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Intervening of Electrochemical Machining Parameters on Particle Size of ZnO Powder and Metal Removal Rate

Abstract- Electrochemical machining (ECM) is an advanced machining process belonging to electrochemical category. Where in the material removal takes place by anodic dissolution of work piece in an electrolytic solution. This research presents results of the Electrochemical Machining (ECM) process, which was used to remove metal from the internal hole of the work piece (pure Zinc) by brass tool in an aqueous solution NaCl solution. The experimental study the effect of (ECM) process parameters such as (Current density, Gap distance, Electrolyte concentration) on Metal Removal Rate (MRR) and particle size of (Zinc oxide) sludge waste that precipitate from ECM. X-ray diffraction pattern for the resultant powder shows well-crystallized Zinc oxide powder The results indicated that particle size decreases from (82.432 to 24.6μm) and enhancement of MRR by (58.15%) with increasing current density. The increasing in gap distance between tool and work piece from (0.5 to 1.5) mm causes increasing in particle size from (76.451 to 91.81) μm and decrease (MRR) to (11.07%). For electrolyte concentration increasing from (100 to 300 g/l) leads to decrease in particle size from (89.218 to 32.406) μm, while improvement in MRR by (4.83%).

Keywords: Electrochemical machining, Particle size, Metal removal rate (MRR), Current density, Gap distance, Electrolyte concentration.

1. Introduction

Electrochemical machining (ECM) is a non-conventional process that depends on the removal of workpiece atoms by electrochemical dissolution process (ECD) in accordance with Faraday's principle [1]. ECM is one of the best methods to machine hard materials of complex geometry [2]. It is opposite of electrochemical coating or deposition process. In ECM controller removal process of metal was done by anodic dissolution in an electrolytic cell, where the anode is the workpiece and tool is the cathode. To dissolve metal from the work piece, electrolyte is pumped through the gap between the workpiece and the tool, while the current is passed through the cell [3]. A special property of electrolyte needs in this dissolution, including a high pH solution. The pH solution, around between 8-9, which is high enough that, as the part material is dissolved, the metals precipitate as metal hydroxide solids. The metal hydroxide are separated from the solution by filtration. If these solids, produced from superalloy material, include high concentrations of chromium, nickel and sometimes cobalt, rhenium, niobium, and titanium, these solids are disposed of in dangerous waste sites, but because of their high value, some are reprocessed [4]. The researches that had deal with ECM process are Hocheng et al. [5] studied the effect of machining parameters

(voltage, gap size, electrolyte concentration and time of electrolysis) on the MRR and diameter of machined hole. The results showed that the increasing of voltage, electrolyte concentration, time of electrolysis and decrease gap size causing increases the MRR. The electrolysis time is the most influential parameter on the diameter of hole. When the time increases from (60 to 240 sec), the depth of hole increases by four times. Ganjir [6] investigated the improvement in the material removal rate, overcut diameter and overcut depth of steel workpiece by using a U-tube copper rotating tool. The parameters were taken as process variables (voltage, feed rate, diameter and electrolyte concentration). The results show that the material removal rate (MRR) increases with increasing the voltage, feed rate and electrolyte concentration while decreases with increasing tool diameter, max MRR $(0.1364mm^3/min)$ at voltage (15 v), feed rate (0.6 mm/min) and electrolyte concentration (50 g/l). The overcut depth and overcut diameter are increases with increasing feed rate, voltage and electrode diameter but both of them decrease with increasing the concentration of electrolyte. Max. Overcut diameter and overcut depth are (7.376, 5.256) mm at voltage (15v), feed rate (0.6mm/min), tool diameter (6mm), and electrolyte concentration (30g/l). Jasim [7] concentrated the impact of statement voltage and

