



ENHANCEMENT OF METAL REMOVAL RATE (MRR) AND SURFACE FINISH IN ELECTROCHEMICAL MACHINING

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Abstract:

Electro chemical machining (ECM) is a non traditional process that can machine difficult to cut material. This paper was focused on methods which are used to enhance metal removal rate (MRR) and surface finish during experimental investigations, were the work materials are two aluminum alloy (AL Zn Mg Cu 1.5-DIN 1725-1) and aluminum 1100 with using brass and steel CK35 tools, also NaCl solution as electrolyte was used. Experiments prove that increasing electrolyte flow rate from 6-14 l/min at electrolyte concentration 200g/l lead to increase metal removal rate reach to (63.07%) and enhancement of surface finish by reducing roughness from (5.07 to 3.25 μm) minimum and from (6.63 to 1.2 μm) maximum using work material from aluminum alloys to perform that. Also there are another factors influencing in metal removal rate and surface finish such as voltage and frequency when increasing them from (10-30)V lead to increase MRR about (29.45%) and frequency from (100-500)HZ improved MRR by (34.17%).

Keyword:- Electro chemical machining, metal removal rate MRR, Electrolyte flow rate, Voltage, frequency, surface roughness.

تحسين معدل إزالة المعدن (MRR) والإنهاء السطحي في التشغيل الكهروكيميائي

الخلاصة:

التشغيل الكهروكيميائي هو أحد العمليات الغير تقليدية والتي تستخدم في قطع المواد الصعبة. ركز البحث على الطرق المستخدمة لتحسين وزيادة المعدن المزال وتحسين الإنهاء السطحي من خلال التجارب المتحققة حيث ان القطع المشغلة هي سبيكتين من الالمنيوم أحدهما سبيكة (AL Zn Mg Cu 1.5-DIN 1725-1) والآخرى سبيكة الالمنيوم 1100 مع استخدام عدتين من البراص والآخرى من الفولاذ CK35 والمحلول المائي NaCl كألكتروليت. وقد اثبتت التجارب ان زيادة تدفق المحلول الألكتروليتي يؤدي الى زيادة المعدن المزال ليصل الى نسبة (63,07%) عند (6-14) لتر/دقيقة وتركيز يبلغ 200 غرام/لتر مع تحسين خشونة السطح من خلال تقليل الخشونة من (5,07-3,25) مايكرون كحد ادنى وكذلك من (6,63-1,2) مايكرون كحد أعلى باستخدام عينات من سبائك الالمنيوم لأتمام ذلك. كما ان هناك عوامل اخرى مؤثرة في زيادة المعدن المزال وتحسين الإنهاء السطحي مثل الفولتية والتردد حيث ان زيادتها يؤدي الى زيادة المعدن المزال وتحسين السطح من (10-30) فولت تؤدي الى الزيادة (29,45%) والتردد من (100-500) هرتز مع تحسين في المعدن المزال بنسبة (34,17%).

INTRODUCTION:

Electrochemical machining (ECM) is a non-traditional process used mainly to cut hard or difficult to cut metals, where the application of a more traditional process is not convenient. Those difficult to cut metals demand high energy to form chips, which can result in thermal effects due to the high temperatures inherent to the process in the chip–tool interface. In traditional processes, the heat generated during the cut is dissipated to the tool, chip, workpiece and environment, affecting the surface integrity of the workpiece, mainly for those hard materials. Different from the other machining processes, in ECM there is no contact between tool and workpiece. Electrochemical (electrolyses) reactions are responsible for the chip removal mechanism. The difficulties to cut super alloys and other hard-to-machine materials by conventional process have been largely responsible for the development of the ECM process [1]. It is always used for production of components of complex geometry and difficult to machine materials, e.g., turbine blades, blade disks, engine castings, gun barrel rifles, forge dies and molds, non circular holes [2]. Gusseff first patented electrochemical machining (ECM) in 1929 [3]. Many years later in 1941, Burgess appeared with a publication in the Electrochemical Society. In the autumn of 1959, Anocut Engineering Company established the anodic metal machining technique as a commercially suitable technique. SIFCO (Steel Improvement and Forge Company) followed with a commercial application one year later. The technique was applied in several ways as a machining technique in the 60's and 70's. In particular the gas turbine industry used the technique frequently[4]. The accuracy of machining can be improved by the use of pulsed electrical current. Controlling the wave pattern of pulsed current and the time of pulsed on/off is effective [5]. In this study two aluminum workpieces were used (Al Zn Mg Cu 1.5 DIN 1725-1, and aluminum 1100) to study the effect of electrolyte flow rate on MRR and surface roughness , and the influence of voltage and frequency of pulsed power supply on MRR.

