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RESEARCH ARTICLE

AN EXPERIMENTAL INVESTIGATION OF MACHINING PARAMETERS FOR EDM USING COPPER ELECTRODE OF AISI P20 TOOL STEEL

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ABSTRACT

In this investigation, an optimization approach is used for the estimation of maximum material removal rate and minimal surface integrity of surface created in electrical discharge machining (EDM). The significant input parameters such as pulse current (Ip), pulse duration (Ton), discharge voltage (V) and spark off time (Toff) are considered, and material removal rate, tool wear rate and surface roughness have been considered as responses for this study. Nine experiments were conducted on American Iron and Steel Institute (AISI) P20 tool steel work piece materials based on design. Analysis of variance is used to find the percentage contribution of the input parameters and found that the Ip was the most influencing parameter followed by Ton and voltage in EDM of P20 tool steel. All the experimental results predicted by MINITAB 15 software.

INTRODUCTION

Electric discharge machining (EDM) is one of the most popular non-traditional material removal processes and has became a basic machining method for the manufacturing industries of aerospace, automotive, nuclear, medical and die-mold production (Kiyak and Cakır, 2007). Electrical discharge machining (EDM) is a manufacturing method which could be used to machine hard materials in geometrically complex shapes with high precision. The research in EDM machining is generally focused on maximum material removal rate with good surface finish and lesser tool wear rate (Chikalthankar *et al.,* 2013). The influences of some machining parameters such as pulsed current (Ramarao *et al.,* 1982; Wang *et al.,* 1999; Lee *et al.,* 2001; Halkac and Erden 2002; Lee and Li 2003; Guu *et al.,* 2003; Cogun *et al.,* 2004; Keskin *et al.,* 2006) and electrode material (Singh *et al.,* 2004) have been examined. One study examined P20 tool steel and provided useful information the effects of some machining parameters on surface roughness, but the selected of pulsed current values was very low 1–8A (Amorim and Weingaertner 2005). Literature reports several attempts to develop analytical process models to predict process responses such as material removal rate (MRR) and surface roughness from the process parameters like current, discharge duration, discharge voltage, duty cycle, etc. Simplifying assumptions like constant spark radius, disc or uniform shaped heat flux, constant thermal properties of work and tool material severely restrict their prediction accuracy (Kunieda *et al.,* 2005). The effect of machining parameters of electrical discharge machining (EDM) namely current, pulse-on time and air gap voltage on metal removal rate (MRR) and tool wear rate (TWR) were carried out on Al–4Cu–6Si alloy–10 wt. % SiC_P composite material. A second order, non-linear mathematical model was developed for establishing the relationship among machining parameters by using ANOVA technique. They reported that the MRR and TWR increase with increasing in current in a non-linear manner (Dhar *et al.,* 2007). The AISI H13 hot work tool steel was used during a die sink operation using partially sintered WC/Co electrodes operated in a hydrocarbon oil dielectric. An L8 fractional factorial *Taguchi* experiment was used to identify the effect of key operating factors on output parameter (electrode wear, work piece surface hardness, etc.). It was reported that the small effect of process parameters was seen on micro hardness (Simao *et al.,* 2003). The influences of EDM parameters (namely pulsed current, pulse time and pulse pause time) on surface roughness for machining of 40CrMnNiMo864 tool steel (AISI P20) was reported by Kizak and Cakir (2004). They reported that the surface roughness of work piece and electrode were influenced by pulsed current and pulse time, higher values of these parameters increased surface roughness. Lower current, lower pulse time and relatively higher pulse pause time produced a better surface finish (Kizak *et al.,* 2004). The experimental study on mathematical molding of EDM with aluminum-silicon carbide

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particulate composites for three levels full factorial design was carried out by was Karthikeyan *et al.* (1999). The effect of machining parameters like current, pulse duration and percent volume fraction of SiC on MRR, TWR, and surface rough (SR) were taken into account by using the ANOVA techniques. The MRR was found to decrease with an increase in the percent volume of SiC, whereas the TWR and the surface roughness increase with an increase in the volume of SiC (Karthikeyan *et al.,* 1999). The present study examines the effects of pulsed current, and voltage on material removal rate (MRR), and tool wear rate (TWR) with positive polarity of electrode in the AISI P20 tool steel.