time underway of zinc powder by utilize electrochemical cell with zinc anodes have virtue of (97.4%) in electrolytic arrangement comprising predominantly of zinc oxide (ZnO) and Sodium hydroxide (NaOH). The variables affecting the electro statement creation of zinc powder are the physical test are done on the powder, similar to particles immaculateness powder, shape, estimate appropriation and molecule measure. The outcomes demonstrate that variety in voltage, the heaviness of zinc powder increment with expanding in voltage while particles estimate diminishes with expanding in voltage. Cathode terminal and framing of shape dendritic particles. Shather et al. [8] focused on the effect of machining parameters (currents density and gap size) on the surface roughness and MRR of steel work piece. The results obtained show that increasing of gap size between the tool and the work piece from (1 to 3mm) leads to increase the surface roughness(46%) ,while (MRR) decreases to (16%) at a current density (2.856A/cm^2). In addition, the increasing of the current density from (2.4485 to3.6728 A/cm^2), the surface roughness of the workpiece decreases (31%) while (MRR) increases (93.9%) at a gap size of (1mm). Ahmed et al. [9] in this review the ECM is utilized to expel metal from the inside opening of the workpiece from aluminum compound utilizing NaCl arrangement. The outcome demonstrate that rates of change in MRR are (6.48, 1.81, 3.74,13.24, 3.11) % for current densities of (2.82, 4.24, 5.65, 7.07, 8.48) A/cm^2 respectively, when contrasted and the stationary apparatus, and the pivoting electrode gives preferable surface complete over the stationary terminal, were the upgrade rates in harshness are (7, 31.72, 7.91, 15.49, 1.34)% for current thickness estimations of (2.82,4.24, 5.65, 7.07, 8.48) A/cm^2 separately. Oladiran, et al. [10] aimed to preparing zinc oxide nano particle were synthesized by wet chemical method using Sodium Hydroxide and Zinc Chloride as precursors. The optical analysis and structural has been done using UV-VIS spectroscopy and XRD, which reveals hexagonal structure with crystal size of (5.3689nm) and excitonic absorption peak at (277nm and 235nm) wavelength respectively.

2. Mechanism of Electrolysis Process

Electrolyte is different from metallic conductor of electricity in that the current is carried by atoms (or group of atoms) not by electrons which has either lost or gained electrons, thus either positive or negative charges are acquiring, these atoms called ions. Ions, which have positive charges, move to the direction of positive current that is, toward the cathode and are called cations. On the other way, the negative charged ions travel toward the anode and called anions [11]. Electrolyte in its bulk must be electrically neutral; that is, there should be equal numbers of adverse charges within it, and thus there should be equal quantities of reaction at both electrodes [12]. Electrochemical Machining (ECM) is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the workpiece is anode and 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 .

In this study a workpiece was pure Zinc (98.878%), the electrolyte is taken as a neutral solution of sodium chloride (NaCl). When a potential difference is applied, the electrolyte and water undergo ionic dissociation as shown below:

$$NaCl \leftrightarrow Na^+ + Cl^-$$
(1)

$$H2O \leftrightarrow H^+ + OH^-$$
(2)
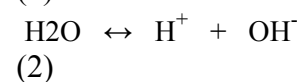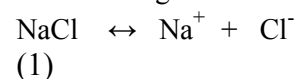
In this case, the positive charge, which is carried by ions, moves to the direction of the positive current through the electrolyte, and toward cathode, which is called cation. Similarly, anion is the process of travelling the negative charge ions towards anode. The (OH$^-$) and (Cl$^-$) (negatively charged) anions move toward workpiece (the anode), and the positive charged move toward to the cathode [13].

Each (Na$^+$) ions are converted to sodium hydroxide according to the following reaction. Hence. Therefore, the reactions at cathode are [1]:-

$$Na^+ + OH^- \rightarrow NaOH$$
(3)

$$2H2O^+ + 2e^- \rightarrow H2 \uparrow + 2(OH-)$$
(4)

$$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$$
(5)
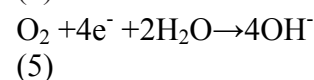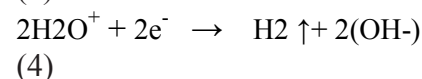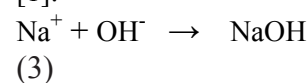
Reaction at anode (workpiece), dissolution of metal can occur:

$$M \rightarrow M^+ + e^-$$
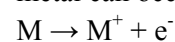
M: represents any metal.

Therefore, the anode metal (workpiece) becomes [14]:

$$Zn \rightarrow Zn^{+2} + 2e^- \qquad (6)$$

When the metal ions leave the workpiece surface (anode), many reactions occur in the electrolyte [15,16].
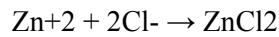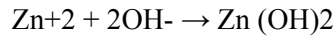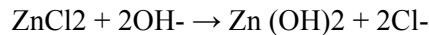
Zn+2 + 2Cl- → ZnCl2
(7)
Zn+2 + 2OH- → Zn (OH)2
(8)
ZnCl2 + 2OH- → Zn (OH)2 + 2Cl-
(9)
 (OH)2(aq.)   ↔   ZnO(s) +H2O(l)
(10)
ZnO powder would precipitated in the form of white particles, and then these particles will be taken to measure their size. It can be observed that the workpiece is machined and precipitated as a slurry. Besides there is no coating on the tool, just hydrogen gas develops at the cathode (tool).

