Influence of Currents Density and Gap Size on Metal Removal Rate and Surface Roughness in Electrochemical Machining (ECM)

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ABSTRACT

Electrochemical machining one of non traditional method which is used to machine a complex shape such as that uses the chemical reaction associated with electric current to remove metals. In this study the ECM was used to remove the metals from the internal hole of the workpiece (medium carbon steel) by immersing it in electrolyte (250g of NaCl for every litter of H_2O) with tool is made of brass.

The,m research focuses on the effect of the change in gap dimensions and the currents density on the metal removal rate (MRR) and surface roughness of the workpiece the results obtained show that increasing of gap size between the tool and the workpiece from (1 to 3mm) leads to increase the surface roughness (46%) and while the material removal rate (MRR) decreases (16%) at a current density (2.856 Amp/cm^2). Also increasing of the current density from (2.4485 to 3.6728 Amp/cm^2), the surface roughness of the workpiece decreases (31%) while the Material Removal Rate (MRR) increases (93.9%) at a gap size of (1mm).

Keywords: Electrochemical machining, currents density,gap size, surface roughness.

تأثير كثافة التيار وحجم الفجوة على كمية ازالة المعدن والخشونة السطحية في عملية التشغيل الكهروكيميائي

الخلاصة

التشغيل الكهروكيميائي هو نوع من انواع القطع اللاتقليدي الذي يستخدم لتشغيل الاشكال المعقدة والتي تستخدم التفاعل الكيميائي مع التيار الكهربائي لازالة المعدن. في هذا البحث تم استخدام (ECM) لازالة المعدن من الثقب الداخلي للقطعة المشغلة (نوع فولاذ متوسط الكاربون) من خلال غمرها بمحلول الكتروليتي (250 غم من NaCl لكل لتر من H_2O) وأستخدام اداة من البراص.

ركز البحث على دراسة تأثير التغير بأبعاد الفجوة وقيم كثافة التيار على كمية ازالة المعدن والخشونة السطحية للقطعة المشغلة واظهرت النتائج عند زيادة حجم الفجوة مابين الاداة والقطعة المشغلة عند قيم (من 1 مم الى 3 مم) تؤدي الى زيادة الخشونة السطحية (46%) بينما كمية ازالة المعدن تقل بنسبة (16%) عند استخدام كثافة تيار (2.856 امبير/سم^2).

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كذلك عند زيادة قيمة كثافة التيار (من 2.4485 امبير/سم2 الى 3.6728 امبير/سم^2) تقل الخشونة السطحية بنسبة (31%) وتزداد كمية ازالة المعدن بنسبة (93.9%) عند حجم فجوة (1مم).

INTRODUCTION

Electrochemical machining is one of the latest and potentially the most useful operations of metal removal of the non-traditional machining process. It is called by this term, because electrical energy is used in combination with chemical reaction to accomplish material removal [1, 2]. This process relies on the principle of the electrolysis for material removal, which is based on a controlled anodic electrochemical dissolution process of the work piece (anode) with the tool (cathode) in an electrolytic cell as shown inFigure (1) [3, 4].

The metal removal rate is governed by the well-known Michael Faraday's laws of electrolysis. Gusseff introduced the first patent on ECM in 1929, and the first significant development occurred in 1950, when the process was machining of high-strength and heat resistance alloy. It was accepted worldwide as a standard process in manufacturing and is capable of machining hard material components that are precise and difficult-to-machine. After the Second World War, the technique became more common due to demanding processing of hard alloys by military and aerospace applications [5, 6]. Mcgough (1988) claimed that when a potential difference is applied across the electrodes, several possible reactions occur at the anode and the cathode. Electrolysis has involved the dissolution of iron from the anode and the generation of hydrogen at the cathode [7]. As of the 1990s, ECM is employed in many ways, for example, by automotive, and medical engineering industries, as well as by aerospace firms, which are its principal user. This process has found good applications in industries associated with the manufacture of aircraft edging parts, turbine blades and grinding of carbide tools and dies. Parts may be produced from virtually any commercially available metal and alloy of any hardness [8, 9].

