Studying The Affect of Current on (MRR) and (EW) in Electrical DischargeMachining (EDM)

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ABSTRACT

The experimental work of this study leads with electro discharge machining (EDM). A system for machining in this process has been developed. Many parameters are studied such as current, dielectric fluid, thickness of the workpiece. The main aim of this work is to calculate the metal removal rate (MRR), electrode wear (EW) using copper electrode when machining stainless steel 304 specimens of thickness (0.4, 0.5, 1mm). Different current rates are used ranging from (10, 15, 20, 25, 30)Amp, and using tap water as a dielectric solution, it found that low current gives a less material removal rate and electrode wear while high current gives a high material removal rate and electrode wear, the dielectric fluid is changed in order to enhance results. The results show that maximum MRR is achieved ١,٠١١٦٤mm^3/min when machining thickness of workpiece 0.4mm and using electrode of copper metal which gives minimum EW 0.04gm, while when using thickness 0.5mm it gives MRR ٠,٤٣٨٢٨mm^3/min and EW 0.12gm, for thickness 1mm the MRR ٠,٣٣٩٦٤mm^3/min and EW is ٠,١١gm. The results show also that using distilled water as a dielectric fluid with copper electrode and thickness of workpiece 0.5mm gives minimum MRR ٠,١٣٨٥٤mm^3/min and less EW ٠,٠٨gm compared with using tap water.

Keywords: EDM, electrode wear, material removal rate

دراسة تاثير التيار على (MRR) و(EW) في عملية التشغيل بالتفريغ الكهربائي (EDM)

الخلاصة

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تعد عملية القطع بالشرارة الكهربائية من ابرز الأساليب اللآتقليدية لتشغيل المواد المستخدمة على نطاق واسع التي أجريت بسبب الميزات التي يوفرها. في الجانب العملي للدراسة الحالية تم تطوير واستخدام منظومة شرارة كهربائية لقطع المواد الموصلة ودراسة عدة متغيرات منها (التيار ، السائل العازل، سمك مشغولة) والغرض الرئيسي من ذلك لمعرفة تأثيرها على معدل إزالة المادة (MRR) وبلى القطب الكهربائي (EW) باستخدام قطب النحاس مع استخدام مشغولات من الفولاذ المقاوم للصدأ (stainless steel 304) بأسماك مختلفة (٠,٤, 0.5, 1 ملم). وباستخدام التيارات المختلفة (٣٠،٢٥،٢٠،١٥،١٠) أمبير لكل سمك وباستخدام ماء الحنفية كسائل عازل , وقد وجد عند اقل تيار يعطي اقل معدل ازالة مادة واقل بلى قطب بينما عند استخدام أعلى تيار يعطي اعلى معدل ازالة معدن واعلى بلى قطب. وقد تم تغيير السائل العازل للحصول على افضل نتائج. وتبين من نتائج الجانب العملي انهُ عند استخدام قطب النحاس مع سمك مشغولة ٠,٤ ملم يعطينا أعلى معدل إزالة مادة ١,٠١١٦٤ ملم^{٣}/دقيقة وأقل بلى قطب 0.04 غم وهذا يختلف عند استخدام سمك مشغولة ٠,٥ ملم الذي يعطينا معدل إزالة مادة ٠,٤٣٨٢٨ ملم^{٣}/دقيقة وبلى قطب ٠,١٢ غم أما عند استخدام سمك مشغولة ١ ملم فيكون معدل إزالة المادة ٠,٣٣٩٦٤ ملم^{٣}/دقيقة وبلى القطب بمعدل ٠,١١ غم. كما تم استخدام الماء المقطر كسائل عازل مع قطب النحاس وسمك المشغولة ٠,٥ ملم والذي اثبت اعطائنا أقل معدل ازالة مادة ٠,١٣٨٥٤ ملم^{٣}/دقيقة واقل بلى قطب ٠,٠٨ غم مقارنة مع استخدام ماء الحنفية.

