Influence of Acidic and Salt Media on The Corrosion Behavior of Aluminum Matrix Composites Reinforced by Al_2O_3 Particles

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ABSTRACT:
   Corrosion behavior of pure Al and Al/ Al_2O_3 composite with five weight percent of Al_2O_3 particles (5,10,15,20 and 25) were investigated in 0.1M H_2SO_4 and 3.5 % NaCl solutions at room temperature. The composites were prepared by powder metallurgy and their corrosion behavior were evaluated by potentiostatic polarization and scan rate 3mV.sec^{-1}.
It's observed that pure Al/Al_2O_3 composites exhibited excellent corrosion resistance in NaCl medium than in the H_2SO_4 media. The pure aluminum exhibited slightly superior corrosion resistance than the composites in NaCl medium but the composites had better corrosion resistance in H_2SO_4 medium.
Insulator Al_2O_3 particles are perceived to act as inert material and degrade the integrity of the protective oxide layer on the Al matrix.
Al/Al_2O_3 composites have lower corrosion rate than pure aluminum in 0.1 M H_2SO_4, but increasing of wt% of alumina led to increase the corrosion rate. While in 3.5% NaCl solution can be seen that corrosion rate of pure aluminum less than that for composites. Generlly, For certain material, the corrosion rate in salt medium less than in acidic medium.

Keywords: Al/Al_2O_3 composites, Al_2O_3 particles, Powder metallurgy, potentiostatic measurements.

تأثير الأوساط الحامضية والملحية على سلوك التاكل للمواد المتراكبة ذات اساس المنيوم مقواة بدقائق الالومينا

الخلاصة

تم دراسة سلوك التاكل للالمنيوم النقي والمواد المتراكبة المنيوم- الومينا مدعمة بخمسة نسب وزنية مختلفة (5،10،15،20،25) في 0.1 مولاري من حامض الكبريتيك و 3.5% من كلوريد الصوديوم في درجة حرارة الغرفة.

تم تحضير المواد المتراكبة المعدنية بطريقة ميتالورجيا المساحيق وتم تقييم سلوكها التاكلي بالمجهاد الساكن عند
معدل مسح 3 ملي فولت لكل ثانية.
لاحظنا ان المادة المتراكبة ذات اساس المنيوم المقوى بالالومينا تبدي مقاومة تاكل جيدة في الوسط الملحي
(كلوريد الصوديوم) مقارنة مع الوسط الحامضي (حامض الكبريتيك). وقد تبين ان الالمنيوم النقي يبدي مقاومة
اعلى مقارنة مع المادة المتراكبة في الوسط الملحي لكن المادة المتراكبة كانت افضل مقاومة تاكل في المحلول
الحامضي من الالمنيوم النقي.
ان وجود المادة المقواة في المعدن الاساس تعمل على زيادة نسبة الكاثود الى الانود في المادة المتراكبة،
وبالنتيجة يتم تكوين النقر من خلال التاكل الموضعي. الفحص المجهري الضوئي للنماذج بيّن وجود النقر وتاكل
السطح.

INTRODUCTION

Metal matrix composites (MMCs) are engineered materials formed by the combination of two or more materials, at least one of which is a metal, to obtain enhance properties. MMCs tend to have higher strength/density and stiffness density ratio, compared to monolithic metals. They are also tending to perform better at higher temperatures, compared to polymer matrix composites. Aluminum and magnesium are lightweight materials,
when compared to iron and steel [1].

Metal matrix composite (MMC) is normally fabricated using a ductile metal (e.g., Al, Ti or Ni) as the base material, which is reinforced by ceramic (e.g., alumina, SiC, or graphite). Combining the metallic properties such as good ductility and toughness of the matrix with ceramic properties such as high strength, hardness and elastic modulus of the reinforcement, the composites exhibiting good wear resistance can be obtained. Consequently, they have extensities interest from defence, aerospace and automotive industries and have become very promising materials for structural applications as well. Particulate reinforced MMCs are promising because of their homogenous and isotropic material properties, low cost and ability to be formed using conventional metal processing techniques. Among the many ceramic reinforcements SiC has been found to be excellent capability with the Al-matrix [2-4].

Aluminum matrix composites (AMCs) exhibited better resistance to mechanical wear than their alloy. One of the main disadvantages in used the metal matrix composites is the influence of reinforcement on corrosion rate. This is particularly important in aluminum alloy based composites, where a protective oxide film imparts corrosion resistance. The addition of a reinforcing phase could lead to discontinuities in the film, thereby increasing the number of sites where corrosion can be initiated and making the composites more susceptible for corrosion in salt medium [5].
Zuhair studied corrosion behaviour of $6061/Al_2O_3$ composite with two volume fraction of reinforced were examined in 3.5% NaCl. He observed that the number of pit sites appears to increase with volume fraction of the reinforcement [6].

Amar studied corrosion behavior of aluminum alloy matrix reinforced by alumina composite in 3.5% NaCl, 1%HCl & 2.5% HCl. He observed that the corrosion rates increased with the increase in the concentration of acid, the corrosion rates were higher in acid medium than salt medium [7].
Corrosion resistance of metal matrix composite is a subject of study to be discussed in order to compare their corrosion resistance towards corrosive environment and some studies have reported based on effect of heat treatment to the corrosion

behavior. Some work on the mechanical properties and corrosion behavior reported [S.B.Jamaludin and et al. 2008] [8].

The aim of this work

This work involves study the corrosion behavior of Al/Al$_2$O$_3$ composites with five wt% of alumina (5,10,15,20 and 25) and compared their behavior with pure aluminum in 0.1M H$_2$SO$_4$ and 3.5% NaCl media by potentiostat and at scan rate 3 mV.sec^{-1}. Optical microscope were carried out to identify the corroded surface.

Experiment procedure:

Materials selection

Pure Aluminum with grain size 53 µm obtained from (Riedel – de Hean AG) was used in this work.