ECM process relies on the principle of electrolysis for material removal. Electrolysis has involved the dissolution of iron from the anode and the generation of hydrogen at the cathode. The usual type of reaction at the cathode is Evolution of hydrogen gas:

$$2H^+ + 2e^- \rightarrow H_2\uparrow \qquad \ldots\ldots. (1)$$

The type of anode reaction is Dissolution of metal ions in electrolytic solution:

$$M \rightarrow M^+ + e^- \qquad \ldots\ldots (2)$$

Where M represents any metal.

METAL REMOVAL RATE

ECM is mostly carried out on hard materials and alloys. For alloys containing (n) components of varying percentages the prediction of the removal rate becomes more difficult, the value of volumetric removal rate (Vu) is used [5].

$$Vu = \frac{100}{\rho F}\left[\frac{1}{\frac{X_1V_1}{M_1}+\frac{X_2V_2}{M_2}+\frac{X_3V_3}{M_3}+\ldots}\right] cm^3/amp\ sec \qquad \ldots..(3)$$

Where Vu is the volumetric removal rate, ρ is the density of the alloy(g/cm^3), F is faraday constant(Amp.sec), Xi is the Percentage of different elements in the alloy, Vi is the valence of elements are dissolute, and Mi is the Atomic weight of elements(g).
While the metal removal rate (MRR) was:
MRRgth-theoritical metal removal rate and to determine it in (g/sec) by multi playing the MRR in (cm^3/sec) unite by the density of metals or alloys

Then :

$$MRRsth = Vu \times I\ (cm^3/sec) \qquad \ldots..(4)$$

Where I is the current(Amp).

$$MRRgth = MRRsth \times \rho\ (g/sec) \qquad \ldots..(5)$$

$$ActualMRRg = \frac{wb\ \ wa}{Time}\ (g/sec) \qquad \ldots..(6)$$

Where Wb is the weight of the workpiece before ECM operation(g), Wa is the weight of the workpiece after ECM operation(g), *time* is the time of ECM operation(sec).

$$ActualMRRs = \frac{actual\ MRRg}{\rho}(cm^3/sec) \qquad \ldots\ldots(7)$$

$$Dissolution\ Rate = \frac{MRRs}{A}\ (cm/sec) \qquad \ldots..(8)$$

Where A is the area of the cathode (cm^2).

EXPEREMENTAL PROCEDURE

1 - Cathode tool:-

The material used for ECM tools should be electrically conductive and easily machinable to the required geometry. The tool used in the process is made from brass metal as cylinder shape with diameter Ø13 mm.

2 - Anode workpiece

For this study, the work piece is a cylinder shaft medium carbon steel (0.35%) with the chemical composition show in table (1) cut in to pieces and the dimensions are different for each operation:-

- The first operation is to study the effect of the gap size (10 mm height, Ø 45 mm outside diameter, Ø15 mm the hole diameter) were used.
- The second operation was to study the effect of the currents of dimensions (30 mm height, Ø 45 mm outside diameter, Ø15 mm the hole diameter) were used.

SURFACE ROUGHNESS

Device was used to measure roughness as shown in Figure (3) the device is small in size, light in weight and easy to carry as shown in Figure (5).it convenient to use and operate , and this device is compatible with four standards of ISO,DIN,ANSI, and JIS and widely used in production site to measure surface roughness of various machinery –processed parts. When measuring the roughness of the internal surface of the hole , the sensor is placed on the surface and then uniformly slide a long the surface by driving the mechanism inside tester. Many reading are taken (four reading from side and other four reading from the other sides of the hole), their average were calculated , as for travel of probe and speed, taken (10mm and 1mm/sec for the samples of the first case and 17.5mm).

ECM CELL

The electrochemical process was done by placing the workpiece in the cell with fixture to prevent the workpiece from vibration during the process. The tool is made from brass as a cylinder shape and fixed in the tool holder using drilling machine. The gap between the tool and the workpiece is controlled manually between the tool and the workpiece. After that the negative pole of the power supply is connected to the tool and the positive pole to the workpiece. Then both tanks are filled with the electrolyte as shown in fig (2). During the process and after power supply is turned on, the electrolyte with the sludge is sending out to the storage tank. From the other side of the storage tank the electrolyte is send to a filtration unit to remove the sludge and is pumped to the reaction zone.