Figure 1: Schematic representation of electrochemical reaction of zinc in NaCl

3. Estimation of Experimental Material Removal Rate

The actual material removal rate can be determined by [17]:

$$MRRexp = \frac{wb-wa}{Time} (g/sec \qquad or \qquad g/min)$$
(11)

Where:
MRRexp: Experimental material removal rate.
Wb = weight the workpiece before ECM operation (g).
Wa = weight the workpiece after ECM operation (g).

4. Experimental Work

I. Design of ECM cell

The ECM cell used in these experiments is shown in Figure 2. It consists of:
1- The drilling machine.
2- Workpiece fixture.
3- Reaction chamber.
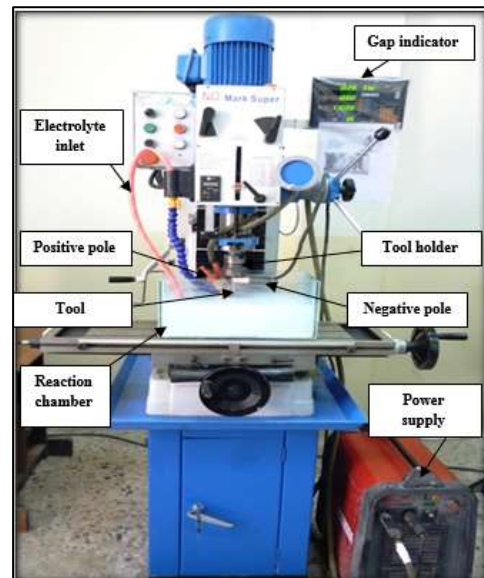4- Electrolyte pump.
5- Power supply.

Figure 2 ECM machine

II. Tool description

The tool is used in experimental work of this study Brass as shown in Figure 3, which is (cathode) with cylindrical shape with diameter (Ø8) mm. The Brass tool is made from brass material as an alloy of copper and zinc (63% Cu -37%Zn). The reason for using brass because it is easy to machine, have high electric conductivity and high corrosion resistance.

III. Workpiece description

The workpiece is square shape made from pure zinc metal (99.87%) and cut in to (15) pieces with dimensions of (50×50×10) mm, and 10 mm hole diameter. Figure 4 shows a sample of these pieces where a thin shaft connector made from same metal of workpiece is used as an electric conductor connected to the positive pole of the power supply.
1-five workpieces used to study effect of current density (11.93, 15.91, 19.89, 23.87, 27.85A/cm^2
2- Five workpieces used to study effect of gap distance (0.5, 0.75, 1, 1.25, 1.5) mm.
3- Five workpieces used to study effect of electrolyte concentration (100, 150, 200, 250, 300) g/l
The workpieces being used to study the influence of current density on MRR are shown in Figure 5, where the brass tool put through the hole of the workpiece to machine the internal surface of the hole.

Figure 3: Brass tool used in experimental work
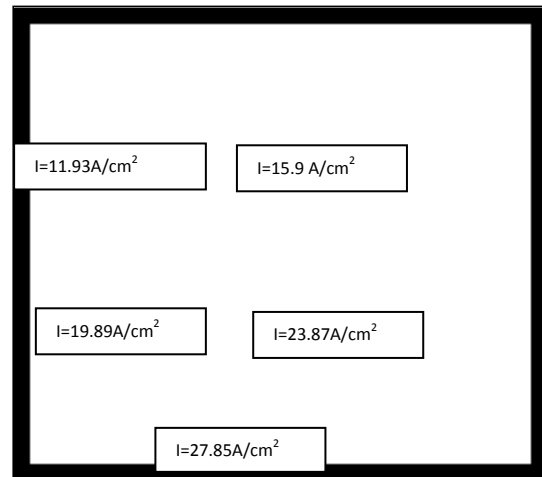

Figure 4: The workpiece

Figure 5: The workpieces that used to study the influence of current density on MRR

