating

A procedure similar to that mentioned in section (1) above was followed.

2. Melting

In addition to the above mentioned in section (2), additional steps have been implemented. The first step was the improvement of the wettability of Al_2O_3 particles by aluminum alloy 7020, the magnesium ribbons (4wt %) were added to the molten inside the crucible via upper orifice of the furnace. While, the second step was the addition of the alumina particles (5wt%, 7wt% or 10wt %) to the molten alloy inside the crucible via upper orifice of the furnace. The holding time for wetting the alumina particles by the aluminum-magnesium alloy was ranged from 25 to 30 min.

3. Atomization

Similar to that in section (3) above. Finally, the system was turned off.

Tests and measurements:

Two principal experimental techniques were used in this study. These are: optical microscope and corrosion device. Atomized base alloy and atomized AMC_S were examined as follows:

Metallographic Examinations

Microstructures to observe corrosion location of atomized base alloy (7020) and atomized AMCs samples were examined by Nikon ME-600 optical microscope provided with a NIKON camera, DXM-1200F.

1. Sample Preparation:

Prior to the experimental performance, the sample preparation required a particular test. The sample preparation procedure should be documented to examine the performance of replicate tests. There are a number of steps that should be taken as outlined below:

a. Samples were firstly machine-finished to a rod shape and then slice with dimensions of about 2.5 mm thickness and 25mm diameter.

b. The samples were cleaned with soapy water or other appropriate solvent.

c. The samples were then polished by using increasingly fine emery paper of 180 grit to 1200 and then finally 4000 grit was adequate. In addition, all scratches from the previous grit paper should be removed by the current paper and the samples were cleaned from polishing media.

d. Surface should be cleaned thoroughly with an appropriate cleaner, after that it should be rinsed by distilled or deionized water to remove any traces of the cleaner.

2. Etching

The samples were etched with Keller solution which contains 1.5%HCl, 2.5%HNO_3, 1%HF, and 95% H_2O [9]. The samples should be cleaned thoroughly with an appropriate cleaner. At the end, demonstrative photographs were taken by a digital camera, type Nikon DXM-1200F.

Corrosion tests

1. Linear Polarization Technique:

In these types of studies, a metal sample with a surface area of one square centimeter was used as a model of the metal in a corroding system. The metal sample was immersed in a solution of typical concentration in the metal environment for the system being study, 3.5% NaCl solution in the case of sea water. Additional electrodes were immersed in the solution, and all the electrodes were connected to a device called potentiostat. Apotentiostat allows changing the potential of the metal sample in a controlled manner and measuring the current that flows as a function of potential.

Potentiostatic mode was used to perturb the equilibrium corrosion process. When the potential of a sample in the solution was forced a way from open circuit potential (OCP), this indicating, that the sample was polarized. Response current of the metal sample was measured as it was polarized. The response was used to develop a model of the samples corrosion behavior [10].

Potentiostatic polarization and (OCP) monitoring were used to find the (icorr) for the atomized base alloy 7020 and atomized AMC_S with (5wt%, 7wt% or 10wt %). All tests were carried out in 3.5% sodium chloride solution, at different temperatures as (30ºC, 38ºC, or 45ºC).Potentiostatic polarization measurements of samples in chloride solution were usually performed by using three electrode arrangements, comprising the working (WE) electrode (aluminum alloy sample or composite sample), a reference electrode and an auxiliary (platinum) electrode.

In order to perform a polarization scan, a number of components must be assembled and appropriately prepared. First, an electrochemical cell, and environment (chloride solution) have been used.

2. Electrochemical Cell

Polarization resistance tests were used to obtain the microcell corrosion rates. In the tests, cell current readings were taken during a short, slow sweep of the potential. The sweep was taken from (-100 to + 100) mV relative to (OCP). Scan rate defines the speed of the potential sweep in mV/sec. In this range the current density versus voltage curve is almost nearly linear. A linear data fitting of the standard model gives an estimate of the polarization resistance, which used to calculate the corrosion current density (Icorr) and corrosion rate. The tests were performed by using a WENKING Mlab multi channels potentiostat and SCI-Mlab corrosion measuring system from Bank Electroniks-Intelligent controls GmbH, Germany 2007, as shown in Figure (4).