Electrolysis:

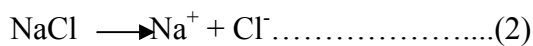
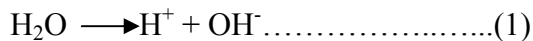
Electrolysis is the name given to the chemical process which occurs, for example, when an **electric current** is passed between two **conductors** dipped into a liquid solution. Electrolytes are different from metallic conductors of electricity in that the current is carried not by **electrons** but by **atoms**, or group of atoms, which have either lost or gained electrons, thus acquiring either positive or negative **charges**. Such atoms are called **ions**. Ions which carry positive charges move through the electrolyte in the direction of the positive current, that is, toward the cathode, and are called **cations**. Similarly, the negatively charged ions travel toward the anode and are called **anions**. The movement of the ions is accompanied by the flow of electrons, in the opposite sense to the positive current in the electrolyte, outside the cell and both reactions are a consequence of the applied **potential** difference, that is, **voltage** from the **electric source**. A cation reaching the cathode is **neutralized**, or **discharged**, by the negative electrons on the cathode. Since the cation is usually the positively charged atom of a metal, the result of this reaction is the **deposition of metal** atoms. To maintain the cathodic reaction, electrons are required to pass around the external circuit. These are obtained from the atoms of the metal anode, and these atoms thus become the positively charged cations which pass into solution. In this case, the reaction is the reverse of the cathodic reaction. The electrolyte in its

bulk must be electrically neutral; that is, there must be equal numbers of opposite charges within it, and thus there must be equal amounts of reaction at both electrodes[6].

Many chemical reactions occur at the cathode, the anode and in the electrolyte, where the electrolysis process that takes place at the cathode liberates hydroxyl ions and free hydrogen. The hydroxyl ion combines with the metal ions of anode to form insoluble metal hydroxides and the material is thus removed

from the anode. This process continues and the tool reproduces its shape in the workpiece (anode). The reactions at cathode are[4,7]:-

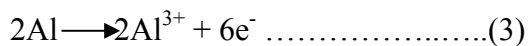
The result of electrolytic dissociation



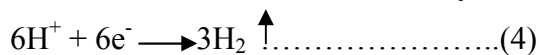
negatively charged anions: (OH^-) and (Cl^-) go towards to anode, and positively

charged cations: H^+ and Na^+ towards cathode.

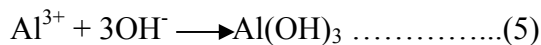
At the anode :



At the cathode, the reaction is likely to be generation of hydrogen gas :



The outcome of these electrochemical reactions is that the ions combine with other ions to precipitate out as aluminum hydroxides $(\text{Al}(\text{OH})_3)$:



Estimation of experimental material removal rate (MRR_{exp}):

The actual material removal rate can be determined by the[8]:

$$\text{MRR}_{\text{exp}} = \frac{wb - wa}{\text{Time}} \quad (\text{g/sec or g/min}) \quad \dots\dots\dots(6)$$

Where:

Wb = weight of the workpiece before ECM machining (g)

Wa = weight of the workpiece after ECM machining (g)

Experimental work:

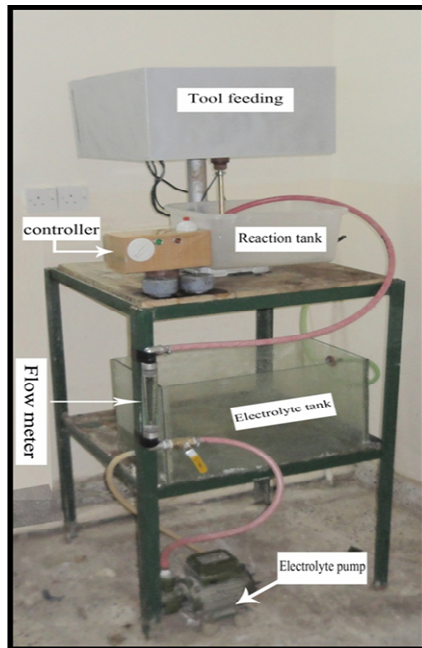
Experimental work was involve the following experiments which were done by electrochemical cell consist of electrolyte solution (NaCl + water) and power supply DC current , and pulses power supply with pump for electrolyte flow rate and flow meter to register the electrolyte flow rate.

1- First experiments was done under the cutting conditions using different values of electrolyte flow rate as shown in table (1) and then calculate Metal Removal Rate (MRR) and surface roughness of work material by using surface roughness tester device.