The solution of electrolyte after machining, which contains precipitated particles as shown in Figure 6, was washed by distilled water by using centrifugal device. The particle size measured by using laser particle size analyzer device.
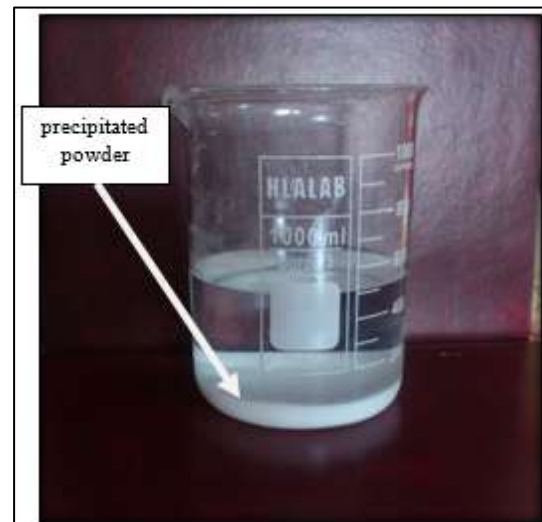

Figure 5: The precipitated powder (ZnO) from ECM

5. Results and Discussion

I. XRD of zinc oxide

X-ray diffraction test was carried out on the specimen of particle that participated in (ECM), the range of the diffraction angle (2θº) was (27.52º-67.86º). Figure 7 shows the XRD pattern of ZnO. The figure shows that all peaks matched well with the hexagonal structure of ZnO, corresponding to JCPDS card No 36-1451.

II. Particle size measurements

Particle size analyzer measured the Particle size distributions of the prepared powders (ZnO). The average particle sizes are tabulated together with the machining parameters in Table 1. The particle

size distributions of the effect of current density on particle size are fully displayed in Figures 8, 9, 10, 11 and 12. It can be showed the increasing in current density from (11.93 to 27.85 A/cm^2) causes decreasing in average particle size from (82.432 to 24.618)μm.
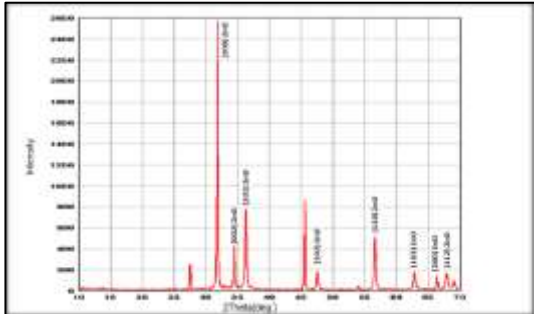

Figure 6: X-ray diffraction pattern of ZnO

Figure 7: Particle size distribution at current density (11.93) A/cm^2

Figure 8: Particle size distribution at current density (15.91)A/cm^2

Figure 10: Particle size distribution at current density (19.89)A/cm^2

Figure 9: Particle size distribution at current density (23.87)A/cm^2

Figure 10: Particle size distribution at current density (27.85) A/cm^2

III. Effect of current density on particle size of ZnO

The values of current density used for this study are 11.93, 15.91, 19.89, 23.87, 27.85 A/cm2.The results are given in Table 1. The machining time 9min, machining gap is 1mm, electrolyte concentration 200 g/l, and electrolyte temperature 40 ºC. Figure 13 shows the average particle size in different current density. It can be noted that the increasing in current density causes decreasing in particle size. When increasing current density the removal of the metal process

more as the Faraday law, where the kinetic energy of particles Transmitted be high and that this rapid movement prevents particles conglomerate and thus be of smaller size. Figure 13 shows the increasing in current density from (11.93 to27.85) A/cm2, the particle size decreases from (82.432 to 24.618) µm.

IV. Effect of gap distance on particle size of ZnO

The values of gap distance used for this experiments are (0.5, 0.75, 1, 1.25, 1.5)mm .The effect of gap distance on particle size are given in Table 1. The current density is (11.93A/cm^2), electrolyte concentration (200 g/l), and electrolyte temperature (40 ºC). Figure 14 shows the increase in gap distance from (0.5 - 1.5) mm due to increase in particle size from (76.451- 91.81) µm. The increase in distance between tool and workpiece causes increase in volume of electrolyte which increases in Ohmic resistance of the electrolyte that causing decrease in current density due to increase in particle size .
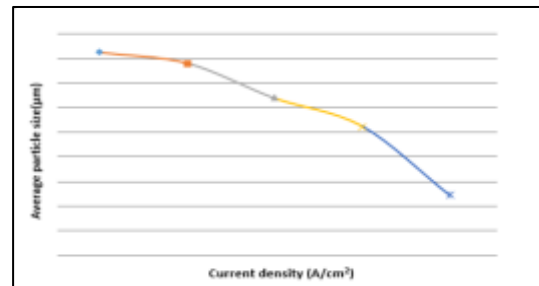