In this study, the experiment is focused on two important characteristics in machining process; one is the surface roughness and the other is the Material Removal Rate (MRR). The surface roughness is measured for the internal surface of the holes in the work piece in all the tests.

1-Study the effect of gap dimensions on the Material Removal Rate (MRR) and comparison with the theoretical MRR, also the change in surface roughness at gap sizes (1, 1.5, 2, 2.5, 3) mm. The experiment used by five workpieces, each test has different gap size, the roughness and the weight of each workpiece is measured before and after operation.

2-The second case is studying the influence of the current density on the MRR which is compared with the thoeretical MRR also the change in surface roughness at currents density (2.448, 2.856, 3.2647, 3.6728) Amp/cm^2. The experiment used by four workpieces, each test has different currents density, the roughness and the weight of each workpiece is measured before and after operation.

RESULT AND DISCUSSION

The results of the effect of change in gap size on the surface roughness is gaven in table (2). At operation time of T = 10 minutes and current density 2.856 Amp/cm^2.

Fig (4) show the increase for the gap size causing the surface roughness increase after ECM due to the increase in the distance between the tool and the work piece that causing dicrease in the conductivity of the electrolyte (increase in ohmic resistance) causing unequal distribution of the current density on the machining surface which causing unequal anodic dissolution on the machining surface of the workpiec. The increasing of the surface roughness at gap size (3mm) arrived to (46.7%) when compared with gap size (1mm). While practically there is a decrease in the value of material removal rate (MRR) as shown in Figure (4) and given in table (3) due to the increase in the distance between the tool and the work piece that causing increasing in Ohmic resistance of the electrolyte which reduce the amount of the current and decreasing the amount of anodic dissolution. The approximate value of the theoretical MRR which is considered best at the gap sizes of (1 – 1.5) mm because the different between both theoretical and practical is less than other gap sizes, the value is approximately (0.005 gm/sec).

The Dissolution Rate is given in table (4) and shown in Fig (5) found decreases with the increase of the gap size and the best result is at the small gap sizes. The dissolution rate of the workpiece decreased (16%) with the increase of the gap size. For this reason the (1 mm) gap size is chosen for the others tests. Fig (7) shows the samples that used in this experiment.

The results of surface roughness at different current values are given in the table (5). At time of operation T = 10 min and the gap size between the tool and the work piece = 1 mm. Fig (8) shows that the effect of the current density on the roughness that decreases at increase in the value of current density, the roughness decreases rapidly arriving at the value of (1.8 µm) that decreased (31%)as was shown in table (6) with a current density (3.6728 Amp/cm^2) that because the high value of current causes a better decrease in the peaks of the workpiece surface and high current density distribution at all the machining surface of the work piece. The better declining of these values was at high current values so the value (3.6728 Amp/cm^2) gives the best decrease of the surface roughness arrived to (46.69%) when compared with the surface roughness before ECM operation. Fig (9) shows that the theoretical MRRg is increasing with current density arrived to (93.9%) at a gap size of (1mm). The high value of current is rushing the chemical reaction in the medium of operation which gives the best results.

CONCLUSIONS

- The distance between the tool and the work piece is larger; the surface finish will be rougher.

- It was found that material removal rate (MRRg) and dissolution rate , decreases with increase in the distance between the tool and workpiece.
- . The best value that gives better material removal rate (MRR) with high efficiency (77.7%) is the (MRR) at the (1 mm) gap size.
- From using different currents, it was found that the surface roughness of the workpiece is decreasing with increasing in current values.
- The material removal rate (MRR) and dissolution rate increases with increase of current density and the best results were at (3.6728 Amp/cm^2) for both tool surface Roughness. The efficiency arrived to (93.9%).

