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INFLUENCE OF ELECTROCHEMICAL MACHINING INPUT PARAMETERS ON MATERIAL REMOVAL RATE OF 2024 T3 ALUMINIUM ALLOY

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ABSTRACT: Electrochemical machining (ECM) is a one of non-traditional machining process belonging to electrochemical type. ECM is one of the commonly used advanced machining processes particularly employed for manufacturing complicated or complex geometry on difficult-to-machine materials. In today’s manufacturing era, electrochemical-machining process provides good surface finish due to its controlled atomic dissolution of work material involving chemical reactions during machining. To enhance the machining performance, precise selection of machining parameters is still a demanding job in ECM process as it is very complex process involving so many unpredictable chemical reactions while machining. In this work, material removal rate (MRR) has been investigated. Aluminium alloy was used as work material and sodium chloride (NaCl) solution was selected as electrolyte. The effect of three parameters namely (voltage, flow rate of electrolyte and electrolyte concentration) on the material removal rate (MRR) has been considered. Thirty-five experiments were carried out. Three various values for each parameter were selected to carry out this study for voltage (10, 15, 20) V, for flow rate (8, 10, 12) l/min, and for concentration (50, 75, 100) g/l. The results indicated that the higher values of MRR were (0.1598, 0.1216, and 0.1485) g/min when value of each parameter voltage, flow rate and concentration was 20 V, 12 l/min, and 100 g/l respectively. In addition, the MRR generally increased with increase of the voltage, flow rate, and concentration of electrolyte as the trend might be different in each condition. However, the voltage was the prominent factor that affects the MRR significantly.

***Key words**: Electrochemical Machining, Metal Removal Rate, Aluminium Alloys.*

1-INTRODUCTION

Before the intricate shaped designs were difficulty machined, however, the production processes have been resumed themselves through integration of the principles of chemistry, electricity and mechanics (1). Electrochemical machining (ECM) is an unconventional process for machining (2, 3). Recently it has been discerned for carrying out many machining processes (4). In electrochemical machining, the metal is removed by the anodic dissolution in an electrolytic cell in which workpiece is the anode and the tool is cathode. The electrolyte is pumped through the gap between the workpiece and the tool, while direct current is passed through the cell, to dissolve metal from the workpiece (5). ECM is mainly used to cut hard or difficult to cut metals. Conventional processes are not suitable for these metals because there are many difficulties face these processes. Such as the cut of them needs to high energy and, this maybe lead to thermal effects because of high temperature, also the wear of tool owing to the contact between tool and workpiece. Those difficulties played important role for the development of the ECM process (6). ECM has been used widely in the manufacturing of semiconductor devices and this process is also used in aerospace and electronic industries (7).

Nowadays good accuracy and sense of time, ECM has common range for uses (8). Compare to others machining operations, ECM has more benefits such as, wear, stress/ burr do not occur owing to no contact between tool and work-piece, high MRR, high surface finish, and the capability for machining the complicated parts for hard metals. ECM acts as mirror, where the shape of tool is copied into the work-piece (9). B. Bhattacharyya, et al. reported that that the increases in voltage will increase MRR and overcut, the increase in electrolyte concentration will increase MRR and over cut which reduce the accuracy of machining process (10). H. Hocheng, et al. studied the effect of several parameters such as electrolyte concentration, supply voltage, electrolysis time, and tool-workpiece gap experimentally on the MRR and machined hole diameter. Experimental results illustrated, that the increase of voltage, electrolyte concentration, electrolysis time, and reduced the gap resulted in increase the MRR. Hole diameter has been effected highly by the electrolysis time (11). S.K. Mukherjee, et al. They investigated the influence of the various current densities on MRR of aluminium by the compared the experimental and theoretical values of MRR. They indicated that the increase of current density lead to sharp decrease in the resistance of electrolyte, and at the same time the value of over voltage firstly increases and thereafter reaches at the saturation with increase current density (12). Joao Cirilo da Silva et al. they studied the effect of both NaCl and $NaNO_3$ solutions on the MRR. They observed that, Application of NaCl led to higher MRR in comparison with $NaNO_3$. In addition, MRR was controlled voltage and fed rate for NaCl and $NaNO_3$ solutions (13). The inter electrode gap, concentration of electrolyte current, and voltage are important parameters of ECM (14). However, the accuracy of work can be enhanced, the precision of machine relies on several parameters request that wide research should be executed to establish the explanation to different parameters. From the above mentioned, the present work was performed to estimate the best conditions of ECM parameters (voltage, flow rate, and electrolyte concentration) and their effect on the material removal rate.