INTRODUCTION

~~Electro discharge machining (EDM) is a non-traditional machining process for~~ metals removing based on the fundamental fact that tool force is negligible during the machining process. The removal of metals in the process is characterized by the erosive effects from a series of electrical sparks generated between tool and workpiece materials with constant electric field emerged in dielectric environment [1]. This machining process of controlled erosion of electrically conductive materials by the rapid and repetitive spark discharge between the workpiece (anode) and the tool (cathode) separated by flooded dielectric fluid through the small gap (about 0.02 to 0.5) mm, and known as spark-gap [2]. Since the cutting tool does not touch the workpiece, it is made of a soft, easily worked material such as brass. The tool works in a fluid such as mineral oil or kerosene, which is fed to the work under pressure. The coolant serves as a dielectric, to wash away particles of eroded metal from the workpiece or tool, and to maintain a uniform resistance to current flow [3]. The tank is filled with the dielectric fluid, the workpiece and the electrode end are submerged. An electrode chosen depending on the shape of the cut, is positioned on the top of the workpiece leaving a small gap [4].

Haron et al (2001) [5] use copper electrode of diameter 9.5, 12 and 20mm in electro discharge machining (EDM) of AISI 1045 tool steel at two current values (3.5 , 6.5)A, . It was found that the material removal rate as well as the electrode wear rate is not only dependent on the diameter of the electrode but also has close relation with supply of current. Low current was found suitable for small diameter electrode 9.5mm, while high current for big diameter electrode 20mm.

Khan and Saifuddin (2005) [6] have studied comparative analysis of the performance of copper and aluminum electrodes for machining stainless steel and carbide. It was found that MRR (material removal rate) increases with increase in current and voltage.

Seong et al. (2007) [7] demonstrated the influence of EDM pulse condition on the micro EDM properties. The experimental results show that the voltage and current of the pulse exert strong effect on the machining properties and the shorter EDM pulse is more efficient to make an accurate part with a higher material removal rate.

Khan (2008) [8] studied an analysis that has been done to evaluate the electrode wear along the cross-section of an electrode compared to the same along its length during EDM of aluminum and mild steel using copper and brass electrodes. He found that the electrode wear increases with an increase in both current and voltage.

1- Electrode Wear (EW)

Electrode wear rate is the weight difference of the electrode before and after machining. Electrode wear depends on a number of factors associated with the EDM like voltage, current, electrode material and polarity [9]. The melting point is the most important factor in determining the tool wear [10]. Electrode erosion cannot be prevented, but it can be minimized by choosing the proper electrode material/work metal combination and machining at the optimum settings. Minimizing corner wear requires choosing an electrode material that combines high strength with high temperature resistance [9]. Four main factors determine the suitability of a material for use as an electrode [11]

1. The maximum possible metal removal rate
2. Wear ratio
3. Ease with which it can be shaped or fabricated to the desired shape.
4. Cost

2- Phases of Discharge [12]

The discharge process during EDM can be separated into three main phases, they are:

3-1 Preparation Phase

On switching on the power supply, electric field is set-up in the gap between the electrodes. The electric field reaches maximum value at the point where the gap between the electrodes is smallest. Spark location is determined by the gap distance and the gap conditions. In the presence of electrically conductive particles in the gap, thin particle bridges are formed. When the strength of the electric field exceeds the dielectric strength of the medium, electric breakdown of the medium takes place.

3-2 Discharge Phase

A high current flows through the plasma channel and produces high temperature on the electrode surfaces. This creates very high pressure inside the plasma channel creating a shock wave distribution within the dielectric medium. The plasma channel keeps continuously expanding and with it the temperature and current density within the channel decreases. Plasma channel diameter stabilizes when a thermal equilibrium is established between the heat generated and the heat lost to the evaporation of the electrodes and the dielectric. During this phase, high energy electrons strike the workpiece and the positively charged ions strike the tool (for negative tool polarity). Due to low response time of electrons, smaller pulses show higher material removal from the anode whereas, longer pulses show higher material removal from the cathode.

3-3 Interval phase

The plasma channel de-ionizes when power to the electrodes is switched off. The gas bubble collapses and material is ejected out from the surface of the electrodes in the form of vapors and liquid globules. The evaporated electrode material solidifies quickly when it comes in contact with the cold dielectric medium and forms solid debris particles which are flushed away from the discharge gap. Some of the particles stay in the gap and help in forming the particle bridges for the next discharge cycle. Power is switched on again for the next cycle after sufficient de-ionization of dielectric has occurred.

3- Experimental Conditions

Experimental work includes the machine tool, power supply, mechanical and chemical properties of workpiece material, electrode tools and the dielectric solution; in addition it will show the process mechanics, and measurements of the electrode wear (EW), material removal rate (MRR) and the relation of these parameters with others such as; current, thicknesses of workpiece and machining time using different metals of electrode.

