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Effects of Sodium Chloride and Sodium Sulphate Solutions on the Output of the Electrochemical Machining

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Abstract

Electrochemical Machining is a term given to one of nontraditional machining that uses a chemical reaction associated with electric current to remove the material. The process is depending on the principle of anodic dissolution theory for evaluating material removal during electrochemical process. In this study, the electrochemical machining was used to remove 1 mm from the length of the a workpiece (stainless steel 316 H) by immersing it in to electrolyte (10, 20 and 30 g) of NaCl and Na_2SO_4 to every (1 litter of filtered water). The tool used was made from copper. Gap size between the workpiece and electrode is (0.5) mm. This study focuses on the effect of the changing the type and concentration of electrolyte solution, the effect of the value of current (2, 5 and 10) A and the effect of the value of the voltage (6, 12 and 20)V on the Surface Roughness (Ra) and Material Removal Rate (MRR) of the workpiece. The results of comparison of experimental showed that (Na_2SO_4) solution give surface roughness less than (NaCl) solution in all levels, maximum (Ra) is (0.658) and minimum (0.420), while (NaCl) solution give maximum (Ra) is (2.913) and minimum is (0.508), also give (MRR) higher from (NaCl) solution in level (30 g/l) at (5 A) , (10 and 20 g/l) at (10 A) ,and (30)g/l at (6 &12 V). This study aims to compare the effect of using different electrolyte solution including sodium chloride (NaCl) and sodium sulphate (Na_2SO_4) on the surface roughness (Ra) and material removal rate (MRR).

Generally increasing in machining parameter (concentration of solution, current and voltage) lead to increase in (MRR) and (Ra).

Keywords: *Electrochemical machining, surface roughness, electrolyte concentration.*

1. Introduction

The Electro-chemical Machining (ECM) is an advanced machining operation and, potentially, it is the highly beneficial process of material removal of non-conventional machining operation [1]. It's named via such term since the electric energy is utilized in a integration with the chemical reaction to complete the sweep of metal [2]. Such process depends upon the electrolysis principle for the removal of metal, which is based on a controlled anodic electrochemical dislocation process of the workpiece (anode) with the tool (cathode) in an electrolytic cell. The solution of electrolyte is generally a mineral salt as a sodium nitrate ($NaNO_3$), acid such as (HCl) and alkaline such as (NaOH) [3]. The metal removal rate is governed by the Miechael Faraday's law of electrolysis. Gusseff presented the first patent on (ECM) in 1929's, and the first important evolution took place in 1950's, when the operation was the high-strength and heat resistance alloy machining [4]. This process was universally accepted as standard operation in production and is able to machine hard material work parts, which are difficult-to-machine and precise. And after the Second World War, the technology became more popular result as the demanding processing of hard alloys by martial and aerospace applications [5]. Mcgough 1988 asserted that if a potential discrepancy is exerted across the electrodes, many possible reactions take place at the cathode and the anode. Electrolysis has included the iron (Fe) dissolution from the anode and the hydrogen (H_2) generation at the cathode [6]. ECM is used in many applications, for example, automotive and medical principle user. This operation has found good applications in industries related with the manufacture of aircraft edging parts, turbine blades and grinding of carbide tools and dies [7]. Table (1) represent the difference between conventional machining and ECM. Jo ao Cirilo da Silva Neto, et al. 2006[8] studied the intervening parameters in the ECM of Valve-Steel. The MRR, roughness and over-cut were investigated. 4 parameters were varied within the experiments: electrolyte, voltage, rate of feed, and the electrolyte flow rate. Two electrolytic solutions were employed: NaCl and $NaNO_3$. Results showed that the rate of feed was the major parameter influencing the MRR and the electrochemical machining with the $NaNO_3$ gave the best surface roughness and over-cut results.

Anil Kumar Meher, et al 2009 [9] Intended to deal with the process characteristics of ECM and how it is affected by the process parameters. The electrolyte solution was used NaCl (100gm/lt). And in this research tow parameters was used (voltage and feed rate). The results show that feed rate was the main parameter affecting the MRR. Andi Sudiarso et al. (2016) [10] studied the process parameters, like concentration of electrolyte (NaCl) and voltage. The optimization goal was to get the highest value of material removal rate (MRR) and the lowest overcut (OC). The research was conducted by varying 3 levels of voltage 9.5, 11 and 12.5 V, 3 levels of NaCl concentration 100, 150 and 200 g/L and 3 times the replication of full factorial design approach (FF). Machining was done by using die sinking method with stainless steel 204, for both the electrode and work-piece. The results obtained from this research showed that the voltage and NaCl concentration have a significant influence on the value of MRR and overcut, where their influences are formulated in the form of linear regression models. Besides that, the highest MRR was obtained at a voltage of 12.5 volts and NaCl concentration 200 g/l with value 17.86×10^{-4} g/s.