In the tests, aluminum alloy 7020 samples were used as working electrode (WE), a saturated calomel electrode immersed in the salt solution was used as reference electrode (RE), and a platinum electrode was used as auxiliary electrode (AE).

3. Sample Preparation for corrosion

In addition to the steps (a-d), mentioned in metallographic examination section (1), additional one has been implemented; the samples were carefully slices measuring about 2.5 mm thickness and 25 mm diameter to be fitted in special holder supplied with such apparatus as shown in Figure (5).

4. The Experimental Procedure

The experiments were performed in the following sequence;

a- The heating cooling system was firstly started up to reach a temperature of 30ºC.

b- The sample was placed in the test cell.

c- A stable reading of the OCP was then recorded after a required time of about 20 minutes.

d- The anodic polarization scan was then allowed at a rate of 3 mV/sec or less until either a potential of +1V SCE or current density of $2*10^{-3}$ A/cm^2 (whichever occurred first) were reached and this scan could take a few minutes. The above (a-d) steps were repeated for preset temperature values of 38ºC and 45˚C. Finally the system was turned off.

Results and discussion

1. Effect of Al_2O_3 Addition

Figure (6) depicts the polarization curve of atomized sample of base alloy 7020. The corrosion behavior of aluminum alloy matrix composites significantly varies with the different volume fraction of Al_2O_3 particles as shown in Figure (7). By considering the results of the corrosion tests for the selected materials in 3.5% NaCl solution, it is observed that the trend of the composite materials with the 5wt%, 7wt% and 10wt% Al_2O_3 particles is towards slightly higher corrosion rates or higher icorr than that of the aluminum alloy matrix. The reasons behind the occurrence of corrosion in composite materials can be in terms of; Galvanic coupling between the reinforcement (Al_2O_3 particles) and matrix, selective corrosion at the reinforcement/ matrix interface, and the corrosion of matrix defects arising from composite preparation. When the reinforcement material is an electrical insulator, such as alumina or silicon carbide, there would be a little or no galvanic reaction with the aluminum matrix.

However, during preparation of AMCs, a reaction between the reinforcement material and the metal matrix occurs, forming an interfacial phase which binds the two materials together. When the interfacial phase is strongly anodic or cathodic, preferential corrosion may occur. Despite the non-conductive nature of the Al_2O_3 particles, their cathodic currents are slightly larger than that of the unreinforced matrix alloy. Winkler and Flower [7] have attributed this phenomenon to the presence of some interfacial material at the Al_2O_3/matrix interface. When the AMCs and base alloy are immersed in 3.5% NaCl solution at room temperature, small pits were formed on all the specimens. Further, it was noticed that the pit growth becomes faster on all the AMCs in comparison to the unreinforced alloy. This feature is apparently due to the formation of crevices between the reinforcement material and the matrix generated by the dissolution of the matrix at the pits.

2. Effect of the Solution Temperature:

The effects of the solution temperature on the icorr of aluminum alloy matrix composites reinforced with 10% alumina particles are clearly illustrated in Figure (8).

Generally, the temperature elevation leads to an increase in corrosion rate. This phenomenon is due to combined effect including the dependence of reaction kinetics on temperature and the higher diffusion rate of many corrosive by-products over increasing temperatures. The above observation could also involve some exceptions. One is the increase in solution temperature reduces the oxygen content of the solution. Other exceptions arise where a moderate increase in temperature results in the formation of a thin protective film on the surface of the metal or in passivity. Guo, and Colleagues [11] reported, in their study on 2024 T3 aluminum alloy, that the corrosion rate increases with temperature elevation.

3. Corrosion Locations

Figures (9) (a) and (b) illustrate the atomized base alloy before and after corrosion test respectively. As seen from these Figures, one can report that the corrosion location exist at the grain boundaries and also the observation by optical microscope showed an appearance of general corrosion has the main characteristic feature of the prepared atomized structures. Observations are valid to the atomized AMC_S as demonstrated in Figures (10) (a) and (b).

Conclusions

1-Corrosion rate is enhanced as the Al_2O_3 percentage is increased in the atomization techniques.

2-Corrosion rate was found to increase as the temperature was nominally raised.

3-Observation by optical microscope showed an appearance of general corrosion has the main characteristic feature of the prepared atomized structures.

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Table (1) Standard and measured values of chemical composition of alloy7020.

