EFFECT OF CURRENT AND ELECTRODE MATERIAL ON MATERIAL REMOVAL RATE (MRR) AND SURFACE ROUGHNESS (RA) IN EDM PROCESS +

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Abstract :

Over the past decades, electrical discharge machining (spark machining) has been one of most widely used non-conventional manufacturing process for machining hard metals. It is considered as an electro-thermal machining process, in that the thermal energy resulted from the electric discharge (the spark) is utilized in removing materials from the workpiece. In this study the EDM is used to remove metal from the workpiece (Medium carbon steel alloy) using two types of electrodes (copper and brass) with different values of machining current (10, 20,30,and 40)A. The effects of current and electrode material on the material removal rate (MRR), tool wear rate (TWR), and surface roughness have been investigated. The results show that higher MRR, lower TWR and smother surface is obtained with the copper electrode compared with the brass tool. Higher MRR values with using copper electrode are (59.92, 65.42, 61.51, and 60.77) % at machining current (10, 20, 30, and 40) Ampere respectively.
Keywords: EDM, Surface Roughness, MRR, TWR.

تأثير التيار الكهربائي ومادة العدة على معدل إزالة المادة والخشونة السطحية في عملية القطع بالتفريغ الكهربائي

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المستخلص:

عملية التشغيل بالتفريغ الكهربائي هياحد انواع القطع الغير تقليديوتعتمد على الطاقة الكهربائية- الحرارية في عملية التشغيل حيث يتم استخدام الطاقة الكهربائية لتوليد الشرارة الكهربائية وتتم ازالة المادة بواسطة الطاقة الحرارية المتولدة من هذه الشرارة. في هذه الدراسة تم استخدام عملية (EDM) لازالة المعدن من احد سبائك الفولاذ متوسط الكاربون باستخدام نوعين من الاقطاب (النحاس والبراص) وبقيم تيار (40,30,20,10) امبير.حيث تم دراسة تاثير كل من معدل ازالة المادة ومعدل تآكل القطب (العدة) والخشونة السطحية. وقد اظهرت النتائج ان اعلى معدل ازالة مادة واقل تاكل بالقطب وأنعم سطح تم الحصول علية باستخدام قطب النحاس بالمقارنة مع قطب البراص. اعلى قيم لمعدل ازالة المادة تم الحصول عليها باستخدام قطب النحاس هي (59.92، 65.42، 61.51، 60.77)% لقيم التيار (40,30,20,10) امبير على التوالي.

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Introduction:

Recently, electrical discharge machining (EDM) (also known as spark machining) has been one of most widely used non-conventional manufacturing process for machining hard metals. EDM is classified as an electro-thermal machining process, in that the thermal energy resulted from the electric discharge (the spark) is utilized in removing materials from the workpiece. The EDM is effectively utilized to reshape materials that are significantly hard, high temperature resistance and electrically conductive [1]. The typical setting of any EDM experiment involves motivating an electric spark between two conductive electrodes separated by a dielectric liquid. The spark gap between the electrodes ranges from 0.02mm to 0.5mm. One of the electrode is called the tool while the other is called the workpiece. A series of rapidly repeating discharges can lead to a controlled erosion for the work material [2].According to El-Hofy [3], the temperature accompanying to these high intensity electric discharges are high enough to cause material removal and to lead to a melt or evaporation into the electrodes.

One of the focal advantages of the EDM process is the absence of occurring conventional failures and issues related to mechanical stresses, vibration and chatter. This is a consequence for being the electrode and the workpiece separated by a gap. As a result, this manufacturing process is typically utilized to machine and reshape brittle and hard metals. This distinguishing advantage has made the EDM a very popular process in machining dies and molds used in the nuclear, marine, petroleum, aerospace, surgical and automotive industries [4].

Several studies that dealt with the factors influencing the characteristics of electric discharge machining have been found throughout reviewing the relevant literature. Prajapati and Prajapati [5] carried out an EDM experiment to investigate the effects of using electrodes of several materials on material removal rate (MRR) and surface roughness. Three electrode materials were investigated; copper, brass and graphite. The work material was EN-9. Other parameters included were pulse on time, pulse off time, and peak electric current. They found that among the three electrodes, graphite resulted the highest removal rate. In contrast, regarding surface finish, the best result was associated with the brass electrode. Finally, they also reported that higher material removal rate and high surface roughness were obtained by using powder electrode rather than solid electrode.

