Improving Anodizing Efficiency by Adding Different Amounts of Aluminum Powder to Anodizing Electrolyte for Pure Aluminum and Aluminum Alloy (6063)

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Abstract

Different amounts of aluminum powder (5, 7, 9 and 11g/l) were added to sulfuric acid solution of the specimens under ideal conditions previously obtained (1) and the effect of these additions was studied to find out it's benefit on anodizing efficiency for pure aluminum and aluminum alloy (6063).

The specimens were examined in different conditions using optical microscope, roughness and hardness measurements.

The study shows the anodizing process was improved by adding aluminum powder with ideal conditions and the best value of aluminum powder was 9g/l, where the thickness improved from 72.25µm at ideal conditions to 81.25µm with adding 9g/l aluminum powder and the coating ratio improved from 1.481 at ideal conditions to 1.541 with adding 9g/l aluminum powder for pure aluminum, while the thickness improved from 74.56µm at ideal conditions to 82.29µm with adding 9 g/l aluminum powder and the coating ratio improved from 1.417 at ideal conditions to 1.471 with adding 9g/l aluminum powder for aluminum alloy (6063).

The study also shows that the effective anodic current efficiency was increased about 12.50% when adding aluminum powder of 9g/l compared with ideal conditions for pure aluminum, while this value was increased about 10.20% when adding aluminum powder of 9g/l compared with ideal conditions for aluminum alloy (6063) without adding aluminum powder.

It is found that the surface roughness and hardness value of specimens with adding aluminum powder of 9g/l gives the best result compared with the specimens at ideal conditions and bare specimens.

الخلاصة

أُضيفت كميات مختلفة من مسحوق الألمنيوم تتراوح بين (5,7,9,11) غم/لتر إلى حامض الكبريتيك للعينات الخاضعة للظروف المثالية التي اخذت نتائجها من بحث سابق (1) وتأثير هذه الأضافة على كفاءة الأنودة للألمنيوم النقي وسبيكة الألمنيوم (6063).

أُجري الفحص المايكروسكوبي وقياس الخشونة والصلادة للعينات بظروف مختلفة. أظهرت الدراسة بأن عملية الأنودة تحسنت بأضافة مسحوق الألمنيوم مع الظروف المثالية وأفضل قيمة لها

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هي 9 غم/لتر حيث تحسن السمك من 72.25µm تحت الظروف المثالية الى 81.25 µm عند أضافة 9 غم/لتر من مسحوق الألمنيوم بالنسبة للألمنيوم النقي ومن 74.56 µm تحت الظروف المثالية الى 82.29 µm عند أضافة 9 غم/لتر من مسحوق الألمنيوم بالنسبة لسبيكة الألمنيوم (6063).

وتحسنت نسبة التغطية من 1.481 و 1.417 للظروف المثالية الى 1.541 و 1.471 عند أضافة 9 غم/لتر من مسحوق الألمنيوم بالنسبة للألمنيوم النقي وسبيكة الألمنيوم (6063) على التوالي.

أظهرت الدراسة أيضاً بأن كفاءة التيار الآنودي المؤثر أزدادت حوالي 12.50% عند أضافة 9 غم/لتر من مسحوق الألمنيوم مقارنة مع الظروف المثالية بالنسبة للألمنيوم النقي, في حين أزدادت حوالي 10.20% عند أضافة 9 غم/لتر من مسحوق الألمنيوم مقارنة مع الظروف المثالية بالنسبة لسبيكة الألمنيوم (6063) بدون أضافة المسحوق.

وجد بأن قيمة خشونة وصلادة السطح للعينات المضاف اليها9 غم/لتر من مسحوق الألمنيوم أفضل بالنتيجة مقارنة مع العينات التي أُجري لها أنودة تحت الظروف المثالية والعينات التي لم تجرى لها عملية أنودة.

Key Word: aluminum powder, sulfuric acid, anodizing efficiency, aluminum alloy (6063), effective anodic current efficiency.

1- Introduction

Aluminum is a strong electronegative metal with a strong affinity for oxygen which makes aluminum an excellent corrosion resistant (2).The protective oxide film that forms immediately after the metal is exposed to air , the oxide film is about (0.25-1)x10^{-2} µm thick (3), this film will be replaced by another layer as soon as it damages.

Anodizing is an electrochemical process to produce an oxide film coating on metals or alloys for both protective and decorative purposes. Although many metals can be anodized, aluminum anodizing is the most popular and used in various commercial and military application (4).

The anodic film is chemically stable and relatively hard (5). There are two types of anodic coating:

I- The first type of anodic film is formed in electrolytes such as boric acid and borates which has little solvent action on aluminum oxide. Such coatings are thin and nonporous for all practical purposes and are termed barrier coatings; they are used in forming stages of electrolytic aluminum foil capacitors.

II- The other type of anodic film is formed in electrolytes such as sulfuric acid, chromic acid, oxalic acid (in general dibasic acids). The film structures are duplex in character with a thin nonporous outer layer. The pore size, pore density per unit area, wall thickness of the cells and layer thickness of these duplex coatings are determined by the nature of the anodizing electrolyte and the operating conditions and are termed porous coatings, these coatings find applications as decorative, and for corrosion resistance, architectural, wear resistant, electrical insulation and other uses.

Sulfuric acid is by far the most important anodizing process due to the characteristics of the process (allows a wide variety of thickness). Due to its permeable nature, sulfuric anodizing is excellent for clear coating and color dyeing, provides a base for primers, bonding agent and organic coatings. Its provides corrosion resistance and is very durable, typical application manufacturing automotive and computers (6).

Later studies (7) are concerned with a new factor; this factor is the addition of aluminum powder. These studies showed that the coating ratio of anodic coatings formed in sulfuric acid electrolyte with 7g/l of aluminum powder and additive (Metalast) is higher than that of anodic coating produced without aluminum powder using aluminum alloys (1100, 2024, 3003, 5052, 6061 and 7075).

Ling Hao et al.(8) showed that the alloys (1100) and (6061) between several alloys of aluminum, have high effective anodic current efficiency with (6-8) g/l of aluminum powder and additive compared without them, because there are relatively low contents of alloying elements in these two alloys compared with the other.

In this investigation the efficiency of pure aluminum anodizing is compared with the efficiency obtained during the addition of different amounts of aluminum powder to anodizing electrolyte under ideal conditions.

2- Experimental Procedure

2-1 Materials

2-1-1 Anode

The materials used in this study is pure aluminum .This material is cut of specimens by dimensions of (2*1*0.02) cm. Analysis of these specimens was carried out using (spark technique). Tables (1) and (2) show the nominal and the analytical chemical compositions of two materials used in this work.

2-1-2 Cathode

Aluminum alloy (6063) with dimensions (8*4*0.07) cm was used.