Element wt%	Zn	Mg	Cu	Si	Mn	Zr+Ti	Cr	Fe	Al
Standard value	4.5	1-1.4	0.2	0.35	0.05-0.5	0.08-0.25	0.1-0.35	0.4	Re
Measured value	4.6	1.3	0.3	0.25	0.1	0.13	0.2	0.7	Re

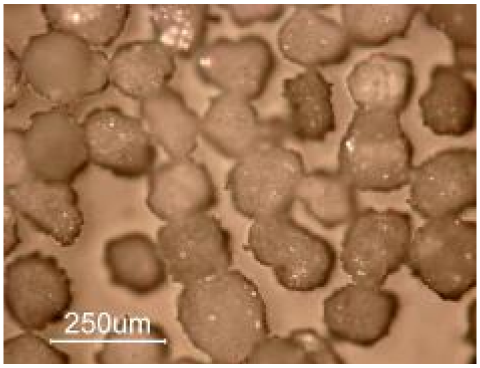

Figure (1) An optical micrograph of The Al_2O_3 powder (380x)

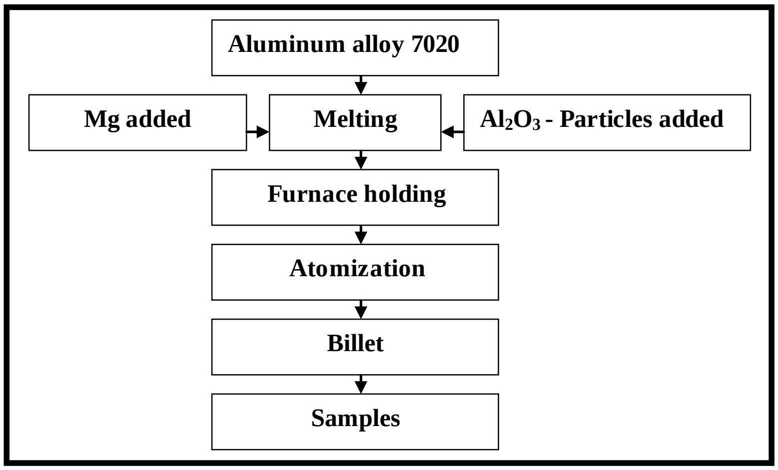

Figure (2) Flow chart of preparation procedures for atomization AMC_S

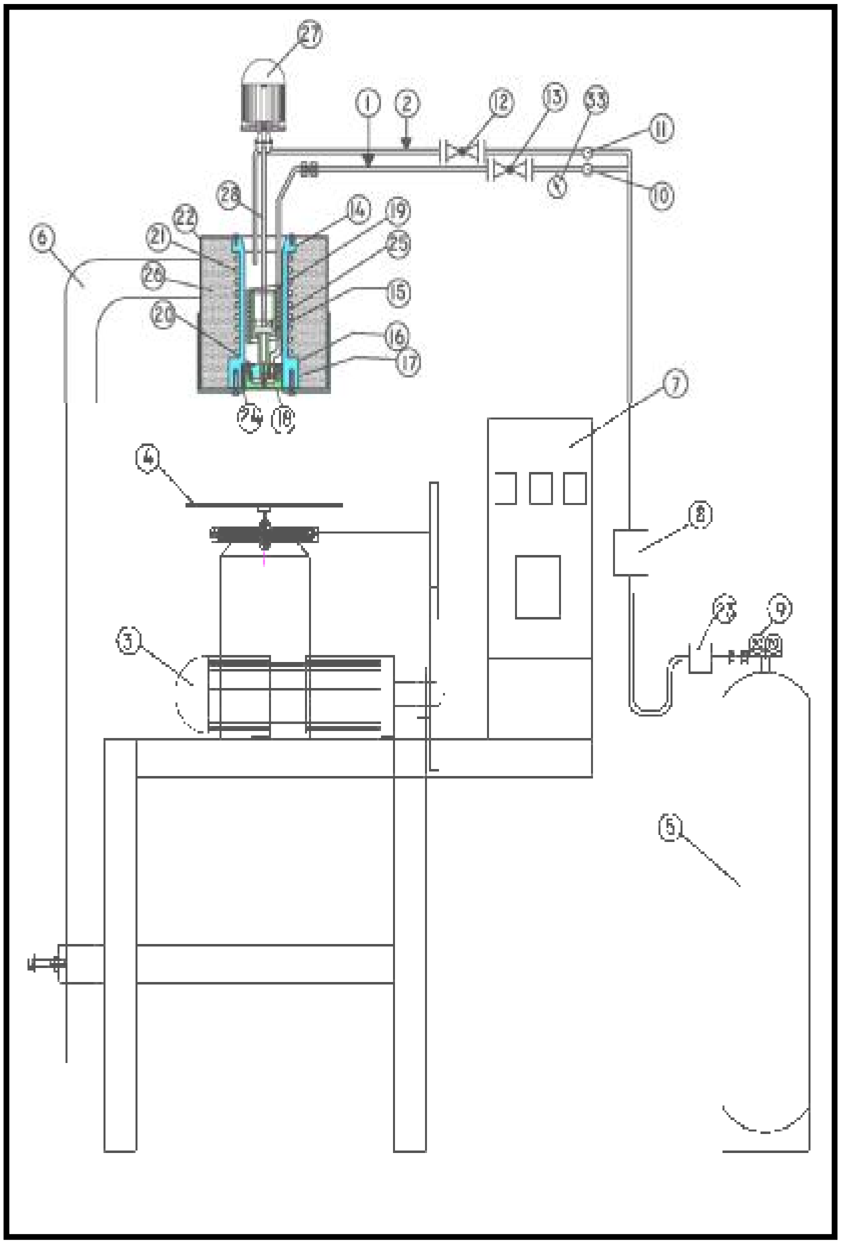