Table,1
The unlikeness between traditional machining and ECM process [11].

Traditional machining	ECM process
a- Communicate between the tool and the WP.	a- No communicate between the tool and the WP.
b- Remove of metal by shearing and friction methods.	b- Remove of metal by anodic dissolutions methods.
c- Relying on the mechanical properties of material.	c- Relying on electrical conductivity of material and chemical reactions of the operation.
d- Requirement for reshape the tools or it sever wear.	d- not requirement for reshape the tools and do not sever wear.
e- The chip forming as a stiff body.	e- The chip forming as a rustiness.
f- The model of the tool depend on the kind of process.	f- The shape of the tools depend on the ultimate shapes of the product.
g- using the cooling liquid to reduce the heat generation during the process.	g- The electrolyte that use in ECM operation can also reduce the heat generation.
h- using the cooling liquid to reduce the heat generation during the operation.	h- the electrolyte that use in ECM operation can also reduce the heat generation.

2. The Electrochemical Reaction

The electrochemical reaction is the chemical reaction that takes place in the solution at the interface of an electronic conductor (a metal) and ionic conductor (electrolyte), and it involves electron transfer between the electrode and electrolyte or species in solution and this reaction is driven by external applied voltage [12]. The chemical reaction is that involved a transfer of electrons can be used to produce an electric current [13]. The material removal is executed by taking part of an electrolyte between the tool material (cathode) and the workpiece (anode) and across a very small cavity between them. Gas bubbles generated in the electrode gap and the dislocation product such metal hydroxide is removed by the electrolyte. Electrochemically using (NaCl) solution as electrolyte [14]:

$NaCL \rightarrow Na^{+} + Cl^{-}$ …(1)

$H_2O \rightarrow H^{+} + OH^{-}$ …(2)

Positive charged captions: H^+ and Na^+ toward cathode and negatively charged anions: (OH) and (Cl^-) go towards anode.
So the anode metal (workpiece) becomes [2]:
$Fe \rightarrow Fe^{+2}+2e$ …(3)
When the metal ions leave the workpiece surface (anode), many reactions occur in the electrolyte.
$Fe^{+2}+2Cl^- \rightarrow FeCl_2$ …(4)
$Fe^{+2}+2OH^- \rightarrow Fe(OH)_2$ …(5)
$FeCl_2+2OH^- \rightarrow Fe(OH)_2+2Cl^-$ ...(6)
This ferrous hydroxide ($Fe(OH)_2$) is a green - black precipitate.
(Cl^-) ions may loose an electron and hence undergoes oxidation at the anode leading to evolution of chlorine gas at anode:
$2Cl^- \rightarrow Cl_2+2e^-$ …(7)
$2FeCl_2+Cl_2 \rightarrow 2FeCl_3$ …(8)
$H^++Cl^- \rightarrow HCl$ …(9)
Green-black ferric hydroxide ($Fe(OH)_2$) reacts with the oxygen to form ferric hydroxid ($Fe(OH)_3$) which is red-brown in color [9]. Figure (1) represent electrochemical reaction during ECM of iron.
$2H_2O \rightarrow O_2\uparrow+4H^++4e^-$ …(10)
$2Fe(OH)_2+H_2O+O_2 \rightarrow 2Fe(OH)_3\downarrow$ ...(11)
$Fe(OH)_3\downarrow 3HCl \rightarrow FeCl_3+3H_2O$ ...(12)
$FeCl_3+3NaOH \rightarrow Fe(OH)_3\downarrow+3NaCl$ ....(13)

