KUFA JOURNAL OF ENGINEERING
ISSN 2071-5528
PRINTED IN IRAQ

Volume 3, Number 2 pp.69- 85 , 2012

Microbiologically Influenced corrosion of Aluminum Alloy by Pseudomnas Aeruginosa Bacteria

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(Received:15/4/2011 ;Accepted :22/2/2012)

Abstract:

The aim of this paper was to study microbiologically influenced corrosion of aluminum alloy in the presence *Pseudomnas aeruginosa* bacteria. Control medium tap water (absence of *Pseudomnas aeruginosa* bacteria) and medium with presence *Pseudomnas aeruginosa* bacteria used in this study. Tafel extrapolation ,weight loss method ,microstructure examination and surface roughness test were carried out to determine the microbiologically influenced corrosion behavior of aluminum alloy. Microbiological analyses, isolation and identification by using appearance factors and biochemical test for biofilm of corrosion product used in this study.

Tafel extrapolation and weight loss method of aluminum alloy showed that the presence *Pseudomnas aeruginosa* bacteria caused corrosion and increasing corrosion current and rate of corrosion. Microstructure examination and surface roughness test showed that the presence *Pseudomnas aeruginosa* bacteria caused pitting corrosion. Microbiological analyses showed that biofilm are formed as micro colonies, which subsequently caused corrosion and shows the role of *Pseudomnas aeruginosa* bacteria in acceleration corrosion on aluminum alloy.

Key words: Microbiologically Influenced Corrosion, Corrosion, Bacteria, Biofilm, Microbiological analyses, Aluminum alloy.

التآكل المتأثر بالفعل الحيوي لسبيكة الألمنيوم باستخدام بكتريا *Pseudomnas aeruginosa*

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الخلاصة:

الهدف من هذا البحث هو دراسة التاكل المتاثر بالفعل الحيوي لسبيكة الالمنيوم بوجود بكتريا *Pseudomnas aeruginosa* . وسط للتحكم ماء حنفية (عدم وجود بكتريا *Pseudomnas aeruginosa*) ووسط مع وجود بكتريا *Pseudomnas aeruginosa* تم استخدامها في هذه الدراسة . اختبار تافل ، طريقة فقدان الوزن ، فحص طوبغرافية السطح و اختبار خشونة السطح نفذت لتقرير سلوك التاكل المتاثر بالفعل الحيوي لسبيكة الالمنيوم ، تحليل مايكرو بايولوجي باستخدام العزل والتشخيص باستخدام العوامل المظهرية وكذلك الفحوصات البايو كيمائية للغشاء الحيوي ناتج التكل تم استخدامها في هذه الدراسة.

اختبار تافل وطريقة فقدان الوزن بينت ان وجود بكتريا *Pseudomnas aeruginosa* سببت التاكل مع زيادة تيار التاكل ومعدل التاكل. فحص طوبغرافية السطح و اختبار خشونة بينت ان وجود بكتريا *Pseudomnas aeruginosa* سبب حصول التاكل النقري. تحليل مايكرو بايولوجي بينت تكوين غشاء حيوي كمستعمرات دقيقة والتي بعد ذلك تسبب التاكل، وبينت دور بكتريا *Pseudomnas aeruginosa* في تعجيل التآكل على سبيكة الألمنيوم.

الكلمات المرشدة: التآكل المتأثر بالفعل الحيوي، تأكل،بكتريا،الغشاء الحيوي،تحليل مايكروبايولوجي،سبيكة الألمنيوم.

Introduction :

The term microbiologically influenced corrosion (MIC) is usually interpreted as to indicate an increase in corrosion activity due to the presence of bacteria(S.C.Dexter,2003). Also known as microbial corrosion or biological corrosion , is the deterioration of metals as result of the metabolic of microorganism(Hector A.Videla & Liz K.Herrera,2005). There are about a dozen of bacteria known to cause microbiologically influenced corrosion of carbon steel, stainless steel, copper alloy and aluminum alloy, these bacteria can be broadly classified as aerobic requires oxygen to become active or anaerobic oxygen is toxic to the bacteria (C.U.Schwermer etal,2008 , D.Weismann & M.Lohse,2007). Pitting corrosion of integral wing aluminum fuel tanks in aircraft that use kerosene- based fuels has been a problem ,the fuel becomes contaminated with water by vapor condensation during variable – temperature flight conditions , attack occurs under microbial deposits in the water phase and at the fuel – water interface the organisms grow either in continuous mats or sludges or in volcano – like tubercules gas bubbling from the center (R.Donal &

P.Pradeep,2003). The organisms commonly held responsible are *Cladosporium* and *Desulfovibrio, Cladosporium* resinae is usually the principal organism involved ; it produce a variety of organic acids pH 3 to 4 or lower and metabolize certain fuel constituents (S.C.Dexter,2003).