2-2 Mechanical Pre-Treatment

Raw materials of pure aluminum were received in the form of foils. The foils were cut into small specimens with dimensions previously mentioned where sharp edges and then chamfered via grinding wheel.

2-3 Chemical Pre-Treatment

(I) Oil, grease and general dirt where properly removed with acetone at 25°C. Grease tends to float on surface, which was removed later by filtration. After this stage, the specimen was rinsed in running water then in distilled water to remove the excess of acetone on the specimen.

(II) Alkaline Etching**:** The specimen was etched by dipping in 5% volume sodium hydroxide solution for 5 minutes at temperature of 45°C , the the specimen was rinsed by tap water and then by distilled water to ensure the removal of the excess solution of sodium hydroxide.

(III) Desmutting: The specimen was treated in 5% nitric acid solution for about 5 minutes at 25°C to remove the black layer that formed on the surface and to activate the surface for the anodizing stage. After ward, the specimen was rinsed with running water followed by distilled water and dried by means of air.

(IV) Electropolishing: The specimen was polished by using the electro - polishing technique by immersion in the solution consists of :

75%	Phosphoric acid
25%	Sulfuric acid
0.1%	Nitric acid

The temperature of electrolyte is 90°C and the time immersion is 10 min. and the current density is 15 A/dm^2 . The specimen was rinsed with running water after electropolishing followed by distilled water and dried, then kept in the desiccator over a silica gel before being weighed (W_1).

2-4 Anodizing

2-4-1 Operating Procedure

The following steps were followed in this stage:

1- After pretreatment, weighing specimens before anodizing (W_1).

2- The solution of desired acid concentration (sulfuric acid) was placed in anodizing cell.

3- The thermostat was set to the desired operating temperature.

4- When all the requirements of experiment were set up, the power supply was switched on a fixed constant current at the desired value. The electrodes were immersed in the solution while the power supply was switched on, in which voltage increased gradually.

5- At the end of the desired time, the power supply is switched off and the anode was removed from anodizing cell immediately.

6- After the specimen was removed from anodizing cell, it rinsed with running water, followed by distilled water to remove the excess solution on the specimen.

7- The specimen was dried in a drying furnace at 50°C for 30 minutes and stayed in desiccator about 30 minutes.

8- The specimen was weighed after anodizing (W_2).

9- Using the ideal conditions for anodizing pure aluminum previously obtained , these conditions are Current Density 4 (A/dm^2), Electrolyte Concentration 6 (vol%), Electrolyte Temperature 19 (^{o}C), Anodizing Time 60(min.), different amounts of aluminum powder (5, 7, 9 and 11) g/l were added to anodizing solution to calculate the best efficiency of them. Figure (1) shows a schematic diagram for the whole assembly of the anodizing apparatus.

2-4-2 Stripping Anodic Coating

Anodic film was stripped using the following solution:

Phosphoric acid	35 ml
Chromic acid	20 g
Distilled water	liter

The temperature of electrolyte is 100°C, and the time for immersion is 10 minutes. After stripping, the specimens were rinsed with running tape water followed by distilled water to remove the excess solutions, then dried in a drying furnace at 50°C for 30 minutes and stayed in desiccator about 30 minutes and weighed (W_3).

2-4-3 Coating Thickness Test

Gravimetric method is one of the method to determine coating weight and thickness according to the standard test method (ASTM B680-80) (10), from the weight loss measured in equation (1). The specimen was weighed after anodizing (W_2) and weighed after stripping (W_3).

$$Wc = \frac{W_2 - W_3}{A} \quad \text{.....(1)}$$

where:

$Wc =$ coating weight.

$W2 =$ weight of a sample with anodic coating in (g).

$W3 =$ weight of a sample after stripping in (g).

$A =$ surface area (dm^2).

From the weight loss measured above, the coating thickness can be calculated from the equation (2) (3, 5, 11):

$$Y = \frac{(W_2 - W_3)\times 10^4}{A\times \rho} \quad \text{............(2)}$$

where:

$Y =$ coating thickness in micron

$\rho =$ density of coating thickness in g/cm^3 is about 2.4 for unsealed coating (2).

2-5 Roughness Test

Surface roughness of the anodized film measured by using (Talysurf-England) with the following specifications:

Stylus material:	Diamond
Stylus force:	100 mg.f

The arithmetic average values (Ra) for anodized specimens were calculated directly from the instrument. The examinations were carried out for bare and anodized aluminum under ideal conditions and anodized aluminum after added (5, 7, 9 and 11) g/l of powder aluminum to the electrolyte solution.

2-6 Hardness Test

Vickers microhardness test is the ratio of the load (P) applied in grams to the contact area of the impression, in square millimeters and the value given by the equation (3):

$$Hv = \frac{1.854P}{D^2} \quad \text{...........(3)}$$

where (D)is the measured diagonal of the square produced by the indent.

The test was carried out for bare and anodized specimens under ideal conditions and anodized specimens after added (5, 7, 9 and 11) g/l of aluminum powder to the electrolyte solution by using Micromet Optical Microscope (U.S.A).

The applied load was 100 g kept for 20 seconds for each reading, taking 5 reading and calculates the average values.

3- Results and Discussion

3-1 Effect of Aluminum Powder in Anodizing Pure Aluminum

3-1-1 Effect of Thickness

Figure (2) shows the effect of adding aluminum powder to anodizing solution at ideal conditions for pure aluminum on film thickness.

From examining this Figure, it can be seen that the film thickness increases as the concentration of aluminum powder increases until reaches the maximum value at 9g/l, then the thickness decreases.

From the obtained results, the average thickness at ideal conditions of pure aluminum is equal to 72.25µm; while aluminum powders of 9g/l are used it is equal to 81.25µm.

This increase is due to the increase in Al^{+3} ions concentration in the solution, thus reducing the rate of dissolution of the coating film.

The film thickness continues to increase until reaches the counter balance (9g/l), which the formation rate of film thickness is equal to the dissolution rate of the anodic coating. After 9g/l the dissolution rate increases, while the thickness was decreased.

3-1--2 Effect of Coating Ratio

How much of the consumed aluminum is converted to the anodic coating (oxide) will depend on the coating formation efficiency, which may be related to the type of material anodized and the anodizing electrolytes used. This characteristic can be assessed by the coating ratio of anodic coatings. Generally, the higher the coating ratio (R_c) of anodic coating obtained, the higher the coating formation efficiency (7).

The coating ratio (R_C) is defined by the following formula:

$$R_C = \frac{W_C}{W_A} \qquad \ldots\ldots(4)$$

where:

W_A : Aluminum reacting (g/dm^2) is defined by the following formula:

$$W_A = \frac{W_1 - W_3}{A} \qquad \ldots\ \ldots\ldots (5)$$

Figure (3) shows the effect of adding aluminum powder to anodizing solution at ideal conditions for pure aluminum on coating ratio.

