Heba S. Qasim

Production Engineering and Metallurgy Dept., Baghdad, Iraq.
gaithalaa468@yahoo.com

Shukry H. Aghdeab

Production Engineering and Metallurgy Dept., Baghdad, Iraq.
shukry_hammed@yahoo.com

Effect of Potassium Chloride and Potassium Sulphate Electrolyte Solution on Surface Roughness and Material Removal Rate in Electro Chemical Machining (ECM)

Abstract-Electrochemical machining (ECM) is nontraditional machining which is used to remove metal by anodic dissolution. In this study the metal workpiece (WP) was stainless steel (AISI 316) and potassium chloride (KCl) and potassium sulphate (K_2SO_4) solutions were used as electrolyte, and the tool was used from copper. In this work the experimental parameters that used were concentration of solution, current and voltage as input. While surface roughness (Ra) and material removal rate (MRR) were the output. The experiments on electrochemical machining with using concentration (10, 20 and 30) g/l, current (2, 5 and 10) A and voltage (6, 12 and 20)V. Gap size between tool and WP (0.5) mm. The results showed that (K_2SO_4) solution gave surface roughness and material removal rate less than (KCl) solution in all levels, maximum (Ra) is (0.471) and minimum (0.049), while (KCl) solution gave maximum (Ra) was (4.497) and minimum was (0.837). Generally increasing in machining parameter (concentration of solution, current and voltage) lead to increase in (Ra) and (MRR). This study aims to compare the effect of using different electrolyte solution including potassium chloride (KCl) and potassium sulphate (K_2SO_4) on the surface roughness (Ra) and material removal rate (MRR).

Keywords: electro-chemical machining, surface roughness, concentration of solution.

1. Introduction

Electrochemical machining (ECM) is the material processing technology, that the workpiece (WP) is a molded by electrochemical cell as anodic in electrolyte solution , and the material is a removed from the workpiece in an ionic form, and have a priority such as no processing stress and a lossless tool electrode [1]. Machining method known as Electrochemical Machining (ECM) can be an alternative solution in treating the surface of stainless steel. ECM works by using the principle of electrolysis. ECM is profitable in many district related to the semiconductor, bio-hygiene, medical, ultra-clean gas, large vessel, and atomic energy industries [2]. This process (ECM) is a based on the same precepts using in an electroplating, accepting the tool is a (cathode) and WP is the (anode). The electrolyte is a solution of mineral salt like, sodium chloride (NaCl), potassium chloride (KCl), acid such as (H_2SO_4) and alkaline such as (NaOH) [3]. The ruthless materials that are difficult to machine by conventional machining, it can be machining by ECM [4]. Electrochemical machining of stainless steel is rather a complex process, hence many parameters are involved. Thus an optimization to find the best combination of parameters needs to be conducted. Optimization plays an important role in a process to avoid waste; specifically, waste of time and eff optimal process will lead to optimal production result [5]. Kumar and Kr were used the WP from steel and tool material from copper and KCl as electrolyte solution. The parameters used in this study were (voltage, gap size, feed rate and electrolyte concentration), voltage is 8, 10 and 12 V and electrolyte concentration 15, 20 and 25 % respectively. The output of this study is material removal rate (MRR) and surface roughness (Ra). And by using artificial neural network showed that minimum mean squared error the best network were selected [6]. Hammed et al. [7] were studied the experimental parameters (current, gap and electrolyte concentration), the output is a surface roughness (Ra). The current used (30, 50 and 70) (A), gap (1.00, 1.25 and

1.50) (mm) and electrolyte concentration (100, 200 and 300) (g/L) and by using ANOVA showed that the current is the most influential factor of the other factors on surface roughness (Ra). The workpiece was used from aluminum alloy 7025 in this study. And tool used were made from the copper. The optimum of comparisons of experimental parameters is current at step (1) 30 A, gap at level (1) 1.00 mm and electrolyte concentration in the step (1) 100(g/L) shown the average experiments and prediction surface roughness1.352 μm and 1.399 μm respectively. Unare and Attar [8] were studied the experimental parameters (voltage, tool feed and electrolyte concentration). The value of voltage is 15, 18 and 21 V, tool feed 0.3, 0.6 and 0.9 and electrolyte concentration is 10, 15 and 20. WP was used from aluminium alloy 7075, tool material was used from copper and KCl solution. The optimum parameters was found out by Gray-Taguchi method, output in ECM operation is metal removal rate (MRR) and surface roughness (SR). The optimum parameter found in: Voltage 15 V, Feed rate 0.9 mm/min and electrolyte concentration 20%.