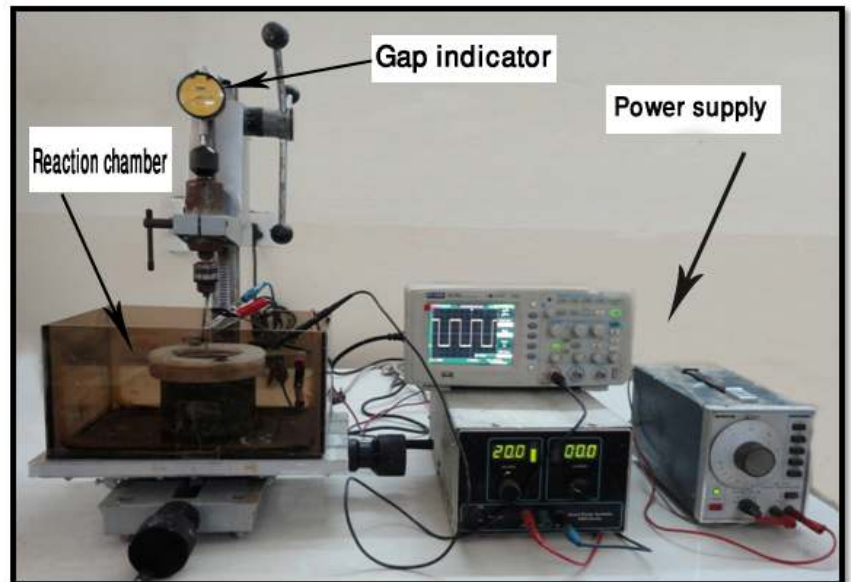
2- Second experiments was done at different voltage to study the influence of machining voltage on MRR.

3- Third experiments was done at different frequency of pulses power supply to study the effect of frequency on MRR.

The ECM cells that used in experimental work are shown in figure (1).



(A)ECM cell being used to
study the effect of electrolyte flow rate



(B) ECM cell used to study
the effect of voltage & frequency

Figure (1) ECM cells being used in the experimental work

Power supply: The power supply is a very important device to provide the current that help the electrochemical reaction to occur by forcing the electrons to move from the workpiece through it to the tool. The power supply used in the experiment is a D.C power supply with a variable current (5 A/10V – 400A/36V) . Also pulses power supply is used with ECM cell 2 (0-32 VDC- 0-15 A).The positive pole is connected to the workpiece ,while the negative pole to the tool.

Tool feeding device and controller:- Provide the required feeding by using the controller which control the vertical movement of the machining tool with adjustable feeding speed , were two electrical motors are used to control the vertical movement of tool ,one motor used for feeding the tool down and the other for rising the tool up.

Electrolyte pump:- Pump the electrolyte from the storage tank towards reaction chamber.

Electrolyte filtration:- The filter is used to remove the sludge from the electrolyte. It is put inside the pump to clean the electrolyte before pumping.

Flow meter: Control the flow of electrolyte from storage tank towards reaction chamber.

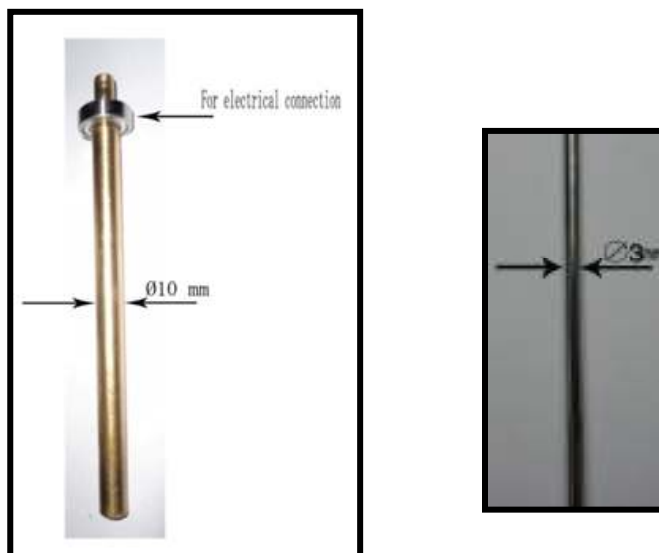
Electrolyte tank : Store the electrolyte for recycling to the reaction chamber.

Reaction chamber: The machining operation occur in this part of ECM cell, were required chemical reaction happen.

Gap indicator:- The gap indicator used to determine the gap before and through machining of ECM operation.