The results indicate that the coating ratio for anodizing pure aluminum at ideal conditions is about 1.481, while this value is about 1.541 with 9g/l aluminum powder at a maximum value for pure aluminum.

3-1-3 Effect of Effective Anodic Current Efficiency (η_E)

The effective anodic current efficiency (η_E), is describing the effective portion of the current contributing to the formation of an anodic coating during anodizing. Its evaluated in terms of the percentage of aluminum in an anodic coating and the total current consumed in an anodizing process (7).

The effective anodic current efficiency (η_E) is calculated using the following definition:

$$\eta_E = \frac{W_{AL.C}}{W_{A.t}} \times 100\% \quad \text{…….(6)}$$

where:

$W_{AL.C}$ **:**Aluminum content in anodic coating per unit surface area

$W_{A.t}$: the theoretical alloy weight loss per unit surface area, calculated from the electricity consumed.

The weight percent of aluminum in aluminum oxide (Al_2O_3) equal to 52.941%, therefore:

$$W_{AL.C} = 0.52941 \times W_C$$

$$W_{AL.C} = 0.52941 \times 0.1577 = 0.08348 g/dm^2$$

$$W_{A.t} = \frac{I \times t \times M}{n \times F \times A} \quad \text{…(7)}$$

where: M : molar mass.

n : is the electron number in the material.

I : the average current density in amperes passing through the anodizing sample

t : time of anodizing

F : the Faraday constant (96480).

Figure (4) shows the effect of adding aluminum powder to anodizing solution at ideal conditions for pure aluminum on effective anodic current efficiency.

It can be seen from Figure (4) that effective anodic current efficiency increases with increase in concentration of aluminum powder until it reaches a maximum value at 9g/l, equal to 76.72%, while it's equal to 68.19% on anodizing aluminum without aluminum powder, i.e. improvement in current efficiency is about 12.50 % due to aluminum powder.

The differences in the result are due to the relatively high dissolution rate of the anodic coating of anodizing without aluminum powder at ideal conditions comparing with anodizing with aluminum powder.

Table (2) shows experimental results for pure aluminum by using the ideal conditions without added aluminum powder. The obtained parameters for anodizing film at the ideal conditions are (R_C), % η_E and thickness. These parameters are used to compare with similar results with adding aluminum powder to anodizing electrolyte.

Aluminum powder is considered to be one of the important additives to anodizing solution. Application of additives is increasingly popular in contemporary anodizing technologies. Using the ideal conditions for anodizing, different amounts of aluminum powder (5, 7, 9 and 11) g/l were added. Table (3) shows the experimental runs for pure aluminum by using the ideal conditions with adding different amounts of aluminum powder.

3-1 Effect of Aluminum Powder in Anodizing Aluminum alloy (6063)

3-1-1 Effect of Thickness

Figure (5) shows the effect of adding aluminum powder to anodizing solution at ideal conditions for aluminum alloy (6063) on film thickness.

From examining this Figure, it can be seen that the film thickness increases as the concentration of aluminum powder increases until reaches the maximum value at 9g/l, then the thickness decreases.

The average thickness of ideal conditions of aluminum alloy (6063) is equal to 74.56μm, when aluminum powders of 9g/l are used it is equal to 82.29μm.

3-1-2 Effect of Coating Ratio

Figure (6) shows the effect of adding aluminum powder to anodizing solution at ideal conditions for aluminum alloy (6063) on coating ratio.

The results indicate that the coating ratio for anodizing aluminum alloy (6063) at ideal conditions is about 1.417, while this value is about 1.471 with 9g/l aluminum powder at a maximum value for pure aluminum.

3-1-3 Effect of Effective Anodic Current Efficiency (η_E)

Figure (7) shows the effect of adding aluminum powder to anodizing solution at ideal conditions for pure aluminum on effective anodic current efficiency.

Figure (7), indicates that effective anodic current efficiency for aluminum alloy (6063) increases with increase in aluminum powder until it reaches a maximum value at 9g/l, equal to 77.64, while it's equal to 68.19% on anodizing the alloy without aluminum powder, i.e. improvement in current efficiency is about 10.20% due to aluminum powder.

It is noticed that the effective anodic current efficiency is less in aluminum alloy(6063) in comparison with pure aluminum, because alloy(6063) contains higher than 2% alloying elements, that do not contribute to the formation of the anodic coating (12).

Table (4) shows the experimental runs for aluminum alloy (6063) by using the ideal conditions with adding different amounts of aluminum powder.

Using the ideal conditions for anodizing, different amounts of aluminum powder (5, 7, 9 and 11) g/l were added. Table (5) shows the experimental results for aluminum alloy (6063) by using the ideal conditions with adding different amounts of aluminum powder.

3-2 Film Thickness

Figures (8) and (9) show the anodic film thickness on pure aluminum under ideal conditions and ideal with 9g/l aluminum powder respectively, the white surface indicates the base metal and the next layer represents the aluminum oxide.

Figures (10) and (11) show the anodic film thickness on aluminum alloy (6063) under ideal conditions and ideal with 9g/l aluminum powder respectively

The behavior of intermetallic compounds during anodizing is different depending on the type of intermetallic and anodizing solution.

Some of the intermetallic compounds are oxidized or dissolved much more rapidly than aluminum (ßAl-Mg) producing porous coatings. Others such as silicon particles are practically insoluble during anodizing, producing inclusions in the anodic film. Intermediate between the two extremes are constituents (Fe Al_3, αAl-Fe-Si etc) part of which is dissolved and part remains in the coating, and which affects the colour transparency and continuity of the film to varying degrees (13).

3-3 Roughness Test

The arithmetic average values of the roughness are listed in Table (6) Anodizing process does affect the surface finish of the aluminum substrate; the extent of change in the surface roughness depends largely on the type of anodic process performed. The roughness of anodized surface is greater than that of untreated one because during anodizing a new phase is formed, i.e. Al_2O_3. Figures (12) and (13) show the surface of pure aluminum and aluminum alloy (6063) before and after anodizing respectively. In Figure (12), it is clearly noticed that the rough surface is higher than unprotected specimen due to the anodic layer created on the surface. This figure consists of shallow depressions; the surface layer appears as spherical or semi-spherical. Precipitation process depends on surface cleaning; the presence of a small amount of impurities (especially Fe and Cu) slows down the anodizing process in these sites. These observations are also shown In Figure (13) for aluminum alloy (6063). Weight and dimensions of this phase are different from that of base metal that is already replaced by the anodic film.

