Effect of Electrode Material and Electrical Discharge Machining Parameters on Machining of CO-CR-MO

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***Abstract*- The adequate selection of machining parameters is of prime importance to take into the account in of advanced engineering materials. The main focus of this experimental study is to observe the effect of electrode material and machining parameters viz. peak current, main voltage and duty factor on Electrical Discharge Machining(EDM) of Cobalt-Chromium-Molybdenum (Co-Cr-Mo) using copper and brass electrodes. The findings highlight that electrode material significantly affects the process performance with respect to material removal rate and electrode wear as indices to examine machinability. Better performance and higher efficiency is achieved by copper electrode. Peak current, voltage and duty factor play important roles in EDM performance and efficiency in terms of reducing machining time and improve tool utilization time and life.**

***Index Term*-- EDM, Electrode, Copper, Brass, MRR, EWR, Current, Voltage**

INTRODUCTION

Globalization and customized market in manufacturing require high quality and reliable products at lowest cost and highest productivity. Electrical discharge machining (EDM) has become a promising widely used non-traditional machining process in the manufacture of mould, die, aerospace parts, complex components due to its exclusive feature of applying electrical discharge and thermal energy to cut conductive material without respect to their hardness. Moreover, no mechanical stress, chatter and vibration are imposed to product by EDM, because there is no direct contact between tool and work-piece [1, 2]. Cobalt Chromium Molybdenum (Co-Cr-Mo) is a super alloy and advanced engineering material which brings superior mechanical properties such as high specific strength, high resistance to corrosion and higher biocompatibility and commonly used in gas turbines and orthopedic and dental implants. In terms of machining, Co-Cr-Mo alloy is categorized as a difficult-to-cut material. A number of efforts and observations have been made in the past on the effect of machining condition of EDM on advanced material engineering and super alloys such as Inconel 718 and results show that MRR is significantly affected by gap voltage and peak current while in contrast the most influential parameter on tool wear is duty factor [3]. The effect of EDM parameters on drilling of Inconel 718 by copper electrode have been examined and findings reveal that peak current and duty factor are the most influential factors on MRR [4]. A series of observations have been performed on EDM of Ni-Ti using two different types of electrodes, copper and tungsten-copper. The results provide evidence that adequate selection of electrode produces better surface integrity and increases efficiency by reducing machining time [5]. Higher values of peak current and duty factor have been suggested in EDM of hard material to cut to achieve higher MRR [6]. Kao et al. [7] optimized the EDM parameters to increase process efficiency in terms of electrode wear, MRR and surface integrity. Two different electrode material copper and brass have been used in EDM of AISI D3,and it has been highlighted that interaction of electrode material type and pulse on time affects MRR [8]. Hasçalık [9] discussed the effect of EDM parameter and three different electrode materials including copper, aluminium and graphite on machinability of Ti-6Al-4V. It has been concluded that MRR is a function of electrode material and that electrode material properties affect the machinability aspects such as MRR, tool wear, surface roughness and dimension accuracy [10, 11]. Cobalt Chromium Molybdenum (Co-Cr-Mo) is a novel material. The main problem associated with the conventional machining of Co-Cr-Mo is formation of inhomogeneous inelastic deformation on machined surface that imposes residual stresses in work-piece, therefore contactless manufacturing process such as EDM can be a promising alternative to avoid the negative effect of conventional machining process [12]. No research has addressed the effects of EDM parameters and electrode material on Co-Cr-Mo material and it is difficult to select suitable machining parameters in order to maximize MRR and minimize EWR.

EXPERIMENTAL PROCEDURE

In order to use die-sinking CNC EDM machine (Sodick- AG40L), work-piece was cut by wire cut EDM to achieve adequate dimensions of 130×32×6 mm^3. Two different types of electrodes, copper and brass with dimension of 40 mm in length and 6.35 mm and 6.15 in diameter respectively were chosen. All electrodes come from the same batch and rod to guarantee constant mechanical properties and composition. A fresh electrode was used for each test to encourage accurate reporting. Table I summarizes chemical composition of two different electrodes, and work-piece.