Figure (3) 1. N_2 Gas to nozzle, 2. N_2 Gas to furnace, 3. Gearbox, 4. Rotating substrate, 5. N_2 Cylinder, 6. Furnace holder, 7. Control panel, 8. Dryer, 9. Regulator, 10. Flowmeter, 11. Flowmeter, 12. Valve, 13. Valve, 14. Furnace, 15.Crucible, 16. Nozzle, 17. Lower flange,18. Plate, 19. Coil, 20. Upper flange, 21. Heater, 22. Galv-plate, 23. Oil trap, 24. Thermocouple, 25. Blade, 26. Kaol, 27. Mixer, 28. Shaf

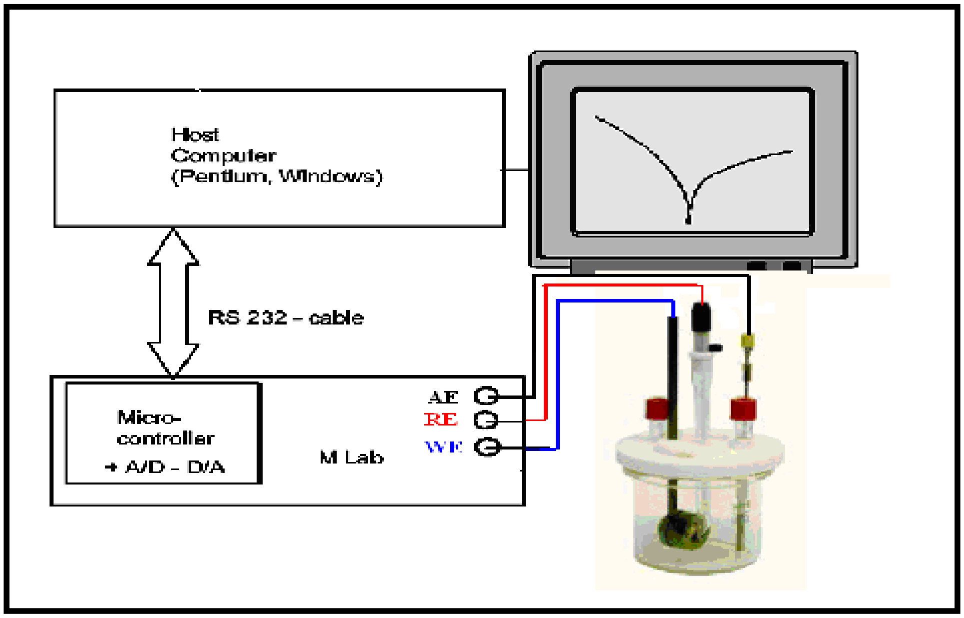

Figure (4) Schematic diagram of the electrochemical corrosion unit.