Table (6) shows that the roughness measurement values for aluminum alloy (6063) are higher than those of pure aluminum due to the presence of (Si and Mg) as alloying elements, these two elements form spheroidising of Mg_2Si, and existing iron may be present as Fe_2SiAl_8 (14). These phases are observed in the microstructure of aluminum alloy (6063) shown In Figure (13-a).This microstructure is relatively similar to the standard microstructure of the aluminum alloy (6063) with [0.5% Mg, 0.4 Si, 0.25% Fe] which contains coarse phase of Mg_2Si and Fe_2SiAl_8 (14, 15).

3-4 Hardness Test

Table (7) shows that the hardness of anodized specimens is higher than that of untreated specimens. This refers to the great influence of aluminum oxide on the hardness values.

The Vickers micro-hardness testing results are listed in Table (7).

From above results, it is obvious that the hardness of aluminum alloy (6063) is higher than that of pure aluminum due to the presence of Si and Mg as impurities in the composition of the alloy; these impurities increase the mechanical properties of the alloy but reduce the corrosion resistance (14).

From Table (7), it can be seen that the hardness values of the specimens after anodized under ideal conditions with adding different amount of aluminum powder are more than the hardness of the specimens anodized without adding powder because of the more thickness and more layer of Al_2O_3.

4-Conclusions

The anodizing process is improved by adding aluminum powder under optimum conditions and the best value is at 9g/l, where the thickness improves for 72.25 µm under optimum conditions to 81.25 µm when 9g/ l aluminum powder is added and the coating ratio improves from 1.481 at optimum conditions to 1.541 when adding 9g/l aluminum powder for pure aluminum, while the thickness improves for 74.56 µm under optimum conditions to 82.29 µm when adding 9 g/l aluminum powder and the coating ratio improved for 1.417 at optimum conditions to 1.471when adding 9g/l aluminum powder for aluminum alloy (6063).

The increased is about 12.50% when effective anodic current efficiency was adding the best amount of aluminum powder of 9g/ l compared with anodizing at ideal conditions for pure aluminum. while this value is increased to about 10.2% when aluminum powder of 9g / l is added compared with ideal conditions for aluminum alloy (6063).

The roughness value and hardness for specimens with adding 9g/l is the highest value compared with the specimens at ideal conditions and bare specimens.

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Table (1) A Nominal (9) and Analytical chemical composition of pure Al.

Metal	Al	Si	Fe	Cu	Mn	Mg	Zn	Other
	99.95	0.030	0.040	0.010	0.01	0.01	0.01	----
Analyt	Rem.	0.030	0.035	0.02	0.01	0.01	0.01	----

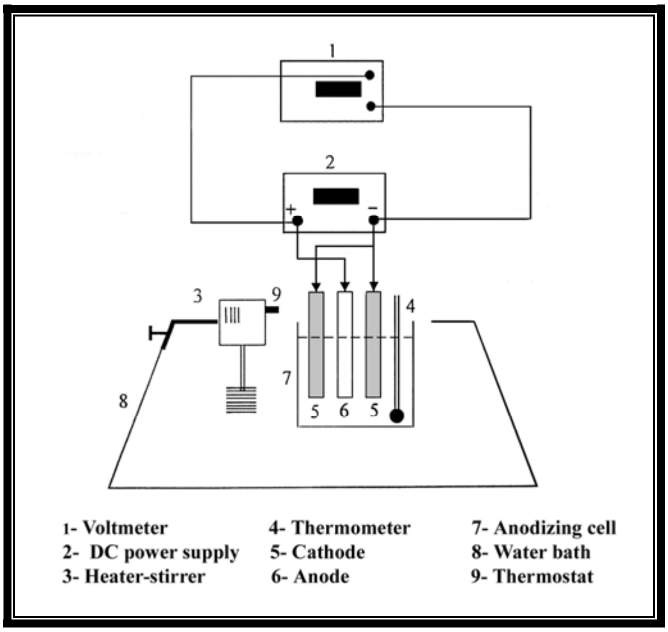


Figure (1) schematic diagram for the whole assembly of the anodizing apparatus.

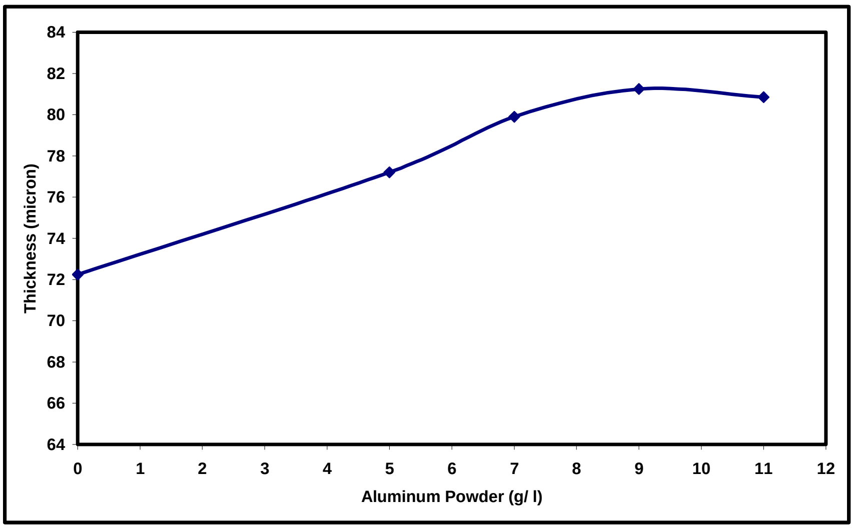


Figure (2) the effect of adding aluminum powder to anodizing solution at ideal conditions for pure aluminum on film thickness.

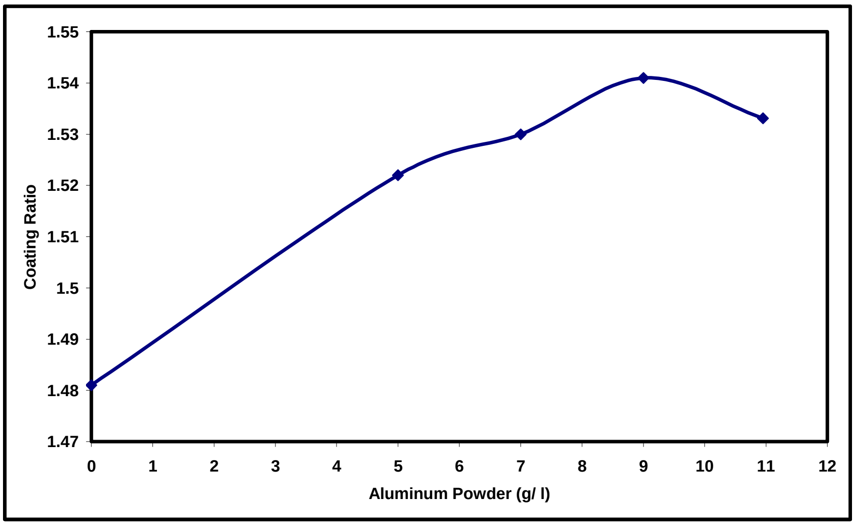


Figure (3) the effect of adding aluminum powder to anodizing solution at ideal conditions for pure aluminum on coating ratio.