Table I
The chemical composition of electrodes and work-piece material (wt.%)

Brass electrode	Cu	Zn	Sn	Pb	Fe	Ni
	59.68	38.81	0.73	0.28	0.27	0.23
Copper electrode	Cu	Zn	Sn	Al	Pb	Bi
	97.3	2.35	0.06	0.15	0.11	0.03
work-piece (Co-Cr-Mo)	Co	Cr	Mo	C	O	Si
	55.65	25.02	5.76	10.10	2.60	0.87

The polarity of the electrode was chosen positive to ensure work-piece underwent majority of erosion rather than the tool [13]. Oil-based dielectric fluid mixed with aluminium powder (PGM WHIT 3) was applied for all tests. Addition of aluminium powder in the dielectric enhances machining efficiency by making discharge breakdown easier and enlarges discharge gap [14, 15]. There are a large number of different parameters associated with EDM, which can be considered, but in this observation only four parameters viz. main current (I_p), peak voltage (V), duty factor (D_f) and electrode material type were taken into account as illustrated by Table II. Table III illustrates experimental trials and related result obtained using two different electrode materials. It is interesting to note that servo voltage was kept constant at the values of 90 V.

Table II
Experimental and machining conditions

Main voltage (V)	60 and 120 V
Servo voltage (SV)	90 V
Discharge current (I_p)	6 and 10 A
Duty factor (D_f)	30, 40, 57 and 67 %
Electrode material	Copper and Brass
Electrode polarity	Positive
Work-piece	Co-Cr-Mo
Work-piece hardness	43.6 HRC

Table III
Experimental trials and results

Run	**Parameters**			**Electrode type**			
				Brass		Copper	
	D_f (%)	I_P (A)	V (V)	EWR (mm^3/min)	MRR (mm^3/min)	EWR (mm^3/min)	MRR (mm^3/min)
1	30	6	60	1.75	0.20	0.10	1.74
2	30	6	120	7.91	1.77	1.26	4.63
3	30	10	60	2.49	0.61	0.54	2.47
4	30	10	120	9.29	1.79	2.90	5.62
5	40	6	60	2.14	0.49	0.12	1.99
6	40	6	120	9.79	2.14	1.03	4.86
7	40	10	60	3.55	0.86	0.48	3.45
8	40	10	120	10.27	2.46	1.83	6.66
9	57	6	60	4.30	1.53	0.05	2.84
10	57	6	120	12.11	2.90	0.44	6.62
11	57	10	60	5.76	2.07	0.14	4.70
12	57	10	120	12.19	3.20	1.02	8.63
13	67	6	60	5.20	1.68	0.04	2.90
14	67	6	120	13.70	2.78	0.44	6.70
15	67	10	60	8.04	2.12	0.14	4.74
16	67	10	120	14.69	3.36	0.85	8.70

Material removal rate (MRR) and electrode wear rate (EWR) were considered as indices to assess the effect of electrode material and machining parameters on the process. MRR and EWR have been computed based on Eqs. 1 and 2 respectively. Precise electronic balance with 0.0001 gram precision was applied to measure the work-piece and electrode weight before and after each performed experiments.

$$MRR = \frac{W_{iW} - W_{fW}}{t_m \times \boldsymbol{\rho_W}} \qquad Eq.1$$

$$EWR = \frac{W_{iE} - W_{iE}}{t_m \times \boldsymbol{\rho_E}} \qquad Eq.2$$

RESULT AND DISCUSSION

In EDM electrode is responsible for transmitting the electrical impulses and erosion of work-piece with designed shape takes place with no or little wear. Capabilities of electrode material directly affect accuracy, efficiency and finally associated costs. Adequate selection of electrode material with respect to electrical and thermal conductivity as well as mechanical properties influences EDM performance. Copper and brass are most common electrode materials. Fig. 1 compares the effect of electrode material on EWR with respect to machining parameters (a) EWR on copper electrode and (b) EWR on brass electrode. In all experiments copper electrode underwent lower EWR as opposed to brass electrode, copper with face-centered-cubic(fcc) crystal structure has the most densely packed configurations and melting point of 1100 °c in comparison with brass with body-centered-cubic (bcc) with lower density and melting point of 900 °c. On the other hand, higher energy is required to erode copper electrode considering crystal structure (fcc) and higher density, so EWR on copper electrode was negligible compared to EWR on brass electrode.