2- EXPERIMENTATION WORK

2-1 Electrochemical machining (ECM):

Figure 1 shows a schematic diagram of Electrochemical machining set up with all accessories (2). In which two electrodes are placed at a distance of about 0.5to 1mm & immersed in an electrolyte, which is a solution of sodium chloride (15). When an electrical potential of about 20V is applied between the electrodes, the ions existing in the electrodes migrate toward the electrodes. Positively charged ions are attracted towards the cathode & negatively charged towards the anode. This initiates the flow of current in the electrolyte. This process continues and tool reproduces its shape in the workpiece (anode). The high current densities promote rapid generation of metal hydroxides and gas bubble in the small spacing between the electrodes.

2-2 Experimental setup

Figure 2 illustrates a photograph of the experimental setup of ECM, which is manufactured by the researcher team, to show the experimentation process of this work wherein Figure 3 illustrates the performance of the ECM during the process.

2-3 Specification of work-piece material:

In this research work, a Al 2024-T3 metal has been selected for work-piece. The thermo ARL3460, optical emission spectrometer was used for chemical analysis of metal. The chemical composition for this metal is shown in Table 1. The tool was made from aluminium. The Work-piece dimensions were (70 x 50 x 3) mm whilst the circular tool was of 5 mm diameter.

2-4 Experimental Procedures

A setting of parameters, used in the experiments, is shown in Table 2. The machining was achieved by applying voltage between the tool electrode and the workpiece at three voltages 10, 15, 20, volts respectively, with average five experiments for each voltage and for time 10 min. for each experiment. The flow rate and electrolyte concentration were kept at (10 l/min, 50 g/l) respectively. The experiments for the electrolyte flow rate parameter were carried out at a flow rates (8, 10, and 12) l/min. which measured by flow meter equipment, with average five experiments for each flow and for time 10 min. for each experiment. Whilst, voltage and concentration were kept at 15 v, 50 g/l respectively. The experiments of concentration were carried out at concentrations of (50, 75, and 100 g/l) with average five experiments for each concentration and for time 10 min. for each experiment. The voltage and flow rate were remained at 15 v, and 10 l/min respectively as shown in table 3. Aqueous solution of sodium chloride (NaCl) was used as electrolyte. The machining was started by setting the gap width of 0.5 mm between the electrode and the workpiece at electrolyte temperature 35 C$^{\circ}$. The metal removal rate was assessed by the below equations. (16)

$$Wl = M_f - M_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$MRR = \frac{M_f - M_i}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$DissolutionRate\,(\frac{mm}{min}) = \frac{MRR}{\rho A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where Wl is weight loss in (g), M_f, is the work mass in (g) before machining, M_i is work mass (in g) after machining, MRR is material removal rate in (g/min), t is the machining time in minutes, ρ is the density of metal, and A is area of electrode (tool). A digital weight scale was used to measure the weight of workpiece before and after the ECM operation to calculate weight loss, and MRR and dissolution rate.

3- RESULTS AND DISCUSSION

3-1 Effect of voltage variation:

The influence of voltage on metal weight loss is presented in Figure 4 as the details are shown in Table 3. At low applied voltage, less current in the Inter-Electrode Gap IEG passes which resulted in uneven dissolution of material resulting in lower weight loss and vice-versa. For example, from the curves in Figure 4 and Table 3, the weight loss of metal at (V = 10, 15, and 20 V) is (2.05, 3.05, and 4.68 g) respectively at a machined time of 30 min. wherein, the weight loss values have become to be (3.54, 5.43, and 7.99 g) when the time is 50 min. Higher value of MRR was 0.1598 g/min as higher value of voltage was 20 V.

The stages of progress for electrochemical machining process are illustrated in Figure 5. From the Figure 6, it can be observed that the relationship between MRR and the energy was linear this corresponding to Faraday's law. Due to the increment in the applied voltage, passive film formed on the anode surface is get teared and allows more electrochemical reaction which enhances the chemical dissolution of the material and results in loosening the particles, thus facilitating the removal of the particles (17). From Figures 6 and 7, it can be seen that both the MRR and dissolution rate increase with increasing in voltage. In fact, this occurred owing to the increase of current in tool-workpiece gap because of increase in voltage, which resulted in that both the MRR and desolation rate increased.