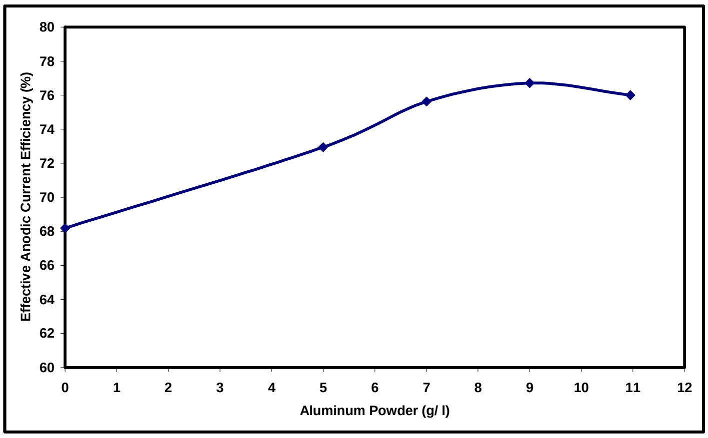


Figure (4) the effect of adding aluminum powder to anodizing solution at ideal conditions for pure aluminum on effective anodic current efficiency.

Table (2) Experimental runs for pure aluminum by using the ideal conditions without added aluminum powder.

Run No.	W_1 (g)	W_2 (g)	W_3 (g)	Wc (g/dm^2)	W_A (g/dm^2)	Rc	$W_{AL.C}$	W_{At} (g/dm^2)	% η_E	Thick.
1	0.091	0.114	0.043	1.737	1.169	1.486	0.919	1.344	68.40	72.41
2	0.092	0.115	0.044	1.729	1.171	1.476	0.915	1.344	67.99	72.10
Av	0.092	0.115	0.043	1.733	1.170	1.481	0.917	1.344	68.19	72.25

Table (3) Experimental runs for pure aluminum by using the ideal conditions with adding amount of aluminum powder.

Adding 5g/l of Aluminum Powder

Run No.	W_1 (g)	W_2 (g)	W_3 (g)	Wc (g/dm^2)	W_A (g/dm^2)	Rc	$W_{AL.C}$ (g/dm^2)	W_{At} (g/dm^2)	% η_E	Thick. (Y) µm
1	0.0992	0.1257	0.0500	1.8373	1.194	1.538	0.9726	1.344	72.33	76.55
2	0.0910	0.1169	0.0399	1.8689	1.2402	1.506	0.9894	1.344	73.58	77.87
Av	0.0951	0.1213	0.0449	1.8531	1.2171	1.522	0.9810	1.344	72.95	77.21

Adding 7g/l of Aluminum Powder

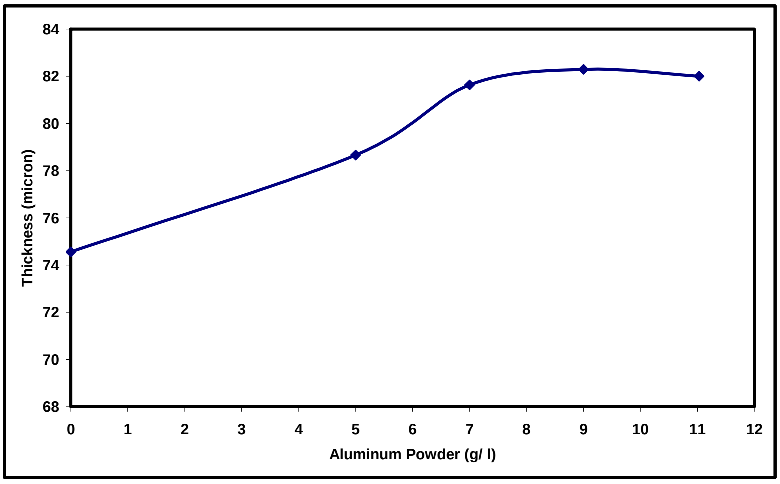
Run No.	**W_1 (g)**	**W_2 (g)**	**W_3 (g)**	**Wc (g/dm^2)**	**W_A (g/dm^2)**	**Rc**	**$W_{AL.C}$**	**W_{At} (g/dm^2**	**% η_E**	**Thick.**
1	0.093	0.120	0.041	1.932	1.262	1.530	1.022	1.344	76.06	80.50
2	0.124	0.151	0.072	1.910	1.247	1.531	1.011	1.344	75.20	79.57
Av	0.108	0.136	0.057	1.921	1.254	1.530	1.017	1.344	75.63	79.90

Adding 9g/l of Aluminum Powder

Run No.	**W_1 (g)**	**W_2 (g)**	**W_3 (g)**	**Wc (g/dm^2)**	**W_A (g/dm^2)**	**Rc**	**$W_{AL.C}$**	**W_{At} (g/dm^2**	**% η_E**	**Thick.**
1	0.126	0.154	0.074	1.951	1.264	1.543	1.033	1.344	76.06	81.31
2	0.119	0.147	0.066	1.949	1.266	1.538	1.031	1.344	76.73	81.20
Av	0.122	0.150	0.070	1.950	1.265	1.541	1.032	1.344	76.72	81.25

Adding 11g/l of Aluminum Powder

Run No.	**W_1 (g)**	**W_2 (g)**	**W_3 (g)**	**Wc (g/dm^2**	**W_A (g/dm^2)**	**Rc**	**$W_{AL.C}$**	**W_{At} (g/dm^2**	**% η_E**	**Thick.**
1	0.122	0.149	0.070	1.929	1.254	1.537	1.021	1.344	75.97	80.40
2	0.116	0.143	0.064	1.924	1.257	1.530	1.018	1.344	75.78	80.19
Av	0.119	0.146	0.067	1.927	1.256	1.533	1.020	1.344	75.87	80.25



Figure(5) The effect on film thickness of adding aluminum powder to anodizing solution at ideal conditions for aluminum alloy (6063).