4-1 Selection of Set Up of EDM

The set up of EDM is shown in Fig. (1) which includes the following items:

1. Table made of wood with dimensions (36 × 28)mm.
2. Micrometer to measure the internal depth with a range of measurements (0-25)mm and the accuracy is up to 0.01mm.
3. Tool holder (two aluminum bars Φ 12 * 120mm length) for relative motion of this tool holder slides on the guides.
4. Workpiece holder.
5. Dielectric solution with 5 liter capacity.
6. A tank for dielectric solution made of Pyrex material.
7. Capacitor 5μF, and conducting electric wires.

4-2 Power Supply

The source of power for the experimental work is the generator power supply. The EDM power supply unit also operates with manual control. Manual control is more or less a feedback loop, as data is fed to the controller from the workpiece; the controller is able to change its inputs thus affecting the workpiece. The unit uses AC 380V input voltage which contains (three phases), and output voltage 70V (two phase), other current rates are available such as 10-30A. A generator for the experimental work unit used is available in welding machine (50/60HZ) type MMA 4040/ T- cell (Cebora-Italian model). The generator current range is (10-400A) depending on its industrial application.

4-3 Workpiece

The workpieces (anode) used are made of stainless steel 304, in different thicknesses (0.4, 0.5, and 1mm). the properties and chemical composition of the workpiece from that testing are given in Table (1) and Table (2) respectively.

Table (1) Physical and Mechanical properties of AISI stainless steel 304 [13].

Property	Description	
Physical		
Density (Kg/m^3)	8000	
Elastic Modulus (MPa)	193	
Thermal conductivity (W/m.K)	16.2 at 1000C 21.5 at 5000C	
Electrical Resistivity (nΩ.m)	720	
Specific Heat (J/kg.K)	500 from 00C-1000C	
Mean Coefficient of Thermal Expansion	17.2 From 00C-1000C 17.8 From 00C-3150C 18.4 From 00C-5380C	
Melting Point	1400-1450°C	
Mechanical	Typical	Minimum
Tensile Strength (MPa)	600	515
Proof Strength, (off set 0.2%) (MPa)	310	205
Elongation (Percent in 50mm)	60	40
Hardness (Brinell)	170	-
Endurance (fatigue Limit) (MPa)	240	-

Table (2) Chemical composition of 304 stainless steel workpiece.

Material	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Cu%	V%	W%	Fe%
% weight	0.043	0.3	1.52	0.03	0.0005	19.4	0.222	8.60	0.33	0.064	0.059	Balance

4-4 Dielectric Solution

The dielectric solution selected in our tests is the tap water and distilled water, The dielectric solution flushes out the chips from the machined area and reduces temperature of the workpiece. To analysis the tap water use Instrument Meter is used in measurements of PH (Hydrogen Power)/EC (Electrical Conductivity) /TDS (Total Dissolve Solution) model HI 9811 (Hanna Portable Instruction Manual)/CL / Na , as shown in Table (3).

Table (3) Measurements of pH/EC/TDS of Tap water.

Test	Results
TDS	522 ppm

PH	7.4
EC	0.7 ms/cm
CL	54.593 mg/l
Na	187.541 ppm

4-5 Electrodes (tool)

Three types of electrodes metals are used copper (Ø 3mm), brass (Ø 2.6mm) and tool steel (Ø 5.55mm). The gap between the electrode and the workpieceas is 0.20 mm using depth micrometer. The physical properties of three electrodes (copper, brass, carbon tool steel) are given in Table (4).

Table (4) Physical properties of the electrodes being used in the tests [14].

Physical properties	Copper	Brass	carbon tool steel
Electrical conductivity (10.E6 Siemens/m)	58,5	15,9	5,9
Electrical resistivity (10.E-8 Ohm.m)	1,7	6,3	16,9
Thermal Conductivity (W/m.k)	401	150	90
Thermal expansion coef. 10E-6(k-1)	17	20	12
Specific heat capacity (J/kg-K)	335	375	480
Density (g/cm^3)	8,9	8,5	7,7
Melting point (°C)	1083	900	1400

SELECTION OF MACHINING PARAMETERS

5-1 Calculating of Material Removal Rate (MRR)

Removal rate is calculated according to the Equations (1), which depends on the diameter of the hole resulting from the process of cutting by electric spark.

$$MRR = \frac{V_{wp}}{t} \qquad \dots (1)$$

where:

Vwp = volume of material removed from workpiece (mm^3).
$Vwp = \pi . r^2 . h$
t = time of machining (min).
r = radius of the resulting hole (mm).
h = thickness of workpiece (mm).