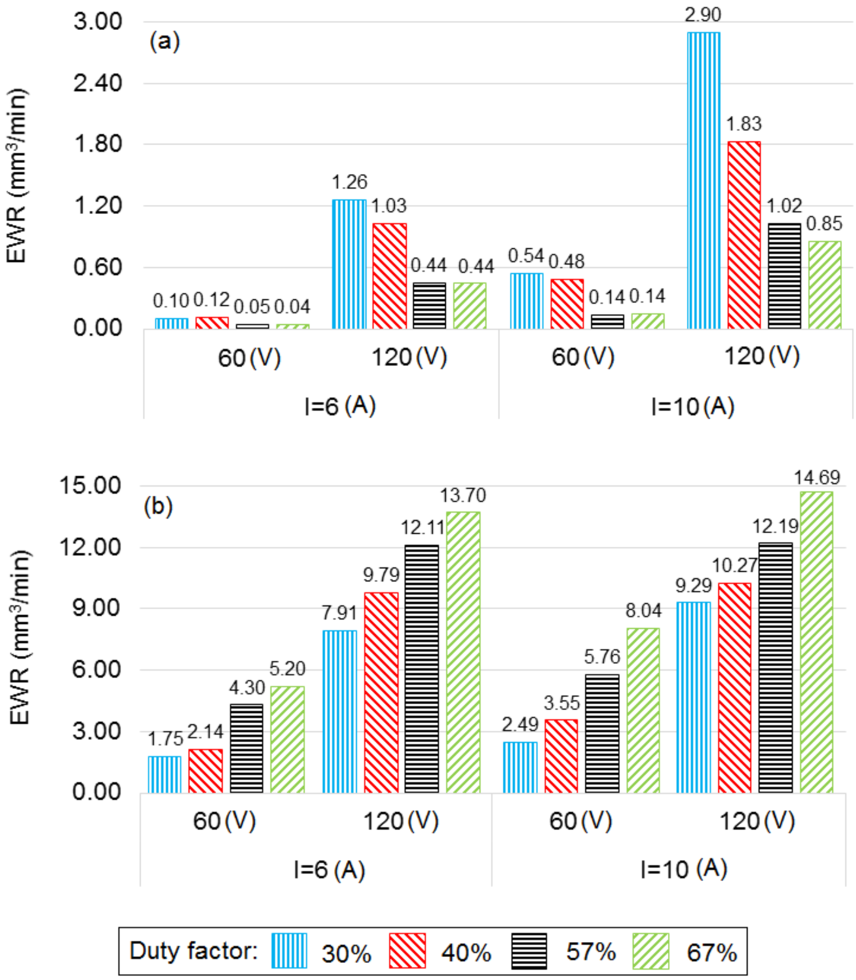

Fig. 1. Effect of machining parameters and electrode material on EWR, (a) EWR on copper electrode and (b) EWR on brass electrode

Observations have shown that higher MRR was given by applying copper electrode Fig. 2 (a) instead of brass electrode Fig. (b). Brass electrode with higher electrical resistivity of around 0.6 to 0.9×10^{-7} Ω.m and lower thermal conductivity of 150 W/(m·K) gave lower MRR. In contrast, copper with lower electrical resistivity of 0.17×10^{-8} Ω.m and higher thermal conductivity of 400 W/(m·K) increased process efficiency. For each test after setting reference points and inputs, it was anticipated to produce through holes but at the end of each test by brass electrodes, all holes were blind due to high rate of electrode erosion and computer program of machine assumed that the cutting process was finished with respect to movement in –Z axis direction. Fig. 3 illustrates through and blind holes produced by copper and brass electrodes at different machining conditions. Detailed information about Fig. 3 is summarized in Table IV. Higher EWR on brass electrode affected the cutting accuracy, and blind holes with different geometry were generated as opposed to the generation of through holes formed by copper electrodes which provided evidence of electrode material influence on process and productivity.