3. Electrochemical Reactions for Sodium Sulphate (Na2SO4)

$H_2O \rightarrow H^++OH^-$ …(14)
$Na_2SO_4 \rightarrow 2Na^++SO4^{-2}$ …(15)
$Fe \rightarrow Fe^{+2}+2e^-$ …(16)
When the metal ions leave the workpiece surface (anode), many reactions occur in the electrolyte.
$Fe^{+2}+SO_4^{-2} \rightarrow FeSO_4$ …(17)
$Fe^{+2}+2OH^- \rightarrow Fe(OH)_2$ …(18)
$FeSO_4+2OH^- \rightarrow Fe(OH)_2 + SO_4^{-2}$ …(19)
This ferrous hydroxide ($Fe(OH)_2$)is a green - black precipitate.
$2SO_4^{-2} \rightarrow SO_4+2e^-$ …(20)
$2FeSO_4+SO_4 \rightarrow 2Fe(SO_4)_3$ ...(21)
$H^++SO_4^{-2} \rightarrow {}^-HSO_4$ ..(22)
Green-black ferric hydroxide ($Fe(OH)_2$) reacts with the oxygen to form ferric hydroxid ($Fe(OH)_3$) which is red-brown in color
$2H_2O \rightarrow O_2\uparrow+4H^++4e^-$ …(23)
$2Fe(OH)_2+H_2O+O_2 \rightarrow Fe_2(OH)_3\downarrow$ ...(24)
$Fe_2(OH)_3+3HSO_4 \rightarrow Fe_2(SO_4)_3+3H_2O$ ...(25)
$Fe_2(SO_4)_3+6NaOH \rightarrow 2Fe(OH)_3\downarrow+3Na_2SO_4$ ...(26)

4. Calculation of MRR exp

The actual MRR can be determined by the [15]:

$$MRR\ exp = \frac{Wb-Wa}{MT} \quad (g/min) \quad ...(27)$$

Where:
MRR exp = experimental material removal rate.
Wb = weight of the workpiece before ECM machining (g).
Wa = weight of the workpiece after ECM machining (g).
MT =machining time (min).

5. Experimental Work

5-1 In electro-chemical machining (ECM) using drilling machine, as shown in Fig (2), WP material was chosen from (stainless steel AISI 316), with dimension (40x 30) mm and thickness (2) mm. figures (2) and figure (3) represents the workpiece before and after machining. The percentages of chemical composition is given in Table (2).
5-2 Tool material was chosen from copper dimension (110x30) mm and thickness (6) mm, as shown in Fig (4), with using nine sample and change in machining parameter (concentration of electrolyte solution, current and voltage).
5-3 The main parts of ECM machine, as shown in figure 5.
a- Power supply The power supply is a very important device to provide the current that helps the electrochemical reaction to occur by forcing the electrons to move from the work piece through it to the tool. The power supply used in the experiment work a D.C power type with different currents from (0-30 A). and voltages from (0-50V).
b- Electrolyte pump: It is put into the chamber of reaction. It will pumping the electrolyte into the cavity between the tool and workpiece to prevent sludge for plain operation.
c- Reaction chamber: It is the cell used for the electrochemical reaction between the workpiece and the electrolyte, this chamber is made from glass, with the dimensions (450x200x260) mm^3.
d- Electrolyte: The electrolytes were used in this process mixture from a water filtered and sodium nitrite (NaCl), and the other solution using (Na_2SO_4) (sodium sulphate) with concentrations (10, 20 and 30) (g/l).

6. Surface Roughness Measurements

In this work, the surface roughness (Ra) measurement was taken at three different regions on the machined surface. The mean of these three measurements was taken as the final value for the surface roughness and measured in µm. A profile-meter made by Maher Federal Company, type Pocket surf PS1 was used to measure Ra. The probe scans the surface and compares between peaks and valleys to indicate the SR.

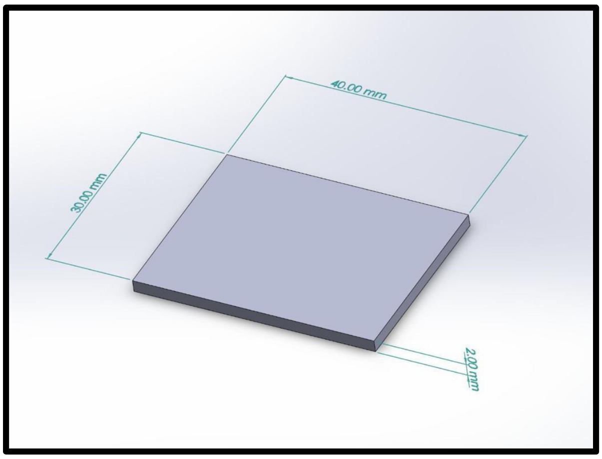

Fig. 2. Chemical Compositions of WP (stainless steel 316)