Anexnic aerobic biofilms inhibit corrosion of copper and aluminum has been studied by A.Jayaraman etal 1999 (A.Jayaraman etal 1999), this study the first report of axenic aerobic biofilms inhibiting generalized corrosion of copper and aluminum. Pitting corrosion inhibition of aluminum 2024 by bacillus biofilms secreting polyaspartate had been presented by D.Ornek etal 2002 (D.Ornek etal 2002),pitting corrosion of aluminum 2024 in luria baertani medium was reduced by the secretion of anionic peptides by engineered and natural bacillus biofilms and was studied in continuous reactors using electrochemical impedance spectroscopy. Evaluation of microbiologically influenced corrosion inhibition (MICI) with EIS and ENA had been reported by A.Nagiub etal 2002(A.Nagiub etal 2002), MICI has been observed for Al 2024 ,mild steel and cartridge brass when an artificial seawater solution containing growth medium was contaminated by bacteria. New evidences on the catalase mechanism of microbial corrosion had presented by J.P.Busalmen etal 2002(J.P.Busalmen etal 2002), in this study changes on the oxygen reduction rate induced on aluminum brass by cell-free bacterial cultures of an isolated belonging to the genus pseudomonas were studied in relation to bacteria phase of growth and to the surface oxide layer composition after various electrochemical pre-treatments of the metal samples. Biocorrosion and biofouling of metals and alloys of industrial usage present state of the art at the beginning of the new millennium had been reported by H.A.Videla 2003(H.A.Videla 2003), in this study biocorrosion of aluminum and its alloys by fungal contaminants of jet fuels were studied. The importance of live biofilms in corrosion protection had been presented by Rongjun Zuo etal 2005 (Rongjun Zuo etal 2005) ,Al 2024 samples are used in this study , the result showed when antibiotics were added to the artificial seawater to kill the bacteria in the biofilm pitting occurred within a few hours as indicated by characteristic changes in the impedance. Filiform corrosion attack on pretreated aluminum alloy with tailored surface of epoxy coating had been studies by X.F.Liu 2007 (X.F.Liu 2007), in the study, on the basis of material analysis of 6016 aluminum alloy widely used in Europe automotive industry, the influenced of surface pretreatment on filiform corrosion and adhesion of epoxy coating/aluminum alloy interface were investigated and the effect of rolling direction and coating property on filiform corrosion was also examined. Investigations on reducing microbiologically – influenced corrosion of aluminum by using super- hydrophobic surfaces had been reported by Tao Liu etal 2010 (Tao Liu etal 2010) the results showed that neither anodization nor chemical modification could decrease the bacterial adhesion and corrosion rate

individually. Microbial corrosion of aluminum 2024 aeronautical alloy by hydrocarbon degrading bacteria *bacillus cereus* ACE4 and *serratia marcescens* ACE2 had been presented by Aruliah Rajasekar etal 2010 (Aruliah Rajasekar etal 2010) , this paper reports the microbiologically induced corrosion and electrochemical behavior of aluminum alloy AA 2024 in the presence of hydrocarbon – degrading bacteria *Bacillus cereus* ACE4 aGram-positive bacteria and *Serratia marcescens* ACE2 aGram –negative bacteria. Inhibition of biocorrosion of aluminum 2024 aeronautical alloy by conductive ladder polymer poly(o-phenylenediamine) had been studies by Aruliah Rajasekar etal 2011(Aruliah Rajasekar etal 2011), this study examines the role of conductive polymer poly (o-phenylenediamine) in corrosion inhibition and its antibacterial activity against bacterial biofilm on aluminum 2024 aeronautical alloy .The purpose of this study was to investigate the effect bacterial contaminant on the corrosion behavior of aluminum alloy , using a Gram-negative bacteria, *Pseudomnas aeruginosa*.

Experimental:

Table 1 shown the chemical composition of aluminum alloy used in this study. Samples of Al alloy with dimensions of 20mmx10mmx1.5mm are used in tafel extrapolation test and weight loss method for corrosion analyses.

Surface Preparations of Samples:

All Samples used in this work were grinded by an emery papers with (180, 400, 600, 800, 1000, 1200 grit size) respectively and polished with natural diamond size 0.1 micron with lubricating oil for lapping with diamond paste code PL0001 at room temperature by using a rotary grinding wheel (type-Hergon-mp 200V). After each stage the samples were washed with distilled water rinsed with ethanol , then the samples immersion in (3%HCl)by volume at room temperature for (2min.) for pickling process, after the pickling process the samples are washed by distilled water and ethanol and drying using electric drier.

Collection of Samples and Characterization of Bacteria.

Samples of water wear taken from water river and then cultures in Nutrient medium. After the growth of culturing (mixed bacteria) *Pseudomnas aeruginosa* bacteria is isolated from this mix depending on their morphology, Catalase production, Oxidas production ,Pyocyanin prod, Geiatin liqufication ,Starch test, Motility test,Indole test, Methyl red test, Voges proskaure test, Citrate utilization,Nitrate reduction,Lipase production, and then add to the medium test.

Corrosion Analyses:

Tafel Extrapolation Test:

This method is used to estimate the corrosion current and corrosion potential .This test is carried out for Al-alloys.The results of this test which is carried out in the (*Ministry of Sciences and technology/chemical research office*) using potentiostat apparatus, which consist of:-

A. Electronic processor.

B. Electrochemical cell, which consists of glass cell of 1 liter in volume and three electrodes:-

1.Reference electrode: saturated calomel electrode.

2. Auxiliary electrode: platinum electrode.

3. Working electrode: testing electrode (sample using) that will be Al-alloy .

Testing Procedure:

The glass cell is filled with test solution(control water(absence of *Pseudomnas aeruginosa* bacteria) or water with presence *Pseudomnas aeruginosa* bacteria) , also the bridge tube is filled with the test solution , then reference electrode, auxiliary electrode, and working electrode that are previously prepared(with surface area 2 cm^2) are immersed in solution as shown in figure (1).In order to estimate the open circuit potential (opc), the auxiliary electrode is closed(current=0)and estimate potential for 30 minute , corrosion potential (Ecorr) can be found where : Ecorr ≈ opc.