Reinforcement

Al$_2$O$_3$ A.R. Grad was obtained from (BDH chemicals LTD pool England) used as reinforcement with grain size 53 µm.

Composite preparation

The composites examined in this study were fabricated by using powder metallurgy technique.

α- alumina particles were added to aluminum powder in different weight percents (5,10,15,20&25) using Satorius electronic balance with an accuracy of ± 0.1 mg. The powder were mixed manually.

Mixed powders according to the above weight percentages were pressed at (300 MPa) using hydraulic press. Die wall lubrication was applied by brushing a thin layer of graphite powder over die cavity and the top punch, Fig. (1) shows the compaction press used in the research. Sintering was carried out at 600°C for 3 hrs. In the furnace and slow cooling until reached room temperature in an argon atmosphere as show in Fig. (2).

Figure (1) Compaction press used in the research.

Figure (2) Furnace used for sintering with argon gas.

Specimen Preparation for corrosion measurment

Mounting

The mounting process was performed by using XQ-2B mounting press, where the specimen was placed with phenolic resin in mold and heated up to 140°C under

pressure of 3500 – 4000 psi, for 5 – 10 minutes. For electrochemical studies, suitable provision was made on the other side for electrical contact.

Grinding and Polishing

The mounted specimens were ground with SiC emery papers in sequence of 400, 600, 800, 1000, and 2000 grit to get flat and scratch- free surface.
The specimens were polished using polish cloth and alpha alumina 0.5µm and 1µm, and then washed with distilled water. The polished specimens were degreased with acetone, dried and used for microstructure evolution and electrochemical investigation.

Polarization Test

All experiments were carried out using a three electrode cell with saturated calomel electrode (SCE) as reference, platinum electrode as counter electrode and the cylindrical specimens of the alloy with active flat disc of (0.78 cm^2) as the working electrode. The SCE was connected via Luggin capillary, the tip of which was held very close to the surface of the working electrode to minimize the IR drop. Open circuit potential (OPC) measurements were recorded for 15 minutes, the time necessary to reach quasi stationary state for open circuit potential, Followed by polarization measurements at a scan rate of 3 mV/s for Tafel plots.
Fig. (3) shows the experimental arrangements for electrochemical measurement.
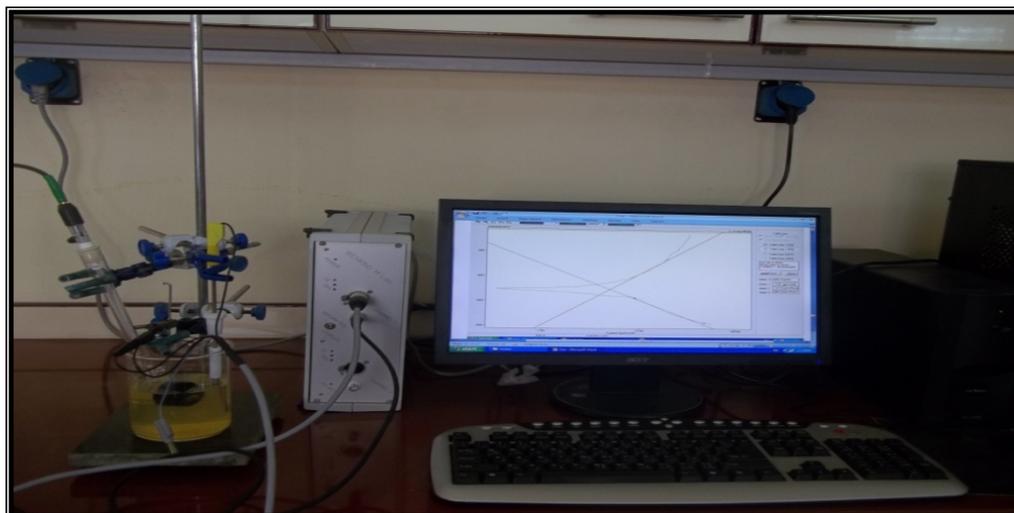

Figure. (3):experimental arrangements for electrochemical measurement.

Optical Microscopic

The specimens were etched by etchant reagent used for aluminum (killers' reagent (composition: 95ml water, 2.5ml HNO₃, 1.5ml HCL, 1.0ml HF)), the regent stay on the specimen surface for 10 second then clean by water and dry.

Results and Discussion
Corrosion Behavior in 0.1 M H₂SO₄ solution

The corrosion parameters of pure aluminum and its composites in 0.1 M H_2SO_4 are given in Table 1 . The corrosion current density i_{corr}, decreases with increase of Al_2O_3 content in the composites, corroborating the results that reinforcement with Al_2O_3 does influence and increase the corrosion rate of the aluminum matrix.

Table (1) Corrosion parameters of pure aluminum and its composites in 0.1 M H_2SO_4

Composite Al/Al_2O_3	0.1 M H_2SO_4		
	i_{corr} (A/cm^2)	E_{corr} (mV)	Corrosion Rate (mpy)
0%	654.14×10^{-6}	-335.9	280.31
5%	0.0061×10^{-6}	-585.3	0.0026
10%	27.34×10^{-6}	-958.5	11.71
15%	133.71×10^{-6}	-542.1	57.29
20%	190.26×10^{-6}	-874.3	81.52
25%	213.07×10^{-6}	-877.3	91.30