Using two work materials (aluminum and mild steel) and two electrodes (brass and copper), Khan [6] investigated the factors that can influence electrode wear rate during spark machining. The study findings imply that as electric current and voltage increase, electrode wear rate increases. Such wear was more obvious on the electrode cross section than on its length.

Another experimental study on the EDM was conducted by Keskin et al. [7]. They interrogated the expected parameters that could influence surface roughness (SR). One of their main findings was that as discharge duration increases, surface roughness increases too. A logical explanation is that increasing sparking time will generate more thermal energy and hence expanding the channel of electric discharge.

In 2012, another experimental research was undertaken by Gopalakannan and Senthilvelan [4] in order to interrogate the impacts of pulsed current of several EDM output parameters on a stainless steel work material. Specifically, the parameters included MRR, tool wear rate (TWR), surface roughness and diameteral overcut. Graphite, copper and copper-tungsten are the three electrode materials adopted. Their experiments results indicate that increasing pulsed current can lead to a rise in the MRR, TWR and SR. The copper electrode gave the higher removal rate. In contrast, the copper-tungsten electrode gave the lower tool wear rate, smoother surface and adequate accuracy.

The possible impacts of discharge current, pulse and voltage on EDM output parameters such as material removal rate and surface roughness were also investigated by Chikalthankar et al [8]. They used tool steel of WPS DIN 1.2379 / AISI D2 with copper electrode material. Their results imply that both material removal rate and surface finish are very influenced by the applied discharge current. Finally, Singh and Singh [9] described the effect of different parameter such as pulse current and tool materials on surface roughness produced. They confirmed that the Surface roughness and electrode wear were increased with increasing of pulse current and pulse time. As a consequence, the effect of wear rate on electrode could increase the surface roughness of the workpiece.

The purpose of the current paper is to investigate the influences of electrode materials and machining current on material removal rate (MRR), electrode (tool) wear rate and surface roughness.

Principle of EDM operation :

Thermoelectric energy is considered as the underlying concept of the controlled electric discharge machining. The machining motivates material removal to happen due to the high temperature generated as a result of passaging the electric current between the workpiece electrode and tool electrode. The two electrodes are supposed to be separated by a dielectric liquid such as deionized water or hydrocarbon oil. The small gap between the workpiece and electrode (tool) is called the spark gap. The pulsed discharge is typically happened in this gap. The series of rapid sparks is the cause of material removal (erosion) process [10].

According to several researchers such as Gaurav et al. [11], the spark-based erosion process is to large extent analogous to having electric short that could lead to melt the material it contacts. For assuring adequate and effective EDM the work materials and the electrode (tool) should be conductive; otherwise no electric discharging is occurred. In this electric discharging the anode is the workpiece whereas the cathode is the tool. A typical schematic illustration of the EDM process can be seen in Figure (1).

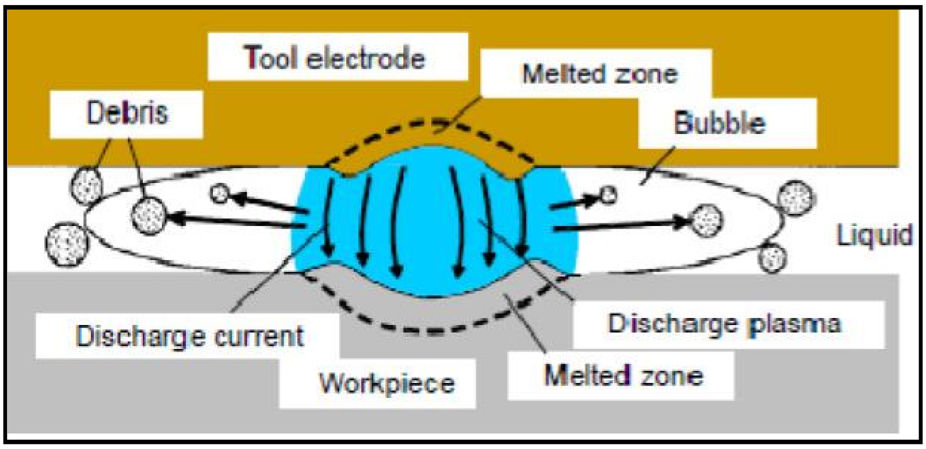

Figure (1) Schematic view of discharge gap [10].