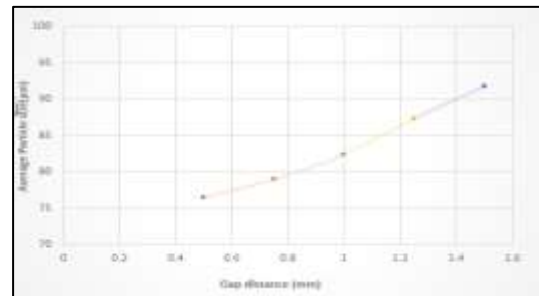**Figure 11: the effect of current density on Average particle size of ZnO powder**

Figure 12: The relationship between gap distance and particle size of ZnO powder

NO. of exp.	Current A	Current Density (A/cm^2)	Gap Distance (mm)	Electrolyte concentration (g/l)	Tool Roughness (µm)	Average Particle Size (µm)
1	30	11.93	1	200	1.07	82.432
2	40	15.91	1	200	1.07	77.966
3	50	19.89	1	200	1.07	64.062
4	60	23.87	1	200	1.07	52.401
5	70	27.85	1	200	1.07	24.618
6	30	11.93	0.5	200	1.07	76.451
7	30	11.93	0.75	200	1.07	78.967
8	30	11.93	1	200	1.07	82.432
9	30	11.93	1.25	200	1.07	87.391
10	30	11.93	1.5	200	1.07	91.81
11	40	15.91	1	100	1.07	89.218
12	40	15.91	1	150	1.07	86.045
13	40	15.91	1	200	1.07	77.966
14	40	15.91	1	250	1.07	56.148
15	40	15.91	1	300	1.07	32.406

Table 1: Experimental results of the effect of machining parameters on particle size of ZnO

V. Effect of electrolyte concentration on particle size of ZnO

The values of electrolyte concentration used for these experiments were 100, 150, 200, 250, 300 g/l. The results are shown in Table 1. The machining time (9min), the current density is (15.91A/cm^2), machining gap (1mm), and electrolyte temperature (40 ºC). Figure 15 shows

particle size in different electrolyte concentrations. The particle size decreases from (87.391-32.406) µm with increasing electrolyte concentration from (100-300) g/l. The cause of decreasing in particle size that when increases in electrolyte concentration due to increase electrical conductivity of the electrolyte, which means increase in machining current that due to decrease in particle size.

VI. The effect of current density on MR

The values of current density used for these experiments are (11.93, 15.91, 19.89, 23.87, 27.85) A/cm². The results of the effect of this parameter on MRR are shown in Table 2. The machining gap is (1mm), electrolyte concentration (200g/l), electrolyte temperature (40ºC). Figure 16 shows that material removal rate increases with increasing in current density. Faraday᾽ s law states, "The amount of mass dissolved (that removed by machining), is directly proportional to the amount of electricity which has flowed".
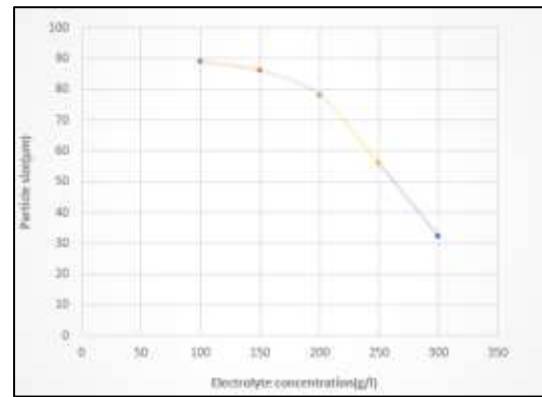

Figure 13: The effect of electrolyte concentration on particle size of ZnO powder