Polarization curves for pure Al and its Al_2O_3 composites, are shown in Figures (4) to (9). The composites however, had better resistance to corrosion   in 0.1M H_2SO_4 solution in comparison with the unreinforced matrix possibly due to the inhomogeneous structure of an aluminum metal matrix composite which must be considered in designing a corrosion protection system.
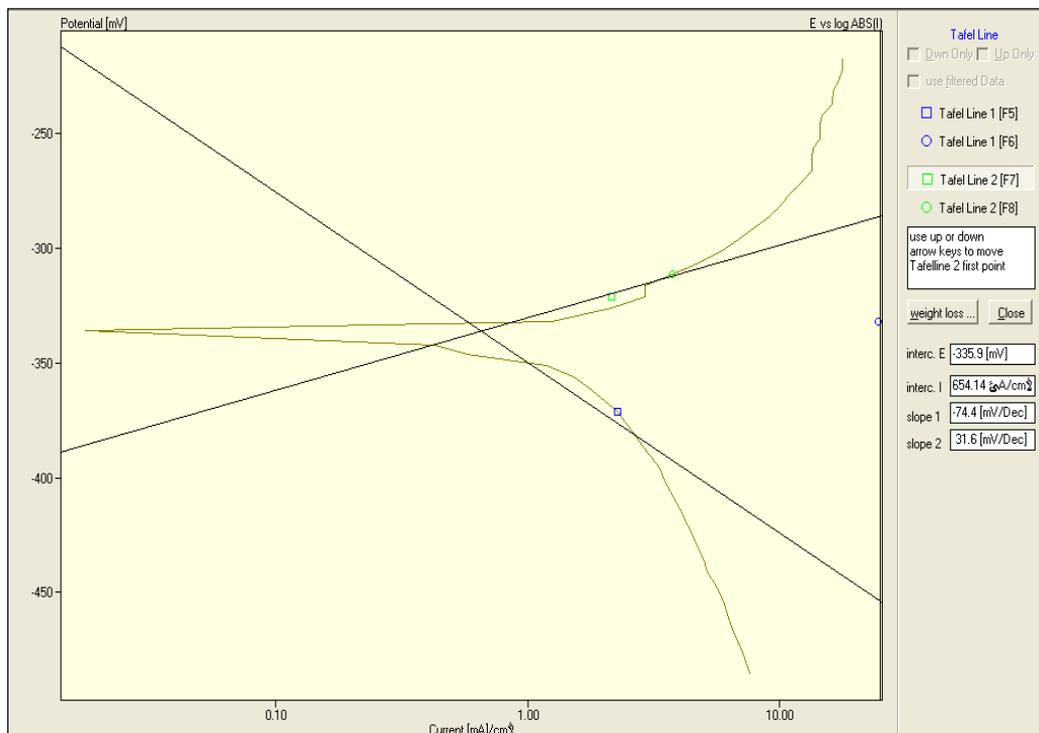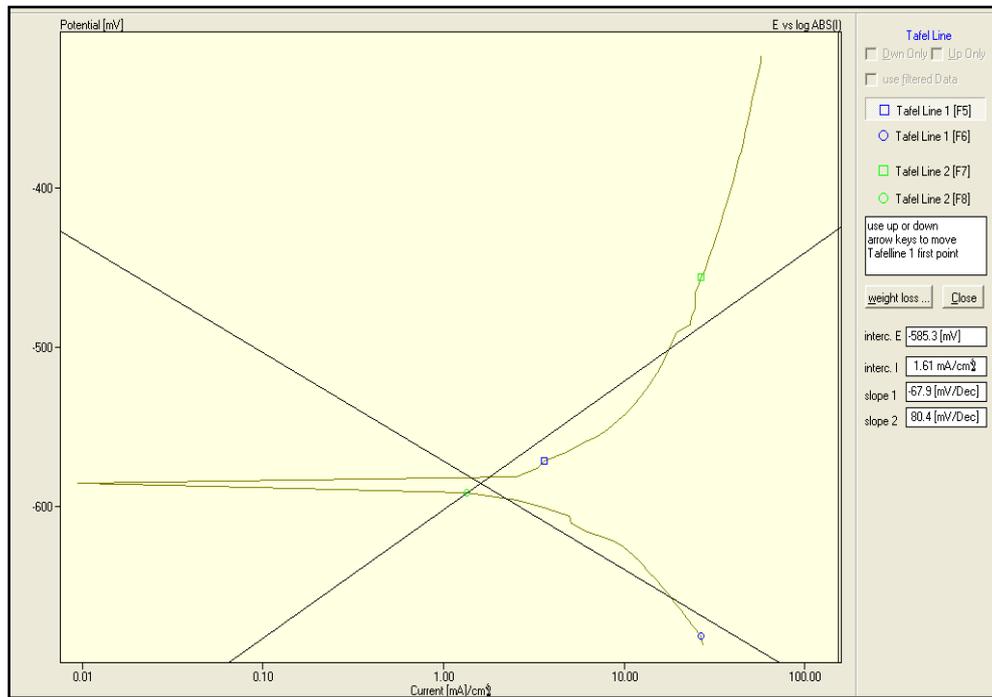

Figure.(4) Polarization curves for pure Al in 0.1 M H_2SO_4.