Experimental Work :

The impacts of EDM operating factors (electrode material and electric current)on material removal rate, tool wear rate and Surface Roughness (Ra) have been investigated. The experiments were conducted on EDM CM323Cwhich is available in the Training and Workshop Center / University of Technology / Baghdad as shown in Figure (2) and its specifications listed in table (1). Two types of electrodes (copper, and brass electrode) have been used. The work material used in this paper is medium carbon steel. The chemical composition and mechanical properties of the work material are given in Table 1 and Table 2 respectively.

Figure(2) EDM CM323C machine.

Table (1) Specification of machine used

Model	Unit	CM323C
Table size (WxD)	mm/inch	500x350/19.7x13.8
Work tank size(WxDxH)	mm/inch	820x500x300/32.3x19.7x11.8
Table travel (X,Y)	mm/inch	300x200/11.8x7.9
Ram travel (Z1)	mm/inch	300/11.8
Distance from RAM platen to work table	mm/inch	250~550/9.8~21.7
Max. electrode weight	kg/lb	60/132
Max. workpiece weight	kg/lb	500/1100
Outside dimensions	mm/inch	1200x1350x2250/47.2x53.1x88.5
Weight	kg/lb	1000/2200
For Dielectric	-	D323

1- Tool (Electrode)

Two types of tool were used in the experimental study, pure copper and pure brass electrodes made as a rod with diameter (16mm) and length (56mm), as show in figure (3).

Figure (3) copper and brass electrode after machining.

2-Workpiece

Eight workpieces were used of solid cylindrical shaft with dimensions of (Ø50mm outside diameter, and 9 mm thickness) which was drilled by drilling tool (Ø 14 mm) to reduce the machining time and get the best results. Workpiece was inspected in (Central Organization for Standardization and Quality Control). The chemical composition and mechanical properties are listed in tables (2) and (3) respectively. One of workpieces is shown in figure (4).

Table (2) Chemical composition of workpiece.

Element	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Al%	Co%	Cu%	V%	Fe%
Wt %	0.415	0.205	0.655	0.006	0.008	0.036	0.002	0.071	0.003	0.006	0.099	0.0005	Remain

Table (3)Mechanical properties of workpiece.

Mechanical Properties	AISI 1045 Medium Carbon Steel
Tensile Strength	310 MPa
Shear Modulus	80 GPa
Hardness Brinell (BHN)	163
Elongation at Fracture (in 50mm)	16.0 %
Machinability	55.0 %
Poisson's ratio	0.290
Specific heat capacity	0.486 J/g-°C
Thermal conductivity	49.8 W/m-K
Density	7.87 g/cc

Figure (4) workpiece used in the experimental work.

The surface roughness (Ra) is measured by the POCKET SURF EMD-1500 tester, on the inner surface of the resulting hole; the roughness measuring device is shown in figure (5).

Figure (5) Automatic digital POCKET SURF EMD-1500.

3- Estimation of material removal rate (MRR)

This paper is focused on the effect of tool (electrode) type and machining current on Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (Ra).Eight experiments have been conducted on the two types of electrode with same different values of discharging currents. The machining condition selected as the feed (1mm) up and dawn, machining gap (1mm), pulse on time (24µs), and pulse off time (10µs) .The weight of the workpieces are computed before and after machining process by using digit electronic balance, the tool weight were also computed before and after machining. The equation being used to determine the experimental metal removal rate is given below [1]:

$$MRR = \frac{\text{Weight befor machining} - \text{Weight after machining}}{\text{Time duration} \times \text{material density}} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

And the equation being used to determine Tool Wear Rate (TWR) is as follows [1]:

$$TWR = \frac{\text{Weight befor machining} - \text{Weight after machining}}{\text{Time duration}} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

<u>Results and discussion:</u>

4-1- Copper Electrode:

The results that obtained from copper electrode are shown in the table (4):

Table (4) Experimental results of machining with copper electrode

No	Current (A)	Cu electrode Weight before machining (g)	Cu electrode Weight after machining (g)	Workpiece Weight before machining (g)	Workpiece Weight after machining (g)	Machining time (min)	MRR cm^3/min	TWR g/min	Ra µm
1	10	99.5434	99.2998	122.4853	120.4572	24.13	0.0108	0.010	3.03
2	20	99.2896	98.9568	136.4912	134.2710	13.33	0.0214	0.024	3.46
3	30	98.8825	98.5820	128.9389	126.6380	10.20	0.0291	0.029	3.63
4	40	98.5820	98.2064	130.7907	128.6690	8.18	0.0334	0.045	3.79