3-2 Effect of electrolyte flow rate

Three workpieces were used to investigate the impact of this machining parameter on MRR. Three electrolyte flow rate values of (8, 10, and 12) l/min at different durations (10, 20 30, 40, and 50) min have been considered herein. Both of voltage and concentration were selected to be constant at 15 V and 50 g/l respectively. The results of the effect of this machining parameter are shown in the table 3 and figure 8. From Table 3 and Figure 8, it can be seen that the weight loss of metal at (Q = 8, 10, and 12 l/min) is obtained to be (2.7, 3.05, and 3.65 g) respectively at the time 30 min and then it becomes (4.5, 5.43, and 5.84 g) when the time is 50 min. At flow rate of (12 l/min), the MRR increases by about (2.7 %) in comparison to the lowest flow rate (8 l/min). It can be observed that, the correlation between weight loss and electrolyte flow rate is interesting. The weight loss increases with increasing the electrolyte flow rate. In fact, that as flow rate is higher the bubbles of hydrogen move actively from tool (cathode) and this lead to an increased ionic strength and thus more effective metal on the (work piece) anode. Figure 9 shows the stages of progress for ECM five experiments respectively. Figures 10 and 11 illustrate the impact of flow rate on the MRR and dissolution rate. It can see that both MRR and dissolution rate increase with increasing the flow rate. This since, the increase in electrolyte flow rate removes the products of reaction from the Inter-electrode gap (IEG) also fresh electrolyte directed into IEG which increases the conductivity of the electrolyte (18).

3-3 Effect of concentration of electrolyte:

The results of the influence of electrolyte concentration on MRR are showed in Table (3) and Figure 14.The conditions for concentration were (50, 75, and 100 g/l) while the voltage and flow rate were kept at (15 V, 10 l/min) respectively, electrolyte temperature (35˚C) and machining time (10 min) for each experiment. The effect of concentration on weight loss is shown in Figure 12. The main effect plot of weight loss vs. concentration indicates the effect of electrolyte concentration on weight loss. It was found that, the weight lost raises from (0.99) to (1.02) and then up to (1.32) g when concentration increases from 50 to 75 and then up to 100 respectively for machine time 10 min. In addition, weight lost reaches to (5.43, 6.84, and 7.38 g) after 50 min of machine time as shown in Table3. From Table 3 and Figure 12, for the first case at C1 = 50 g/l NaCl the weight loss is affected by concentration of electrolyte. In second case at C2 = 75 g/l NaCl, the effect on the weight loss is moderate wherein in third case when C3 = 100 g/l the weight loss is dearly influenced by concentration of electrolyte. This can be explained, that when the concentration of electrolyte is higher, the ions number will be increased compared with other levels. Figure 13 shows the stages of progressing for the machine process conditions such that; flow rate = 10 l/min, voltage = 15 V, and concentration = 75 g/l). In electrolyte, there is proportion between the number of ions and electrolyte concentration. More current will be flowed when the concentration is higher because of the high number of ions, this result in faster rate of material removal but the surface finish may be poor. Slow rate of material removal will be obtained at low concentration of electrolyte (19). The effect of electrolyte concentration on MRR and dissolution rate is shown in Figures 14 and 15. It was noticed that, MRR increases with increase the concentration. Increase in concentration, rate of electrochemical action is high (17). Hence, more MRR is obtained. Increase of the concentration leads to higher conductivity and this allows to release higher number of ions, as result more current flows in tool-workpiece gap and result in higher MRR.

3-4 Effect of current density on MRR and dissolution rate

The results of effect of this machining parameter on MRR and dissolution rate are represented in figures 16 and 17 respectively. These results are taken from changing of the machining parameters (voltage, flow rate, and concentration of electrolyte), and then represented as curves in figures 16 and 17 to observe the effect of current density on the material removal rate and dissolution rate.

From figures 16 and 17, it was viewed that the maximum values of MRR and dissolution rate were 0.1488 g/min and 2.7228 mm/min respectively when current density, which resulted of change of voltage, was 1.2732 A/mm^2. In additional, the increase of current density from 0.7639 to 1.2732 A/mm^2 owing to change of voltage led to increase the MRR by 0.082 g/min and dissolution rate by 1.5106 mm/min. While the increase of current density due to change of flow rate from 0.6985 to1.2667 A/mm^2 resulted in increase MRR by 0.028 g/min and dissolution rate 0.5662 mm/min. Whereas the increase of current density from 1.0185 to 1.5278 A/mm^2 because of concentration change brought on increase the MRR by 0.041and dissolution rate by 0.7686 mm/min.

It can be seen that the prominent factor the affect on MRR and dissolution rate is current density as result of change of voltage. It can be observed that the material removal rate and dissolution rate increase with increase in the current density, Faraday’s law states that the MRR is proportional to the machining current. This causes enhancement of MRR.

5- CONCLUSION

The following conclusions can be drawn from the above investigations:

When applied voltage increases the weight loss increase that can be attribute to increase of current density in the inter-electrode gab, and MRR increase. The MRR increases with increase in flow rate outcome increase the activation of chemical reaction because of generated new ions. The increasing of electrolyte concentration leads to increase the weight loss of metal because that Increase of the concentration leads to higher conductivity and this allows to release higher number of ions, as result more current flows in tool-workpiece gap and result in higher MRR.