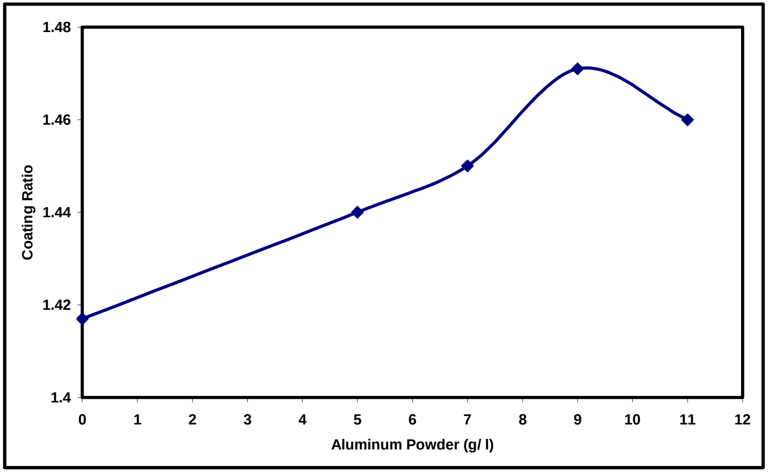


Figure (6) the effect of adding aluminum powder to anodizing solution at ideal conditions for aluminum alloy (6063) on coating ratio.

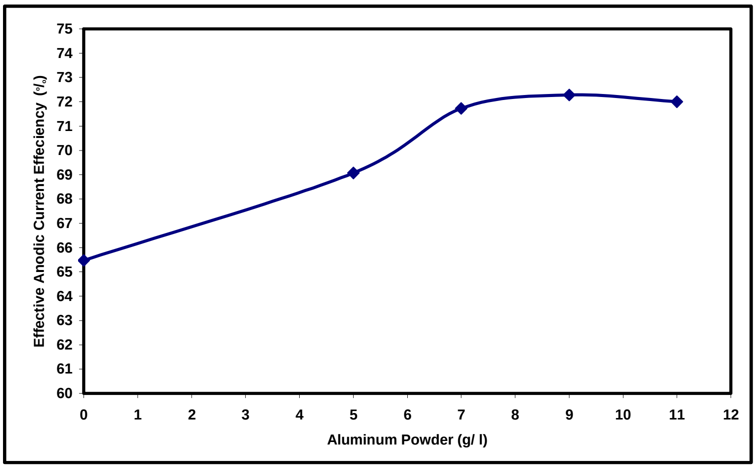


Figure (7) the effect of adding aluminum powder to ideal conditions for aluminum alloy(6063) on effective anodic current efficiency.

Table (4) Experimental runs for aluminum alloy (6063) by using the ideal conditions without added aluminum powder.

Run No.	W_1 (g)	W_2 (g)	W_3 (g)	Wc (g/dm^2)	W_A (g/dm^2)	Rc	$W_{AL.}$ C	W_{At} (g/dm^2)	% η_E	Thick .
1	0.542	0.565	0.486	1.791	1.269	1.411	0.948	1.344	70.54	74.66
2	0.475	0.499	0.420	1.787	1.255	1.423	0.946	1.344	70.37	74.47
Av	0.508	0.532	0.453	1.789	1.262	1.417	0.947	1.344	70.45	74.56

Table (5) Experimental results for aluminum alloy (6063) by using the ideal conditions with adding amount of aluminum powder.

Adding 5g/l of Aluminum Powder

Run No.	W_1 (g)	W_2 (g)	W_3 (g)	Wc (g/dm^2)	W_A (g/dm^2)	Rc	$W_{AL.}$ C	W_{At} (g/dm^2)	% η_E	Thick .
1	0.541	0.567	0.483	1.884	1.312	1.436	0.997	1.344	74.20	78.52
2	0.453	0.479	0.396	1.891	1.307	1.446	1.001	1.344	74.46	78.80
Av	0.497	0.523	0.439	1.888	1.309	1.441	0.999	1.344	74.33	78.66

Adding 7g/l of Aluminum Powder

Run No.	W_1 (g)	W_2 (g)	W_3 (g)	Wc (g/dm^2)	W_A (g/dm^2)	Rc	$W_{AL.C}$	W_{At} (g/dm^2)	% η_E	Thick.
1	0.448	0.475	0.389	1.954	1.350	1.447	1.034	1.344	76.84	81.44
2	0.475	0.502	0.416	1.963	1.348	1.456	1.039	1.344	77.20	81.82
Av	0.462	0.489	0.402	1.959	1.349	1.451	1.037	1.344	77.02	81.63

Adding 9g/l of Aluminum Powder

Run No.	W_1 (g)	W_2 (g)	W_3 (g)	Wc (g/dm^2)	W_A (g/dm^2)	Rc	$W_{AL.C}$	W_{At} (g/dm^2)	% η_E	Thick.
1	0.547	0.575	0.487	1.984	1.352	1.466	1.050	1.344	78.00	82.67
2	0.572	0.600	0.513	1.966	1.332	1.475	1.040	1.344	77.29	81.91
Av	0.559	0.587	0.500	1.975	1.342	1.471	1.045	1.344	77.64	82.29

Adding 11g/l of Aluminum Powder

Run No.	W_1 (g)	W_2 (g)	W_3 (g)	Wc (g/dm^2)	W_A (g/dm^2)	Rc	$W_{AL.C}$	W_{At} (g/dm^2)	% η_E	Thick.
1	0.476	0.503	0.417	1.963	1.346	1.458	1.039	1.344	77.31	81.82
2	0.568	0.596	0.508	1.975	1.350	1.462	1.045	1.344	77.64	82.29
Av	0.522	0.550	0.462	1.969	1.348	1.460	1.042	1.344	77.47	82.05

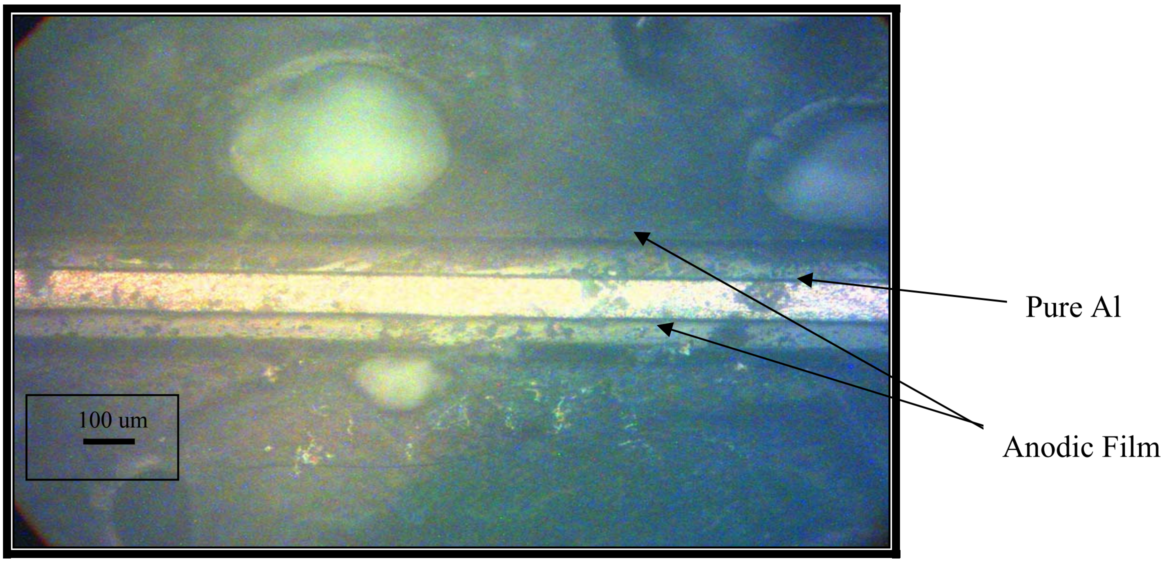


Figure (8) Optical microscope section showing anodic film thickness of pure aluminum under ideal conditions .