Table 2: The experimental results of the effects of machining parameters on MRR

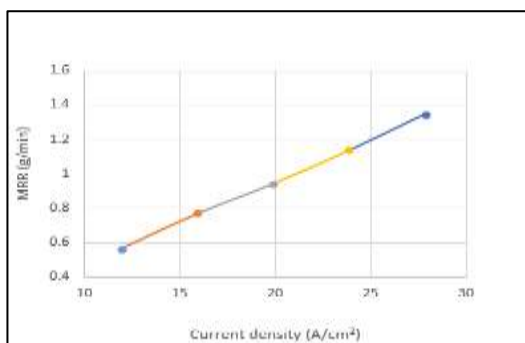| NO. of exp.	Current Amper Value	Current Density (A/cm²)	Gap Distance (mm)	Electrolyte concentration (g/l)	Tool Roughness (μm)	MRR (g/min)
1	30	11.93	1	200	1.07	0.5628
2	40	15.91	1	200	1.07	0.77031
3	50	19.89	1	200	1.07	0.9416
4	60	23.87	1	200	1.07	1.1365
5	70	27.85	1	200	1.07	1.3451
6	30	11.93	0.5	200	1.07	0.60381
7	30	11.93	0.75	200	1.07	0.58176
8	30	11.93	1	200	1.07	0.56286
9	30	11.93	1.25	200	1.07	0.5542
10	30	11.93	1.5	200	1.07	0.5436
11	40	15.91	1	100	1.07	0.74629
12	40	15.91	1	150	1.07	0.75657
13	40	15.91	1	200	1.07	0.77031
14	40	15.91	1	250	1.07	0.77757
15	40	15.91	1	300	1.07	0.7841

Figure 14: The effect of current density on MRR

VII. The effect of gap distance on MRR

The values of gap distance used for this experiments are (0.5 , 0.75 , 1 ,1.25 ,1.5)mm .The results of effect of change in gap distance on the material removal rate are given in Table (2).The operation time is T=9 minutes, current density (11.93A/cm²), electrolyte concentration (200 g/l), and electrolyte temperature (40 ºC). Figure (17) shows that the material removal rate decreases with increase in distance between

workpiece and tool that causes increasing in Ohmic resistance of the electrolyte which reduces the amount of the current and decreases the amount of anodic dissolution.
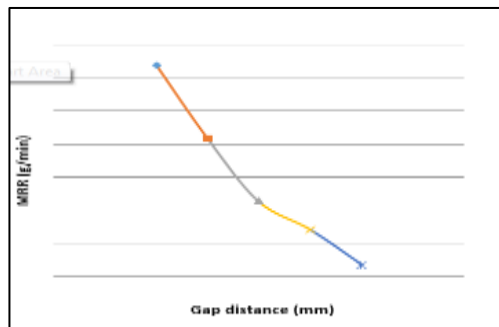

Figure 15: The relationship between the gap distance and the MRR

From theoretical and practical results of MRR were show the best gap distance is (0.5 mm) because the difference between both theoretical and practical MRR is less than other gap distance.

IIX. Effect of electrolyte concentration on MRR

The values of electrolyte concentration used for this experiments were (100, 150, 200, 250, 300) g/l. The results of this parameter are shown in Table 2. The machining gap is (1mm), current density (15.91), electrolyte temperature (40ºC). From figure (18), it is observed that increase in electrolyte concentration increases the MRR. With increasing the electrolyte concentration the electrical conductivity of the electrolyte increases and also that releases large number of ions in IEG, which results in higher machining current in the inter electrode gap (IEG) and causes higher MRR.
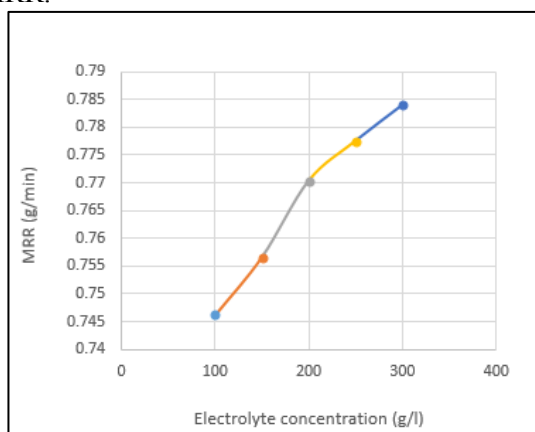

Figure 16: The relationship between electrolyte concentration and MRR

6. Conclusions

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

1-The increasing of current density lead to enhance the material removal rate (MRR). Where decreases in particle size from (82.432 to 24.618µm).

2-It is observed that with the increase in distance between tool and work piece from (0.5-1.5mm), MRR will decrease. Where particle size increases with increase in gap distance from (76.45 to 91.81) µm.

3-The higher electrolyte concentration produces higher MRR. Where decreases in Particle size from (89.218 to 32.406 µm).

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