Experimental details and methodology

Present study is focused on machining of AISI P20 Tool Steel on EDM (model *Electronica* C-3822) die-sinking type with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. The commercial grade EDM oil (specific gravity= 0.763, freezing point= 94°C) was used as dielectric fluid. The preliminary experiments were conducted to understand the effect of current and voltage on material removal rate (MRR) and tool wear rate (TWR) with positive polarity of electrode. Later on, the experiments were carried out on die sinking electric discharge machine, (model: *Electronica*- ZNC EDM 300; machine specification x/y Axis Stroke(mm × mm) = 300×200; x/y Working Tale Dimension (mm × mm)= 450×300; Z/axis Stroke(mm) = 220; Max Load of spindle(kg) = 50; Max Load of Working Table(kg) = 300; Maximum Working Current A = 60; Minimum Electrode wear = ≤0.2%; Best surface finish = Rα≤0.3) with servo-head (constant gap). Plastic mould steel (P-20 tool steel) or AISI P20 tool steel was used in the present work for machining on EDM. The composition of P20 tool steel is presented in the Table 1and thermo physical properties of P20 tool steel at temperature 25 ^{o}C (Density = 7850 kg/m^3; Poisson's Ratio = 0.27-0.30; Modulus of Elasticity = 190-210 GPa and thermal expansion coefficient = $12.8\times10^{-6}/^{o}$C, for the temperature range 20^{o}C to 425^{o}C) as reported in the website (Wikipedia 2014).

Table 1 Composition of AISI P20 Tool Steel Material

Elements	Weight limit (wt. %)	Actual (wt. %)
C	0.28-0.4	0.40
Mn	0.60-1.00	1.00
Si	0.20-0.80	0.40
Cr	1.40-2.00	1.20
Mo	0.30-0.55	0.35
Cu	0.25	0.25
P	0.03	0.03
S	0.03	0.03

The copper electrode with 10 mm diameter and pressure of 0.5 kgf/cm^2 was used for entire experimental work as shown in the Fig.1. The commercial grade EDM oil (specific gravity= 0.757 at 30°C, flash point= 108°C) was used as dielectric fluid. The pulsed discharge current was applied in various steps in positive mode. The material AISI P20 tool steel is used for machining on EDM. The software MINITAB 15 is used to optimize the value of MRR, TWR and SR. So our focus is to maximize the MRR and minimize the TWR and SR which is carried out by selecting input parameters discharge current (I_p), voltage (V), spark on time (T_{on}) and spark off time (T_{off}). All the experimental results predicted by MINITAB 15 software.

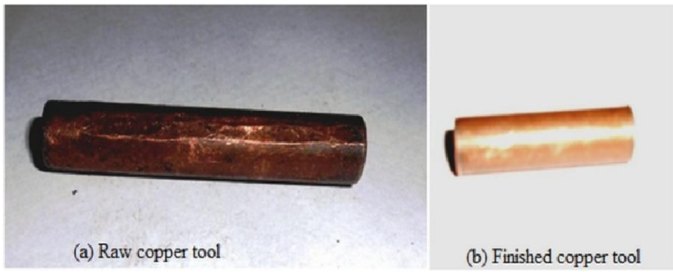

Fig. 1. Copper Tools with 10 mm Diameter (a) raw copper tool (b) finished copper tool

Calculation of metal removal rate (MRR) and tool wear rate (TWR)

The material MRR is expressed as the ratio of the difference of weight of the work piece before and after machining to the machining time and density of the material as shown in Equation 1.0

$$MRR = \frac{W_{wb} - W_{wa}}{t \times \rho} \quad \text{.........................} (1)$$

Where as

W_{wb} = Weight of work piece before machining (g.).
W_{wa} = Weight of work piece after machining (g).
t = Machining time (min.).
ρ = Density of the work material (7850 kg/m^3).