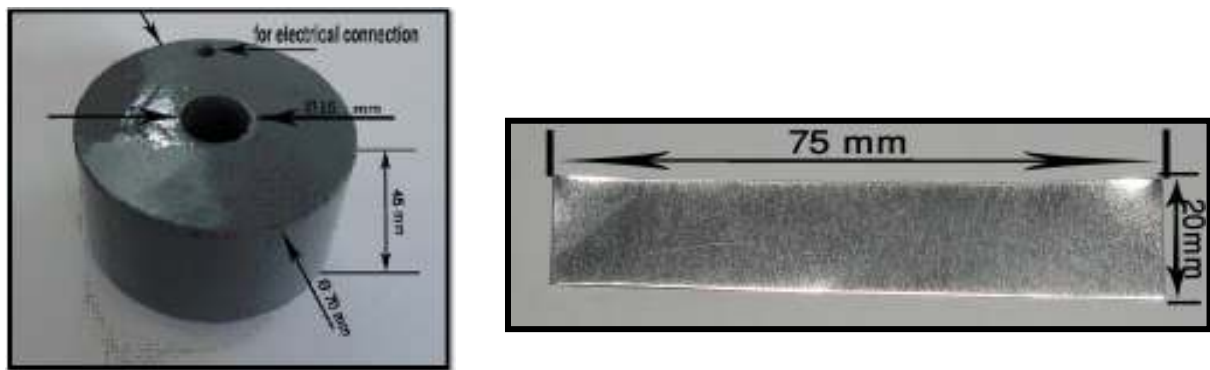
Tools and workpieces description:

The tools (cathodes) used to study the effect of electrolyte flow rate is a cylindrical rod made from brass (63% Cu – 37% Zn) with a diameter of (\varnothing 10mm). The reason for using brass metal is easy to machining, having high electrical conductivity, and high corrosion resistance. The tool used to study the influence of voltage and frequency on material removal rate is made from steel Ck35 rod of diameter (\varnothing 3mm).As shown in the figure(2).



Figure(2) Tools being used in experimental work

Workpieces description: The workpieces are five pieces from cylindrical shaft Aluminum alloy (AL Zn Mg Cu 1.5-DIN 1725-1) with dimensions of (Ø70mm outside diameter, 15mm hole diameter, and 45 mm height) being used study the effect of electrolyte flow rate, with five values of electrolyte flow rate (6, 8, 10, 12, 14) L/min. Were internal diameter of these workpieces being machined. And five workpieces made from aluminum plate(aluminum 1100 alloy) with dimension of (75 X 20 X 0.7)mm, to study the influence of voltage variation and frequency of pulsed power supply with(10,15,20,25,30)V, and (100,200,300,400,500)Hz respectively.



Figure(3) Workpiece being used in the experimental work

Results and discussion:

According to machining parameters as shown in table (1) such as gap size (2.5mm), machining time(8minute), electrolyte concentration (200 g/l), current density (4.59 A/cm^2), electrolyte temperature (35°C), and tool rotation (620 r.p.m). Five workpieces are used to study the effect of this machining parameter on material removal rate and surface roughness with a five values of electrolyte flow rate of (6, 8, 10, 12, 14) l/min.

The results shows that great amount of MRR when using the rotational tool compared with the stationary tool, where the significant effect of rotary action of tool over MRR is better than the stationery tool[9]. Also Figure (4) shows a great effect of flow rate on MRR, where the MRR increases with increasing the electrolyte flow rate. This can be attributed to the fact that the higher flow rate removes hydrogen bubbles more effectively from the cathodic grooves resulting in an increased ionic strength and therefore, more effective metal removal on the anode. Maximum increasing (8.28%) of MRR occurs by flow rate from(8 to 10) l/min, and minimum increasing(0.71%) from (10 to 12)l/min. The MRR increases at flow rate of (14 l/min) by (17.74%) as compared with (6 l/min).