In order to measure the passage current and voltage between the auxiliary electrode and working electrode a voltage with a range of (±250 mV) above &under open circuit potential is applied, with scanning rate(3mv/sec) for each 10 mV. The value of passage current can be found for each value of voltage in the range of (±250 mV). The program using in this test is *ELECTROCHEMICAL SeI* program .

Weight Loss Test:-

Another vital method for estimating corrosion rate that is adopted in this work is using simple immersion test. This test has been implemented to estimate the corrosion rate for the aluminum alloy.

Testing Procedure:-

This test is carried out in order to study the behavior of aluminum alloy in water with bacteria and control medium as follows:-

a. Samples of aluminum alloy that were previously prepared and kept with high attention are now re-washed with distilled water, rinsed with ethanol and dried. A precise weighing process is now carried out to record the initial weight of samples(W_1). The samples is weight by using ±0.0001g accuracy electric balance.

b. Aluminum alloy samples are re-weighed (W_2) after 30and 60day (i.e.360&720 hrs.). The process of re-weighing is carried out under high attention by a perfect cleaning of samples by using distilled water and rinsing in ethanol with sufficient drying.

c. The purpose of re-weighing process is to determine the weight loss as referred to by ($\Delta W=W_1-W_2$) in results and findings.

d. The corrosion rates of the aluminum alloy calculate in mils per year according to the following formula; the corrosion rate is calculated assuming uniform corrosion over the entire surface of the sample (E.J.Akpabio,etal,2011).

$$\text{Corrosion rate} = (W_1-W_2)\, k/AtD$$

Where:

W_1 and W_2 are weights in gram of aluminum alloy before and after immersion; k=3450000 (corrosion rate cost in mils per year) ; t=time of exposure(h); A=Expanded surface area (cm^2); D=Density of alloy sample($g.cm^{-3}$).

Microstructure Examination:

Light optical microscope type (Union ME-3154) with fitted digital camera is used for imaging of specimen surface before and after corrosion test.

Roughness Test:

This test to measure surface roughness of aluminum alloy before and after immersion in control and bacterial water by using surface roughness tester type (Hand –held Roughness Tester TR200,by Time Group Inc.).

Microbiological Analyses:

The aim from this analyses to determine if *Pseudomonas aeruginosa* bacteria is responsible for accelerating the corrosion of aluminum alloy. Subsamples of biofilm and corrosion product collected each 15 and 30 days from surface of aluminum alloy after immersion in medium with bacteria and culturing on suitable medium.

Isolation and Identification:

Bacteria isolated from biofilm (corrosion product) after culturing on nutrient agar (24hr.) and the diagnosing depending on the appearance factors (Microscopic and Culturing factors) and biochemical tests(Catalase production, Oxidas production ,Pyocyanin production, Geiatin

liquefaction ,Starch test, Motility test, Indole test, Methyl red test, Voges proskaure test, Citrate utilization, Nitrate reduction, Lipase production).

Result and Discussion:

Corrosion Analyses:

Tafel Extrapolation Test:

Tafel polarization curve and data are presented in Figure 2 and Table 2 for aluminum alloy in control solution(absence of *Pseudomnas aeruginosa* bacteria) after immersion for 15 days; Figure 3and Table 3 shows the Tafel polarization curve and data for aluminum alloy in control solution after 30 days immersion. Figure 4 shows the Tafel polarization curve for aluminum alloy in the presence *Pseudomnas aeruginosa* bacteria solution after 15 days immersion; the corresponding data are presented in Table 4; Tafel polarization curve and data are presented in Figure 5 and Table 5 for aluminum alloy in presence *Pseudomnas aeruginosa* bacteria after immersion for 30 days. The corrosion current $i_{corr.}$ was higher in the presence of *Pseudomnas aeruginosa* bacteria (2.36µA) compared with the control , $i_{corr.}$(1.39µA) after 15days immersion. In the presence of *Pseudomnas aeruginosa* bacteria i_{corr}(12.97µA) was much higher than in control i_{corr}(4.91µA) after immersion 30 days. Furthermore the result shows that the presence of *Pseudomnas aeruginosa* bacteria brought about a negative shift in the corrosion potential E_{corr}, which indicates that the bacterium enhanced the cathodic process by uptake of hydrogen on metal surface this led to pitting corrosion (Aruliah Rajasekar and Yen-Peng Ting,2010). The corrosion potential is more negative in the presence of *Pseudomnas aeruginosa* bacteria, E_{corr}(-990.7mv;-1012.6mv) after immersion for days 15and 30 days respectively in comparison to the control,E_{corr}(-985.9mv;-986.9mv). At the same time the corrosion current shifted to the right in the presence of *Pseudomnas aeruginosa* bacteria when compared with control, the higher corrosion current is due to pit formation on the metal surface and the result of the oxide layer by accumulated corrosion product (Aruliah Rajasekar and Yen-Peng Ting,2010).

Weight Loss Test:-

The corrosion rate of aluminum alloy obtained from the weight loss study in control solution(absence of *Pseudomnas aeruginosa* bacteria) and in the medium with presence *Pseudomnas aeruginosa* bacteria is shown in tables 6 and 7.The corrosion rate of aluminum alloy in control solution were(0.141mpy;1.482mpy) at 15 and 30 days of immersion respectively. Furthermore the corrosion rate of aluminum alloy in medium with presence *Pseudomnas*

aeruginosa bacteria were(6.354mpy;4.977mpy) at 15 and 30 days respectively. From the result it is noticed the corrosion rate of aluminum alloy in the medium with presence *Pseudomnas aeruginosa* bacteria is approximately(45;3.35) times more than in control medium after 15 and 30 days of immersion respectively.