TWR is expressed as the ratio of the difference of weight of the tool before and after machining to the machining time. That can be explaining in equation 2.0

$$\left[TWR = \frac{W_{tb} - W_{ta}}{\rho \times t} \right] \quad \text{....................................} (2)$$

Where as

W_{tb} = weight of the tool before machining (g)
W_{ta} = weight of the tool after machining (g)
t = Machining time (min.)
ρ = Density of the Tool material (8900 kg/m^3).

RESULTS AND DISCUSSION

The results of performance measures namely MRR, TWR and SR are obtained for 9 experimental trails of EDM given in Table 2. Taguchi method is used to study the effect of different machining variables viz., T_{on}, T_{off}, IP and SV on MRR. As we know that MRR is directly proportional to the power supplied during this pulse-on time (T_{on}). As the pulse-off time (T_{off}) is decreased, more sparks will be generated. It is attributed to more thermal power with increase in T_{on} which results to a faster cutting rate. This leads to improvement in MRR. During the process of electrical discharge machining, the influence of various machining parameter like current, voltage, T_{on} and T_{off} has significant effect on MRR, as shown in main effect plot for S/N ratio of MRR in Fig. 2. The discharge current is directly proportional to MRR in the range of 5 to 10A.

Table 2. Experimental Design using L9 orthogonal array

Expt. No.	IP	SV	T_{on}	T_{off}	MRR(mm^3/min)	TWR(mm^3/min)	SR(μm)
1	5	40	100	5	11.4217	0.03247	5.738
2	5	50	200	10	7.0879	0.03520	7.300
3	5	60	300	15	5.4318	0.03416	5.716
4	10	40	200	15	37.7911	0.13760	10.010
5	10	50	300	5	76.4204	0.05140	11.926
6	10	60	100	10	17.8981	1.56750	8.010
7	15	40	300	10	48.0637	2.99140	12.262
8	15	50	100	15	43.7401	3.05069	8.340
9	15	60	200	5	44.8650	2.34131	12.986