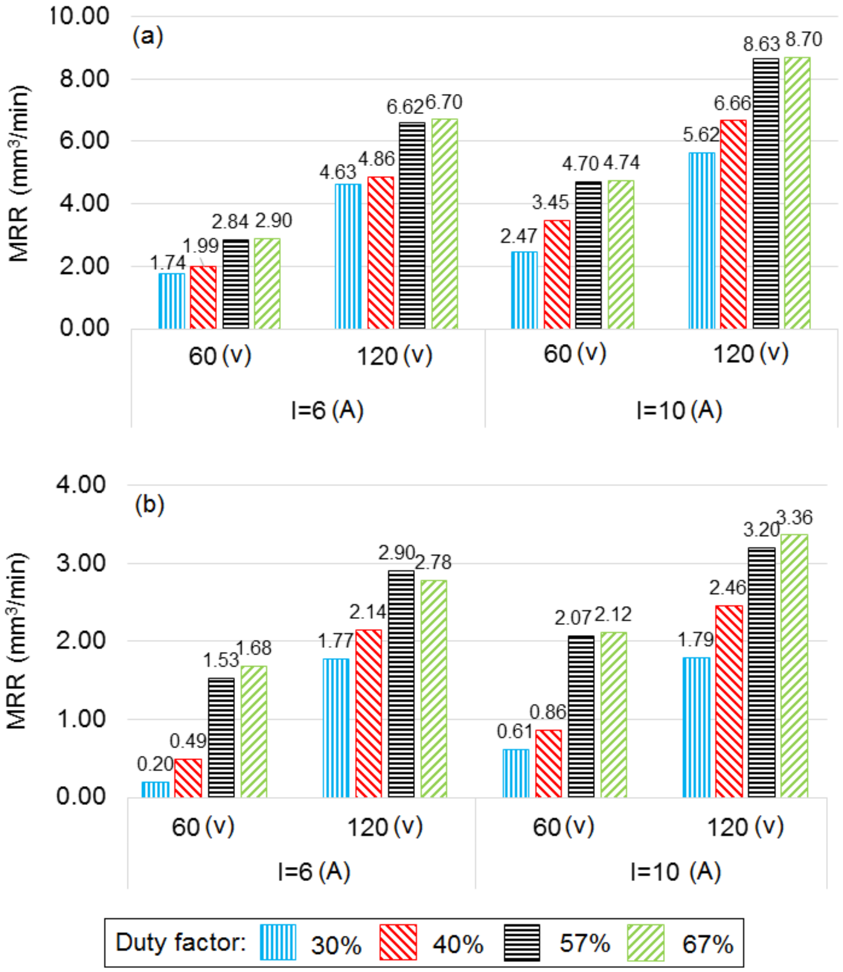

Fig. 2. Effect of machining parameters and electrode material on MRR, (a) using copper electrode (b) using brass electrode