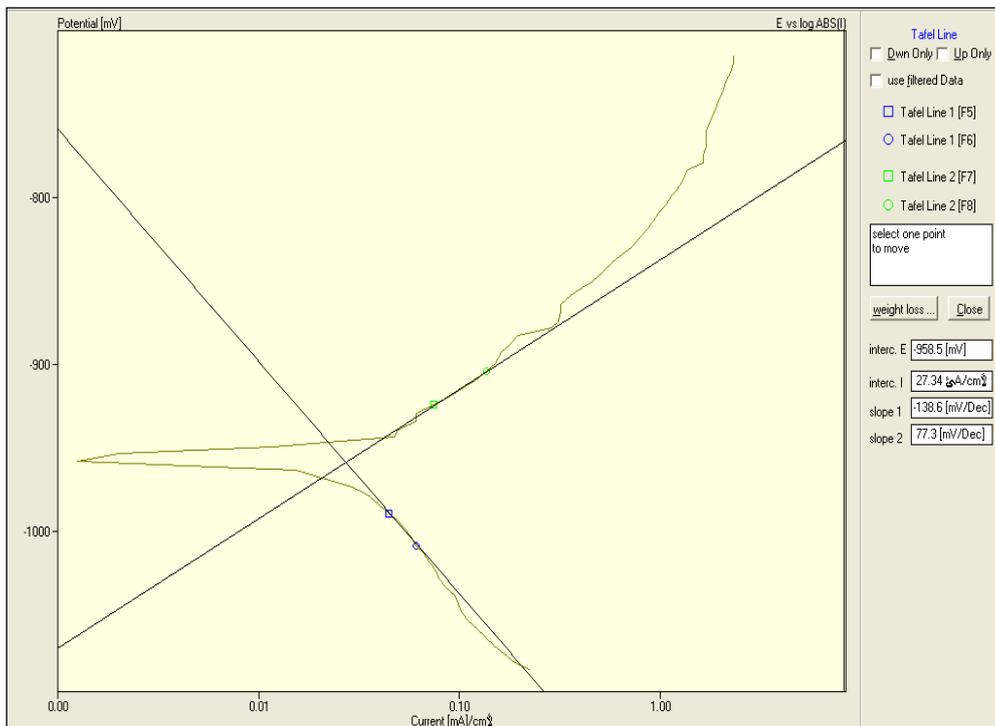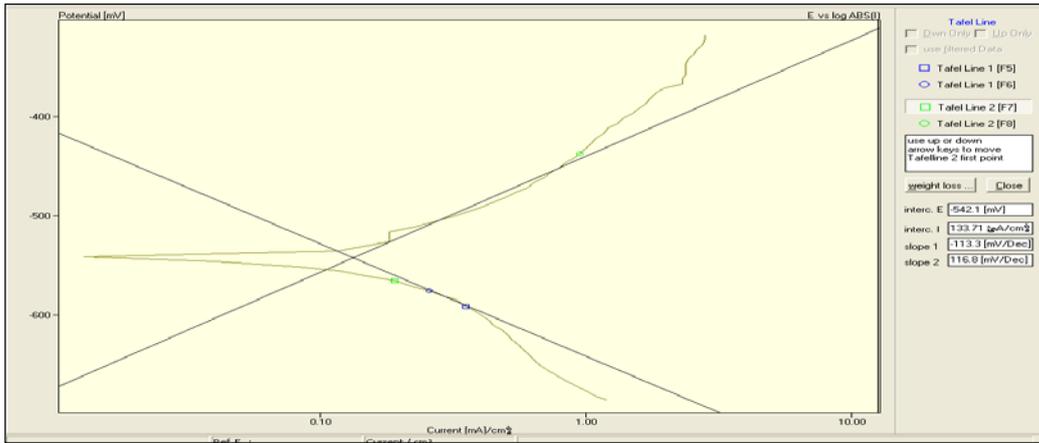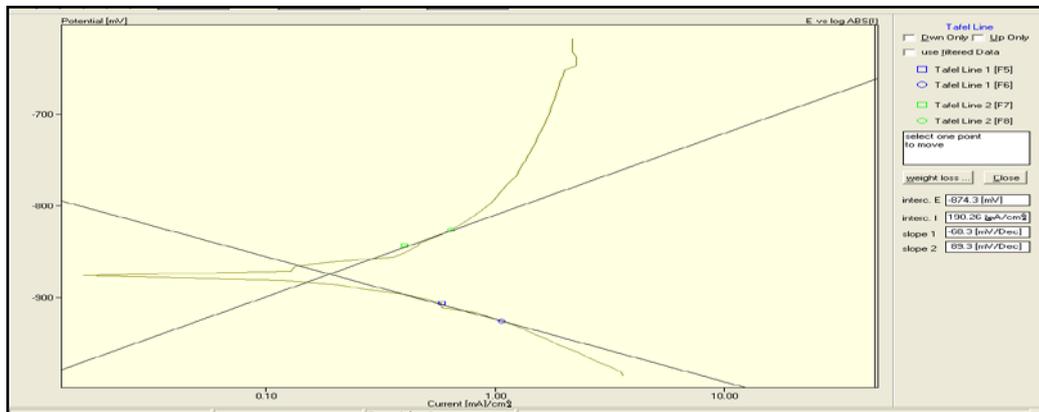**Figure.(5) Polarization curves for pure Al /5%Al₂O₃ in 0.1 M H₂SO₄.**

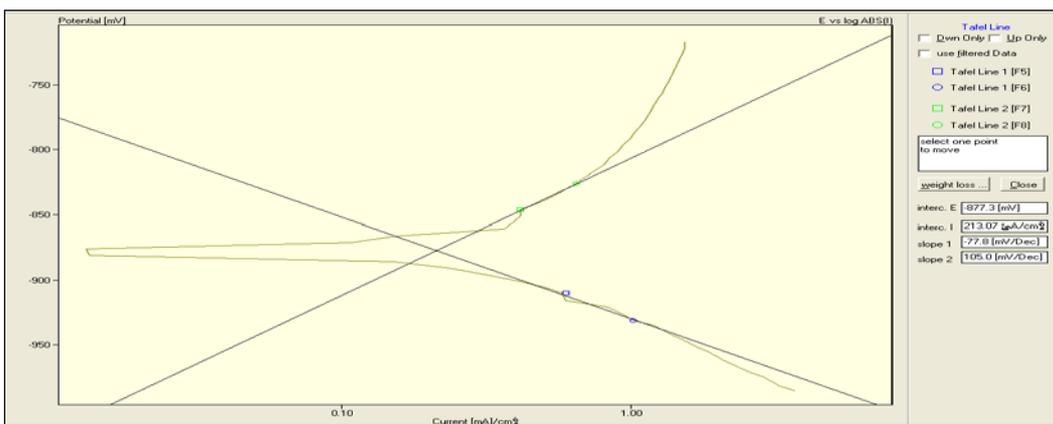**Figure.(6) Polarization curves for pure Al /10%Al₂O₃ in 0.1 M H₂SO₄.**

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Fiureg.(7) Polarization curves for pure Al /15%Al$_2$O$_3$ in 0.1 M H$_2$SO$_4$.