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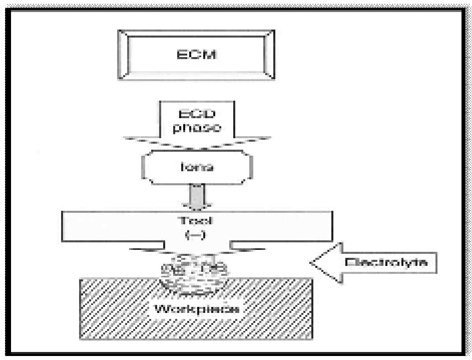

Figure (1)the principle of electrochemical machining [6]

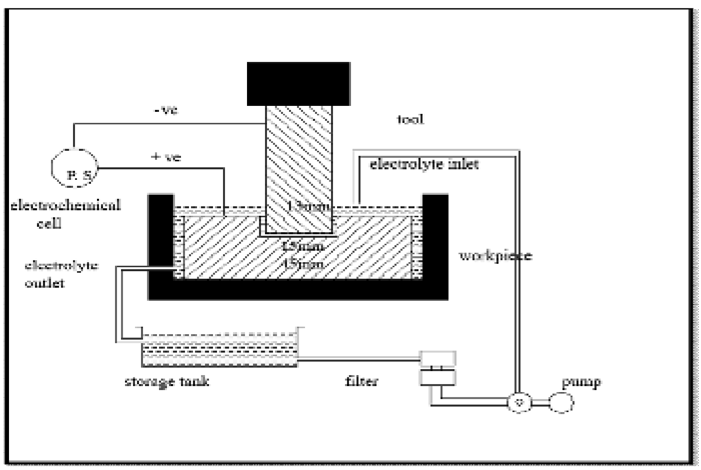

Figure (2) electro chemical machining

Figure (3) Surface roughness device

Table (1) Composition of the alloy

Element	Wt%	Density (g/cm^3)	Atomic weight	Valence
C	0.35	2.26	12.011	4
Mn	0.81	7.84	54.938	4
Si	0.19	2.33	28.086	4
P	0.011	2.93	30.97376	3
S	0.023	1.819	32.066	2
Ni	0.3	8.92	58.693	2
Cr	0.07	7.19	51.996	6
Mo	0.01	10.22	95.94	3
Cu	0.02	8.97	63.546	2
Al	0.05	2.71	26.98	3
Remain	98.436	7.86	55.845	2

Table (2) The surface roughness & the gap size before and after ECM operation

Gap size (mm)	Workpiece Roughness Before ECM operation (µm)	Workpiece Roughness After ECM operation (µm)
1	5.21	2.6
1.5	5.97	3.05
2	5.09	3.22
2.5	5.89	4.32
3	6.01	4.88

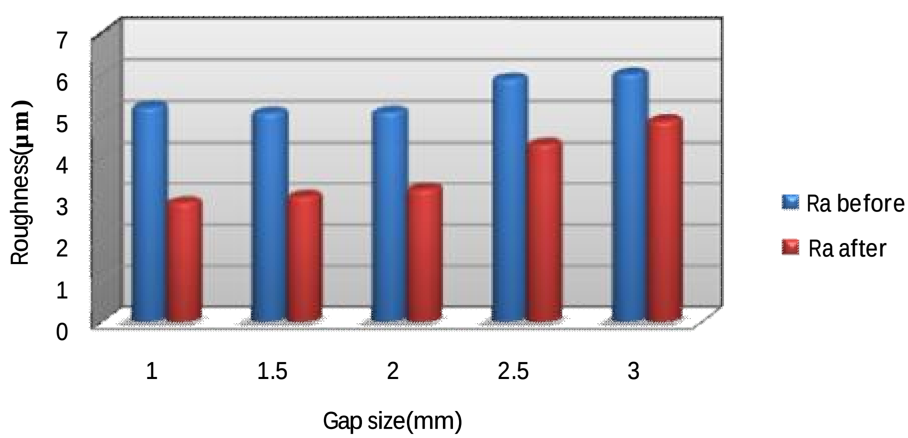

Figure (4) the relationship between the gap size on the surface roughness

Table(3) Theoretical and experimental metal removal rate (MRR)

Gap size (mm)	Workpiece Weight Before ECM operation (g)	Workpiece Weight After ECM operation (g)	MRRg (g/sec)	MRRgth (g/sec)
1	149.5	140.5	0.015	0.0198
1.5	113.6	104.8	0.0146	0.0198
2	157. 4	148.9	0.0141	0.0198
2.5	152.8	144.8	0.0133	0.0198
3	190.2	182.6	0.0126	0.0198