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Table (1): Chemical composition of selected aluminium alloy

Metal	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Standard	90.7-94.7	Max 0.1	3.8-4.9	Max 0.5	1.2-1.8	0.3-0.9	Max 0.5	Max 0.15	Max 0.25
Selected Al	93.689	0.018	4.00	0.381	1.21	0.354	0.246	0.084	0.025

Table (2): Levels of experimental operating conditions

Machining parameter	Notation	Unit	Level		
			1	2	3
Voltage	V	Volts	10	15	20
Electrolyte Flow rate	Q	l/min	8	10	12
Electrolyte concentration	C	g/l	50	75	100

Table (3): Experimental conditions and results

Exp. No.	V volt	Q l/min.	C g/l	Time min	Weight Loss g	MRR g/min	Dissolution rate mm/min
1	10	10	50	10	0.59	0.059	1.08
2	10	10	50	20	1.3	0.065	1.19
3	10	10	50	30	2.05	0.0683	1.245
4	10	10	50	40	2.78	0.0695	1.264
5	10	10	50	50	3.54	0.0708	1.282
6	15	10	50	10	0.99	0.099	1.612
7	15	10	50	20	1.98	0.099	1.813
8	15	10	50	30	3.05	0.102	1.868
9	15	10	50	40	4.13	0.1032	1.886
10	15	10	50	50	5.43	0.1086	1.978
11	20	10	50	10	1.29	0.129	2.363
12	20	10	50	20	2.79	0.1395	2.555
13	20	10	50	30	4.68	0.156	2.857
14	20	10	50	40	6.39	0.1597	2.912
15	20	10	50	50	7.99	0.1598	2.927
16	15	8	50	10	0.96	0.096	1.758
17	15	8	50	20	1.73	0.0865	1.584
18	15	8	50	30	2.7	0.09	1.648
19	15	8	50	40	3.6	0.09	1.648
20	15	8	50	50	4.5	0.09	1.648
21	15	12	50	10	1.17	0.117	2.143
22	15	12	50	20	2.35	0.1175	2.152
23	15	12	50	30	3.65	0.1216	2.216
24	15	12	50	40	4.85	0.1215	2.216
25	15	12	50	50	5.84	0.1168	2.139
26	15	10	75	10	1.02	0.102	1.86863
27	15	10	75	20	2.32	0.116	2.12511
28	15	10	75	30	3.98	0.132	2.41823
29	15	10	75	40	5.38	0.1345	2.46403
30	15	10	75	50	6.84	0.1368	2.50571
31	15	10	100	10	1.32	0.132	2.41823
32	15	10	100	20	2.91	0.1455	2.66555
33	15	10	100	30	4.38	0.146	2.67471
34	15	10	100	40	5.94	0.1485	2.72051
35	15	10	100	50	7.38	0.1476	2.70402

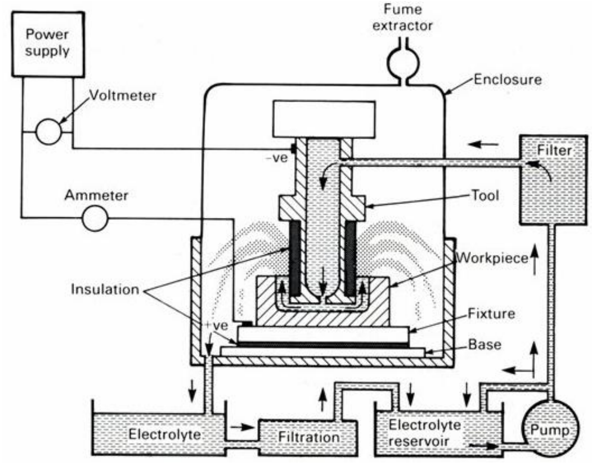

Fig. (1):ECM Setup) [2]