Fig.(8) Polarization curves for pure Al /20%Al$_2$O$_3$ in 0.1 MH$_2$SO$_4$.

Figure.(9) Polarization curves for pure Al /25%Al$_2$O$_3$ in 0.1 M H$_2$SO$_4$.
3.2 Corrosion Behaviour in 3.5wt% NaCl Solution.

The evaluated corrosion parameters for the pure aluminum and the composites in 3.5% NaCl are given in Table 2.

Table (2) Corrosion parameters of pure aluminum
and its composites in 3.5% NaCl

Composite Al/Al$_2$O$_3$	3.5% NaCl		
	i_{corr} (A/cm^2)	E_{corr} (mV)	Corrosion Rate (mpy)
0%	0.0012×10^{-6}	-583.6	0.00051
5%	0.0015×10^{-6}	-266.3	0.00064
10%	0.0091×10^{-6}	-341.1	0.0038
15%	1.57×10^{-6}	-278.2	0.6727
20%	5.01×10^{-6}	-451.9	2.1468
25%	113.02×10^{-6}	-521.8	48.431

It can be observed from the Tafel plots Fig.s (10) to (15) and Table (2) that the corrosion current density (i_{corr}) values and the corrosion rate increase with increase in Al$_2$O content in the composites.
This observation is similar to the findings of Trzaskoma et.al in Al-Al$_2$O$_3$ composites [9], where the composites exhibit reduced corrosion resistance, compared to the matrix alloy.
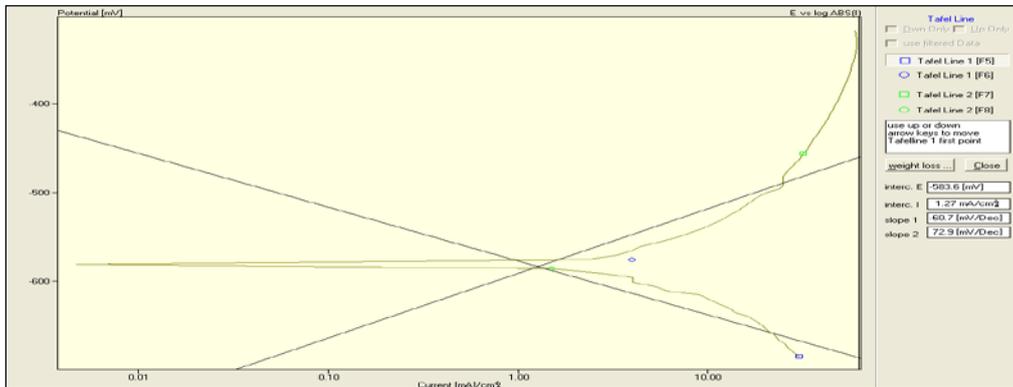

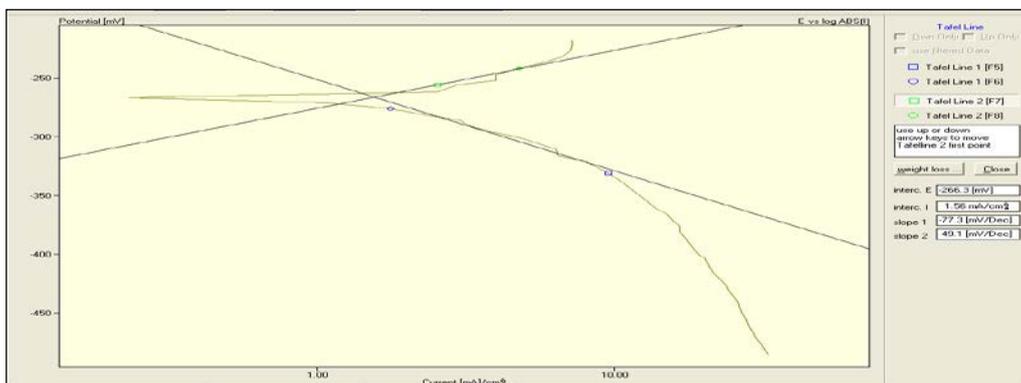**Figure.(10) Polarization curves for pure Al in 3.5% NaCl.**
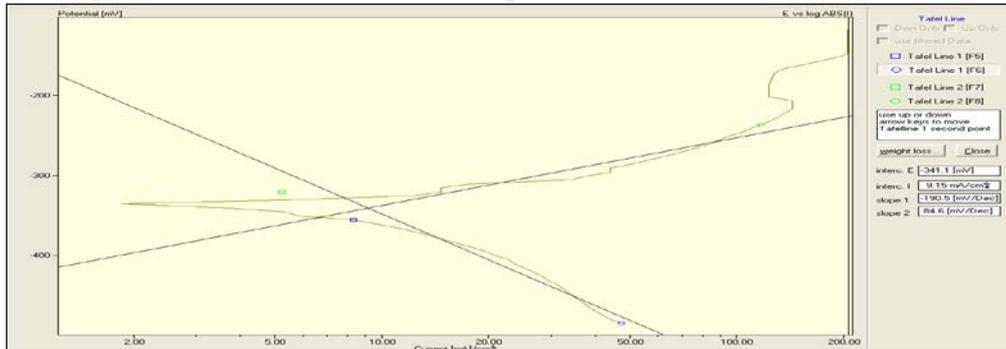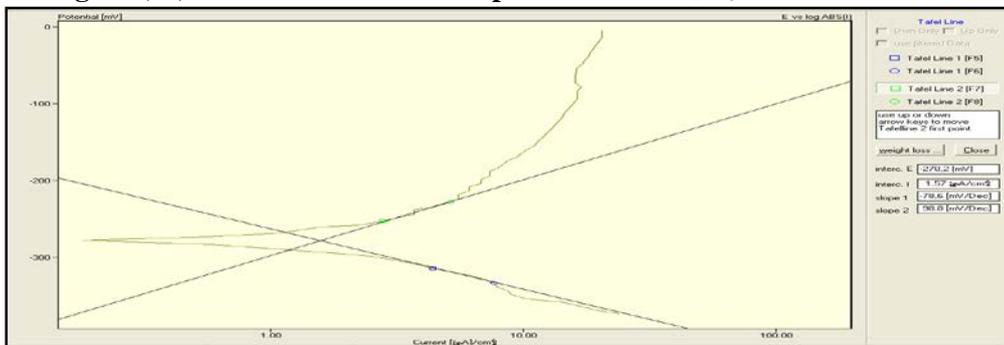
Figure.(11) Polarization curves for pure Al /5%Al$_2$O$_3$ in in 3.5% NaCl.