It is well known that surfaces immersed in natural waters are readily colonised by microorganism, as a consequence of this colonisation and the subsequent development of microorganisms, the surface becomes covered by a biofilm.Biofilm are complex microbial populations composed by microbial clusters separated by channels and void spaces, which develop on virtually all immersed surfaces (J.P.Busalmen,2002).Formation of a passive oxide film on aluminum enhances its corrosion resistance but when aluminum alloy immersion in medium(in the presence of *Pseudomnas aeruginosa* bacteria), *Pseudomnas aeruginosa* bacteria species have been commonly associated with the microbiologically influenced corrosion of aluminum alloy and cause corrosion and increasing the weight loss and corrosion rate compared to control medium. Presence *Pseudomnas aeruginosa* bacteria cause biofilm formation; biofilm affect interactions between aluminum alloy surface and the environment. The role of biofilms in enhancing corrosion in a biologically conditioned metal – surface interface are inducing differential aeration effects as a consequence of a patchy distribution of the biofilm, non-uniform or patchy colonization by microbial biofilm results in the formation of differential aeration cells, where areas under respiring colonies are depleted of oxygen relative to surrounding non colonized areas. These effects give rise to potential differences and consequently, to corrosion rate, the areas under respiring colonies become anodic and there, metal dissolution occurs. Conversely, in the cathodic surrounding areas the counter reaction of oxygen reduction takes place(Hector A.Videla & Liz K.Herrera,2005).

Microstructure Examination:

The extent of corrosion caused by *Pseudomnas aeruginosa* bacteria was also assessed by profiling the pits on the sample surface after removal of the biofilm, using microstructure examination Figure 6:B and D . Unlike the control medium (absence of *Pseudomnas aeruginosa* bacteria) Figure 6:A and C, pitting corrosion of metal occurred with *Pseudomnas aeruginosa* bacteria Figure 6:B and D, the corrosion damage observed on the sample surface revealed major corrosion pits Figure 6:D ;this is attributed to the ability of the bacteria to oxidize aluminum ions to aluminum oxide and form a low- density aluminum hydrated in the corrosion tubercles, which thereafter act as key factors of pitting corrosion of alloy(Aruliah Rajasekar & Yen-Peng Ting,2010).

Roughness Test:

Tables 8 and 9 shows the number of surface roughness of aluminum alloy before and after immersion in control medium(in the absence *Pseudomnas aeruginosa* bacteria) and in medium with presence *Pseudomnas aeruginosa* bacteria; the result show obvious increasing in roughness of aluminum alloy which under the medium with presence bacteria compared to the control; coming with an increasment in the periodic of immersion where the result points to the ability of *Pseudomnas aeruginosa* bacteria to cause corrosion and form defects and cracking result from corrosion process.

Microbiological Analyses:

Biofilm Formation:

Fig 7:A and B shows the microstructure of aluminum alloy after exposure to the bacterial system (in the presence *Pseudomnas aeruginosa* bacteria) without removal of biofilm and corrosion product after 15 and 30days respectively , shows major cracks on aluminum alloy surface; sample were covered with corrosion products, which were dense,brittle and lumpy deposits in bacterial system, Figures7 A and B, the microstructure of the sample after15and 30 days exposure to the bacteria show that the specimens were covered with *Pseudomnas aeruginosa* bacteria biofilm, the bacteria that accumulated on the aluminum alloy exhibited typical phenotypic properties e.g., clumps of cells and microcolonies.A layer of biofilm with clusters of microbial cells and extracellular polymeric substance was observed on the metal surface.

Microscopic Test; Culturing Test & Biochemical Test:

The result of microbiological analyses of subsamples of biofilm and corrosion product collected from surface of aluminum alloy after immersion in medium with bacteria shows small bacilli negative gram strain (G-ve) bacteria; small colonies with 2.5mm in diameter have mucin appearance and green pigments pyocyanin production growthing on solid nutrient agar 24h;27ºC as shown in Figure 8; the culture was oxidase positive, catalase positive.Gram negative;pycyanin positive,starch negative,Indole negative,methyl red ngative,voges-proskauer negative, citrate utilization positive, Geiatain liqufication positive, nitrate reduction negative/ positive, lipase production negative/ positve and it is motile ;bassed on thes characteristics the culture was tentatively indentified as *Pseudomnas aeruginosa*.

Conclusion:

1- The nature of the Tafel curves indicates that the corrosion current was higher in the presence of *Pseudomnas aeruginosa* bacteria compared with the control system.

2- Microstructure examination and Roughness test show that *Pseudomnas aeruginosa* bacteria causes more sever pitting corrosion.

3- Bioflims play a key role in the way how microbiologically influenced corrosion processes.

4- This study shows the role of *Pseudomnas aeruginosa* bacteria in accelerating pitting corrosion on aluminum alloy.

5- *Pseudomnas aeruginosa* bacteria produced heterogeneity biofilm and caused differential aeration on the aluminum alloy surface.

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Table 1 shown chemical composition of sample used.
Ref. State Company for Mechanical Industries.