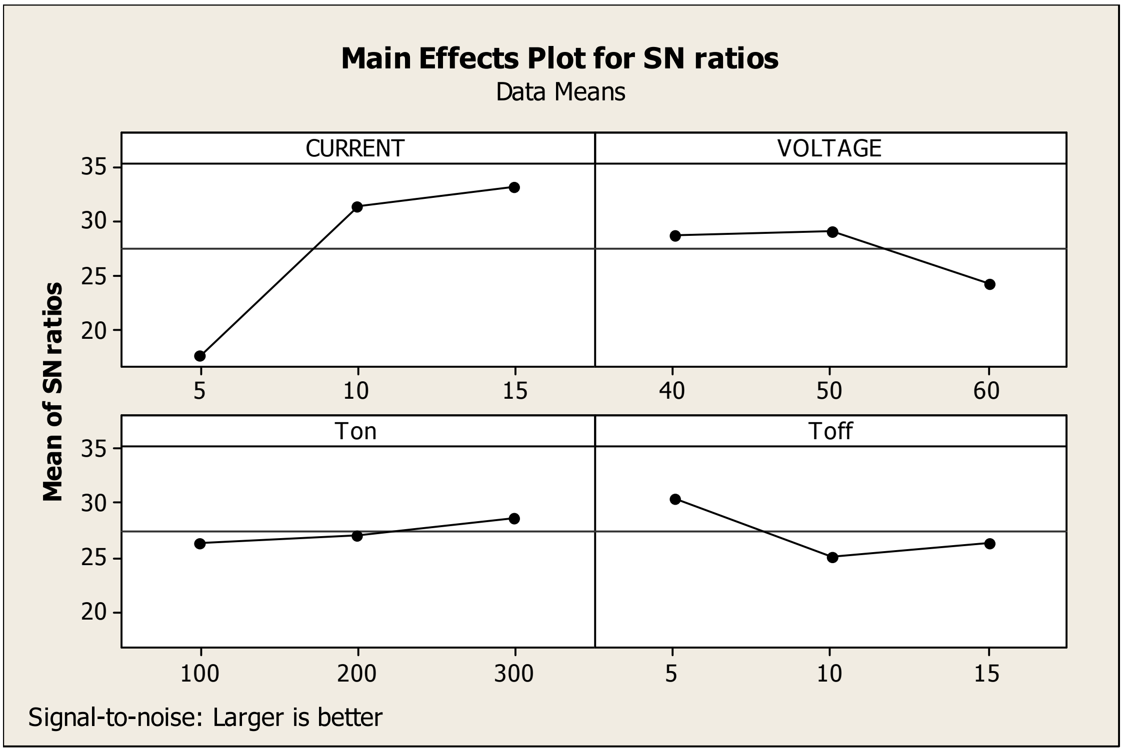

Fig. 2. Effect of process parameter on S/N Ratios for MRR

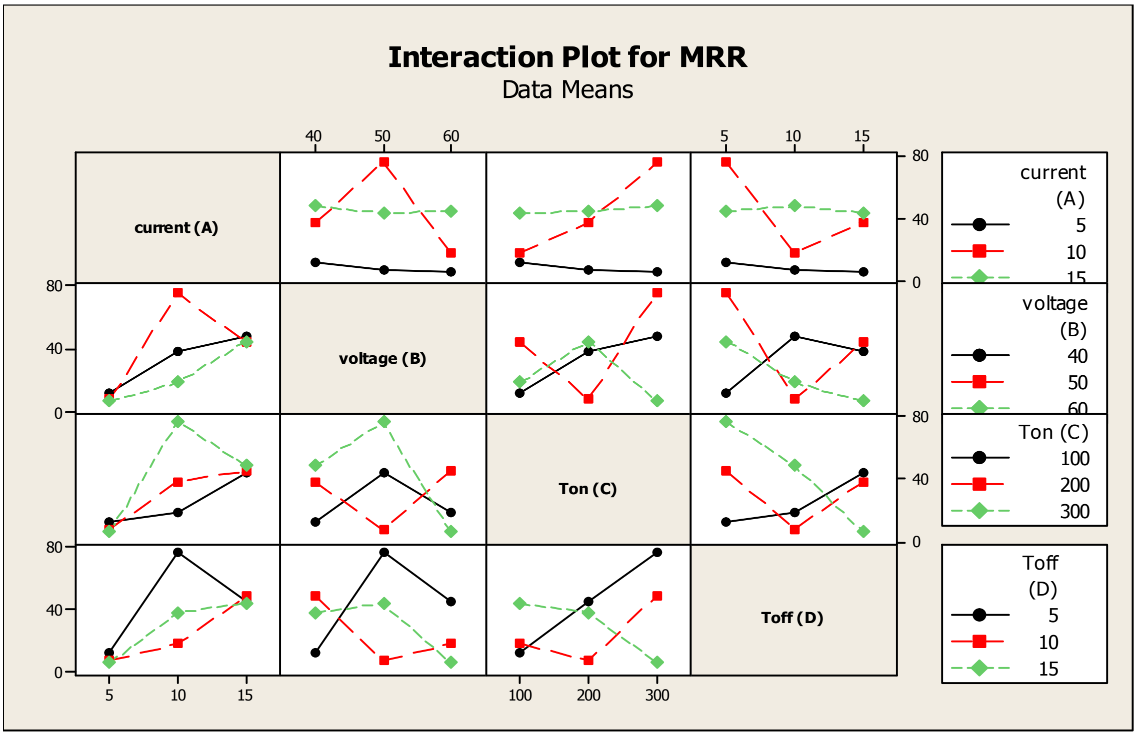

Fig. 3. Interaction effects of parameters on S/N Ratios for MRR

Table 3 Analysis of variance for MRR.