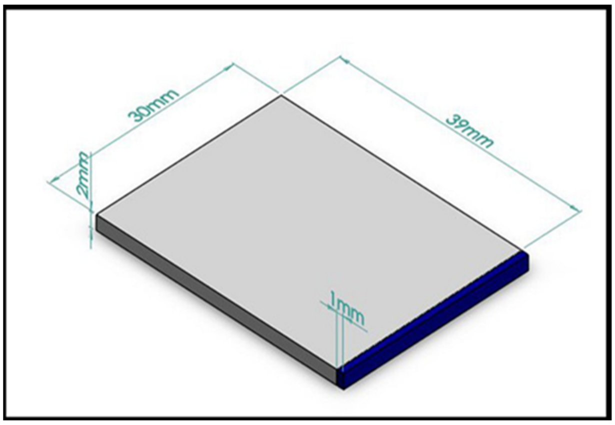

Fig. 3. WP (stainless steel AISI 316) after machining.

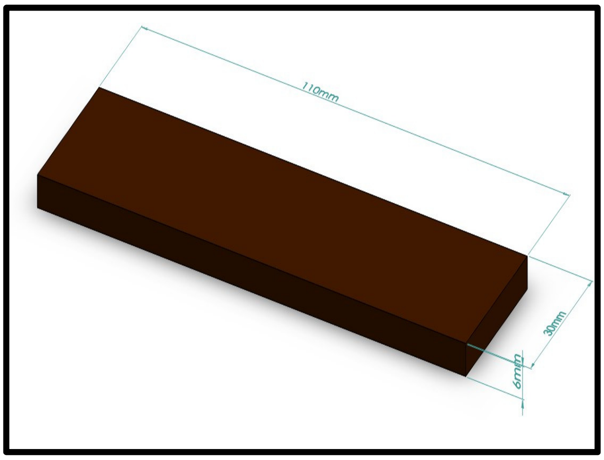

Fig.4. The copper electrode.

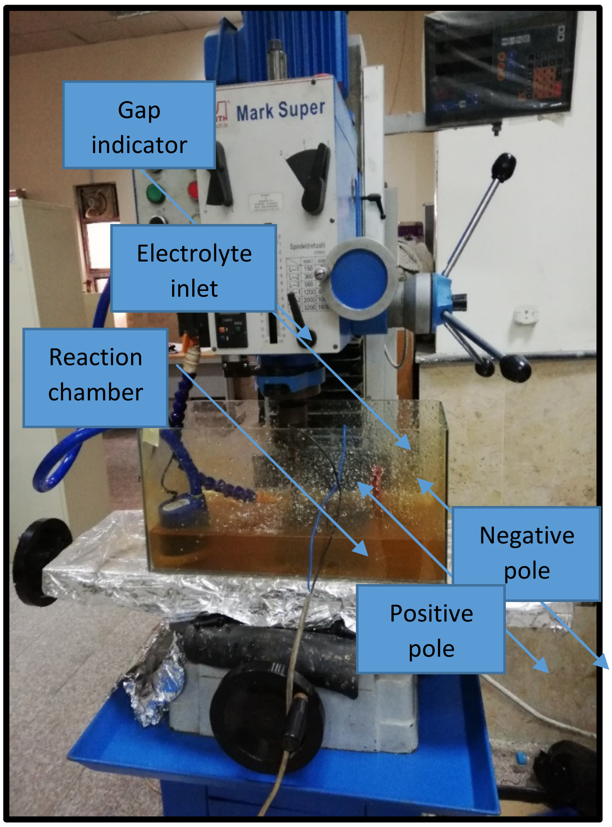

Fig.5. ECM machine.

Fig. 6. surface roughness device.

Table 2,
Chemical Compositions of WP (stainless steel 316).

C%	**Si%**	**Mn%**	**P%**	**S%**	**Cr%**	**Mo%**
0.057	0.391	1.769	0.035	<.0005	18.73	0.284
Al%	**Ni%**	**Cu%**	**V%**	**W%**	**Fe%**	
<.001	8.69	0.338	0.063	0.042	Bal.	