Alloy	**%Mn**	**%Zn**	**%Cu**	**%Mg**	**%Fe**	**%Si**	**%Cr**	**%Al**
Aluminum alloy	0.10	0.10	0.10	2.80	0.40	0.25	0.35	Rem

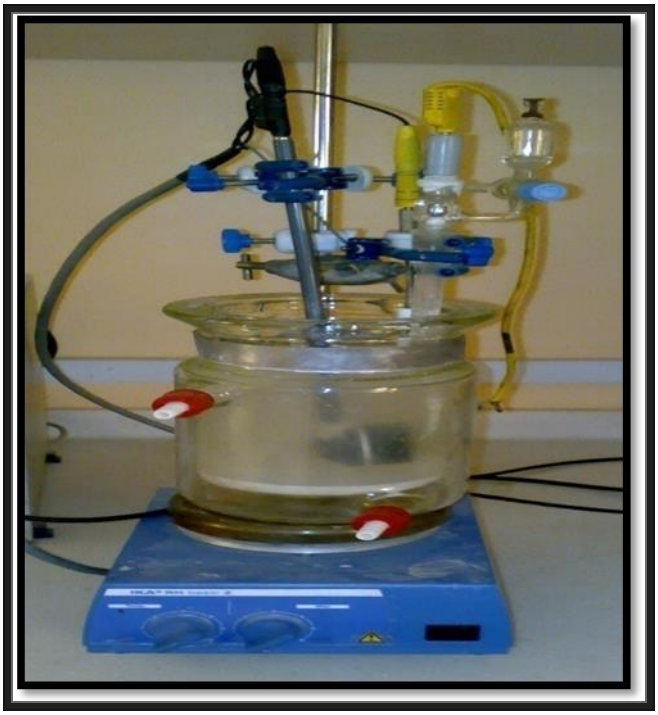

Figure 1.Photo picture shows the use of the electrochemical cell in drawing polarization curves.

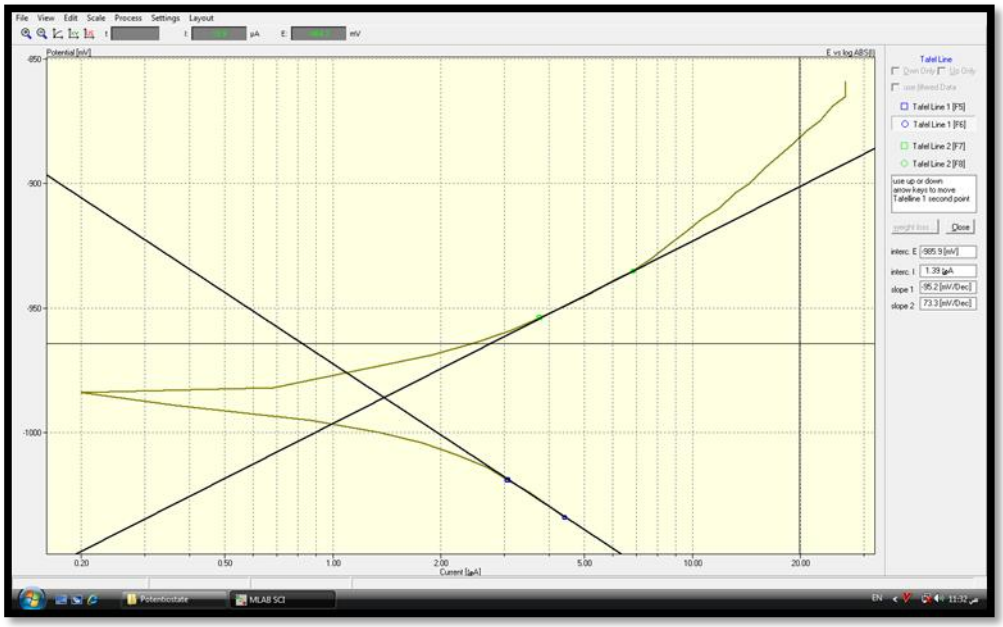

Figure 2. Tafel polarization curve of aluminum alloy after 15days of immersion in control medium(absence *Pseudomnas aeruginosa* bacteria).

Table 2 Polarization Data for aluminum alloy after 15days of immersion in the absence *Pseudomnas aeruginosa* bacteria medium.

Alloy	**Immersion period (days)**	**Slope1 (mv/Dec)**	**Slope2 (mv/Dec)**	**$E_{Corr.}$ (mv)**	**$i_{corr.}$ (µA)**
ALUMINU	15	-95.2	73.3	-985.9	1.39

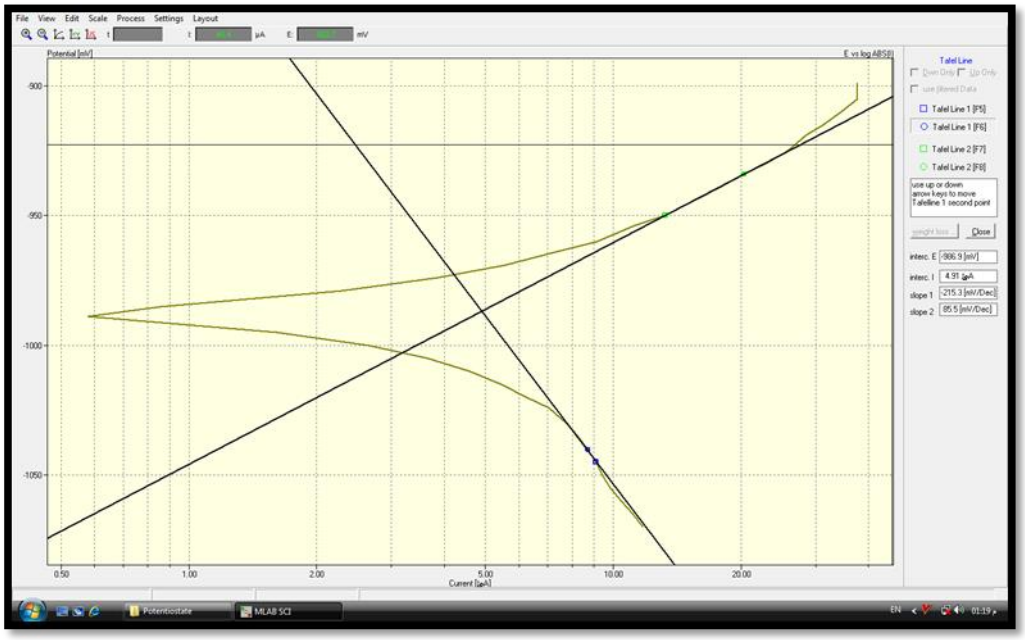

Figure 3. Tafel polarization curve of aluminum alloy after 30days of immersion in control medium(absence *Pseudomnas aeruginosa* bacteria).