Figure (6) shows the effect of machining current on the material removal rate (MRR) with using the copper electrode where four values of currents are taken (10, 20, 30, and 40) Ampere. From the figure (6) it is found that when increasing the machining current from 10 to 40 ampere the material removal rate increases by 67.66%. This is because the electrical spark increases with increasing the current.

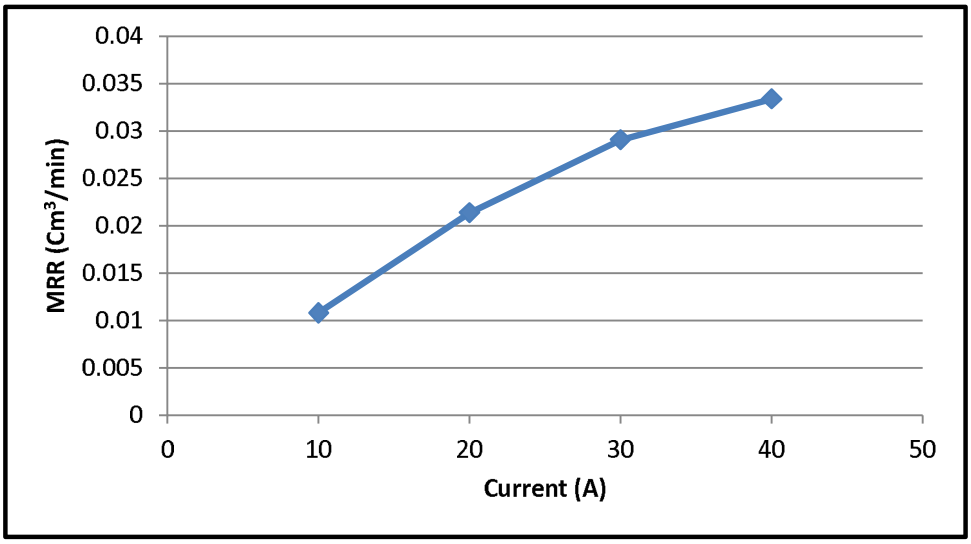

Figure (6) the effect of machining current on MRR with copper electrode.

Figure (7) shows the effect of machining current on tool wear rate (TWR) of copper electrode. It is obvious that the increasing of current from (10 to 40)A leads to an increase in the (TWR) and the maximum wear was occurred at 40A. This is because when the current increases the electrical spark will increase and thus the increasing corrosion in the metal.

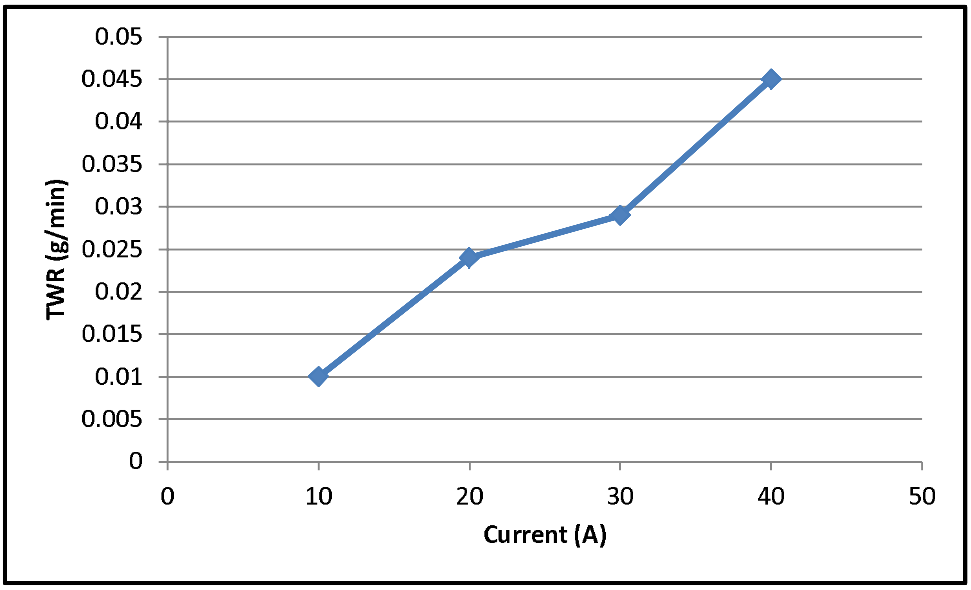

Figure (7) the effect of machining current on TWR of copper electrode.