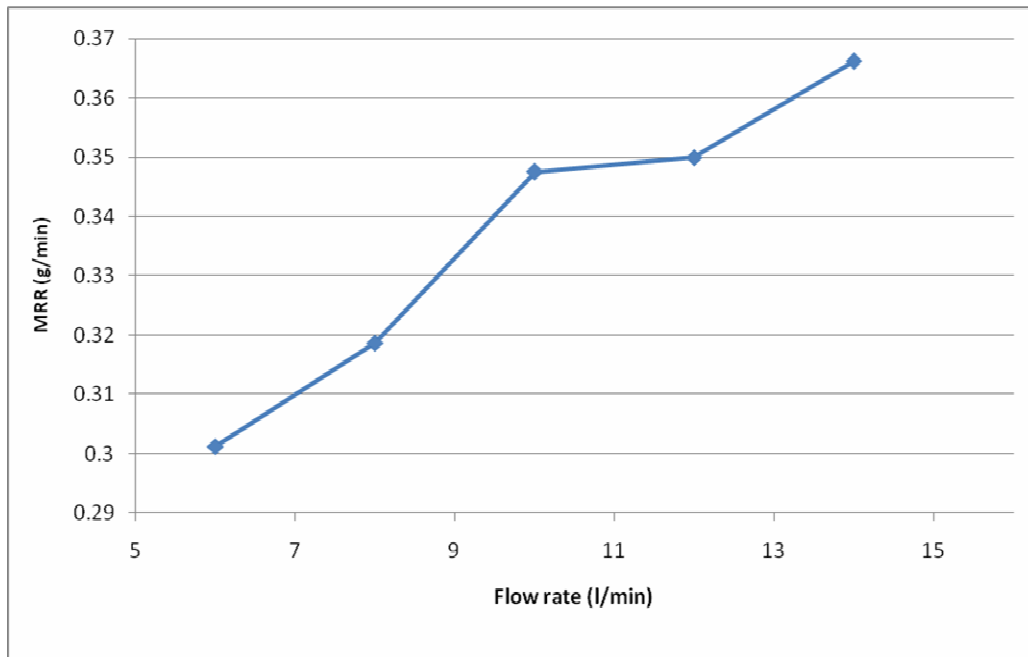


Fig (4) The relationship between MRR and electrolyte flow rate

Machining time (Min)	Electrolyte concentration (g/l)	Current density (A/cm ²)	Tool rotation (r.p.m)	Flow rate (l/min)	Gap (mm) ±0.1	Weight before machining (g)	Weight after machining (g)	MRR _{exp} (g/min)
8	200	4.59	620	6	2.5	390.86	388.48	0.3012
8	200	4.59	620	8	2.5	394.44	391.89	0.3187
8	200	4.59	620	10	2.5	445.92	443.14	0.3475
8	200	4.59	620	12	2.5	404.17	401.37	0.3500
8	200	4.59	620	14	2.5	406.56	403.63	0.3662

Table (1) the experimental results of the effect of electrolyte flow rate on MRR

Also there is another influencing factor for flow rate in surface roughness (**Ra**) when intervening variables in table (2). Figure (5) shows The enhancement with increasing the electrolyte flow rate , the enhancement rate of surface roughness at electrolyte flow rate of (14)l/min reaches (63.07%) when compared with flow rate of (6) l/min. Minimum enhancement rate(5%) occurs from (10 to 12)l/min, while maximum enhancement rate(51.41) occurs at(12 to 14) l/min.

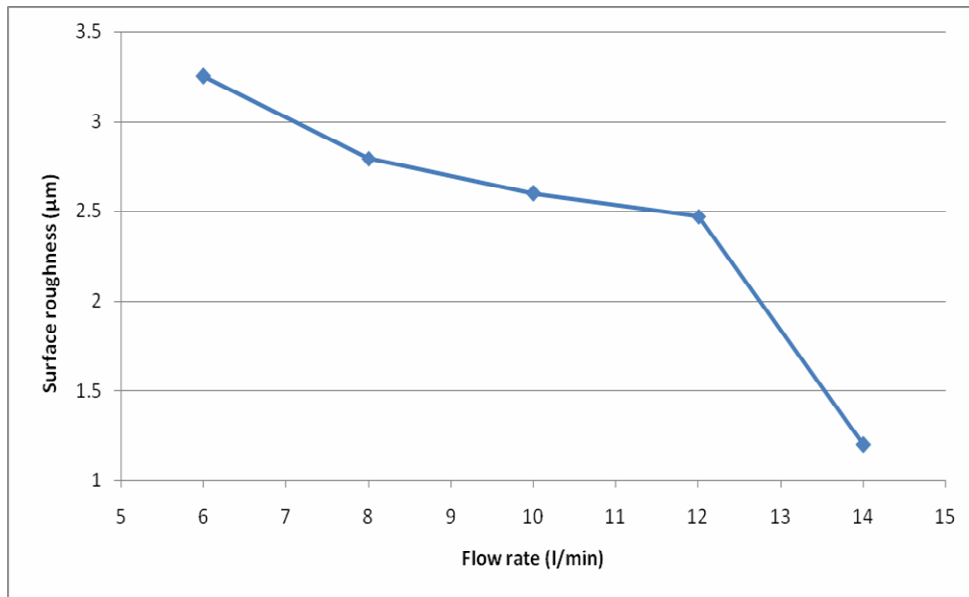


Fig (5) The relationship between R_a and electrolyte flow rate

Table (2) experimental results of the effect of electrolyte flow rate on R_a

No. of exp.	Electrolyte concentration (g/l)	Current density (A/cm^2)	Tool rotation (r.p.m)	Electrolyte flow rate (l/min)	Gap (mm) ± 0.1	Tool roughness (μm)	Work piece roughness before ECM operation (μm)	Work piece roughness after ECM operation (μm)
1	200	4.59	620	6	2.5	2.600	5.07	3.25
2	200	4.59	620	8	2.5	2.600	4.55	2.795
3	200	4.59	620	10	2.5	2.600	9.1	2.6
4	200	4.59	620	12	2.5	2.600	4.03	2.47
5	200	4.59	620	14	2.5	2.600	6.63	1.2

Figure (6) shows that the decreases in surface roughness by using different electrolyte flow rates where the decreasing rates for the five workpieces ,were (35.89, 38.57, 71.42, 38.70, 81.90)% for electrolyte flow rates of (6, 8, 10, 12, 14) l/min respectively. The maximum enhancement of surface roughness occurs at (14) l/min.