Other nonconventional operation is electro discharge machining; the difference between electrochemical machining and electro discharge machining is shown in Table 1.

Table 1: Difference between ECM & EDM Process [9]

| ECM	EDM
Using electrolyte as a conducting medium between tool and WP.	Using dielectric fluid as a conducting medium between tool and WP.
It works on principle faraday's law of electrolysis.	It works on the principle of spark erosion.
Metal is removed by electrochemical reaction.	Metal is removed by melting and vaporization.
Tool used are of required size of the WP.	Tool used are oversize for machining inside surface and undersize for machining outside surface.
No heat is generated during the process.	Heat is generated during the process.
Metal removal rate is high.	Low metal removal rate.

2. The Electrochemical Reaction

The electrochemical reaction is the chemical reaction, which is, happen in the solution at the interface of an electronic conductor (a metal) and ionic conductor (electrolyte), and which contain electron transfer between the electrode and electrolyte or species in solution and this reaction is driven by external applied voltage. The chemical reaction that involves a transfer of electron can be used to produce an electric current. In this process, the reverse is applied. It is possible to use an electric current to force a particular chemical reaction to occur [9]. The metal removal is carried out by maintaining an electrolyte between the WP (anode) and tool (cathode) across a very small gap between them. The electrolyte removes gas bubbles generated in the electrode gap, heat, and the dissolution product such as metal hydroxides. Electrochemically using (KCl) solution as electrolyte. When the circuit power is switched on, the electrolyte gets ionized according to the following relationships [10]:-

$$KCl \rightarrow K^+ + Cl^-$$
(1)
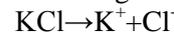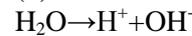
$$H_2O \rightarrow H^+ + OH^-$$
(2)

Positively charged ions: H^+ and K^+ towards cathode and negatively charged ions: (OH) and (Cl^-) go towards anode.
So the anode metal (WP) becomes [11]:-

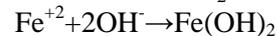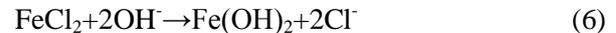$$Fe \rightarrow Fe^{+2} + 2e \qquad (3)$$

When the metal ions leave the WP surface (anode), many reactions occur in the electrolyte.

$$Fe^{+2} + 2Cl^- \rightarrow FeCl_2 \qquad (4)$$

$$Fe^{+2} + 2OH^- \rightarrow Fe(OH)_2$$
(5)

$$FeCl_2 + 2OH^- \rightarrow Fe(OH)_2 + 2Cl^- \qquad (6)$$
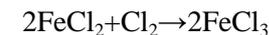
This ferrous hydroxide ($Fe(OH)_2$)is a green - black precipitate[12].

(Cl^-) ions may lose an electron and hence undergoes oxidation at the anode leading to evolution of chlorine gas at anode [13].
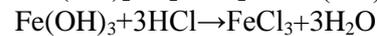
$$2Cl^- \rightarrow Cl + 2e^- \qquad (7)$$

$$2FeCl_2 + Cl_2 \rightarrow 2FeCl_3 \qquad (8)$$

Green-black ferrous hydroxide ($Fe(OH)_2$) reacts with the oxygen to form ferric hydroxide ($Fe(OH)_3$) which is red-brown in color [14]:
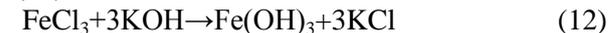
$$2H_2O \rightarrow O_2\uparrow + 4H^+ + 4e^- \qquad (9)$$