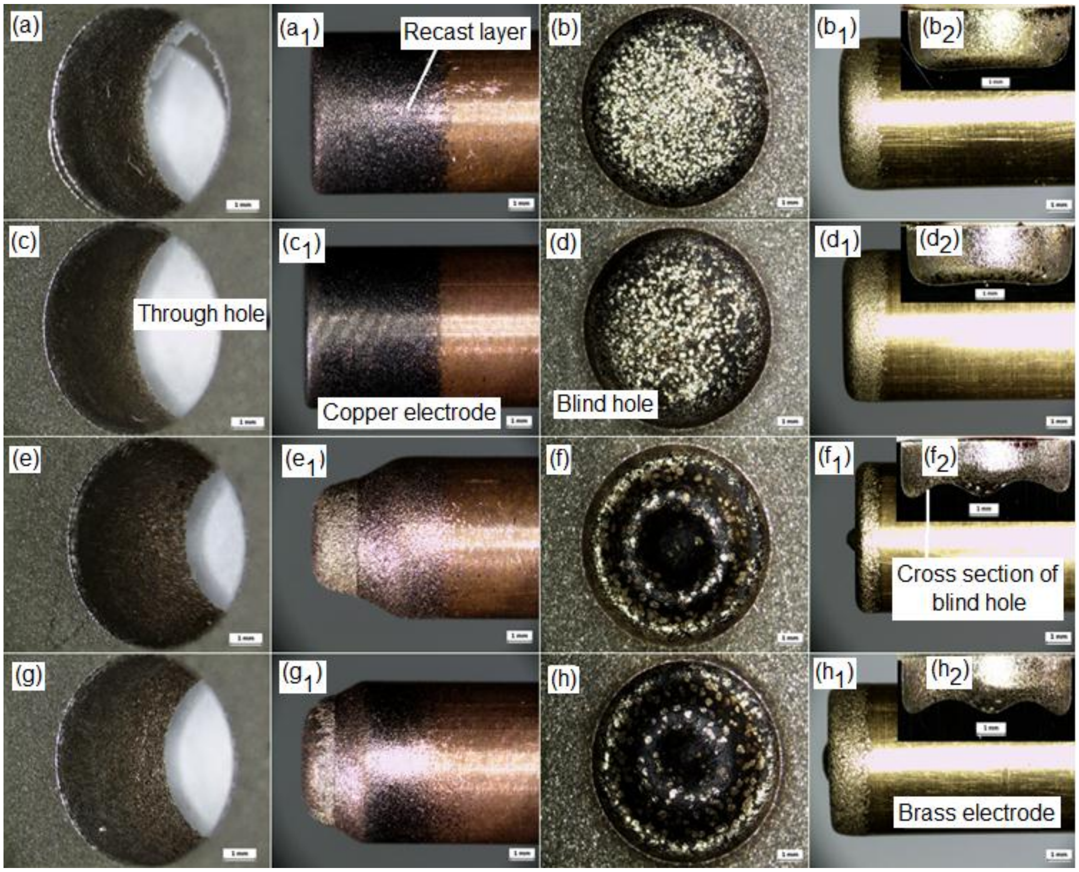

Fig. 3. Through holes produced by copper electrodes, blind holes formed by brass electrode and their cross section

Table IV
Description and machining conditions of holes shown by Fig. 3

Code	Description
(a) and (a_1)	Through hole, copper electrode, D_F= 30%, I_p= 10 A and V= 60 v
(b), (b_1) and (b_2)	Blind hole, brass electrode, hole cross section, D_F= 30%, I_p= 10 A and V= 60 v
(c) and (c_1)	Through hole, copper electrode, D_F= 40%, I_p= 10 A and V= 60 v
(d), (d_1) and (d_2)	Blind hole, brass electrode, hole cross section, D_F= 40%, I_p= 10 A and V= 60 v
(e) and (e_1)	Through hole, copper electrode, D_F= 57%, I_p= 6 A and V= 120 v
(f), (f_1) and (f_2)	Blind hole, brass electrode, hole cross section, D_F= 57%, I_p= 6 A and V= 120 v
(g) and (g_1)	Through hole, copper electrode, D_F= 67%, I_p= 6 A and V= 120 v
(h), (h_1) and (h_2)	Blind hole, brass electrode, hole cross section, D_F= 67%, I_p= 6 A and V= 120 v

Effect of machining parameters, peak current, main voltage and duty factor on electrode wear rate EWR are demonstrated in Fig. 4. It has been observed at the given voltage and duty factor, EWR increased as peak current increased as shown in Fig.4. For instance, EWR increased on both electrodes at duty factor of 30 % and voltage of 60 V with the increment of current from 6 A to 10 A as shown by Figs. 4 (a) and (c). This is because of higher value of current results in more thermal and diffusion energy transfer to the machining gap and consequently higher EWR [16, 17]. Examining EWR on both electrodes demonstrates what appears to be, an increasing trend with increasing of voltage. Discharge gap is controlled by voltage so higher voltage increases the discharge gap and extends the discharge channel fully, consequently enhancing plasma radius and transferred thermal energy to the machining zone [18]. Same EWR trend has been observed on copper electrode with respect to duty factor. The findings provide evidence that EWR on copper electrode gradually decreased with increment of duty factor as shown in Fig. 4, due to higher duty factor is associated with reducing the density of discharge energy and increasing the diameter of discharge column in consequence of enlarging duration of spark [19]. On contrary, erosion on brass electrode increased as duty factor increased because higher duty factor provides higher transferred thermal energy into the machining zone. Thus due to lower melting point, brass electrode gives higher electrode wear rate as shown in Fig. 4.