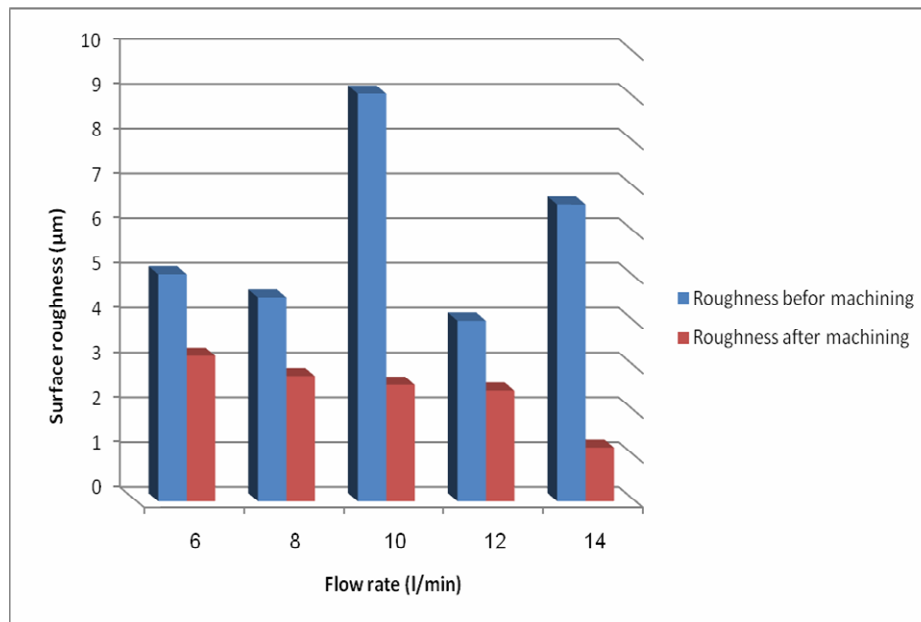


Fig (6) The differences in surface roughness before and after ECM machining at different electrolyte flow rates

The workpieces being used to study the effect of electrolyte flow rate on MRR and R_a are shown in figure (7). Were the brass tool put through the hole of the workpiece to machine the internal surface of the hole.

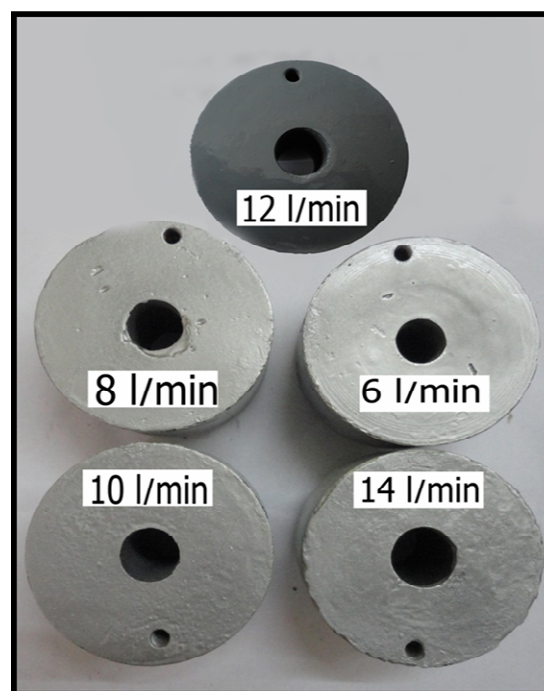


Fig (7) Workpieces being used to study the effect of electrolyte flow rate on MRR and R_a after machining

The third factor Influencing on MRR was voltage variation and frequency , experiments prove that the MRR increase with increasing the voltage, this can be attributed to the fact that the increase in voltage results increase in the current density, Faraday's law states that the MRR is proportional to the machining current. This increase causes enhancement of MRR. From figure (8) it is shown that the MRR increasing firstly from (10 to 15)V with rate (6.18%) then reaching to value of (0.0258)g/min with 30 V . The total increasing rate in MRR from (10 to 30)V is (29.45%).