5-2 Calculating of Electrode Wear (EW)

Erosion in the electrode material is calculated by weighing the electrode before and after the machining process determining the difference in weight which is multiplied by 100 as mentioned in equation (2).

$$EW_g = (W_1 - W_2) \times 100 \quad \ldots$$

where:

W_1 = weight of electrode before machining, gm.
W_2 = weight of electrode after machining, gm.

5-3 Selection of Current (I)

The current is determined manually after several initial experiments by a variable resistance located in the power supply, the chosen current was between (10-30)Amp to test the effect of the current on process gradually from lower to higher values.

5-4 Electrode Material

The electrode material had been chosen for the electrode material copper with 3mm,copper electrode before and after machining can be shown in Figures (2-a,2-b).

5-5 Thickness of Workpiece

The thickness of workpiece has been chosen to be 3 different thicknesses of the stainless steel (0.4, 0.5 and 1)mm, the stainless workpiece before and after machining can be shown in Figures (3-a, 3-b)

5-6 Machining Time

Machining time is determined by calculating the time of the machining from the beginning to the end of the operation for each specimen, using stopwatch with accuracy 0.01sec.

5-7 Dielectric Fluid

The dielectric fluid used in most experiments is tap water and distilled water to knowledge who is the best in performance of electro discharge machining process.

RESULTS AND DISCUSSION

Figure (4) shows the relationship between the MRR and current for three thicknesses of workpiece and five current used (10, 15, 20, 25, 30)A with using copper electrode, At using less thickness 0.4mm the MRR up to ١,٠١١٦٤mm^3/min with higher current 30A, At machining thickness 0.5mm the MRR reach to ٠,٤٣٨٢٨mm^3/min with higher current, while at machining 1mm we get less MRR up to ٠,٣٣٩٦٤mm^3/min with higher current, from result obtained at different thicknesses of workpiece, when current increases the MRR also increases as it is concluded in Refs. [7,8] can be noted a small difference between thickness 0.4 and 0.5mm used, this may be due to the small thickness of the metal, as shown in the Tables (5, 6, 7).

Figure (5) describes the relationship between EW and current using three thicknesses of workpiece and five current with using copper electrode, and indicates electrode wear increases with increase in current as it is concluded in Refs. [8, 15], At current applied from 10 to 30A with machining thickness 0.4mm the EW increases from 0.04 to 0.2gm, followed by thickness 0.5mm EW increase from 0.12 to 0.30gm and then at thickness 1mm electrode wear increases from 0.11

to 0.35gm, from this figure we note that thickness 0.5mm is close to 1mm this is due to the large electrical spark at machining thickness 0.5mm, as shown in Tables (5, 6, 7).

Figure (6) shows that MRR increases with increase in current when using different dielectric fluids (tap and distilled water), and copper electrode with thickness of workpiece is 0.5mm, from this figure we note higher MRR when use tap water reaches 0.438mm^3/min with current supplied is 30A, while when distilled water is used the MRR reaches 0.138mm^3/min at current of 30A, that's due to high electrical conductivity of tap water, as shown in Tables (6, 8).

Figure (7) shows that EW increases with increase in current when different dielectric fluid (tap and distilled water) are used, and copper electrode with thickness of workpiece is 0.5mm, we note higher EW when tap water reaches 0.3gm at current of 30A, but when distilled water gives less EW of 0.26gm at the same current, as shown in Tables (A-2, A-11).

CONCLUSIONS

1- Tap water as a dielectric solution is used in most of the experiments rather than distilled water that is due to its available; few researches have used it and contains salts that helps and speeds up the process.

2- Experiments show that maximum MRR is obtained with machining workpiece of 0.4mm thickness and using copper electrode between (٠,٢٨٦٥-١,٠١١٦)mm^3/min, while for thickness 0.5mm (٠,١٢٢٩-٠,٤٣٨٢)mm^3/min, either for thickness 1mm with low material removal rate (٠,٠٥٨٩-٠,٣٣٩٦)mm^3/min.