7. Results and Discussion

7.1 Effect of the Concentration of Solution, Current and the Voltage on Ra.

The surface roughness of the workpiece increases with increasing the value of the voltage and the value of the current intensity. The increase in the current intensity lead to increase in movement of ions associated with the machining operation in the machining zone metal lead to increase temperature and surface roughness [11]. Also increase in concentration of solution lead to increase in number of positive and negative ions lead to increase speed of chemical reaction and increase the temperature and surface roughness. As shown in figure 7, 8 and 9.

Fig.7 explains the effect concentration of solution (10,20,30)g/l, the value of the current (2)A and the value of the voltage (6)V. Maximum surface roughness for NaCl is (2.088)µm, and minimum value is(0.508), and maximum surface roughness for (Na_2SO_4) is (0.480)µm, and minimum value is (0.420).

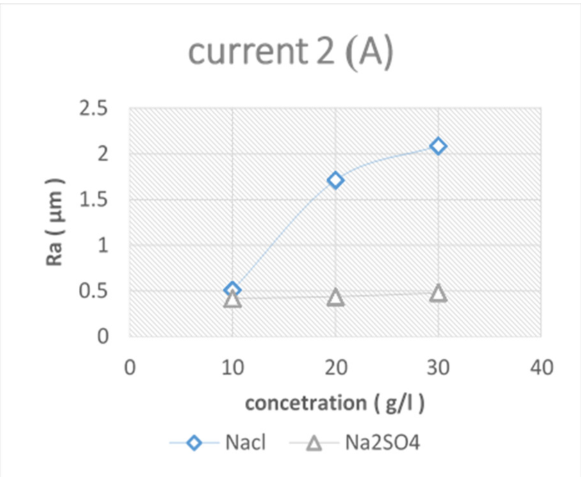

Fig. 7. Effect of concentration at current (2A) and (6V) on surface roughness.

Fig.8 explains the effect concentration of solution (10,20,30)g/l, the value of the current (5 A) and the voltage of (12V). Maximum surface roughness for NaCl is (2.913)µm, and minimum value is(2.043), and maximum surface roughness for (Na_2SO_4) is (0.503)µm, and minimum value is (0.561).

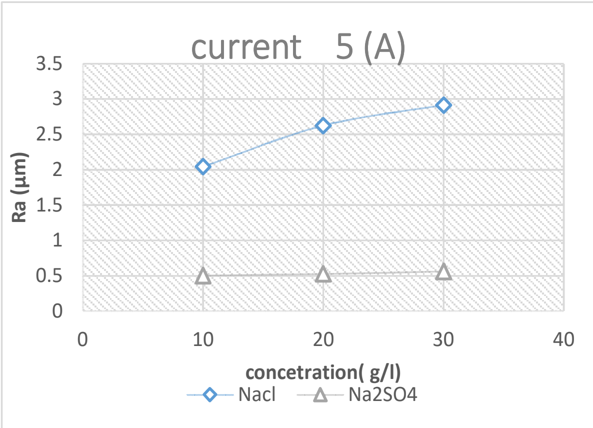

Fig. 8. Effect of concentration at current (5A) and (12) on surface roughness.

Fig.9 explains the effect concentration of solution (10,20,30)g/l, current (10A) and the voltage of (20)V. Maximum surface roughness for NaCl is (2.913) µm, and minimum value is (2.043), and maximum surface roughness for (Na_2SO_4) is (0.503)µm, and minimum value is (0.561).

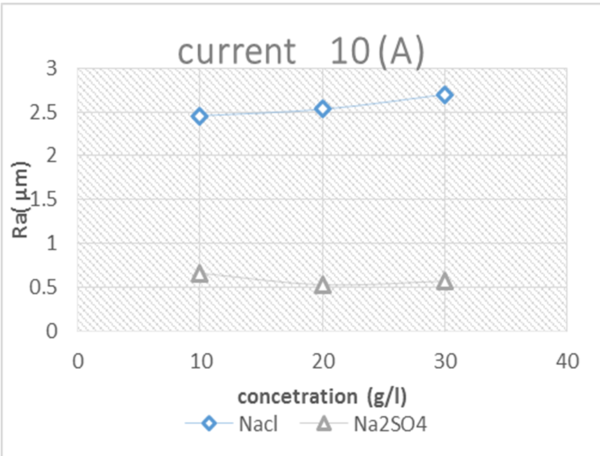

Fig. 9. Effect of concentration at current (10A) and voltage (20) on surface roughness.