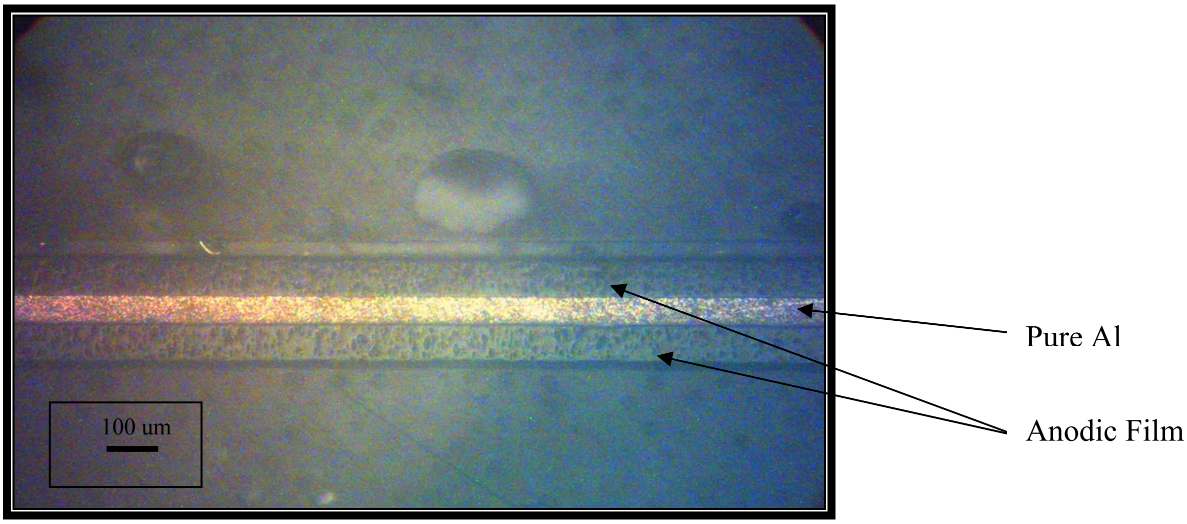


Figure (9) Optical microscope section showing anodic film thickness of pure aluminum under ideal conditions with 9g/l aluminum powder.

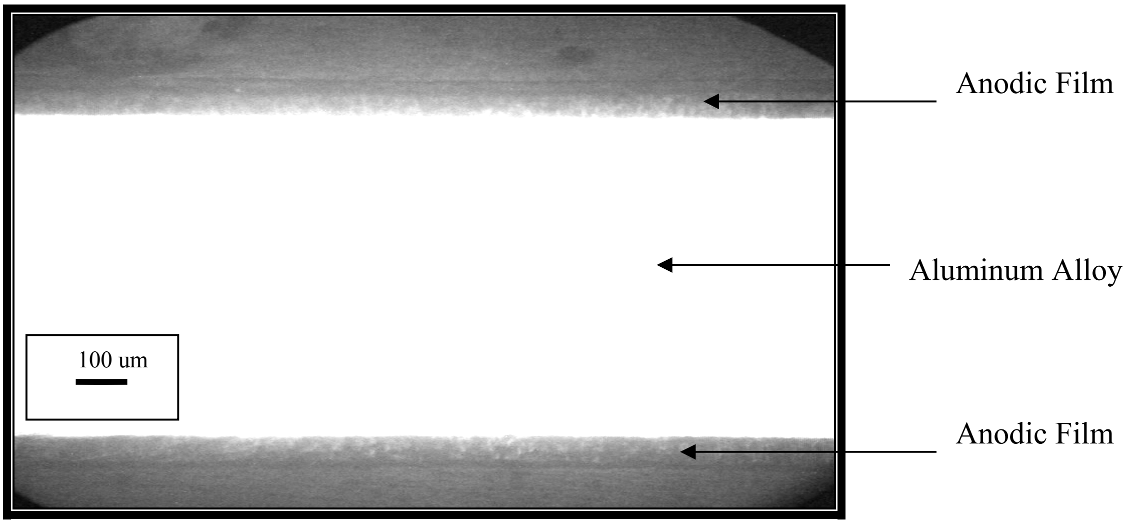


Figure (10) Optical microscope section showing anodic film thickness of aluminum alloy (6063)under ideal conditions .