3- Minimum EW is obtained with machining workpiece of 0.4mm thickness and using copper electrode between (0.04-0.2)gm, while for 0.5mm of (٠,١٢-0.30)gm and for 1mm at max EW is between (0.11-0.35)gm.

4- The efficiency of tap water as a dielectric solution is better than that of distilled water when using copper electrode to get the max MRR and min EW and less machining time.

5- At low current supplied (10A) we get more accurate machining but max machining time (80min) using copper electrode and workpiece of 1mm thickness, the MRR and electrode wear is less, while using high current of (30A) we get less machining time (50min) and low dimensional accuracy.

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Table (5) parameters for workpiece 0.4mm and copper electrode.

No. of experimental	1	2	3	4	5
Voltage (V)	70	70	70	70	70
Current (A)	10	15	20	25	30
Diameter of cut (mm)	٥,٦٥	٥,٨٠	٦,١٠	٦,٥٠	٦,٩٥
Machining time (min)	35	٣٠	25	٢٠	١٥
Volume of cut (mm^3)	10.02874	10.02874	11.68986	13.27322	15.17467
MRR Measured (mm^3/min)	٠,٢٨٦٥٣	٠,٣٥٢٢٧	٠,٤٦٧٥٩	٠,٦٦٣٦٦	١,٠١١٦٤
Weight of electrode wear (gm) (before machining)	١٥,٣٤٤٠	١٥,٣٥٣٨	١٣,٦٨٠٠	١٠,٩٩٦٤	١٥,٣٦٠٥
Weight of electrode wear (gm) (after machining)	١٥,٣٤٣٦	١٥,٣٥٣٢	١٣,٦٧٨٩	١٠,٩٩٤٨	١٥,٣٥٨٥
EW Measured (gm) ×100	0.04	٠,٠٦	٠,١١	٠,١٦	٠,٢

Workpiece	**Stainless steel**
Tool-electrode material	**Copper (3mm diameter)**
Cylindrical bar (conical)	**Shape of tool-electrode**
Negative polarity (-)	**Tool-electrode**
Positive polarity (+)	**Workpiece**
Dielectric	**Tap water**

Table (6) parameters for workpiece 0.5mm and copper electrode.

No. of experimental	1	2	3	4	5
Voltage (V)	70	70	70	70	70
Current (A)	10	15	20	25	30
Diameter of cut (mm)	٤,١٥	٤,٦٥	٥,٠٠	٥,٥٠	٦,٢٥
Machining time (min)	55	٥٠	٤٥	40	35
Volume of cut (mm^3)	6.76325	8.49113	9.81747	11.87914	15.33980
MRR Measured (mm^3/min)	٠,١٢٢٩٦	٠,١٦٩٨٢٢	٠,٢١٨١٦٦	٠,٢٩٦٩٧	٠,٤٣٨٢٨
Weight of electrode wear (gm) (before machining)	١١,٣٧٦٠	١١,٣٨٤٤	١١,٣٩٤١	١١,٤٠١٨	١١,٤١٦٠
Weight of electrode wear (gm) (after machining)	١١,٣٧٤٨	١١,٣٨٢٨	١١,٣٩٢٠	١١,٣٩٩٢	١١,٤١٣٠
EW Measured (gm) ×100	٠,١٢	٠,١٦	٠,٢١	٠,٢٦	٠,٣٠
Workpiece	Stainless steel				
Tool-electrode material	Copper (3mm diameter)				
Cylindrical bar (conical)	Shape of tool-electrode				
Negative polarity (-)	Tool-electrode				
Positive polarity (+)	Workpiece				
Dielectric	Tap water				
Workpiece	Stainless steel				

Table (7) parameters for workpiece 1mm and copper electrode.