Figure (8) shows the effect of machining current on surface roughness (Ra) when using copper electrode. As machining current varies from (10 to 40)A, the surface roughness (Ra) is increased, The lower surface roughness is obtained with lower values of machining current and the percentage of increasing in Ra from (10 to 40)A was 24.8%. That is because lower current lead to low corrosion in metal with low spark generated between the electrode and work piece.

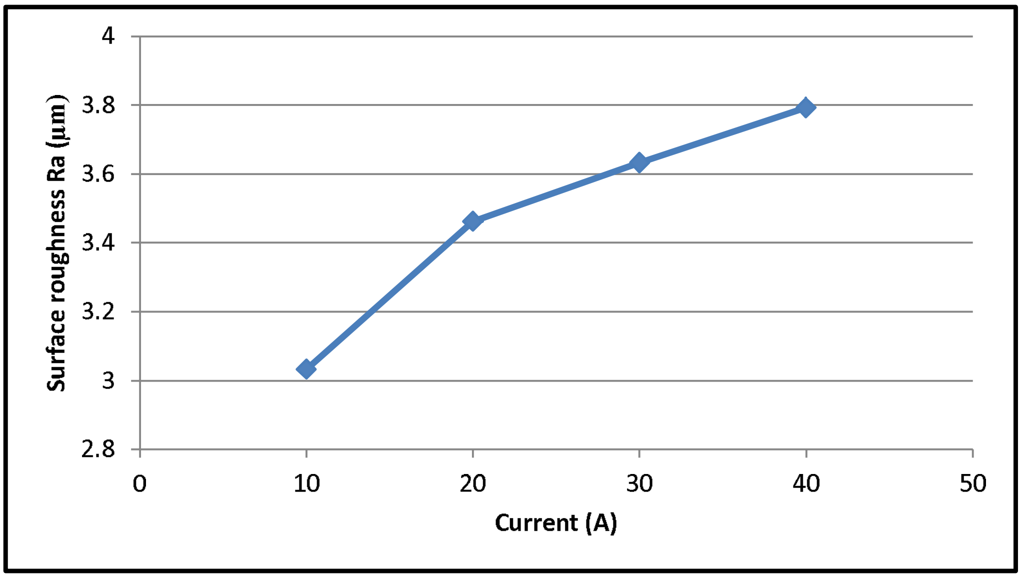

Figure (8) the effect of machining current on Ra of copper electrode.

2- Brass Electrode:

The results that obtained from brass electrode are shown in table (4):

Table (4) Experimental results of machining with brass electrode

No	Current (A)	Brass electrode Weight before machining (g)	Brass electrode Weight after machining (g)	Workpiece Weight before machining (g)	Workpiece Weight after machining (g)	Machining time (min)	MRR cm^3/min	TWR g/min	Ra µm
1	10	83.437	81.508	131.268	130.395	25.05	0.0044	0.077	3.28
2	20	81.508	79.104	127.828	126.823	17.31	0.0074	0.138	3.35
3	30	114.193	111.480	130.185	128.963	14.06	0.0112	0.192	4.01
4	40	111.480	108.435	143.831	142.682	11.30	0.0131	0.269	4.20

Figure (9) shows the effect of machining current on the material removal rate (MRR) with using of brass electrode where four values of currents are taken (10, 20, 30 and 40)A. It can be noticed that the increase in the machining current values from (10 to 40)A resulted in an increase in the material removal rate by 66.41%.That is since any increase in electrical spark is associated with an increase in the current and this accordingly lead to increase the material removal rate.