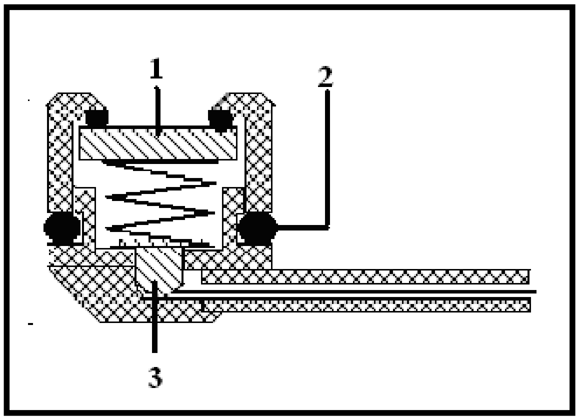

Figure (5) The sample holder (1.Sample, 2.Seal, 3.Electrical connection)

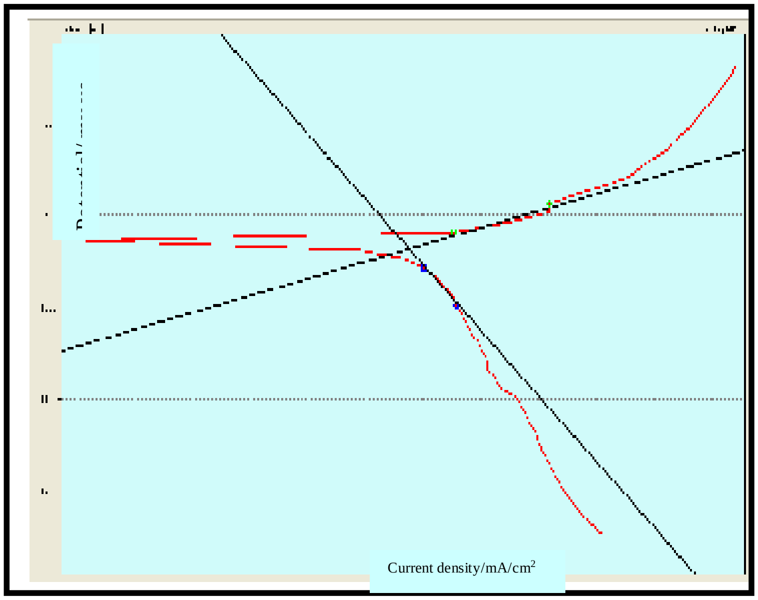

Figure (6) Polarization curve of atomized base alloy 7020 in 3.5% NaCl solution.

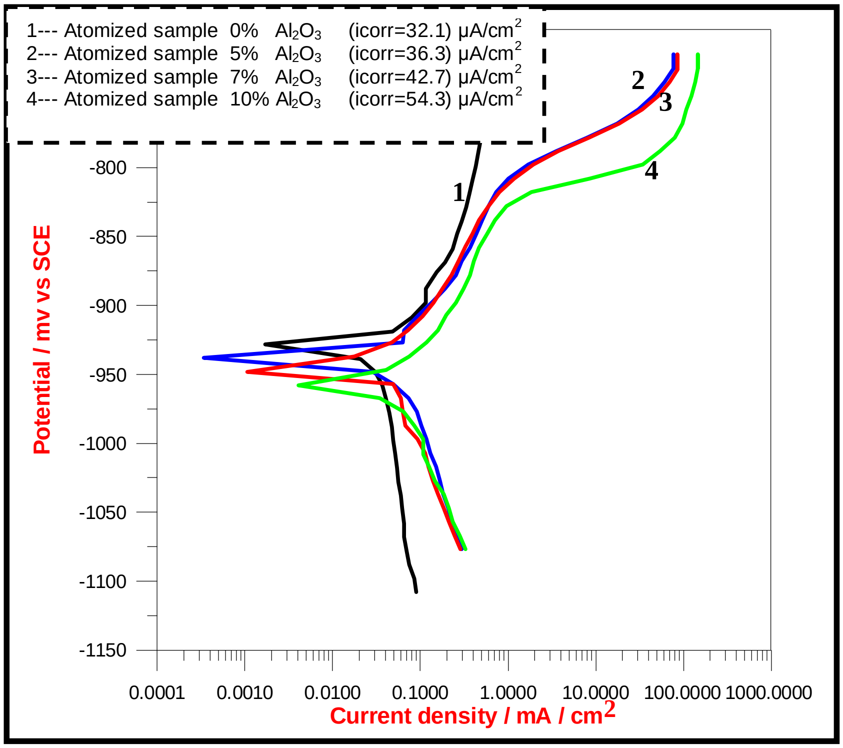

Figure (7) Effect of Al_2O_3 addition on icorr of AMC_S samples in 3.5% NaCl solution at temperature 30°C.