Fig. (2): Experimental set up of ECM .process

Fig.(3): Electrochemical Machining Process

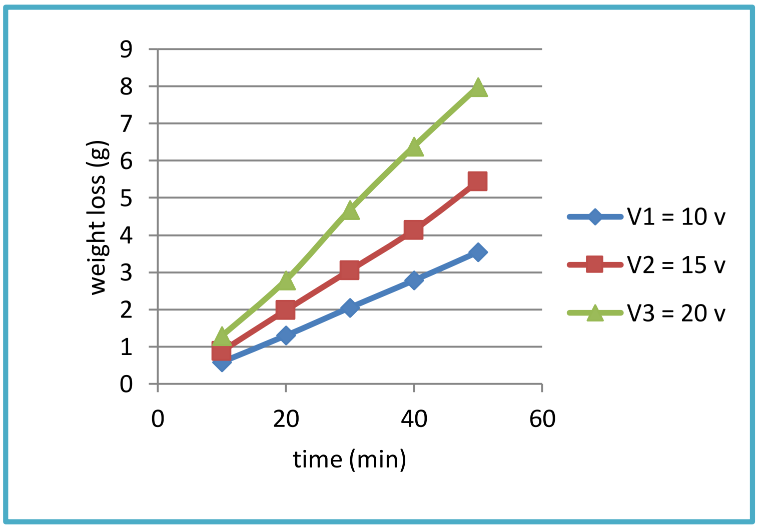

Fig. (4): Influence of voltage vibration and time on weight loss of aluminium

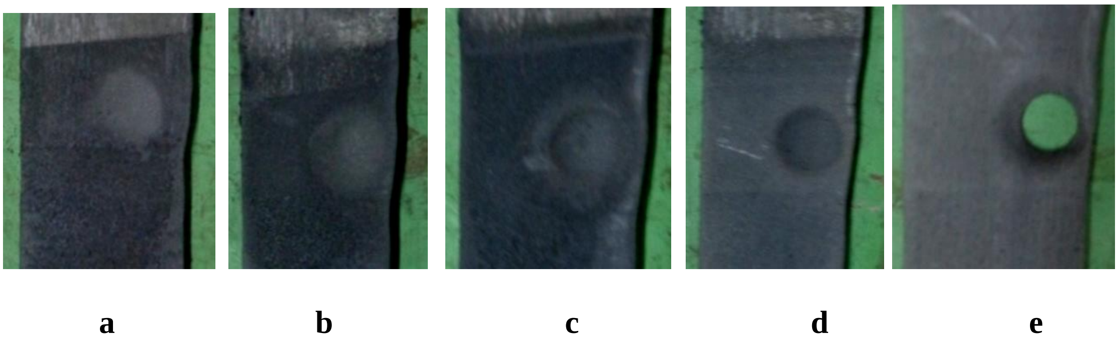

Fig. (5): Stages (a, b, c, d, and e) of progress the machining process until occurrence of hole, conditions used were voltage = 15 V, flow rate =10 l/min, and concentration = 50 g/l

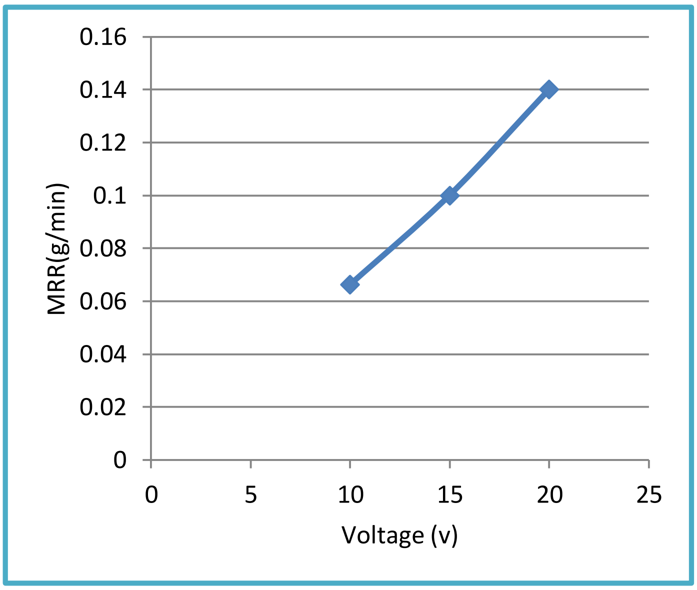

Fig.(6): Effect of voltage on the MRR at 10 l/min flow rate and 50 g/l concentration

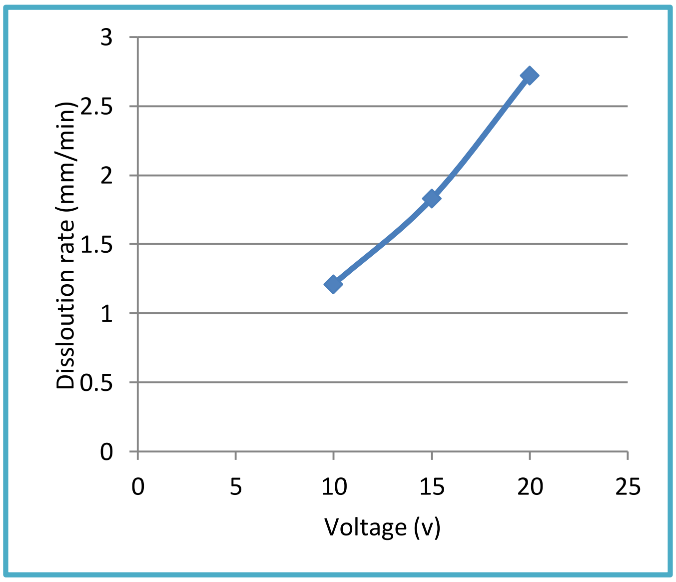

Fig.(7): Effect of voltage on the dissolution at 10 l/min flow rate and 50 g/l concentration