$$2Fe(OH)_2 + H_2O + O_2 \rightarrow 2Fe(OH)_3\downarrow \qquad (10)$$

$$Fe(OH)_3 + 3HCl \rightarrow FeCl_3 + 3H_2O$$
(11)

$$FeCl_3 + 3KOH \rightarrow Fe(OH)_3 + 3KCl \qquad (12)$$

3. Electrochemical Reactions of Potassium Sulphate (K_2SO_4)

$$H_2O \rightarrow H^+ + OH^- \qquad (13)$$

$$K_2SO_4 \rightarrow 2Na^+ + SO4^{-2} \qquad (14)$$

The anode metal (WP) becomes

$$Fe \rightarrow Fe^{+2} + 2e^-$$
(15)

When the metal ions leave the WP surface (anode), many reactions occur in the electrolyte

$$Fe^{+2} + {}^-SO_4^{-2} \rightarrow FeSO_4 \tag{16}$$

$$Fe^{+2} + 2OH \rightarrow Fe \quad (OH)_2 \tag{17}$$

$$Fe(SO_4)_2 + 2OH^- \rightarrow Fe(OH)_2 + 2SO_4^{-2} \tag{18}$$

This ferrous hydroxide $(Fe(OH)_2)$ is a green - black precipitate.

$$2SO_4^{-2} \rightarrow SO_4 + 2e^- \tag{19}$$

$$FeSO_4 + SO_4 \rightarrow Fe(SO_4)_3 \tag{20}$$

$$H^+ + {}^-SO_4{}^2 \rightarrow {}^- HSO_4 \tag{21}$$

$$2H_2O \rightarrow O_2\uparrow + 4H^+ + 4e^- \tag{22}$$

$$2Fe(OH)_2 + H_2O + O_2 \rightarrow Fe_2(OH)_3\downarrow \tag{23}$$

$$Fe_2(OH)_3 + 3HSO_4 \rightarrow Fe_2(SO_4)_3 + 3H_2O \tag{24}$$

$$Fe_2(SO_4)_3 + 6KOH \rightarrow 2Fe(OH)_3 + 3K_2SO_4 \tag{25}$$
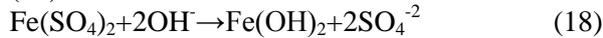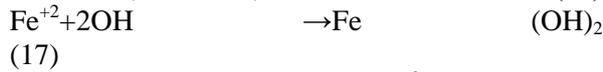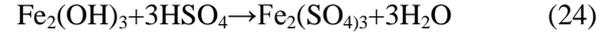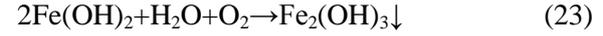
4. Calculation of MRR exp

The actual MRR can be determined by the:[9]

$$MRR\ exp = \frac{Wb - Wa}{MT} \quad (g/min) \tag{26}$$

Where:

MRR exp = experimental material removal rate.

Wb = Weight of the WP before ECM machining (g).

Wa = weight of the WP after ECM machining (g).

MT = Machining Time (min).

5. Experimental Work

I. Electrode and Workpiece

The workpiece was used from stainless steel AISI 316 with thickness of 2 mm and dimensions of (40x 30) mm is shown in Figure 1. The chemical composition of workpiece is shown in Table 2. Tool is made from copper with dimensions of (110x30) mm and thickness (6) mm is shown in Figure 2. The rectangle electrode was used to remove along the surface of the sample, so that it is easy to read the roughness of the device used.

Nine samples were selected in this study of the two solutions and changed in machining parameters (concentration of electrolyte solution, current and voltage). (1) mm was taken from the length of sample after machining as shown in Figure 3.

II. Electrolyte

The tow electrolytes (solutions) were used in this process, the first solution was mixing from water filtered and KCl (potassium chloride) and the second solution was K_2SO_4 (putassium sulphate) with water filtered and concentration (10, 20 and 30) (g/l).