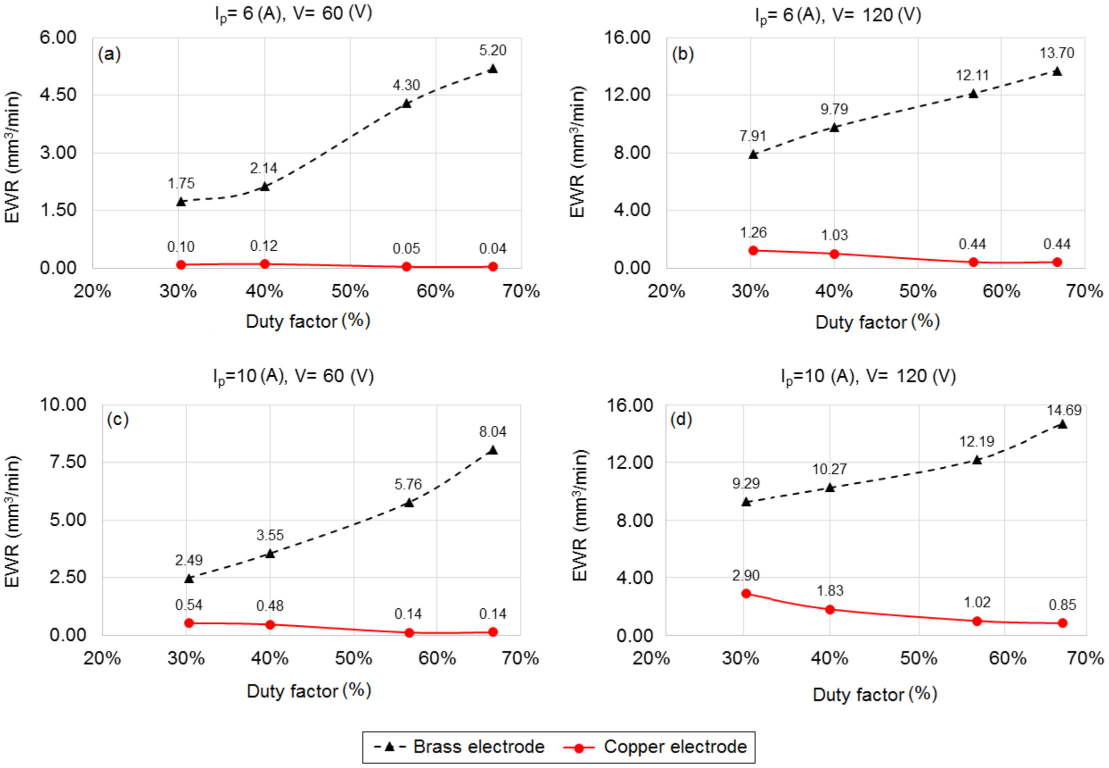

Fig. 4. Effect of current (I_p), voltage (V) and duty factor (D_f) on EWR with respect to electrode material

At constant current and duty factor, increase in voltage gave higher MRR, but copper electrode surprisingly provided faster MRR as opposed to brass electrode as illustrated in Fig. 5. This is due to higher voltage imposes higher thermal energy to machining zone and copper with lower electrical resistivity and higher thermal conductivity in comparison to brass increased machining efficiency. MRR increased with increment of current using both electrode because of higher current generates more spark energy and consequently higher erosion of work-piece[20] . Again better performance was achieved by applied copper electrode. Duty factor had significant effect on MRR and work-piece erosion underwent remarkable increment as duty factor increased due to higher thermal energy generation which results in higher melting and erosion of work piece [21].