Table 3 Polarization Data for aluminum alloy after 30days of immersion in the absence *Pseudomnas aeruginosa* bacteria medium.

Alloy	**Immersion period (days)**	**Slope1 (mv/Dec)**	**Slope2 (mv/Dec)**	**$E_{Corr.}$ (mv)**	**i_{corr} (μA)**
ALUMINUM	30	-915.3	85.5	-986.9	4.91

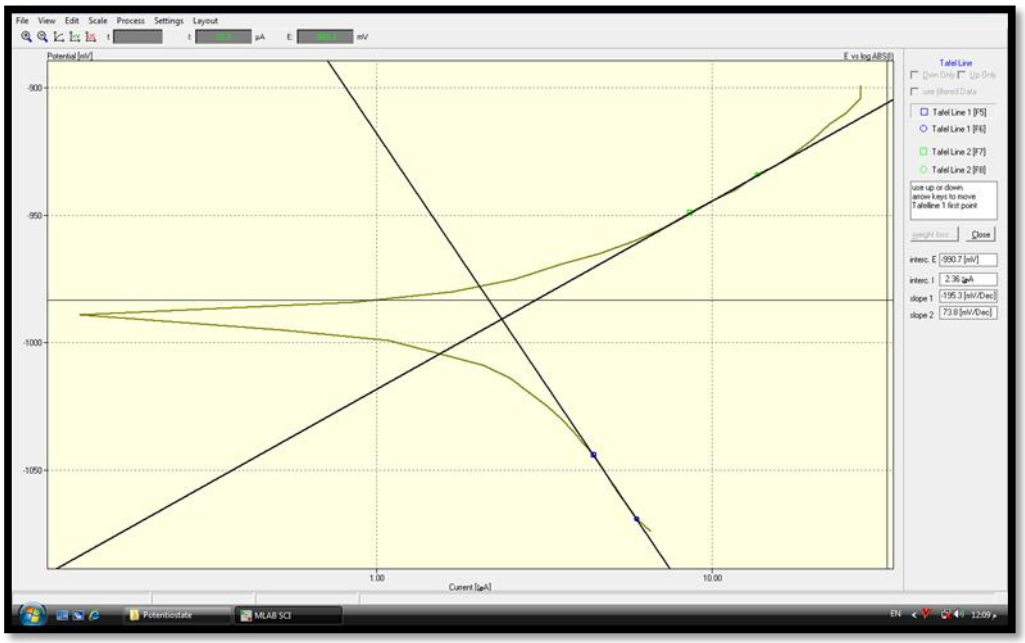

Figure 4. Tafel polarization curve of aluminum alloy after 15days of immersion in medium with presence *Pseudomnas aeruginosa* bacteria.

Table 4 Polarization Data for aluminum alloy after 15 days of immersion in medium with the presence *Pseudomnas aeruginosa* bacteria.

Alloy	Immersion period (days)	Slope1 (mv/Dec)	Slope2 (mv/Dec)	$E_{Corr.}$ (mv)	i_{corr} .(µA)
ALUMINUM	15	-195.3	73.8	-990.7	2.36

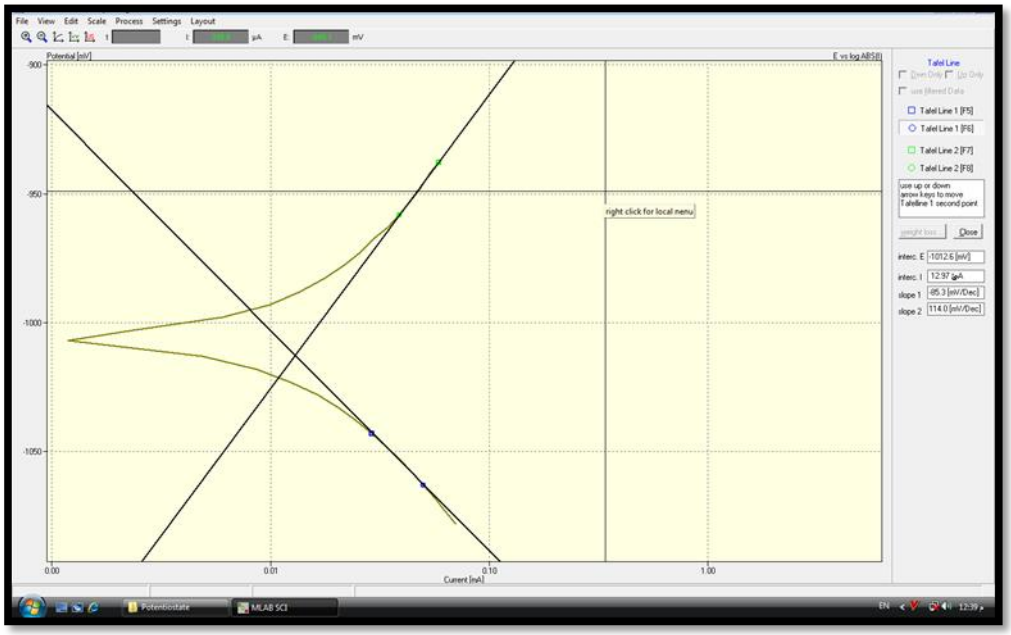

Figure 5. Tafel polarization curve of aluminum alloy after 30days of immersion in medium with presence *Pseudomnas aeruginosa* bacteria.