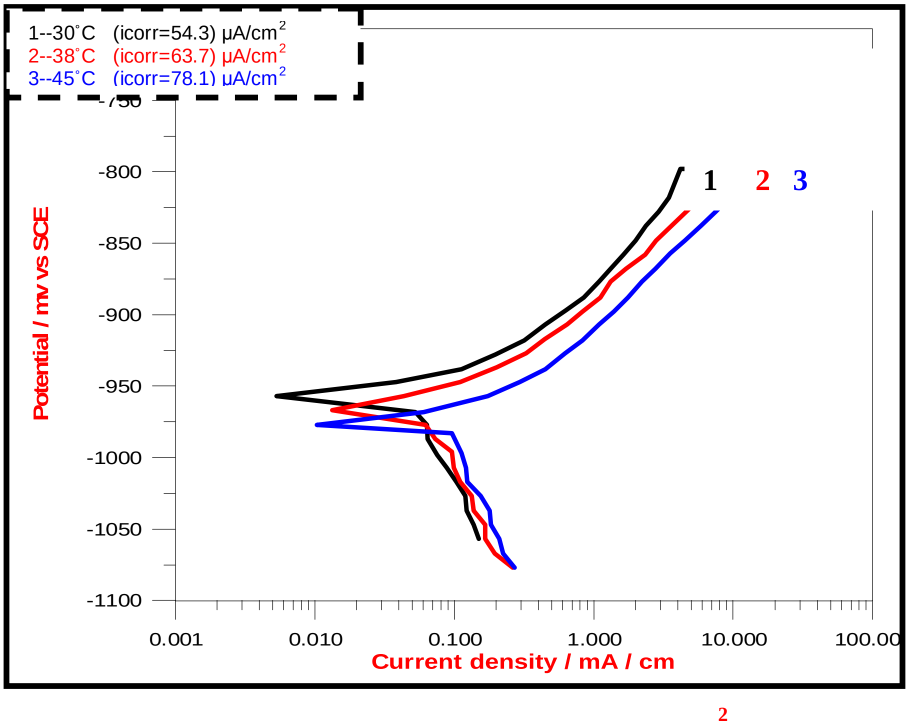

Figure (8) Effect of solution temperature on icorr of 10wt% atomized AMC$_S$ sample in 3.5% NaCl solution.

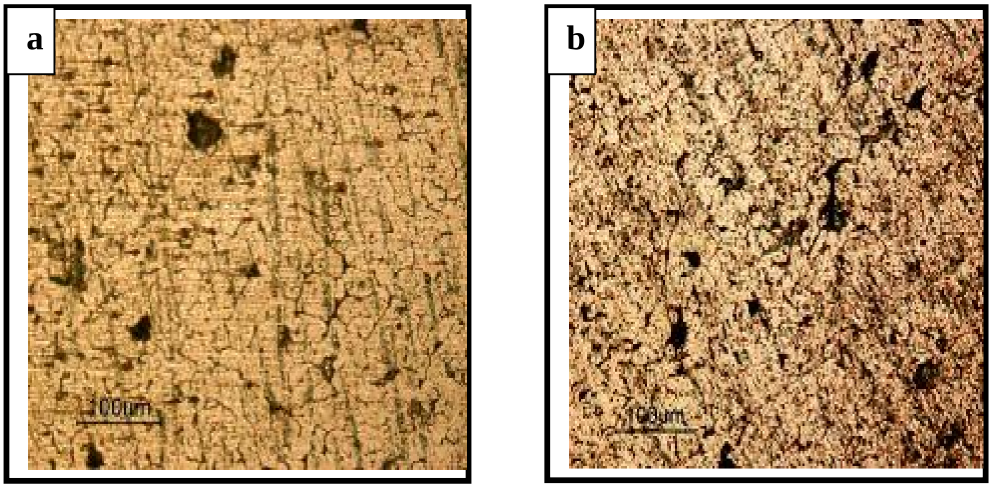

Figure (9): Photographs of (a) Atomized samples before corrosion (200x). (b) Atomized samples after corrosion (200x) in 3.5% NaCl solution.