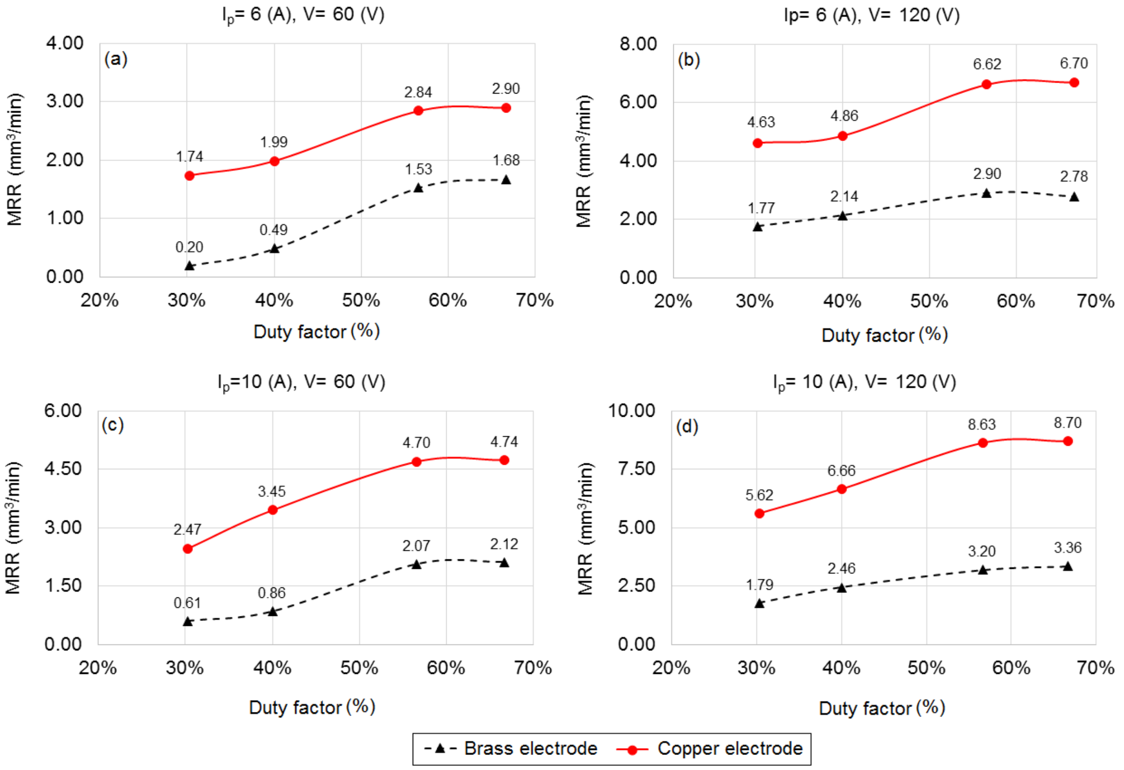

Fig. 5. Effect of current (I_p), voltage (V) and duty factor (D_f) on MRR with respect to electrode material

CONCLUSION

This observation discussed the effect of two different electrode materials and process parameter such as peak current, gap voltage and duty factor on EDM of CO-Cr-Mo. Following conclusions have been supported by experimental findings:

1. The experimental findings confirm adequate selection of electrode material affects process performance, higher efficiency in terms of lower EWR and high MRR is achieved by copper electrode as opposed to brass electrode due to higher thermal conductivity and lower electrical resistivity associated with copper electrode.
2. EWR on copper electrode decreased gradually as duty factor increased due to reducing the density of discharge energy and increasing the diameter of discharge column but surprisingly EWR on brass electrode increased dramatically.
3. Peak current, gap voltage and duty factor directly affect the MRR and EWR, and their higher values increase the MRR and EWR.
4. Copper as electrode due to good electrical conductivity and lower wear rate as well as moderate value of Ip, V and Df are recommended to achieve higher efficiency in terms of maximizing MRR and minimizing EWR.

NOMENCLATURE

Co-Cr-Mo	*Cobalt Chromium Molybdenum*
MRR	*Material removal rate (mm³/min)*
EWR	*Electrode wear rate (mm³/min)*
V	*Main voltage (V)*
I_p	*Peak current (A)*
D_f	*Duty factor (%)*
W_{iW}	*Initial weight of work-piece (g)*
W_{fW}	*Final weight of work-piece (g)*
ρ_W	*Density of work-piece (g/mm³)*
t_m	*Machining time (min)*
W_{iE}	*Initial weight of electrode (g)*
W_{fE}	*Final weight of electrode (g)*
ρ_E	*Density of electrode (g/mm³)*

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