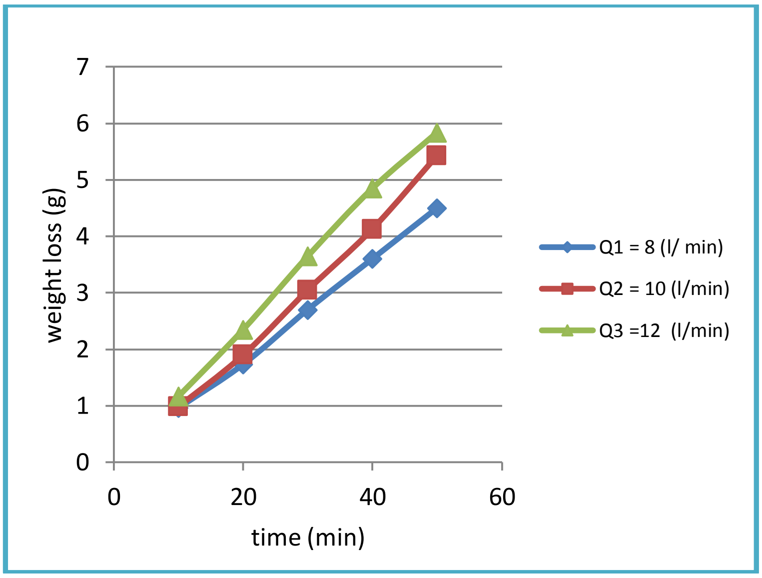

Fig.(8): Impact of flow rate of electrolyte on the weight loss metal

Fig.(9): stages (a, b, c, d, and e) of progress the machining process until occurrence of hole when conditions used flow rate = 8 l/min, voltage = 15 V, and concentration = 50 g/l

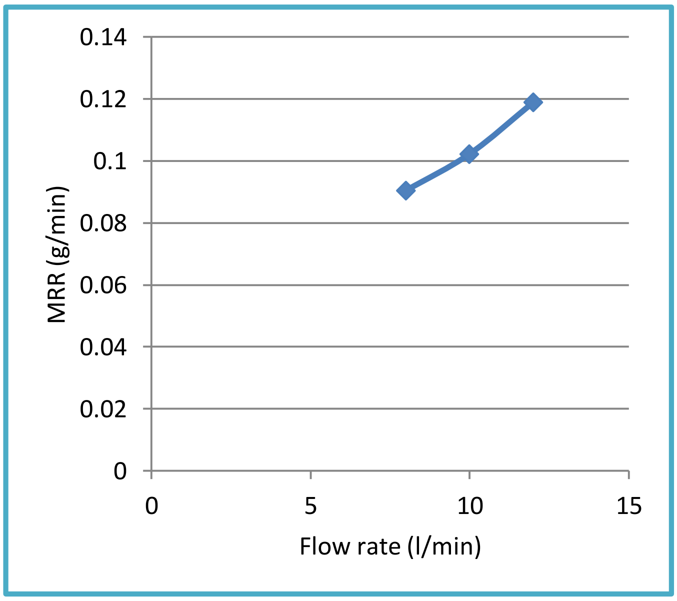

Fig.(10): Impact of the flow rate on MRR at 15 V voltage and 50 g/l concentration

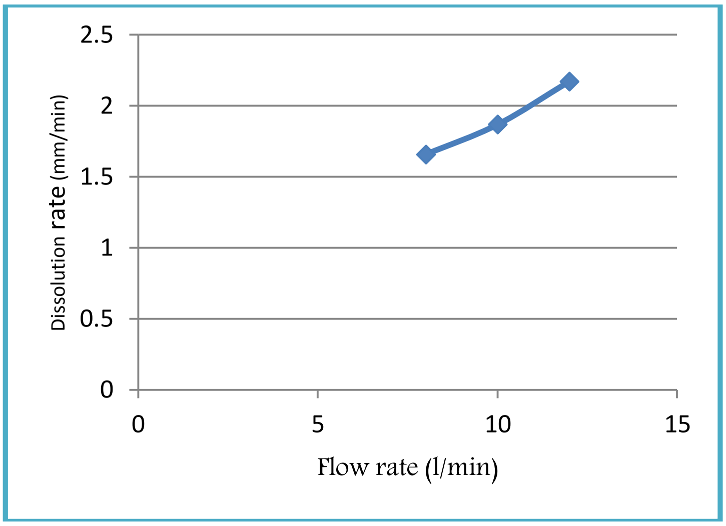

Fig.(11): impact of flow rate on the dissolution rate at15 V voltage and 50 g/l concentration