Figure.(12) Polarization curves for pure Al /10%Al$_2$O$_3$ in in 3.5% NaCl.

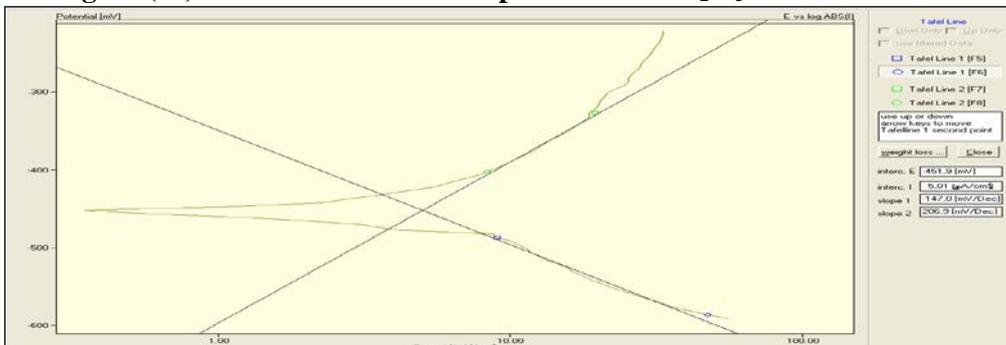**Figure.(13) Polarization curves for pure Al /15%Al$_2$O$_3$ in in 3.5% NaCl.**

Figure.(14) Polarization curves for pure Al /20%Al$_2$O$_3$ in in 3.5% NaCl.
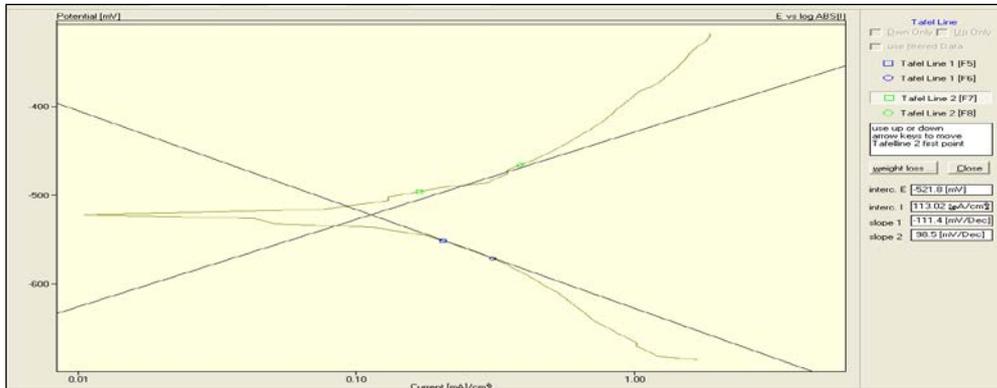
Figure.(15) Polarization curves for pure Al /25%Al₂O₃ in in 3.5% NaCl.

Microstructure

The microstructure of as polished pure Al and Al/Al₂O₃ composites with (5,10,15,20 and 25) weight percentage before corrosion are shown in Fig.16 . Etching in Keller's reagent did not reveal additional contrast.

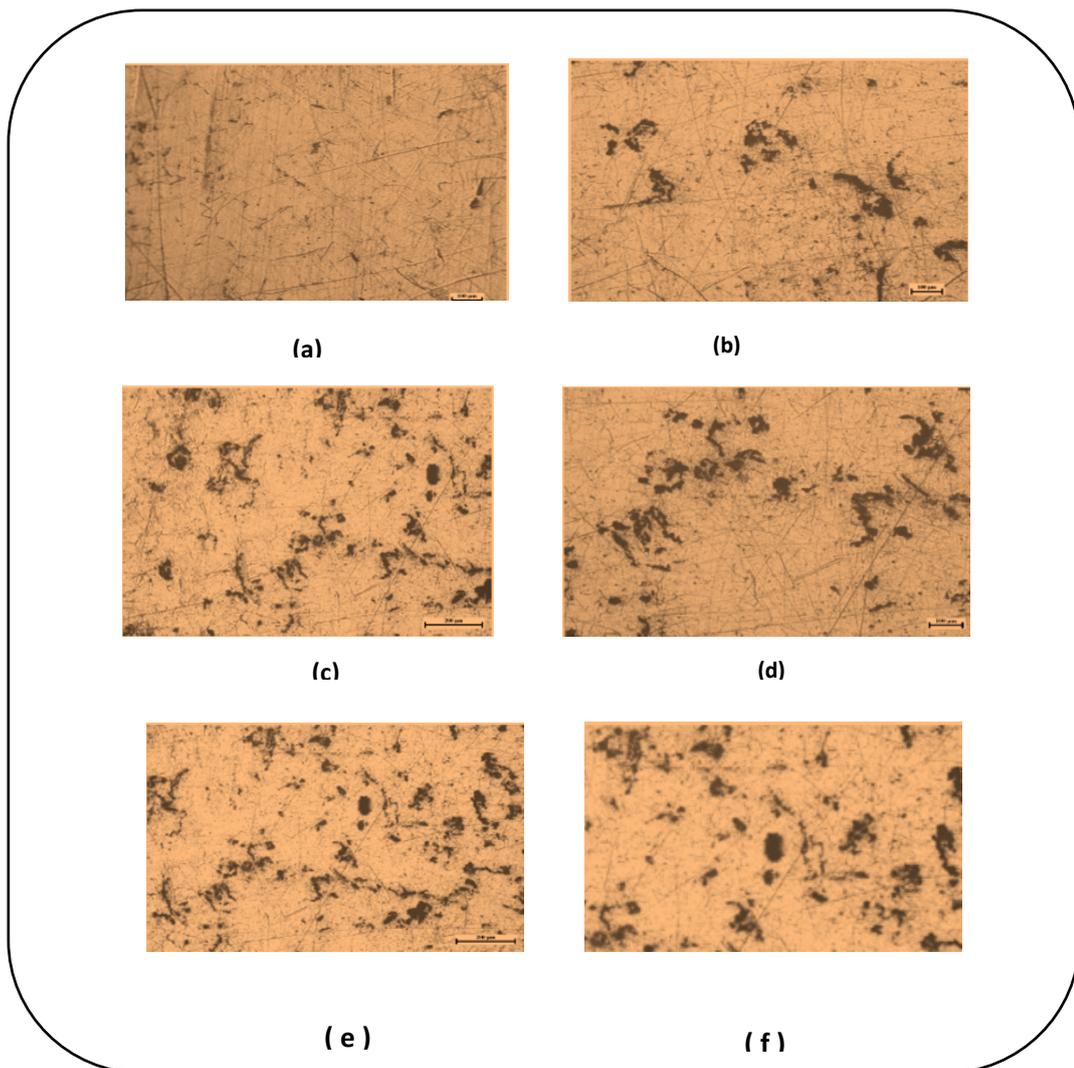Alumina particles appear darker than the aluminum matrix.