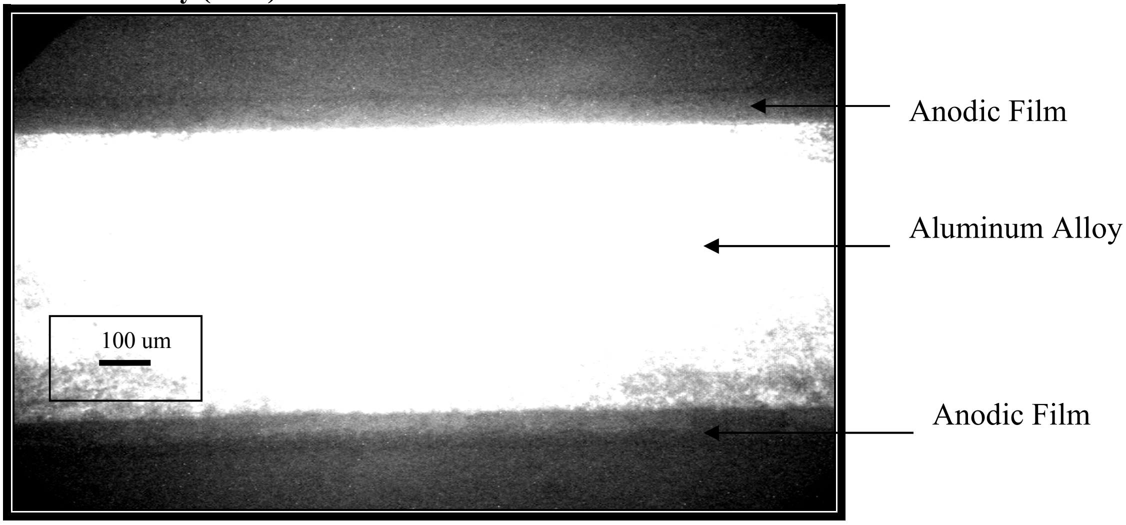
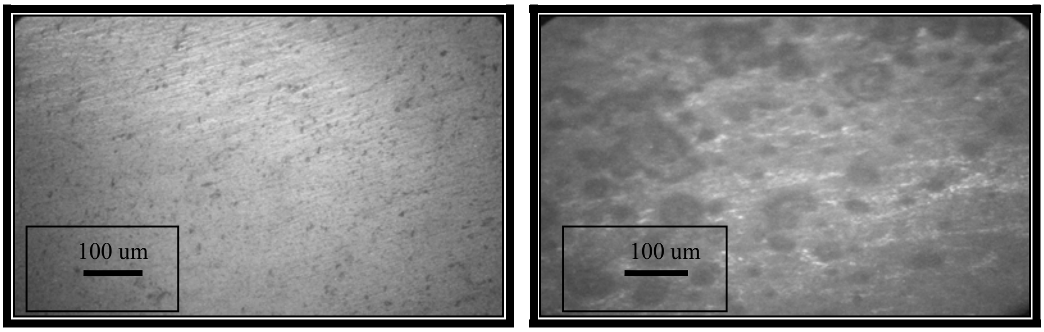


Figure (11) Optical microscope section showing anodic film thickness of aluminum alloy (6063) under ideal conditions with 9g/l aluminum powder.

Table (6) Roughness values for specimens before and after anodizing.

No.	Pure Aluminum	Roughness value(µm)Ra	Aluminum Alloy(6063)	Roughness value(µm)Ra
1	before anodized	0.04	before	0.066
2	After anodized under ideal	0.061	After anodized under ideal	0.080
3	Adding 5g/ l	0.073	Adding 5g/ l	0.085
4	Adding 7g/ l	0.077	Adding 7g/ l	0.088
5	Adding 9g/ l	0.080	Adding 9g/ l	0.090
6	Adding 11g/ l	0.079	Adding 11g/ l	0.090



-a- -b-

Figure (12) Surface of pure aluminum.
-a- surface before anodizing.
-b- surface after anodizing.

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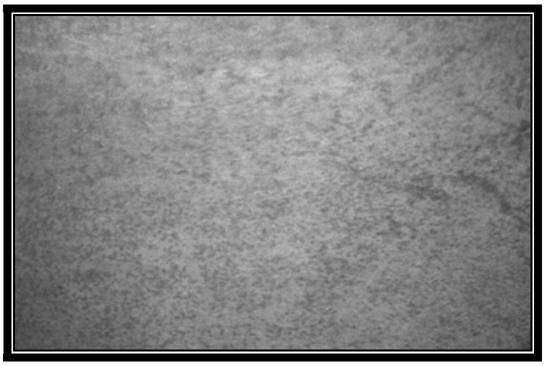
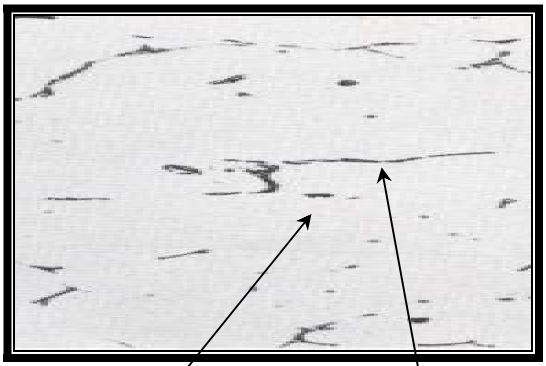
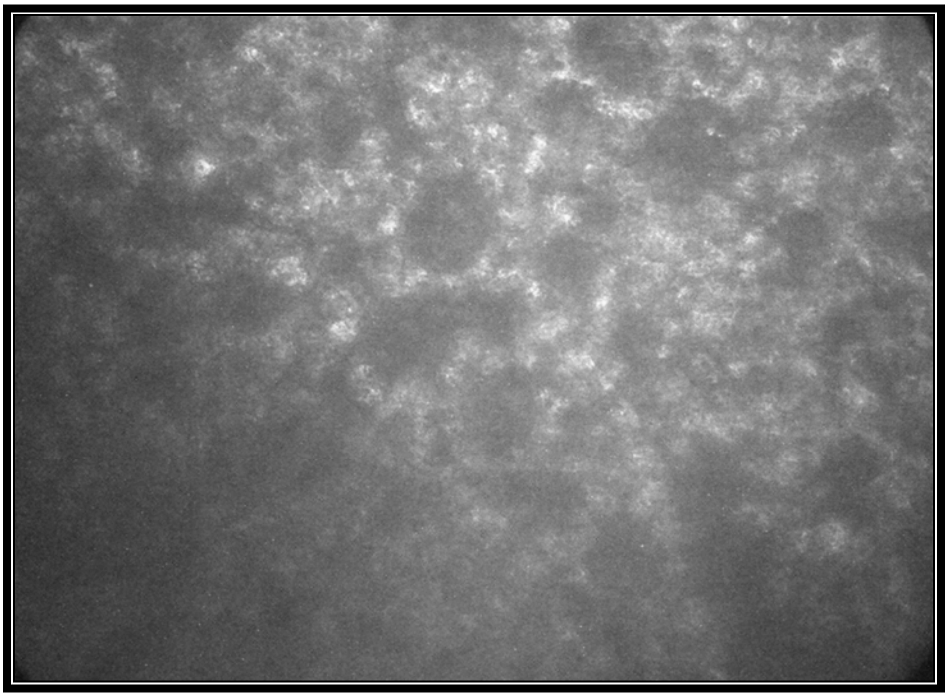


-a-



-b-



-c-

Figure (13) Surface of aluminum alloy (6063).
-a-surface specimen before anodizing.
-b-standard microstructure of auminum alloy (6063) [0.5% Mg, 0.4 Si, 0.25%Fe] (14, 15).
-c- surface specimen after anodizing.

Table (7) Micro-hardness values for anodized specimens prepared and bare specimens.

No.	Type of specimens	Micro - Hardness Value HV of Pure Aluminum	Micro - Hardness Value HV of Aluminum Alloy(6063)
1	before anodized	55	68
2	After anodized under ideal conditions	221	234
3	Adding 5g/ l	258	269
4	Adding 7g/ l	265	278
5	Adding 9g/ l	274	288
6	Adding 11g/ l	270	284