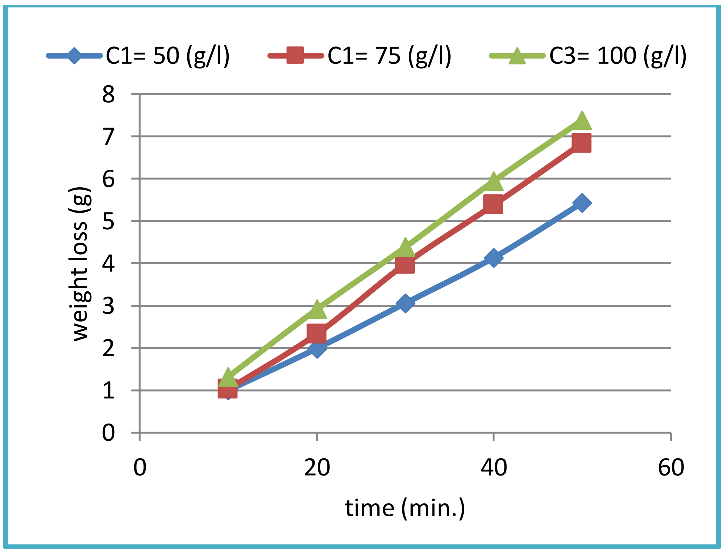

Fig. (12): Effect of electrolyte concentration on weight loss of metal

a **b** **c** **d** **e**

Fig.(13): stages (a, b, c, d, and e) of progress the machining process until occurrence of hole when conditions used flow rate = 10 l/min, voltage = 15 V, and concentration = 75 g/l

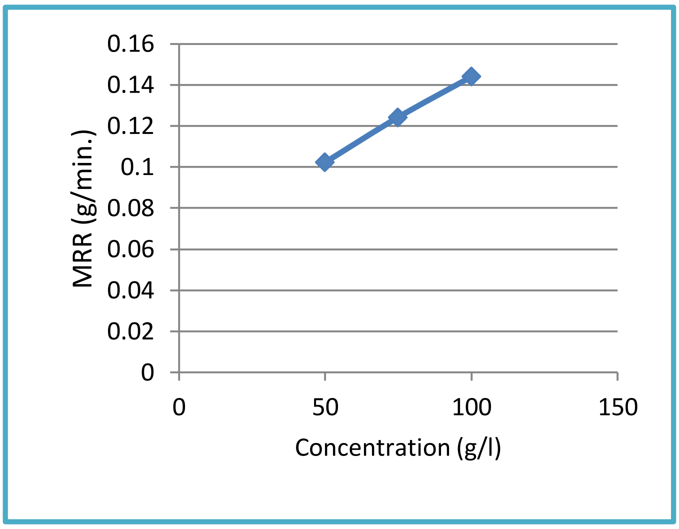

Fig. (14): Impact of concentration on the MRR at 15 V voltage and 10 l/min flow rate

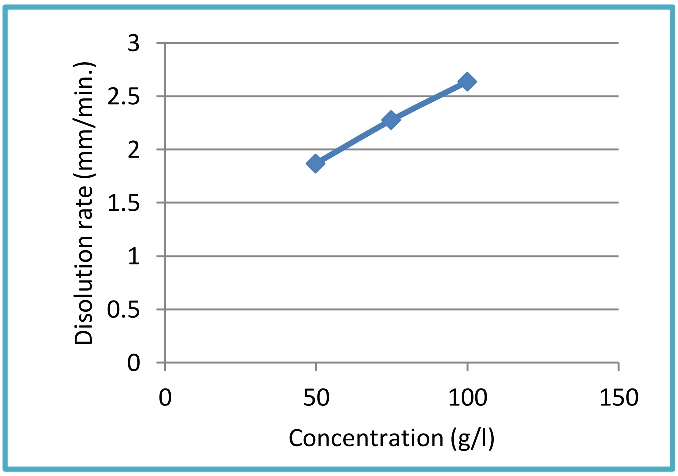

Fig.(15): Impact of concentration on the dissolution rate at 15 V voltage & 10 l/min flow rate