Table 5 Polarization Data for aluminum alloy after 30days of immersion in medium with presence *Pseudomnas aeruginosa* bacteria.

Alloy	Immersion period (days)	Slope1 (mv/Dec)	Slope2 (mv/Dec)	$E_{Corr.}$ (mv)	$i_{corr.}$ (µA)
ALUMINUM	30	-85.3	114.0	-1012.6	12.97

Table 6 Corrosion rate of aluminum alloy by weight loss (in the absence *Pseudomnas aeruginosa* bacteria).

ALLOY	Immersion period (day)	Density (g/cm^3)	Expended area (cm^2)	Weight loss (g)	Corrosion rate (mpy)
ALUMINM	15	2.77	4.9	0.0002	0.141
ALUMINM	30	2.77	4.9	0.0042	1.483

Table 7 Corrosion rate of aluminum alloy by weight loss
(in the presence *Pseudomnas aeruginosa* bacteria).

ALLOY	Immersion period (day)	Density (g/cm^3)	Expended area (cm^2)	Weight loss (g)	Corrosion rate (mpy)
ALUMINM	15	2.77	4.9	0.009	6.354
ALUMINM	30	2.77	4.9	0.0141	4.977

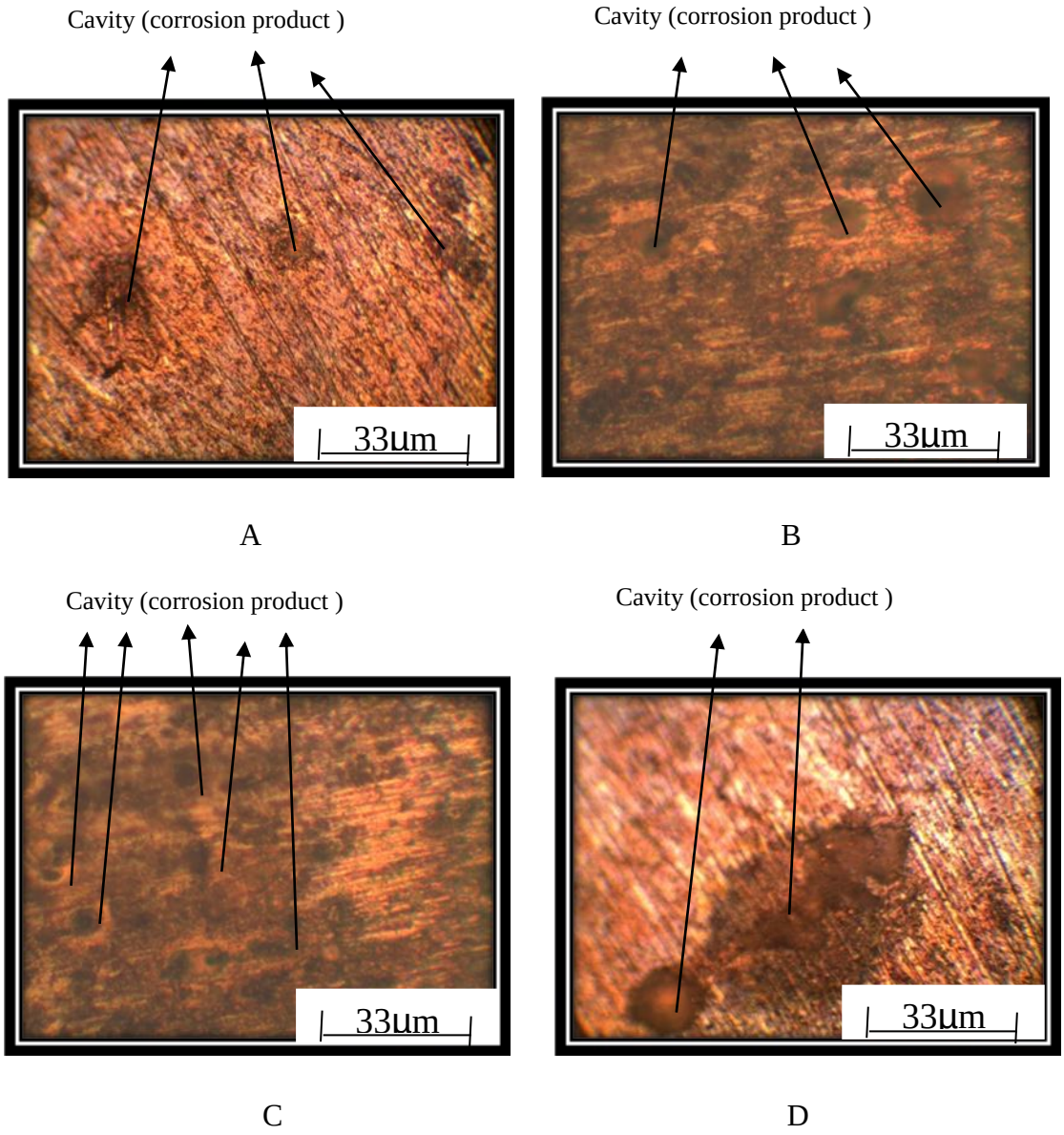

Figure 6:A and C: Surface of aluminum alloy after 15and30days of immersion in control medium respectively; B and D surface of aluminum alloy after 15and30 days of immersion in medium with presence *Pseudomnas aeruginosa* bacteria.