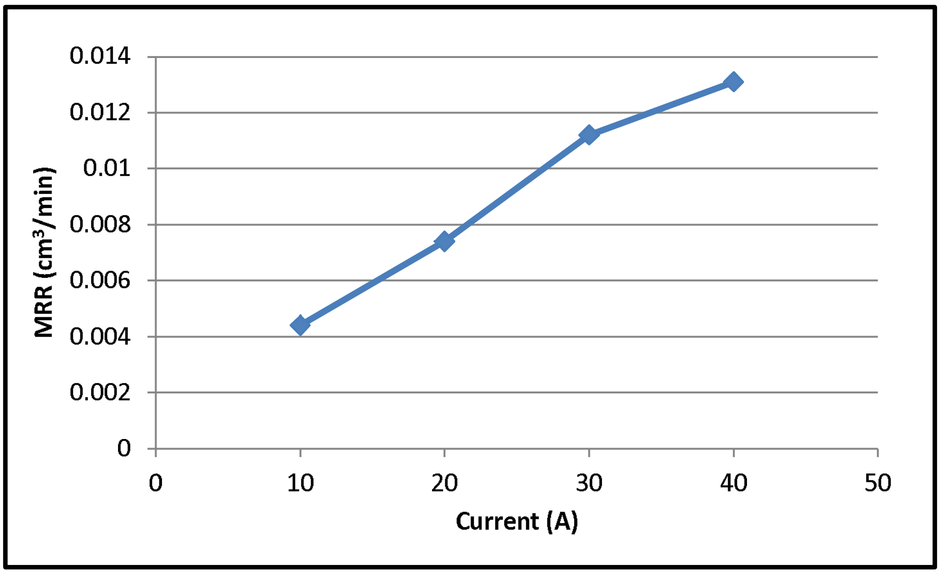

Figure (9) the effect of machining current on MRR with brass electrode.

Figure (10) shows the effect of machining current on tool wear rate (TWR) with using the brass electrode. There is a linear relationship between machining current and TWR of brass electrode, higher tool wear rate was occurred with higher current which reach to 0.269 g/min. This is because higher corrosion in electrode metal is associated with higher current and higher electrical spark.

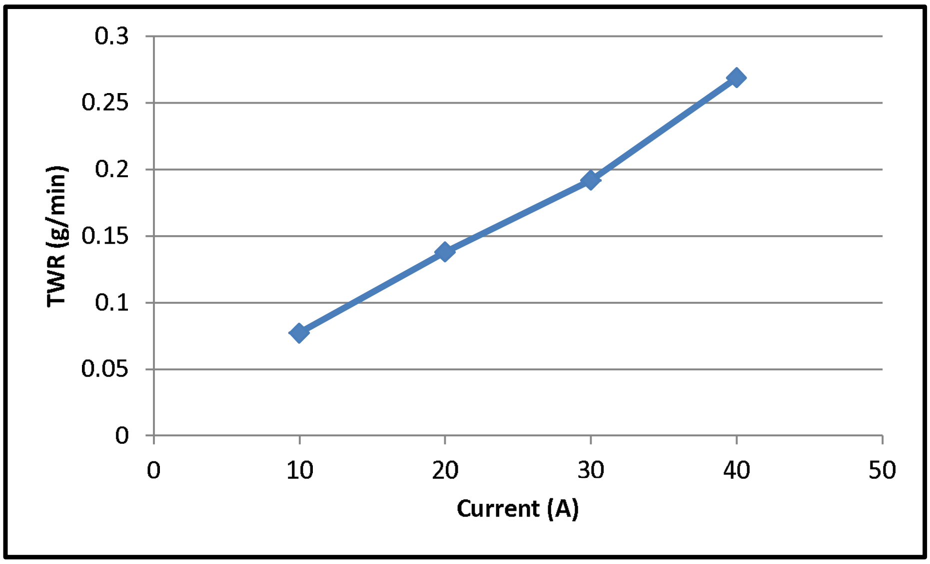

Figure (10) the effect of machining current on TWR of brass electrode.

Figure (11) shows the effect of machining current on surface roughness (Ra) with using brass electrode. It is observed that a slight increases from (10 to 20)A then maximum increases occurred from 20 to 30 A with percentage reached to 16.45%.The expected reason is that because the increase in electrical spark leads to irregular corrosion in electrode metal.