III. ECM machine

ECM machine that used in these experiments is shown in Figure 3. And it consists of:

. The drilling contrivance.

. Electrolyte pour.

. Power equipping.

. WP fitting.

. Electrolyte chamber.

. Gap indicator.

. Electrolyte inlet.

6. Surface Roughness Measurements

The name of device that used to measure surface roughness (Ra) is Marsurf mahr by taking the mean of three results of (Ra).
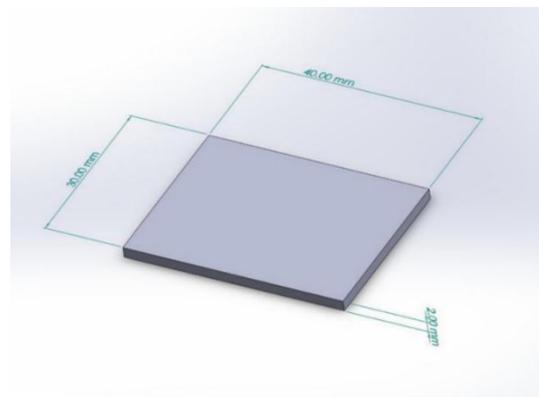

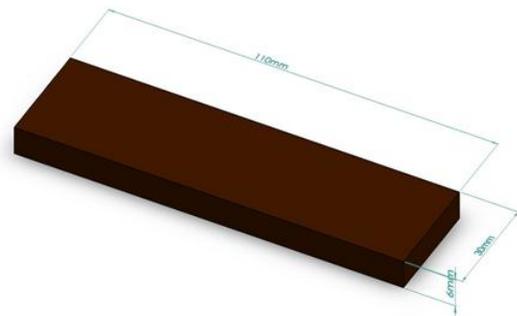**Figure 1: WP (stainless steel AISI 316) before machining**
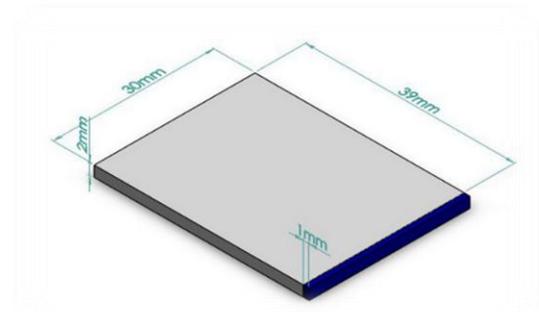

Figure 2: The copper electrode

Figure 3: WP (stainless steel AISI 316) after machining

Figure 4: ECM machine.

7. Results and Discussion

Different parameters used in this process such as current, voltage and concentration of solution, increase in this parameters lead to increases material removal rate because of increase movement of ions metal and increase temperature lead to increase electrochemical reaction. Surface roughness of KCl solution decrease at value of current 5A and surface roughness decrease in KCl solution with increase current at 10A. K_2SO_4 (Potassium Sulphat) give surface roughness and material removal rate less than KCl (Chloride Potassium) in all levels due to content ion (-HSO_4) that product from electrochemical reaction and gave high smooth surface. Potassium chloride solution gave higher roughness and metal removal rate values than potassium sulphate solution due to activity of the potassium element movement, which increases the chemical reaction and increases the heat generated, which affects the softness of the surface.

I. Results of surface roughness

Figure 5 explains the effect concentration of solution (10,20 and 30) g/l,and current (2A), maximum surface roughness for KCl is (3.097)µm, and minimum value is(0.376), and maximum surface roughness for K_2SO_4 is (0.420)µm, and minimum value is (0.124).
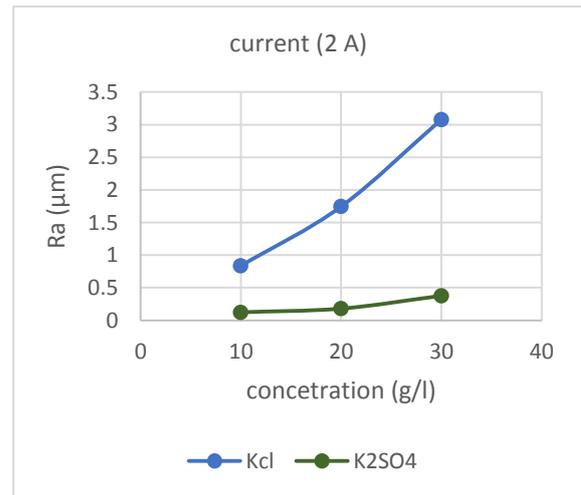