7.2 Effect of the Concentration of Solution, Current and the Voltage on MRR.

Increase in the voltage and current intensity lead to increase in material removal rate because the amount of mass dissolved is straight commensurate to the offset of electricity which has flowing" according to Faraday's lows, in the medium of operations will dash the chemical reactions at high values of current that give better results [12] and increase in electrolyte concentration lead to increases the MRR. This can be attributed to increase in the electrical conductivity of the electrolyte with increase in concentration as a result of which machining current in the inter electrode gap (IEG) increases. Further, at higher concentration, a large number of ions accumulated in the (IEG) increase the machining current and thus enhances the material removal rate [13]. Table 3 and 4 reperesents experimental impact of the machining parameters on and Ra and MRR of (NaCl) and (Na_2SO_4) solution respectivily. Table (3) and(4) represente the values of exeperimental impact of machining parameters on (Ra) and (MRR) of (NaCl) and (Na_2SO_4) respectivily.

Fig.10 explains the effect of current (2,5 and 10) A, voltage (6V) and the concentration (10)g, maximum material removal rate for NaCl is (0.016)g/min, and minimum value is(0.007) g/min, and maximum removal rate for (Na_2SO_4) is (0.023)g/min, and minimum value is (0.0067)g/min.

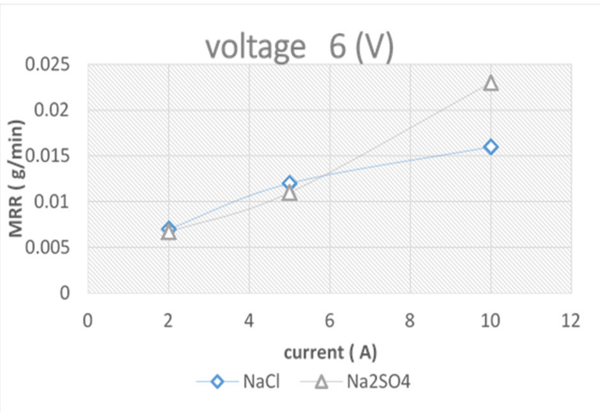

Fig.10 Effect of current at voltage (6V) and the concentration (10) g/l on material removal rate.

Fig.11 explains the effect of current (2,5,10) A, voltage (12V) and the concentration (20)g, maximum material removal rate for NaCl is (0.02)g/min, and minimum value is(0.008) g/min, and maximum removal rate for (Na_2SO_4) is (0.028)g/min, and minimum value is (0.0084)g/min .

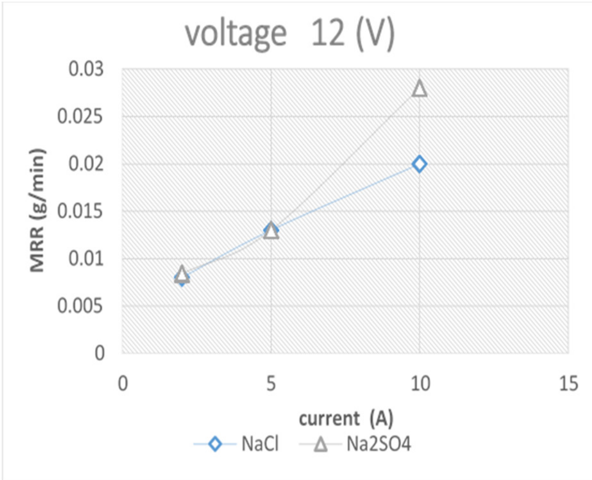

Fig. 11. Effect of current at voltage (12V) and the concentration (20) g/l on material removal rate.

Fig.12 explains the effect of current (2,5,10) A, and voltage (20V), maximum material removal rate for NaCl is (0.038)g/min, and minimum value is(0.01) g/min, and maximum removal rate for (Na_2SO_4) is (0.035)g/min, and minimum value is (0.0089)g/min.

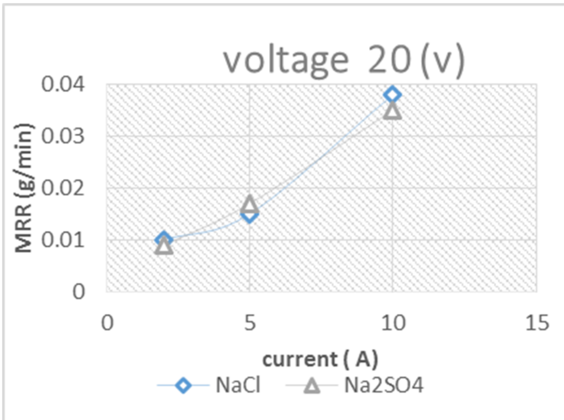

Fig. 12 Effect of current at voltage (20V) and the concentration of (30) g/l on material removal rate.