Source	DF	Seq SS	Adj SS	Adj MS
IP	2	435.087	435.087	217.544
SV	2	44.541	44.541	22.271
T_{on}	2	8.287	8.287	4.143
T_{off}	2	48.434	48.434	24.217
Error	0	0	0	0
Total	8	536.349	0	0

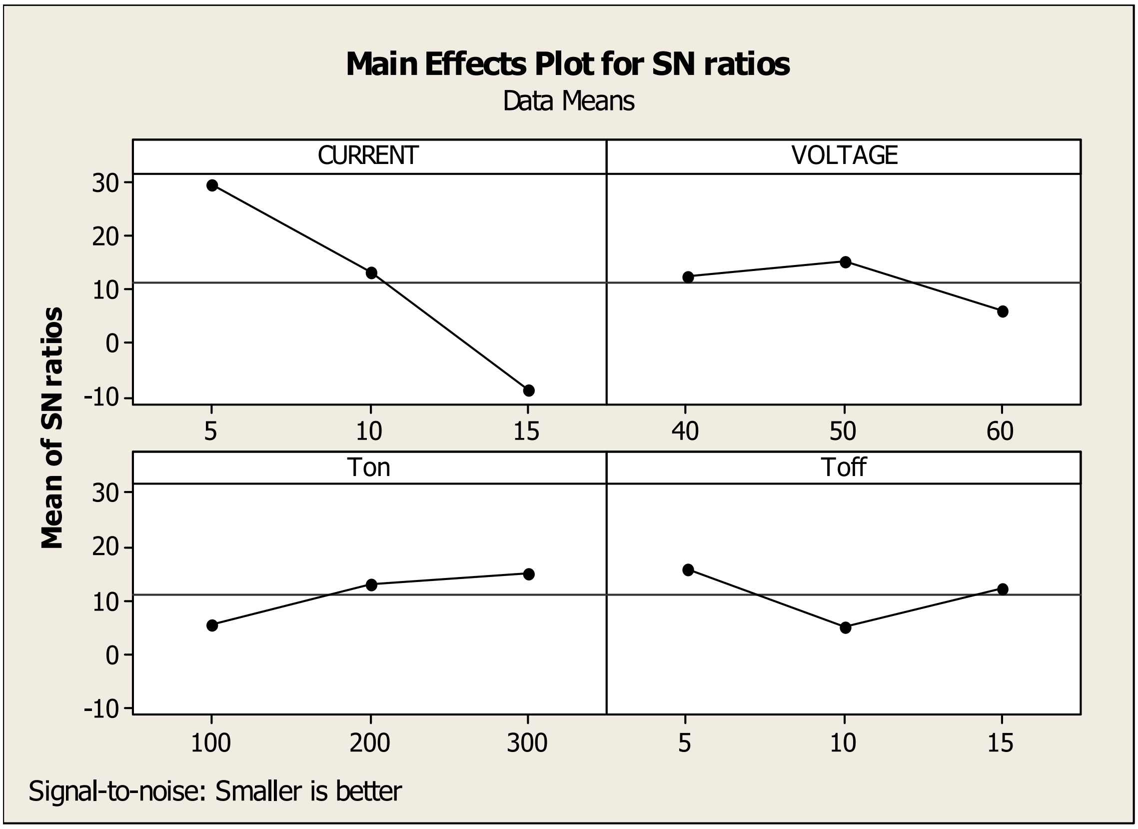

Fig. 4. Effect of process parameter on S/N Ratios for TWR

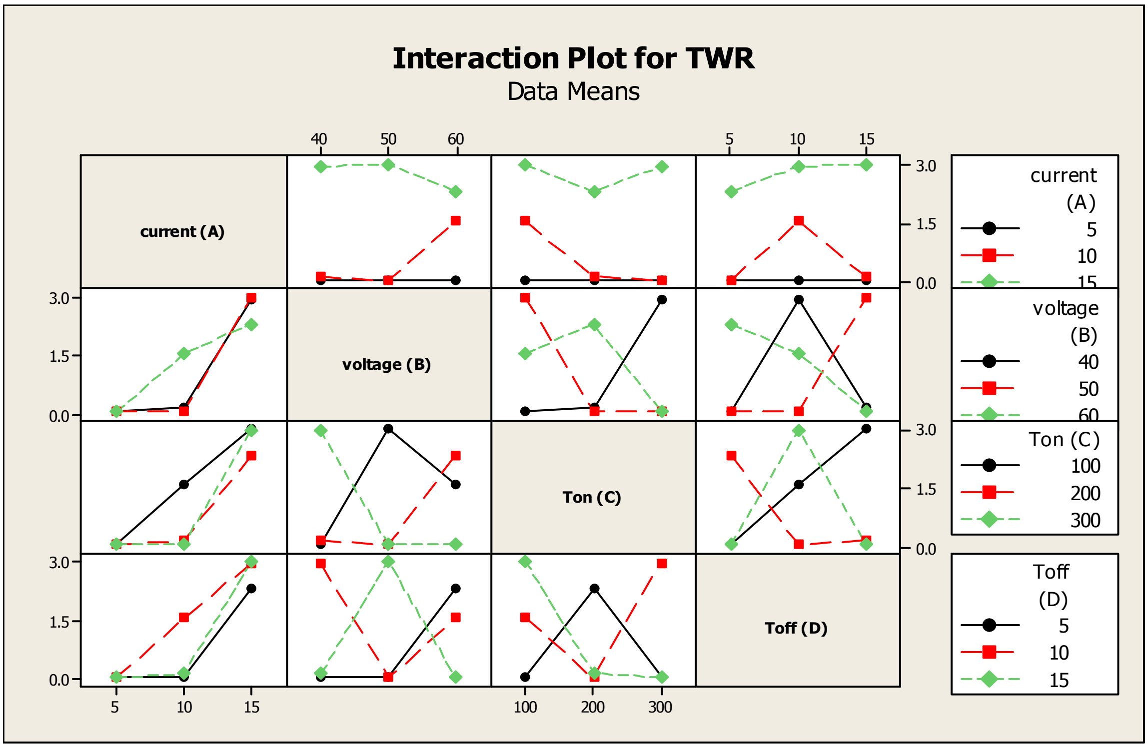

Fig. 5. Interaction effects of parameters on S/N Ratios for TWR

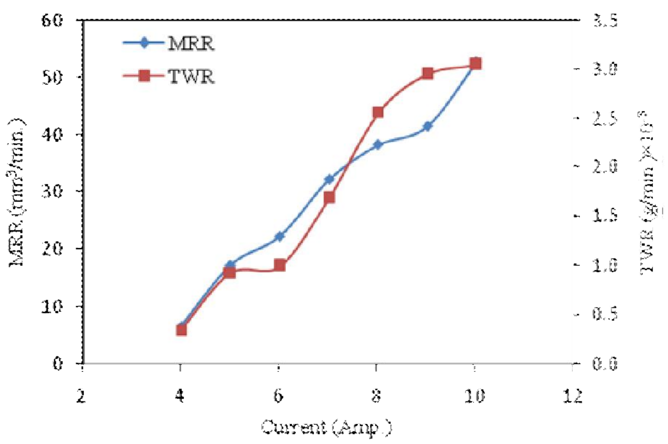

Fig. 6. MRR and TWR Variations with discharge current

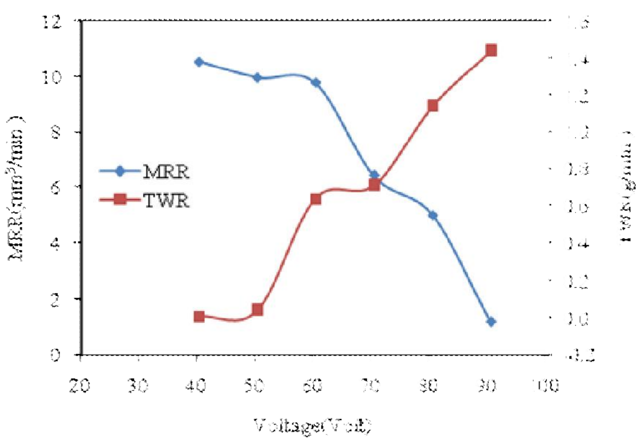

Fig. 7. MRR and TWR Variations with Voltage

This is expected because an increase in pulse current produces strong spark, which produces the higher temperature, causing more material to melt and erode from the work piece(Wikipedia 2014; Ravindranadha *et al.,* 2015). It is clearly evident that the other factor does not influence much as compared to current. The Analysis of factors contributes to fix the optimal process parameters for maximum MRR as IP 1, SV 3, T_{on} 4 and T_{Off} 2. But, with increase in discharge current from 10A to 15A MRR increases slightly. The T_{off} is just opposite in nature of current (IP). MRR decreases with T_{off} in the range of 5 to 10 µs. whereas T_{off} is 10 times of its actual values. Where; it increases slightly in range of 10 to 15 µs. So initially it increase and then decrease within the total range of 5 to 15 µs, and affects the value of MRR by high order. The interaction plot of MRR is shown in Fig. 3, where each plot shows