Table 8 Number of surface roughness of aluminum alloy before and after immersion in control medium(in the absence *Pseudomnas aeruginosa* bacteria).

Solution	**Immersion period (days)**	**No. of Roughness (µm)**
----------	----------	0.004
in the absence *Pseudomnas aeruginosa* bacteria	15	0.005
in the absence *Pseudomnas aeruginosa* bacteria	30	0.007

Table 9 Number of surface roughness of aluminum alloy before and after immersion in medium with presence *Pseudomnas aeruginosa* bacteria.

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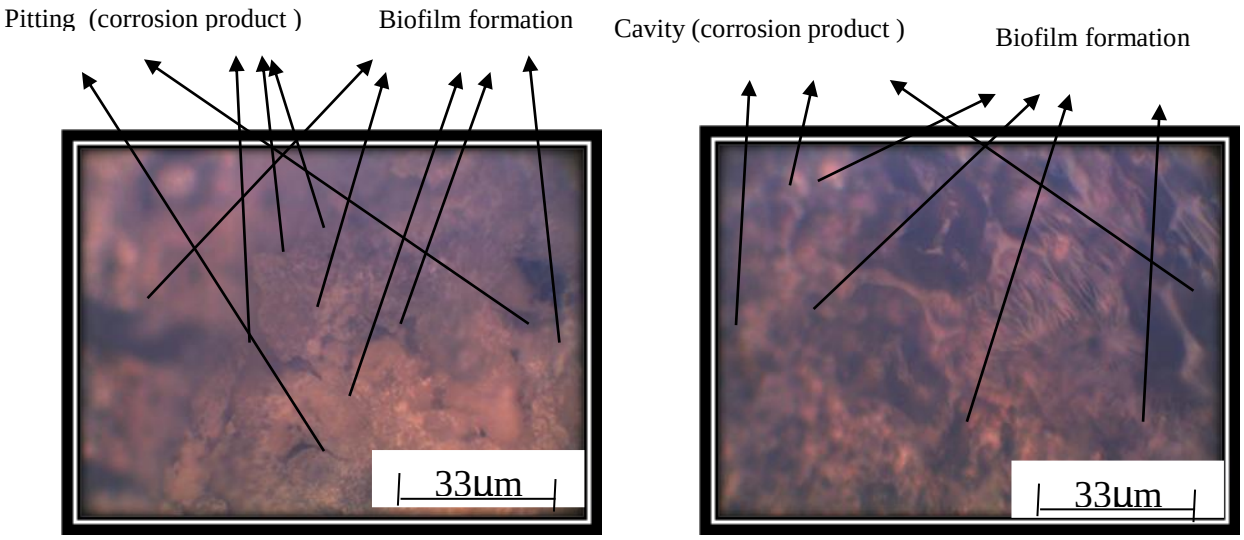
Solution	**Immersion period (days)**	**No. of Roughness (µm)**
----------	------	0.004
presence *Pseudomnas aeruginosa* bacteria	15	0.012
presence *Pseudomnas aeruginosa* bacteria	30	0.014



B A

Figure7: Biofilm formation on the surface of aluminum alloy in 15 and 30 days of immersion in medium with presence *Pseudomnas aeruginosa* bacteria A and B respectively.

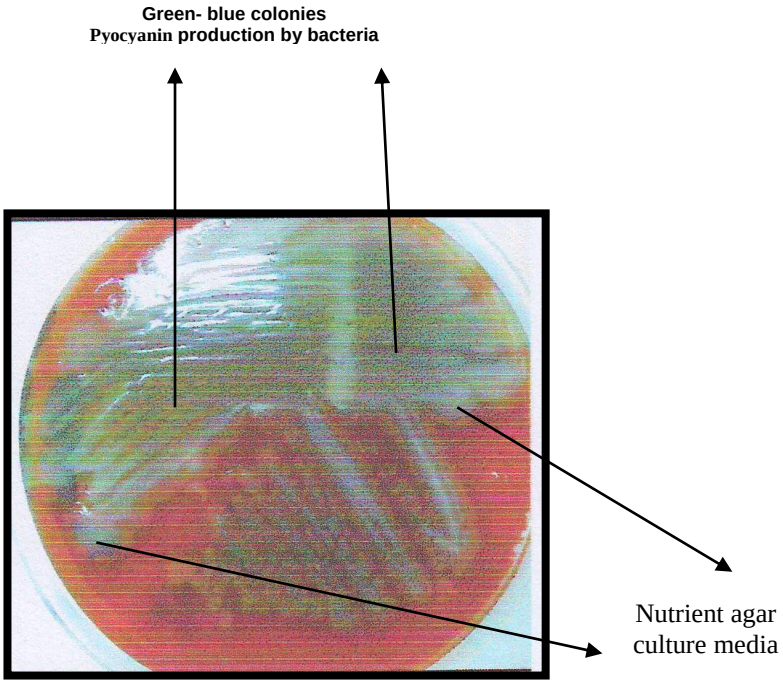


Figure 8: Appearance shape of *Pseudomonas aeruginosa* bacteria in culturing medium of subsamples of biofilm and corrosion product collected from surface of aluminum alloy.