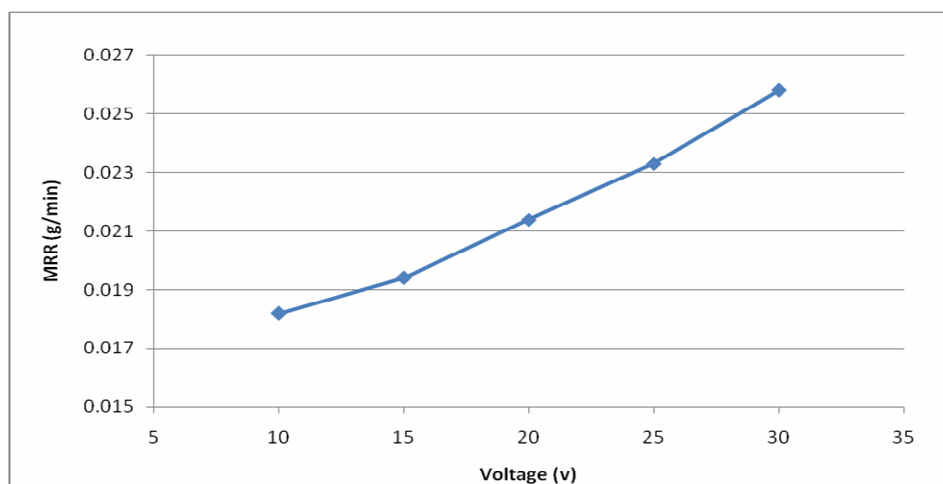


Fig (8) Influence of voltage variation on MRR

Figure (9) shows the relationship between frequency of the pulsed power supply and MRR , it is observed that the increasing of frequency causes improvement in MRR, were the MRR improved by (34.17%) when the frequency increases from (100 HZ) to (500 HZ). This increases can be attribute to the higher frequency which allow higher pulses number to be used in the machining operation with the same period of machining time. Were the machining process occurs only at pulse on time and no machining operation at pulse off time.

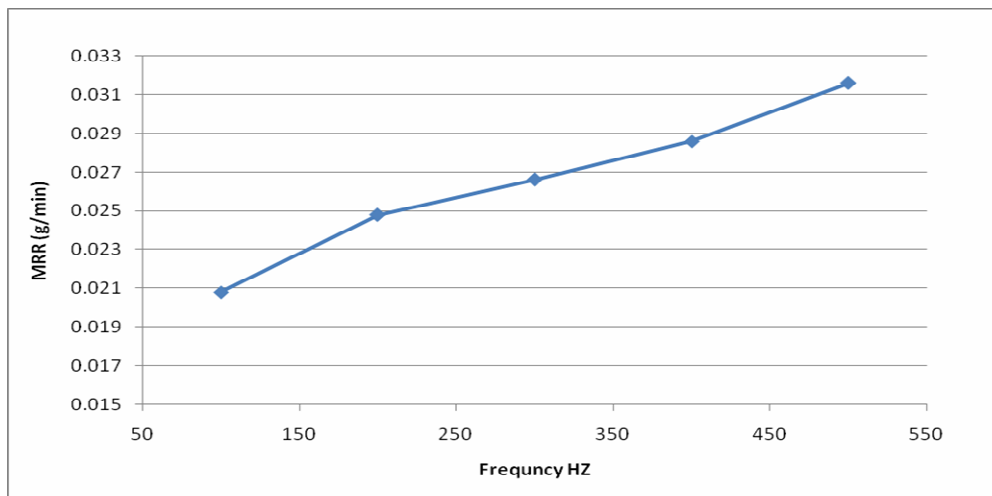


Fig (9) Influence of frequency on MRR

Figure (10) show the five workpieces that being used to study the influence of voltage variation on MRR and figure (11) show the five workpieces that used to study the effect of the frequency of pulsed power supply.

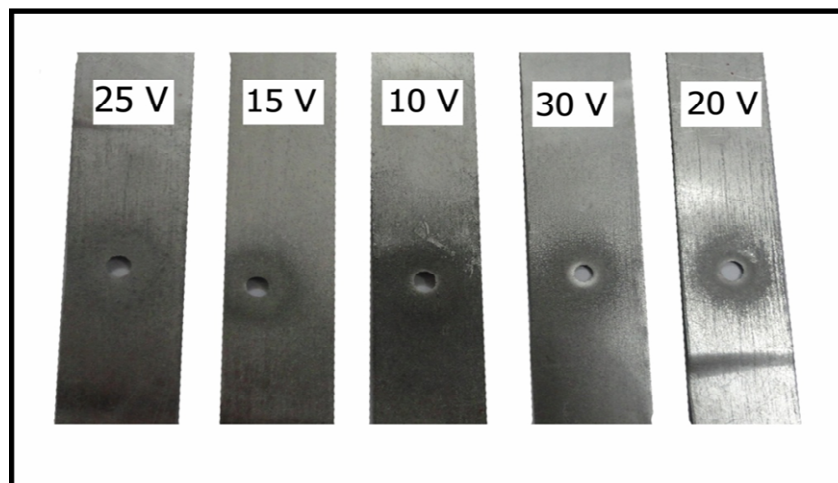


Fig (10) Workpieces used to study the influence of voltage on MRR after machining