Figure 5: Effect of solution concentration on surface roughness at current (2A)

Figure 6 explains the effect concentration of solution (10, 20, 30)g/l and current (5 A), maximum surface roughness for KCl is (4.497)µm, and minimum value is(2.032), and maximum surface roughness for K_2SO_4 is (0.376)µm, and minimum value is (0.124).
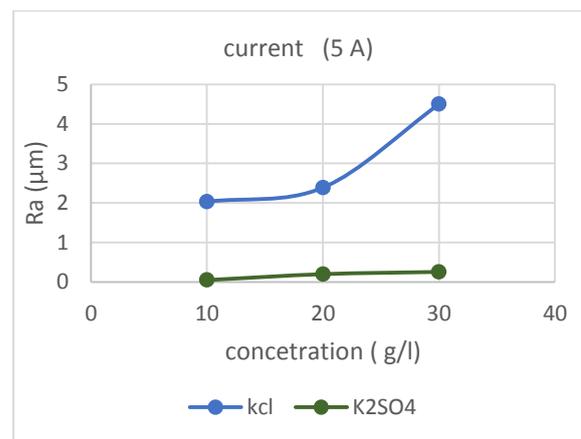

Figure 6: Effect of solution concentration on surface roughness at current (5A)

Figure 7 explains the effect concentration of solution (10, 20 and 30)g/l and current (10A), maximum surface roughness for KCl is (2.614)µm and minimum value is(1.580), and maximum surface roughness for (K_2SO_4) is (0.256)µm, and minimum value is (0.049).
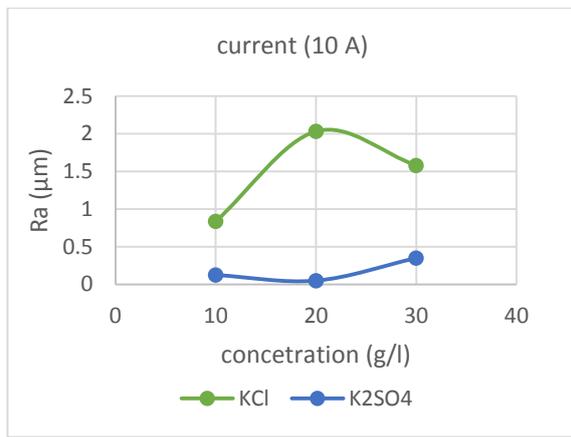
Figure 7: Effect of solution concentration on surface roughness at current (10A)

Increase in current and concentration lead to increase in surface roughness at one level due to increase temperature and electrochemical reaction at one level.

II. Results of MRR

Figure 8 explains the effect of current (2, 5 and 10) A, and voltage (6V), maximum material removal rate for KCl is (0.015)g/min, and minimum value is(0.012) g/min, and maximum removal rate for K_2SO_4 is (0.01)g/min, and minimum value is (0.056) g/min .
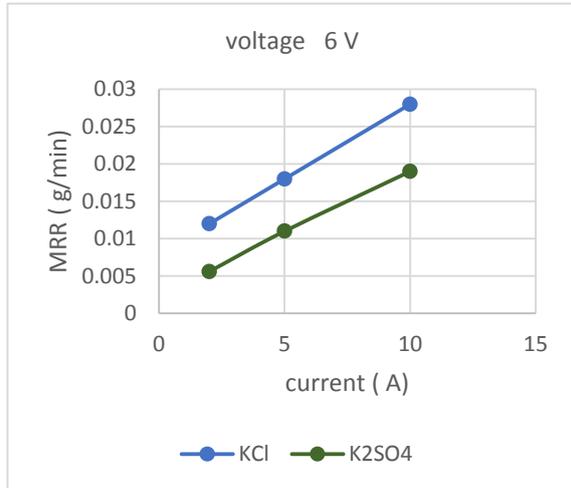