No. of experimental	1	2	3	4	5
Voltage (V)	70	70	70	70	70
Current (A)	10	15	20	25	30
Diameter of cut (mm)	٢,٤٥	٣,٠٥	٣,٦٥	٤,١٠	٤,٦٥
Machining time (min)	٨٠	٧٠	٦٠	٥٥	50
Volume of cut (mm^3)	4.71435	7.30616	10.46346	13.20254	16.98227
MRR Measured (mm^3/min)	٠,٠٥٨٩٢	٠,١٠٤٣٧	٠,١٧٤٣٩	٠,٢٤٠٠٤	٠,٣٣٩٦٤
Weight of electrode wear (gm) (before machining)	١٣,٧٢٦١	١٥,٣٨٩٠	١٣,٧٢٧١	١١,٠١٧٢	١٥,٧٢٥٥
Weight of electrode wear (gm) (after machining)	١٣,٧٢٥٠	١٥,٣٨٧٥	١٣,٧٢٥٢	١١,٠١٤٧	١٥,٧٢٢٠
EW Measured (gm) ×100	٠,١١	٠,١٥	٠,١٩	٠,٢٥	٠,٣٥
Workpiece	Stainless steel				
Tool-electrode material	Copper (3mm diameter)				
Cylindrical bar (conical)	Shape of tool-electrode				
Negative polarity (-)	Tool-electrode				
Positive polarity (+)	Workpiece				
Dielectric	Tap water				

Table (8) parameters for workpiece 0.5mm and copper electrode.

No. of experimental	1	2	3	4	5
Voltage (V)	70	70	70	70	70
Current (A)	10	15	20	25	30
Diameter of cut (mm)	٢,٣٣	٢.84	٣,٤٠	٣,٧٧	٤,٢٠
Machining time (min)	70	65	60	55	50
Volume of cut (mm^3)	2.13192	3.16735	4.53960	5.58139	6.92721
MRR Measured (mm^3/min)	٠,٠٣٠٤٥	٠,٠٤٨٧٢	٠,٠٧٥٦٦	٠,١٠١٤٧	٠,١٣٨٥٤
Weight of electrode wear (gm) (before machining)	١٠,٩٠٠١	١٠,٩٠١٧	١٣,٦٧٧٠	١٠,٩٢٤٥	١٠,٩٢٧٠
Weight of electrode wear (gm) (after machining)	١٠,٨٩٩٣	١٠,٩٠٠٥	١٣,٦٧٥٥	١٠,٩٢٢٥	١٠,٩٢٤4
EW Measured (gm) ×100	٠,٠٨	٠,١٢	٠,١٥	٠,٢	٠,٢6
Workpiece	Stainless steel				
Tool-electrode material	Copper (3 mm diameter)				
Cylindrical bar (conical)	Shape of tool-electrode				
Negative polarity (-)	Tool-electrode				
Positive polarity (+)	Workpiece				
Dielectric	Distilled water				

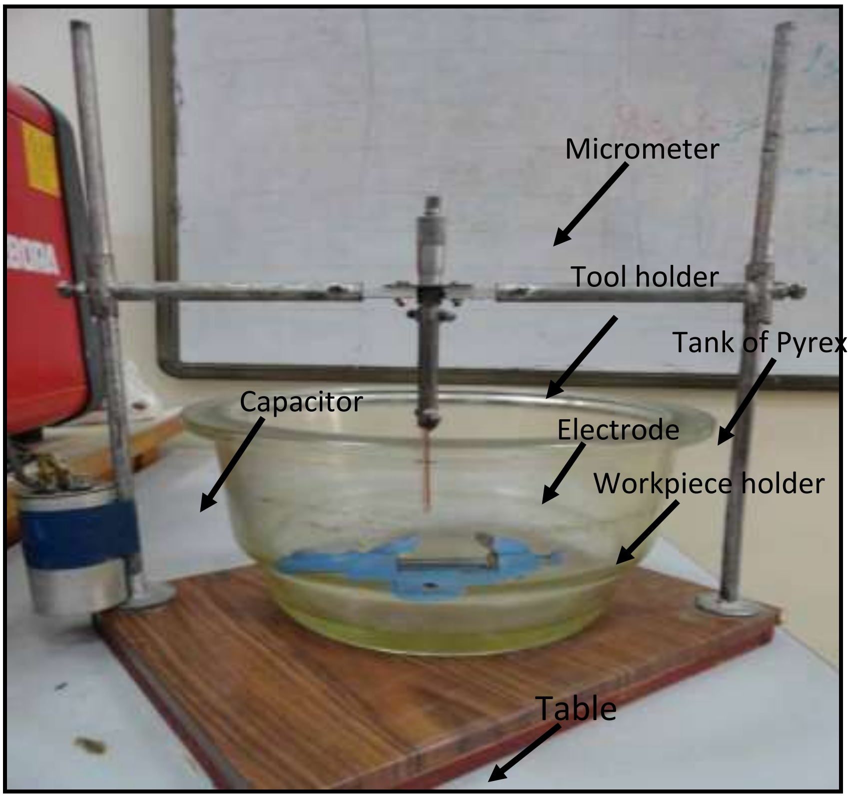

Figure (1) EDM set up.