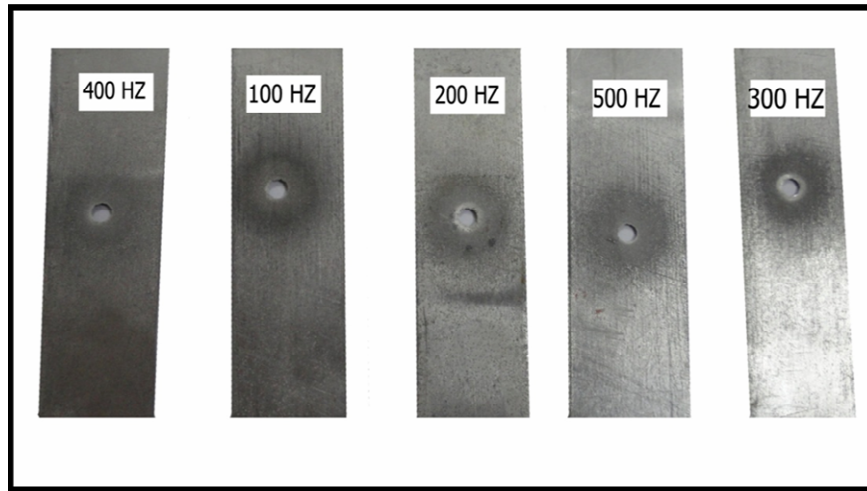


Fig (11) Workpieces used to study the influence of frequency on MRR after machining

Table (3) experimental results of the effect of voltage variation on MRR

Voltage (V)	Gap (mm) ± 0.1	Time (min)	Flow rate (l/min)	Electrolyte concentration (g/l)	Weight before machining (g)	Weight after machining (g)	MRR _{exp} (g/min)
10	1	3	12	100	4.5539	4.4993	0.0182
15	1	3	12	100	4.4492	4.3910	0.0194
20	1	3	12	100	4.5082	4.4440	0.0214
25	1	3	12	100	4.7090	4.6389	0.0233
30	1	3	12	100	4.9265	4.8489	0.0258

Table (4-4) experimental results of the effect of frequency on MRR

Frequency (HZ)	Gap (mm) ± 0.1	Time (min)	Flow rate (l/min)	Electrolyte concentration (g/l)	Weight before machining (g)	Weight after machining (g)	MRR _{exp} (g/min)
100	1	3	12	100	3.8382	3.7757	0.0208
200	1	3	12	100	3.6232	3.5488	0.0248
300	1	3	12	100	3.5070	3.4271	0.0266
400	1	3	12	100	3.8404	3.7545	0.0286
500	1	3	12	100	3.9780	3.8832	0.0316

CONCLUSIONS :

In this research , Experimental investigation lead to the following conclusions:

- 1- There is enhancement of surface finish when increasing electrolyte flow rate more than two time.
- 2- Voltage also has an a great effect on metal removal rate and surface roughness when increasing voltage the metal removal rate will increase reach to 30%.
- 3- High pulses number and high frequency causes enhancement of MRR more than 30%.

REFERENCES:

- [1] J. Cirilo da Silva Neto , E. Malaquias da Silva , M. Bacci da Silva, "Intervening variables in electrochemical machining", Journal of Material Processing Technology, vol.179, pp.92 – 96, Brazil, 2006.
- [2] D.Zhu , H.Y. Xu " Improvement of electrochemical machining accuracy by using dual pole tool" Journal of Materials Processing Technology vol.129 pp.15–18,2002.
- [3] M. Malapati B. Bhattacharyya, J. Munda" Experimental study on electrochemical micromachining" Journal of Materials Processing Technology vol.169 pp.485–492,2005.
- [4] U. Mallick, "Estimation of MRR by using U-shape Electrode in Electrochemical Machining", M.Sc thesis, National Institute Technology, India, 2009.
- [5] H. Hocheng, Y.H. Sun, S.C. Lin, P.S. Kao " A material removal analysis of electrochemical machining using flat-end cathode" Journal of Materials Processing Technology vol.140 pp. 264–268,2003.
- [6] J. McGeough, "Electrochemical machining", United Kingdom, 2005.
- [7] S.K. Mukherjee, S. Kumar, P.K. Srivastava, Arbind Kumar "Effect of valance on material removal rate in electrochemical machining of aluminum "Journal of Materials Processing Technology 2 0 2 pp. 398–401,2007.
- [8] H. H. Alwan" Study of some Electrochemical Machining Characteristics of steel Ck 35", M.Sc thesis University of Technology,Iraq,2011.
- [9] Sekar T., Marappan R., "Improving Material Removal Rate of Electrochemical Machining by Using Rotating Tool", International Journal of Machine Tools & Manufacture vol.44 pp. 60–63,2008.