Figure 8: Effect of current on material removal rate at voltage (6V)

Figure 9 explains the effect of current (2,5 and 10) A, and voltage (12V), maximum material removal rate for KCl is (0.027)g/min, and minimum value is(0.018) g/min, and maximum removal rate for K_2SO_4 is (0.015)g/min, and minimum value is (0.011)g/min.
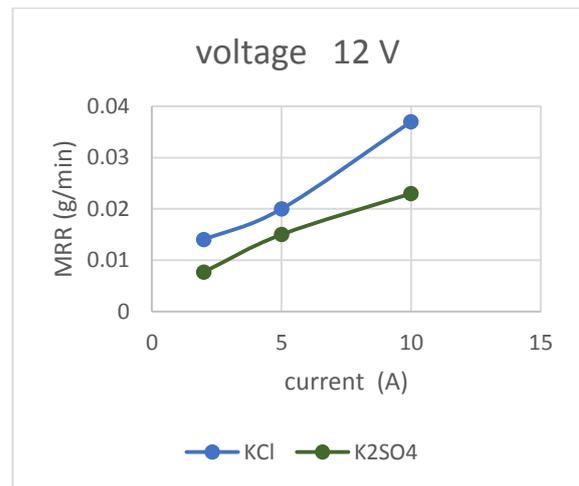
Figure 9: Effect of current on material removal rate at voltage (12V).

Figure 10 explains the effect of current (2,5,10) A, and voltage (20V), maximum material removal rate for KCl is (0.063) g/min, and minimum value is(0.028) g/min, and maximum removal rate for K_2SO_4 is (0.026) g/min, and minimum value is (0.019)g/min.
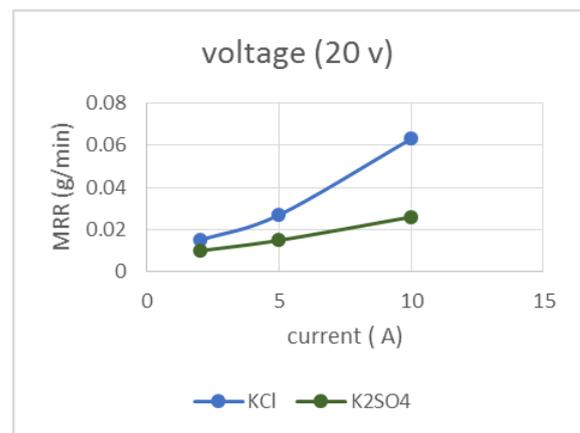
Figure 10: Effect of current on material removal rate at voltage (20) V.

Increase in current and voltage lead to increase material removal rate. And the best MRR of K_2SO_4 and KCl can be obtained at 10A of the current, 30 g/l of the concentration and 12 V of the voltage. The results of experimental special of K_2SO_4 solution is shown in Table 3. In addition, the results special of KCl solution as shown in Table 4.

Table 2: Chemical composition of stainless steel 316

| metal	C%	Mn%	Si%	P%	S%	Cr%	Mo%	Ni%	Fe%
Perc.	0.057	1.769	0.391	0.035	<.0005	18.73	0.284	8.69	Bal.

No. of exp.	Concentration (g\l)	Current (A)	Voltage (V)	Machining time (min)	Ra (µm)	MRR (g\min)
1	10	2	6	65	0.124	0.0056
2	20	2	12	45	0.180	0.0077
3	30	2	20	30	0.376	0.01
4	10	5	6	28	0.049	0.011
5	20	5	12	25	0.199	0.015
6	30	5	20	20	0.256	0.015
7	10	10	6	19	0.349	0.019
8	20	10	12	17	0.471	0.023
9	30	10	20	15	0.327	0.026