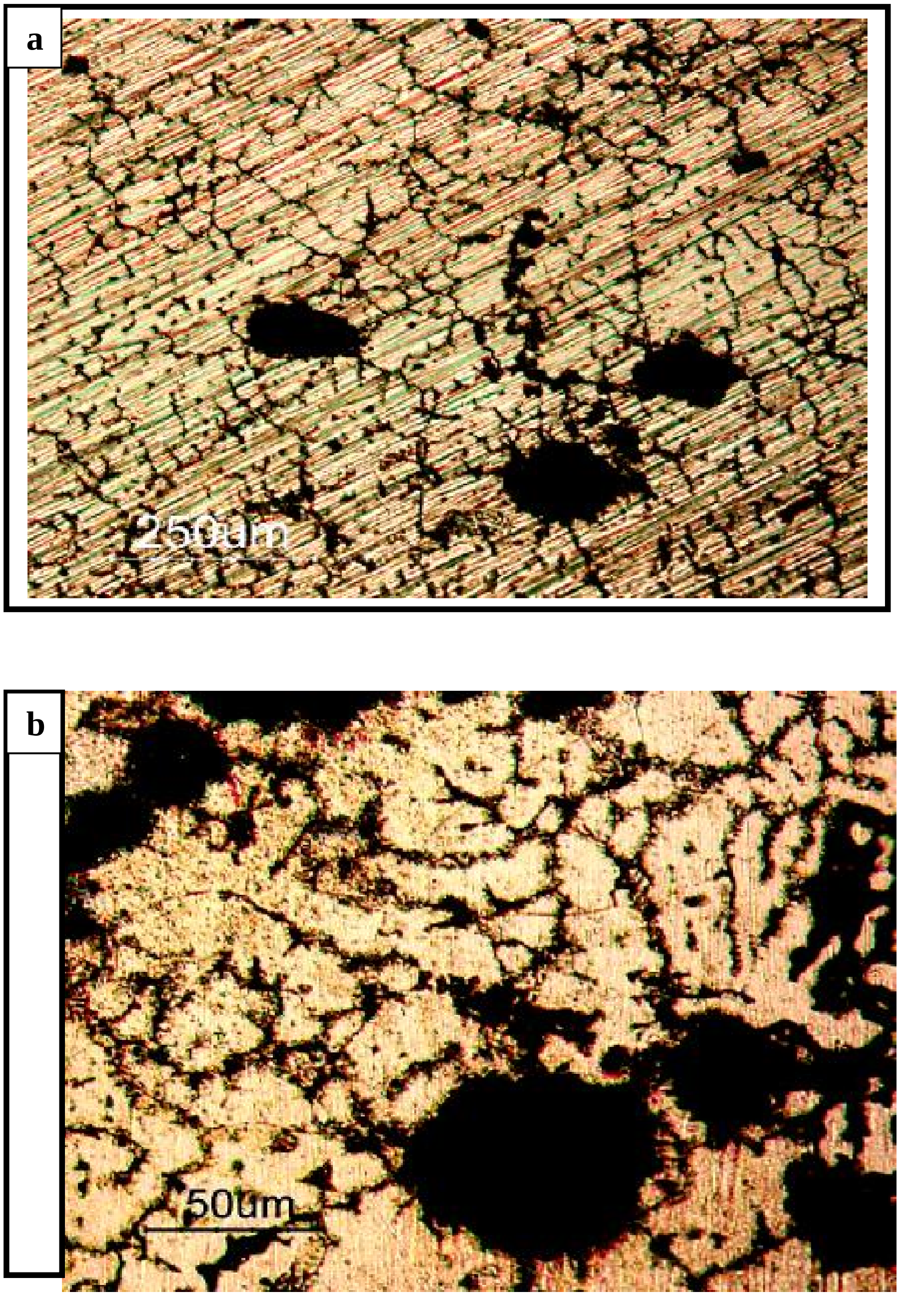

Figure (10) Photographs of ((a) Atomized AMC$_S$ samples before corrosion (200x)
(b) Atomized AMC$_S$ samples after corrosion (500x) in 3.5% NaCl solution.