the interaction between four different machining parameters. This implies that the effect of one factor is dependent upon another factor. This plot is used to find out the interaction between the two input parameters at the same time. For example, the interaction between the current and T_{off} is shown by the lower left corner of Fig. 3. The strongest interaction between various parameters can be seen from Fig. 3. The effect of process parameters on S/N Ratios for TWR is shown in Fig.4. The current has strong effect on TWR, the TWR decreases with increase in discharge current as seen in the Fig. 4. The Analysis of factors contributes to fix the optimal process parameters for minimum TWR as IP 1, SV 4, T_{on} 3 and T_{off} 2. The interaction plot of TWR is shown in Fig.5, where each plot exhibits the interaction between four different machining parameters. For example, the interaction between the current and T_{off} is shown by the lower left corner of the Fig. 5. As seen from the Fig.5, the TWR is maximum for value of IP 15 amp and T_{off} 15(µs) the values for IP at the value of current 15 (Amp.) and T_{off} 15 (µs) whereas TWR is minimum for IP 5 amp and T_{off} 15 (µs).

Effect of discharge current on metal removal rate (MRR) and tool wear rate (TWR)

The effect of discharge current on metal removal rate (MRR) and tool wear rate (TWR) is shown in Fig. 6. The pulsed discharge current was varying in the range of 4 to 10 Amps. A constant voltage (40V), flushing pressure (20 kg/cm^2), T_{on} and T_{off} were 30 and 9 respectively.

The effect of current on the metal removal rate (MRR) is shown in Fig. 6. The MRR increases with increase in current, due to the increase in current; the flow of electron increases which results in higher MRR. As the discharge current increases TWR also increases as seen in the Fig.6.

Effect of voltage on metal removal rate (MRR) and tool wear rate (TWR

The effect of voltage on metal removal rate (MRR) and tool wear rate (TWR) is shown in Fig. 7. The operating conditions were the same as discussed in section 3.1 except the discharge current was 6 amp, which was constant during the test. The voltage was varying in the range of 40V -90V. As shown in the Fig. 7, MRR is decreases and TWR increases with the increase in voltage.

Conclusion

The experimental study of the EDM of AISI P20 tool steel provided important quantitative results for material removal rate and tool wear rate as follows**:**

- The pulsed discharge current was varying in the range of 4 to 10 Amps. A constant voltage (40V), flushing pressure (20 kg/cm^2), T_{on} and T_{off} were 30 and 9 respectively.
- The MRR increases with increase in pulsed current, due to the increase in current; the flow of electron increases (intensity of spark is increased) which results in higher metal removal rate. As the discharge current increases TWR also increases.
- The MRR decreases and TWR increases with the increase in voltage.

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