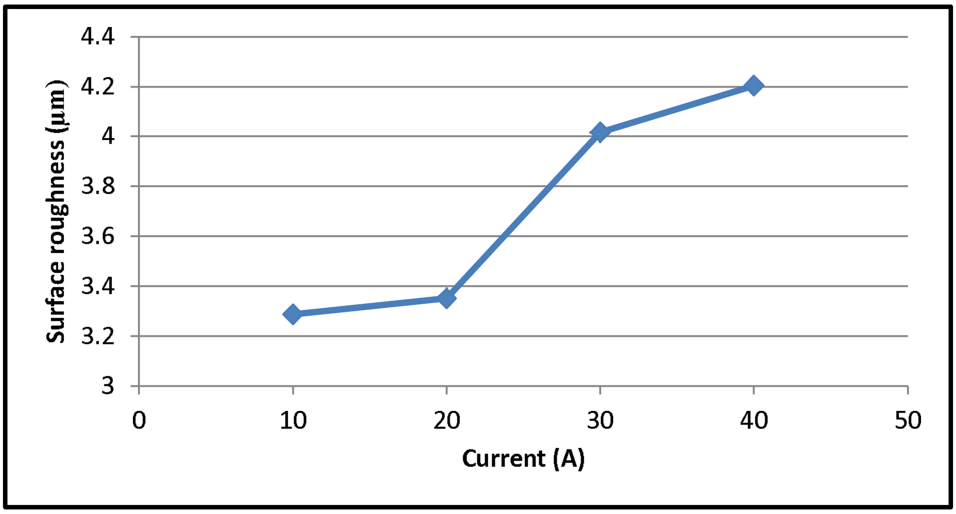

Figure (11) the effect of machining current on Ra of brass electrode.

Figures (12, 13, and 14) show that the comparison between the two types of electrodes for MRR, TWR, and Ra respectively. In figure (12) it is found that higher MRR is achieved with using copper electrode where the enhancement rates in MRR are (59.92, 65.42, 61.51, and 60.77) % at machining current (10, 20, 30, and 40) Ampere respectively. That is obviously because the electrical and thermal conductivity are higher in copper electrode compared with the brass electrode.

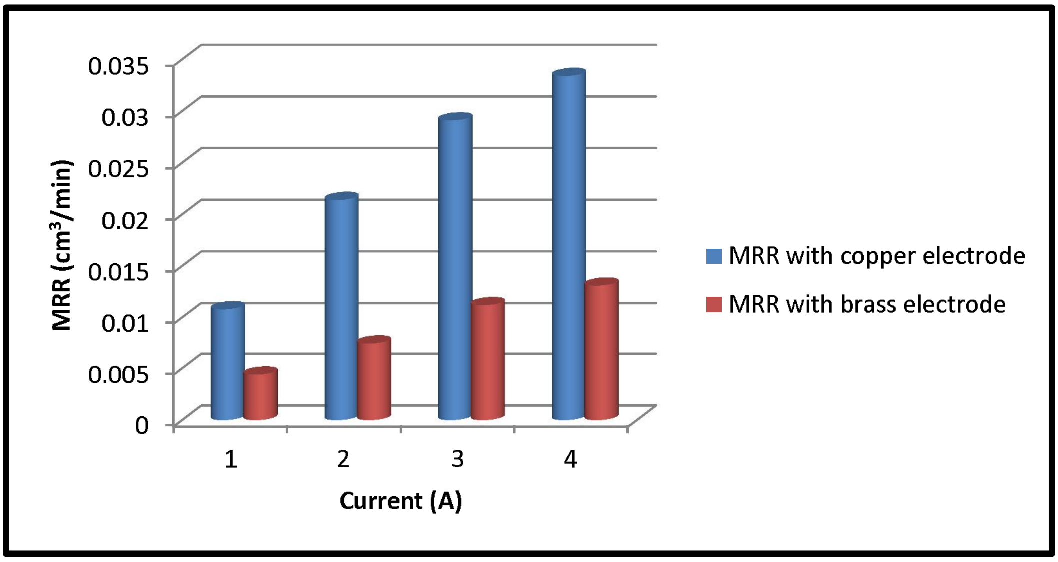

Figure (12) MRR for the two electrodes.

From figure (13) it can be seen that higher TWR is achieved with using brass electrode compared with copper electrode. The maximum value of TWR is 87.01% at machining current 10A; that is because the electrical conductivity in copper leads to higher metal corrosion in copper electrode in comparison with brass electrode.