Table (4) Dissolution rate for different gap sizes

Gap size (mm)	Workpiece Weight Before ECM operation (g)	Workpiece Weight After ECM operation (g)	MRRs $x10^{-2}$ (cm^3/sec)	MRRstx10^{-2} (cm^3/sec)	Dissolution ratex10^{-5} (cm/sec)
1	149.5	140.5	0.191	0.2525	7.79
1.5	113.6	104.8	0.186	0.2525	7.59
2	157. 4	148.9	0.179	0.2525	7.3048
2.5	152.8	144.8	0.169	0.2525	6.8967
3	190.2	182.6	0.16	0.2525	6.5294

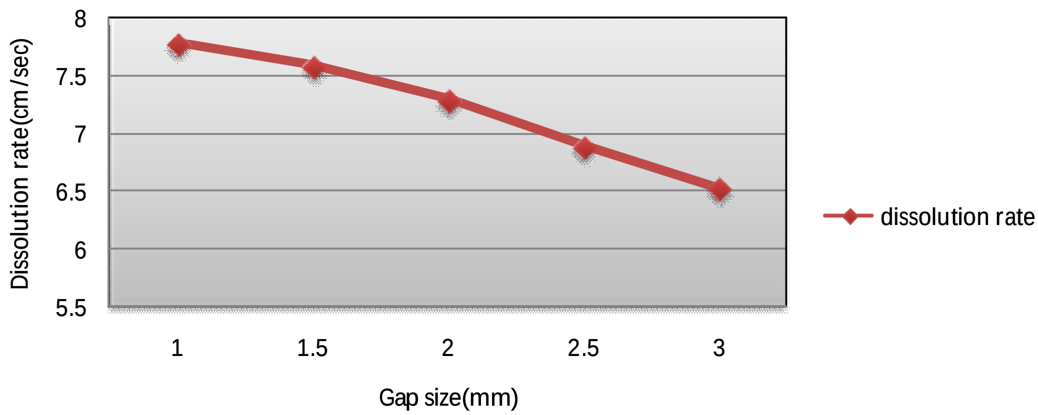

Figure (5) the different metal removal rate (MRR)

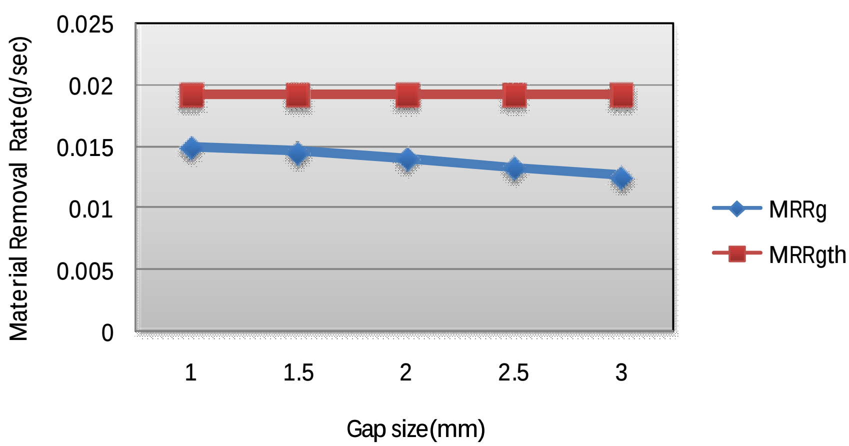

Figure (6) The effect of gap size on the dissolution rate of the work piece.

Figure (7) The samples that used to study the effect of the gap sizes on the surface roughness and MRR

Table (5) surface Roughness & the current density before and after ECM operation.