Figure(2-a) Copper electrode before machining .

Figure (2-b) Copper electrode after machining.

Figure (3-a) stainless steel workpiece before machining.

Figure (3-b) stainless steel workpiece after machining.

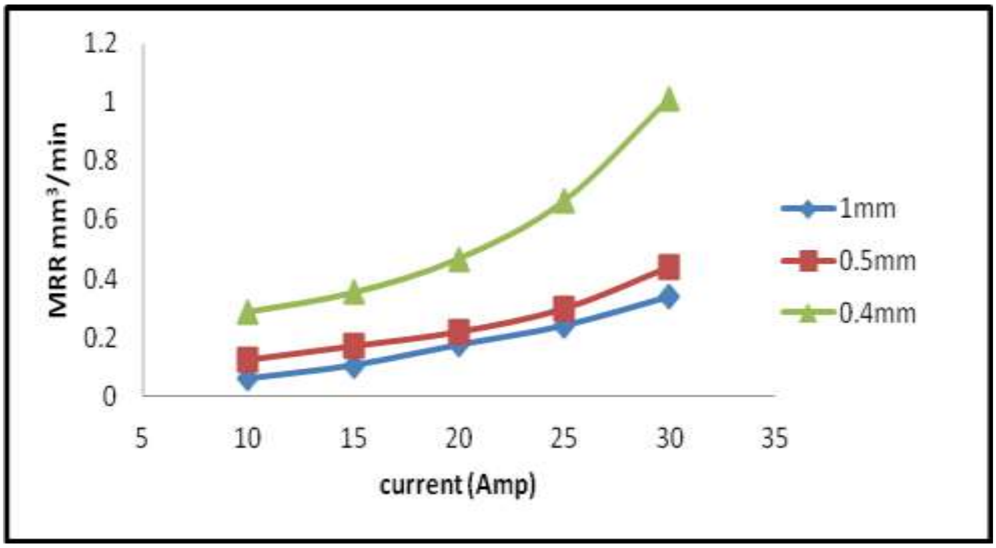

Figure (4) Effect of current on material removal rate (MRR) with using copper electrodes, three different thicknesses of workpiece, tap water as a dielectric fluid and five currents.

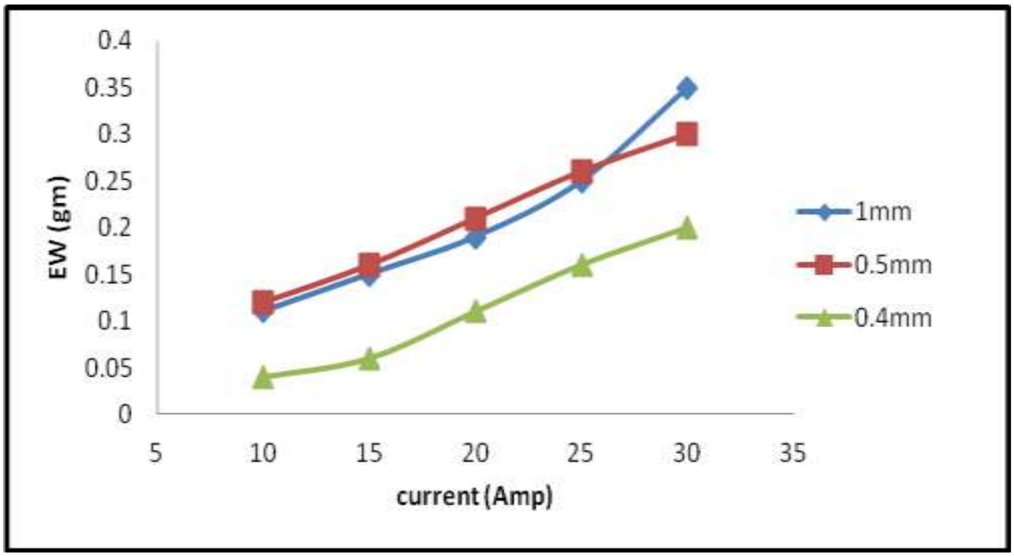

Figure (5) Effect of current on electrode wear (EW) with using copper electrodes, three different thicknesses of workpiece, tap water as a dielectric fluid and five currents.