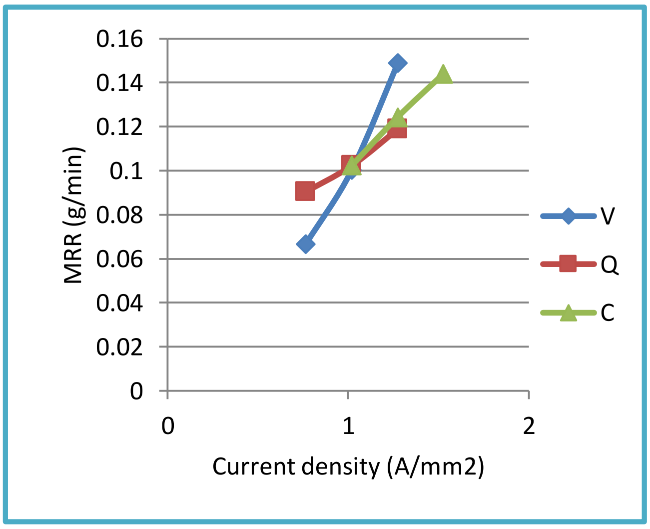

Fig.(16): The effect of current densities on MRR

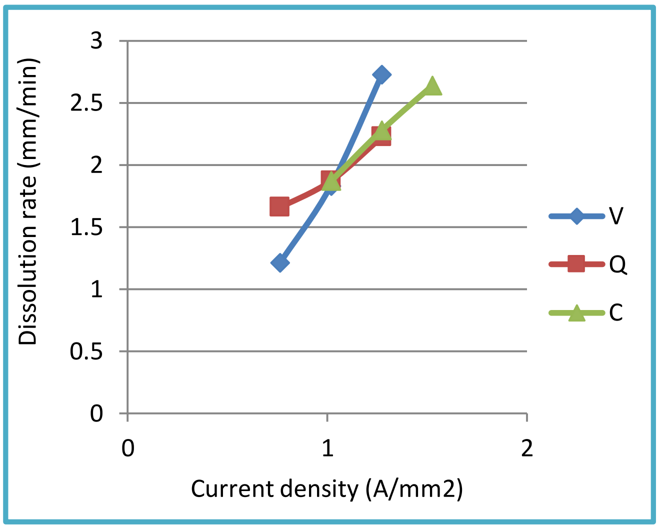

Fig.(17): The effect of current densities on dissolution rate

تأثير العوامل الداخلة في التشغيل الكهروكيميائي على معدل المعدن المزال لسبيكة الالمنيوم 2024-T3

حسين برهان محمد
قسم الهندسة الميكانيكية، جامعة ديالى

الخلاصة

التشغيل الكهروكيميائي هو عملية تشغيل متقدمة تعود الى صنف الكهروكيمياء. هي احد عمليات التشغيل الغير تقليدية والمستخدمة بشكل واسع خصوصا في انتاج الهيئة الهندسية المعقدة او المركبة على المواد صعبة التشغيل. في عصر صناعة اليوم, عملية التشغيل الكهروكيميائي تعطي انهاء سطحي جيد نتيجة اذابتها الذرية المسيطرعليها لمادة المشغولة التي تشرك التفاعلات الكيميائية خلال التشغيل. لدعم اداء التشغيل, الاختيار الدقيق لعوامل التشغيل ما زال عمل مطلوب في عملية التشغيل الكهروكيميائي لانها عملية معقدة جدا تتضمن تفاعلات كيميائية عديدة غير متنبأبها اثناء التشغيل.في هذه الدراسة قد تم دراسة معدل المعدن المزال. سبيكة المنيوم استخدمت كمادة مشغولة و محلول كلوريد الصوديوم استحدم كمحلول الكتروليتي. التأثيرللعوامل الثلاث (الفولتية, معدل الجريان وتركيز المحلول) على معدل المادة المزالة تم دراسته. خمس وثلاثون تجربة اجريت.ثلاث قيم لكل عامل اختيرت لتنفيذ هذه الدراسة, للفولتية (20، 15، 10) فولت ولمعدل الجريان (8، 10، 12) لتر/الدقيقة وللتركيز (50، 75، 100) غرام/ التر. النتائج بينت ان اعلى قيمة لمعدل المعدن المزال كانت (0.1598، 0.1216، 0.1485)غرام/الدقيقة عندما كانت قيمة كل عامل, الفولتية ، معدل الجريان و التركيز (20، 12، 100) على التوالي. بالاضافة الى ذلك, معدل ازالة المعدن ازداد بشكل عام مع زيادة كل من الفولتية ومعدل الجريان و التركيز للمحلول كلا على حده, كذلك النزعة كانت مختلفة مع كل حالة. مع ذلك, الفولتية كانت العامل البارز في التأثير على معدل المعدن المزال بشكل ملحوظ.

الكلمات المفتاحية: التشغيل الكهروكيميائي, معدل المعدن المزال, سبائك الالمنيوم.