Conclusions

The conclusions from experimental work are:

1- Increasing in concentration, current and voltage lead to increase in (Ra) and (MRR), due to increase in electrochemical reaction that lead to increase in the ion exchange between the electrode and the working piece and the heat generated, leading to increased removal and roughness [9].

2- (Na_2SO_4) solution give surface roughness less than (NaCl) solution in all levels, due to existence ion ($^-HSO_4$) which appears as a product of the solution reaction as shown by the equations for K_2SO_4, and acts as an acid and also works as alkaline, so give high smooth surface.

Table 3,
Experimental impact of the machining parameters on and Ra and MRR of (NaCl) solution.

No.of exp.	Con. (g/l)	Current (A)	Volt. (V)	Machining time (min)	Ra (µm)	MRR in (g\min)
1	10	2	6	50	0.508	0.007
2	20	2	12	35	1.712	0.008
3	30	2	20	25	2.088	0.01
4	10	5	6	30	2.043	0.012
5	20	5	12	26	2.625	0.013
6	30	5	20	21	2.913	0.015
7	10	10	6	20	2.457	0.016
8	20	10	12	15	2.530	0.02
9	30	10	20	10	2.699	0.038

Table4,
Experimental impact of the machining parameters on Ra and MRR of (Na_2SO_4) solution

No.of exp.	Con. (g/l)	Current (A)	Volt. (V)	Machining time (min)	Ra (µm)	MRR in (g\min)
1	10	2	6	55	0.420	0.0067
2	20	2	12	45	0.438	0.0084
3	30	2	20	40	0.480	0.0089
4	10	5	6	32	0.503	0.011
5	20	5	12	25	0.526	0.013
6	30	5	20	20	0.561	0.017
7	10	10	6	15	0.658	0.023
8	20	10	12	12	0.525	0.028
9	30	10	20	10	0.567	0.035

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تاثير محا□يل كلوريد□صوديوم وكبريتات□صوديوم على مخر□ات□تشغيل□كهروكيميائي

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□خلاصة

□ُعد عملية التشغيل الكهروكيميائي احدى عمليات التشغيل اللا□قليدية حيث□ستخدم التفاعل الكيميائي المر□بط بالتيار الكهربائي لازالة المعدن و□عتمد على مبدا الانخلاع الانودي . استخدمت في هذه الدراسة عملية التشغيل الكهروكيميائي لازالة (١) ملم من طول الشغلة نوع (ستنلس ستيل ٣١٦) بوساطة غمرها بمحلول الكتروليتي من كلوريد الصوديوم وكبريتات الصوديم بتركيز (١٠،٢٠،٣٠) غم لكل (١) لتر من الماء المفلتر، العدة التي استخدمت من النحاس ومسافة الفراغ بين الشغلة والعدة (٠,٥) ملم ، هذه الدراسة ركزت على□غيير نوع المحلول الالكتروليتي وقيمة التيار التي استخدمت هي (٢,٥,١٠) امبير و□اثير الفولتية بقيمة (٦,١٢,٢٠) فولت على قيمة الخشونة السطحية ومعدل ازالة المعدن ، بينت نتائج المقارنة للتجارب العملية ان محلول كبريتات الصوديوم يعطي □شونة سطحية اقل من محلول كلوريد الصوديوم ولكل المستويات واقصى □شونة سطحية هي (٠,٦٥٨) مايكرون واقل □شونة سطحية هي (٠,٤٢٠) مايكرون بينما محلول كلوريد الصوديوم اعطى اقصى□شونة سطحية (٢,٩١٣) مايكرون واقل□شونة سطحية (٠,٥٠٨) مايكرون . كذلك يعطي اعلى معدل لازالة المعدن من محلول كلوريد الصوديوم في المستويات (٣٠) غم / لترعند (٥) امبيرو□ركيز (١٠,٢٠) غم/لتر عند (١٠) امبير و□ركيز (٣٠) غم/لتر عند (٦,١٢) فولت.