Current density (Amp/cm^2)	Workpiece Roughness before ECM operation (µm)	Workpiece Roughness after ECM operation (µm)
2.4485	3.677	2.687
2.856	3.59	2.49
3.2647	3.55	2.08
3.6728	3.48	1.855

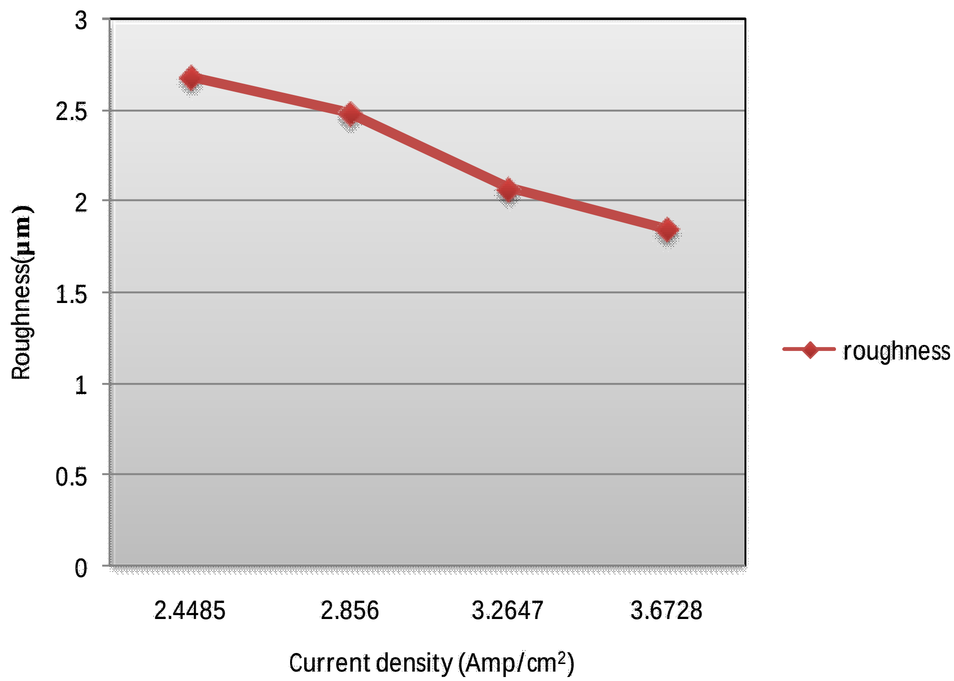

Figure (8) the relationship between the current density and the surface roughness

Table (6) The theoretical and practical MRRg

Current density (Amp/cm^2)	Workpiece Weight before ECM operation (g)	Workpiece Weight after ECM operation (g)	MRRg (g/sec)	MRRth (g/sec)
2.4485	639	632	0.0116	0.0169
2.856	674	665	0.015	0.0198
3.2647	684	673	0.0183	0.022
3.6728	648	634	0.0233	0.025

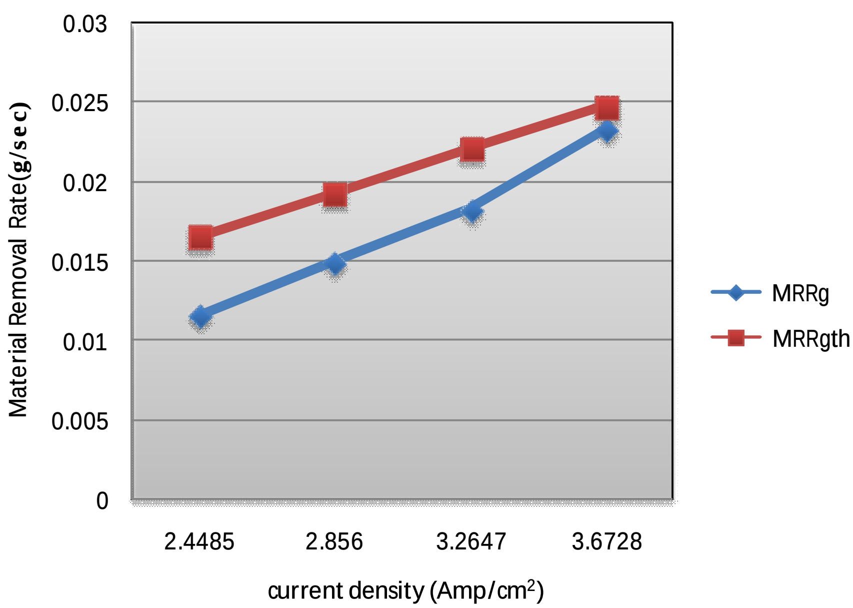

Figure (9) The effect of current density on MRRg