Table 3: Results of experimental of K_2SO_4 solution

Table 4: Results of experimental of KCl solution

No. of exp.	Concentration (g\l)	Current (A)	Voltage (V)	Machining time (min)	Ra (µm)	MRR (g\min)
1	10	2	6	30	0.837	0.012
2	20	2	12	25	1.745	0.014
3	30	2	20	20	3.079	0.015
4	10	5	6	18	2.032	0.018
5	20	5	12	15	2.388	0.02
6	30	5	20	11	4.497	0.027
7	10	10	6	14	1.580	0.028
8	20	10	12	10	1.526	0.037
9	30	10	20	5	2.641	0.063

8. Conclusion

The conclusions from experimental work are:

1- Increasing in concentration, current and voltage lead to increase in material removal rate (MRR) of the solutions.

2- Increase in concentration lead to increase in surface roughness.

3- Increase current lead to decrease in surface roughness.

4- The best surface roughness of K_2SO_4 solution can be obtained at 5A of the current, 10 g/l of the concentration and 6V of the voltage. And the best surface roughness of KCl solution can be obtained at 2A of the current, 10g/l of the concentration and 6V of the voltage.

5- The maximum material removal rate of solutions can be obtained at 30g/l of the concentration, 20V of the voltage and 10A of the current.

Reference

[1] X. Fang, N. Qu, H. Li and D. Zhu, "Enhancement of insulation coating durability in electrochemical drilling," Int J Adv Manuf Technol, Vol. 68, pp. 9–12, 2005–2013.

[2] E.S. Lee, "International Journal of Advanced Manufacturing Technology, Chapter 16, pp. 591-599, 2000.

[3] F. Phillip and O.J. Muñoz, "Manufacturing Process and System," Ninth edition, Chapter 20, Published Simultaneously Canada, pp.482-483, 1997.

[4] R. Ganjir, "Optimization of Process Parameters in ECM by Using Rotary U Shaped Tool," M.Sc. Thesis, National Institute of Technology, India, pp.1-65, 2010.

[5] S.J. Lee, C.P. Liu, T.J. Fan, and Y.H. Chen, International Journal of Electrochemical Science, Chapter 8, pp. 1713-1721 , 2013.

[6] M.K. Das, K. kumar and T. Kr, "Artificial Neural Networks Modeling for the Predication of Surface Roughness in ECM," International Journal of Applied Engineering Research, Vol.9, No.26, PP.9251-9254, India, 2014.

[7] Sh. Hammed, A. Mustafa and K. Safaa, "Optimization of Surface Roughness for Al-alloy in Electro-chemical Machining (ECM) Using Taguchi Method," Journal of Engineering Vol. 23, pp. 62-71, 2017.

[8] A.J. Unare1, P.R. Attar, "Optimaization of process parameter of electrochemical machining of aluminum alloy 7075 by using gray touchy," International Research Journal of Engineering and Technology, Vol. 03, 2016.

[9] H. Al-Hofy, "Advanced Machining Process, Nontraditional and Hybrid machining," First Edition, Chapter 4, McGraw-Hill Company, Egypt, pp. 77-99, 2005.

[10] H.H. Alwan, "Study of Some Electrochemical Machining Characteristics of Steel Ck35," M.Sc. Thesis, University of Technology, Iraq, 2011.

[11] U. Mallick, "Estimation of MRR by using U-shape Electrode in Electrochemical Machining," M.Sc. Thesis, National Institute Technology, India, 2009.

[12] M.K. Singh, "Unconventional Manufacturing Process," First edition, new age international publishers, New Delhi, 2008.

[13] B. Bhattacharyy, M. Malapati, J. Munda, A. Sarkar, "Influence of tool vibration on machining performance in electrochemical micro-machining of copper," Journal of material processing technology, vol. 47, pp.335 – 342, 2007.

[14] U. Rath, "Two Phase Flow Analysis In Electrochemical Machining For L-Shaped Tool," Department of Mechanical Engineering National Institute of Technology Rourkela, M.Sc Thesis, National Institute of Technology, India, pp.1-109, 2013.