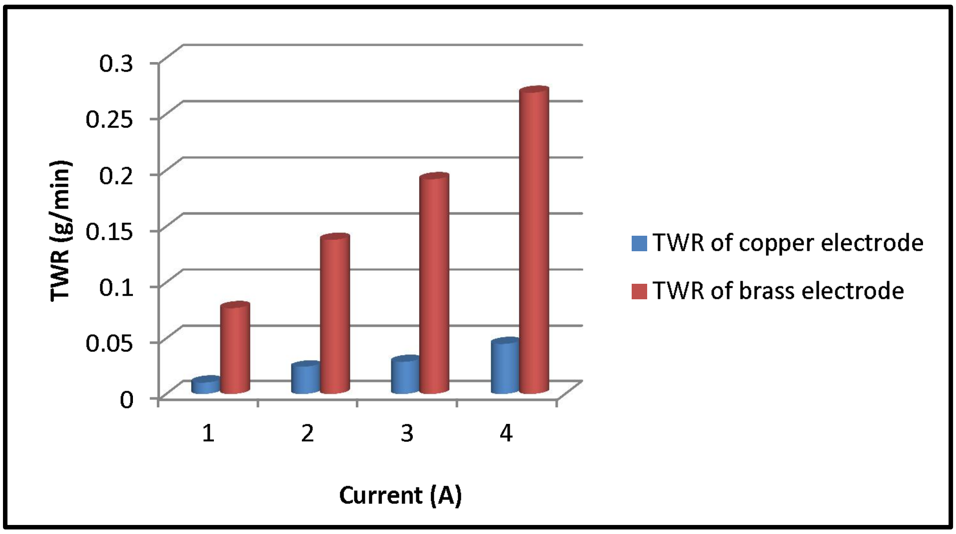

Figure (13) TWR for the two electrodes.

Figure (14) shows the smother surface roughness (Ra) obtained with the using of copper electrode in compare to brass electrode were maximum enhancement obtained was 16.2% with 30 A machining current. This is because the difficulty of controlling the electrical spark with machining brass electrode in comparison with machining copper electrode which is more stable.

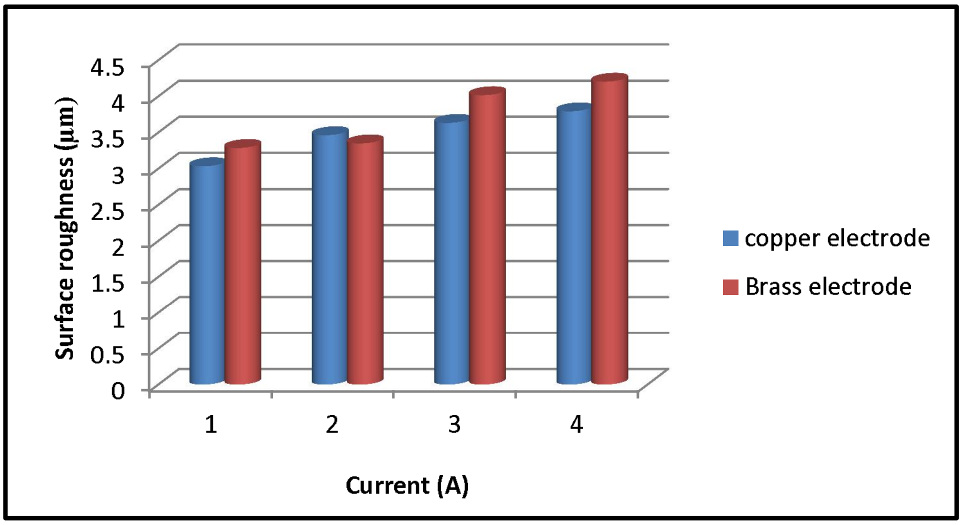

Figure (14) Ra for the two electrodes.

Conclusion:

The main conclusions that can be deduced from this research are summarized as follows:

1- The type of electrode is an important factor that influences MRR, TWR, and Ra.

2- The machining of this type of alloy is better with copper electrode than the brass. Where higher MRR, lower TWR and lower surface roughness obtained with the copper electrode.

3-Higher machining current gives higher MRR but with lower surface quality and higher tool wear rate.

4-Maximum enhancement of MRR is 65.42% for copper electrode in comparison with brass electrode at machining current (20A).
5- The thermal and electrical conductance of copper are higher compared with brass electrode. In addition, better results are achieved with copper electrode.

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