(a)

(b)

(c)

(d)

(e)

(f)

Figure. 16 Optical microscopic images(X100) show alumina particles before corrosion at different weight percent of Al$_2$O$_3$ particulates in Al- matrix, a) 0% wt   b) 5% wt   c) 10% wt   d) 15% wt   e) 20% wt   f) 25% wt

Figures 17 and 18 show microstructure of pure Al and its composite after corrosion in H$_2$SO$_4$ & NaCl solutions respectively.

The specimens showed non – uniform corrosion and pitting corrosion. From the result of microstructure examination it is observed more pits in corroded specimens in acid than corroded specimen in salt, the composite material exhibit more pits than pure Al.

Deep pit (anode

Local cathod

(a)   (b)   (c)   (d)   (e)   (f)
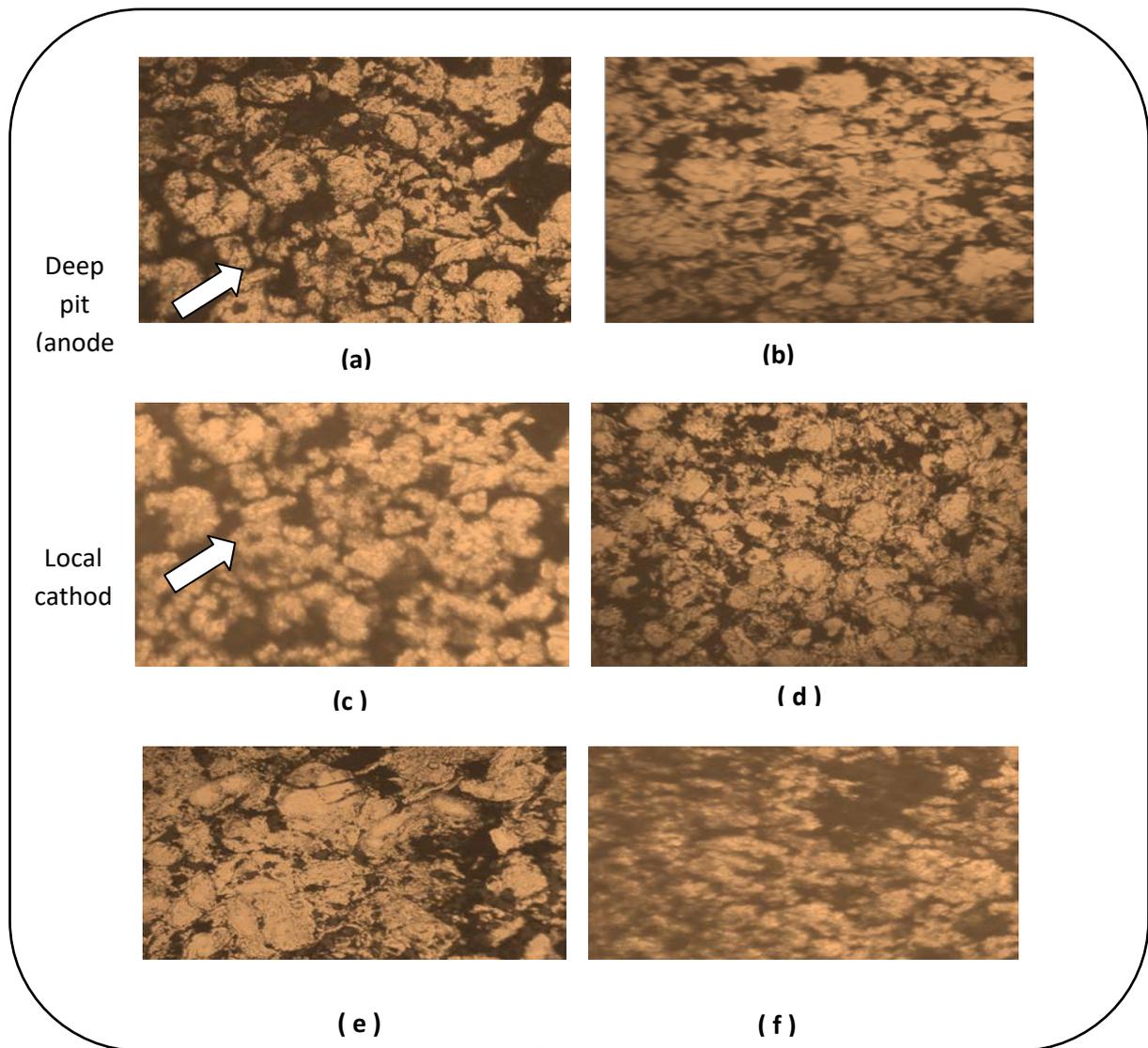
**Figure. 17 Optical microscopic images (X100) show alumina particles after corrosion in
0.1 M H$_2$SO$_4$ at different weight percent of Al$_2$O$_3$ particulates in Al- matrix,
a) 0% wt   b) 5% wt   c) 10% wt   d) 15% wt   e) 20% wt   f) 25% wt**
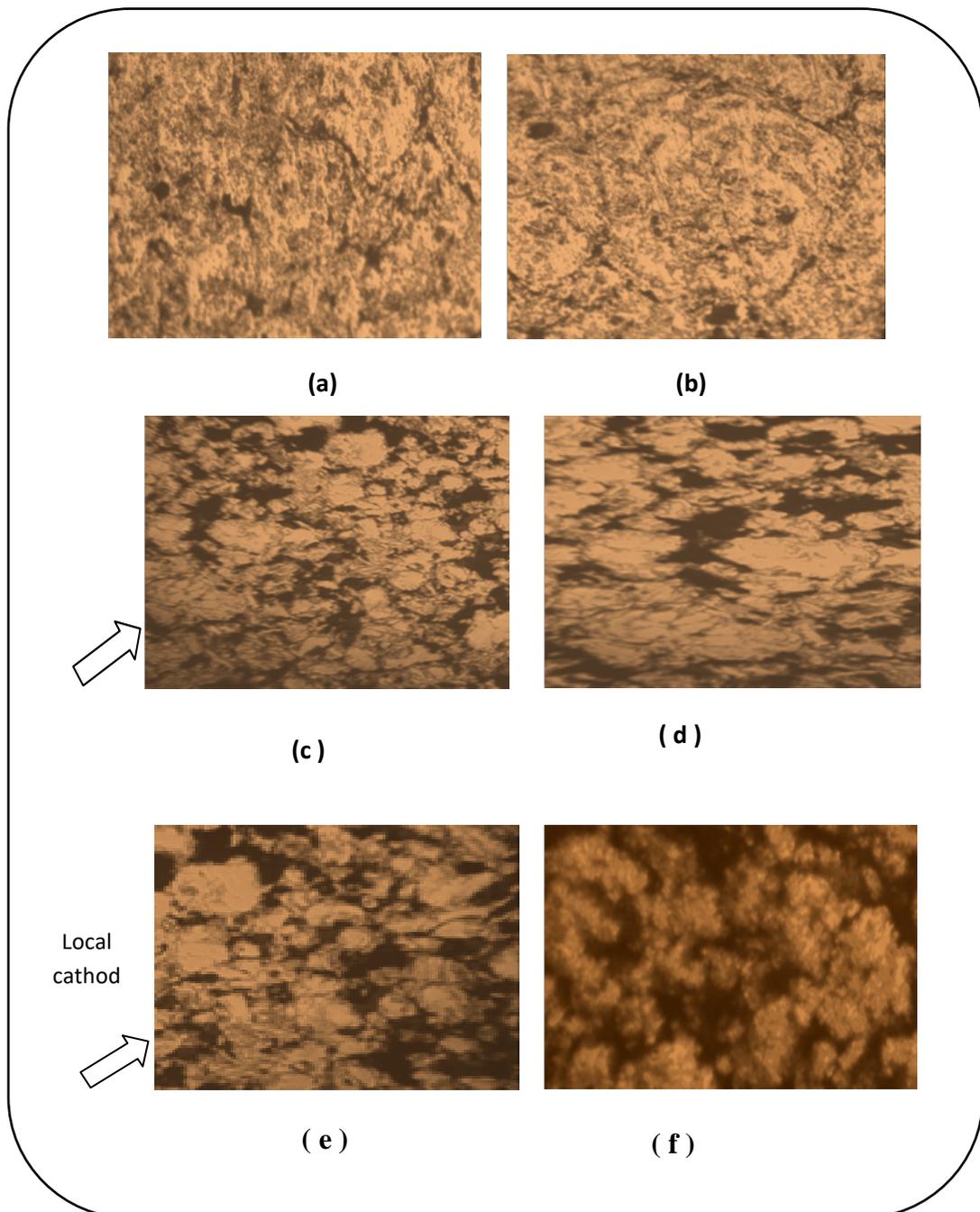
Local
cathod   Deep pit
(anode)

Figure. 18 Optical microscopic images (X100) show alumina particles after corrosion in 3.5% NaCl at different weight percent of Al$_2$O$_3$ particulates in Al- matrix, a) 0% wt   b) 5% wt   c) 10% wt d) 15% wt   e) 20% wt   f) 25% wt

Conclusions

The corrosion behavior of unreinforced pure Al and Al$_2$O$_3$ particulate – reinforced composites (0,5,10,15,20 & 25% by weight) in various media H$_2$SO$_4$ & NaCl has been investigated using potentiostatic polarization technique.

Results of our investigation point out to the following:

1.The Al/ Al$_2$O$_3$ composites exhibited lower corrosion rates in 0.1 M H$_2$SO$_4$ solution than the pure Al.

2. From the results, It is observed that Al/ Al$_2$O$_3$ composites exhibited excellent corrosion resistance in NaCl medium than in the H$_2$SO$_4$ medium.

3. The unreinforced pure Al exhibited slightly superior corrosion resistance than the composites in NaCl media but the composites had better corrosion resistance in H$_2$SO$_4$ media.

4. Corrosion current values (i_{corr}) increase with increase in Al$_2$O$_3$ content in the composites for acidic and salt media.

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