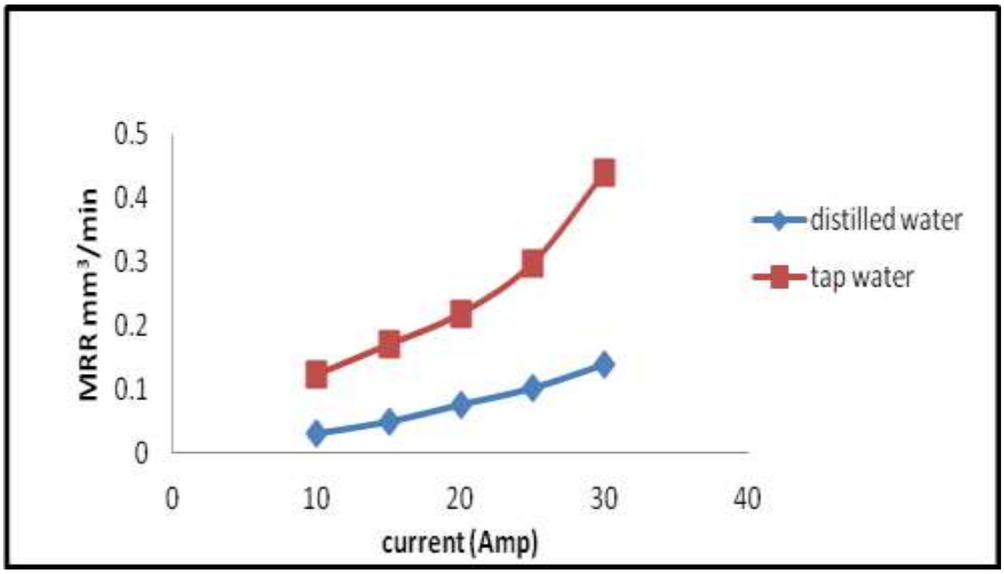

Figure (6) Effect of current on material removal rate (MRR) with using tap water and distilled water at thickness of workpiece 0.5mm, copper electrode and five currents.

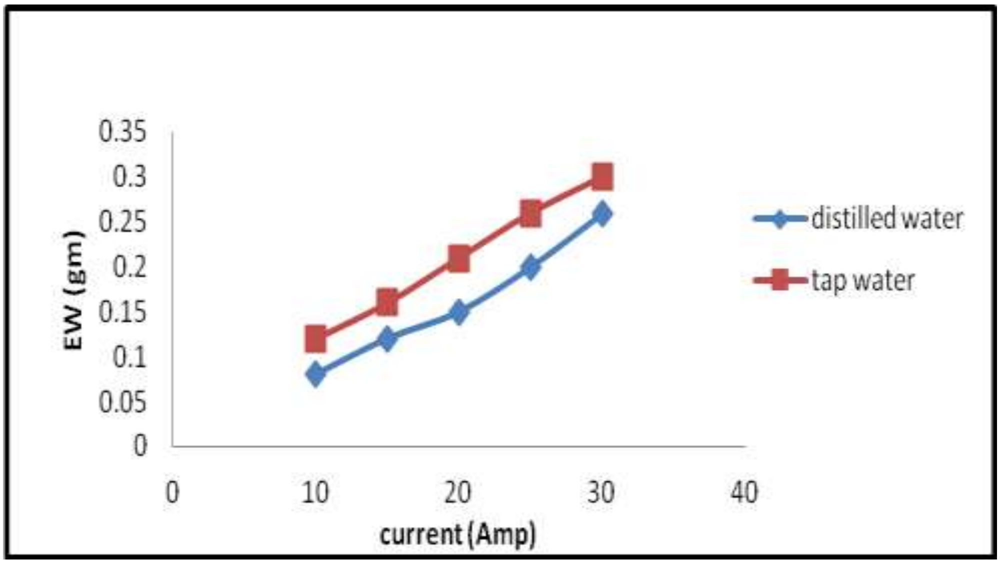

Figure (7) Effect of current on electrode wear (EW) with using tap water and distilled water at thickness of workpiece 0.5mm, copper electrode and five currents.