Optimal parameters on MRR in EDM using Copper-Tungsten composite tool electrode

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Abstract **Electrical Discharge Machining (EDM) is an un-conventional machining process that is replacing the conventional machining processes such as drilling, milling and grinding. EDM is a thermo-electric spark erosion process that uses the current for eroding the metal from the surface of the work-piece. Presently, EDMs are able to make the complex geometries very precisely on the die steel materials and hard to cut metals like heat treated tool steels, composites, super alloys, ceramics etc. The main objective of this paper is to study the effects of parameters like peak current, gap voltage, and pulse-on time on EN-31 die steel material by using copper-tungsten (90:10) composite tool electrode. The selected parameters are further optimised in order to obtain maximum MRR using EDM. From the obtained results, it is clear that the selected parameters have significant effect on MRR.**

Keywords —Composite, Dielectric, Electrical Discharge Machining, Electrode, spark erosion

I. INTRODUCTION

EDM is an un-traditional machining process that machines very hard materials, that are hard to machine by traditional method. It is an electrical-thermal process that uses the current for eroding the metal from the work surface. A small spark happens in the micro gap intervals between the work-piece and the electrode that removes the unwanted material from the work-piece by melting and vaporization. Modern day EDM are capable of machining complex geometries precisely. In this process Electrical energy is provided to the tool that turns it into the heat energy when the number of electrical discharges occur among the tool and the workpiece [1]. This thermal energy creates a plasma between the tool and workpiece [2] and there is also developed a very high temperature in the order of 12000^{0}C [3] the pulsating current is supplied with a frequency of 15000 to 30000 Hz [4] is made to stop then the plasma breaks and due to this sudden decrease in the temperature and the flowing of dielectric between the electrodes this broken plasma channel is flushed along with the dielectric and thus we get the microscopic cavity. The efficiency of the machining is dependent on various input characteristics such as peak current, gap voltage, pulse on time discharge dielectric pressure, polarity, etc. some of these parameters are studied in this research paper like peak current, gap voltage and pulse on time. Through experimentations an attempt has been made to optimize these settings so as to get maximum Material Removal Rate [5] which was considered as an output parameter. The experiments were designed by using Taguchi technique. S/N ratio with larger the better response was used for analysis of Variance.

A very important aspect of the machining of the work material is the choice of tool electrode, as the properties of tool electrode will determine the MRR of the work material. The electrode chosen for machining of die steels is normally of high electrical and thermal conductivity so as to allow the flow of charge from the electrode to the workpiece. In some cases, the pure material is not able to give the desired results. Therefore, to improve the quality of the tool electrode, materials with better properties are reinforced in the main alloying material. In the present research work, copper-tungsten composite has been prepared in the weight ratios of 90Cu-10W by the powder metallurgical route. Copper in the composite will be responsible for high electrical conductivity whereas the tungsten will account for providing the strength to the electrode material.

II. BACKGROUND

Scott [6] et al. laid their study on optimization of cutting parameters which were efficient in MRR and surface finish. They investigated that if the pulse duration and the discharge current are increased then the surface finish will tend to increase. Pellicer et al. [7] presented the effect of the chief EDM process parameters and various tool shapes on base process functioning measures. A series of designated experiments with changing constraints of pulsed current, open Gap voltage, T-on time, were agreed out on H13 steels using different shapes of copper tool along with, MRR and SR. Results helped to choose the EDM process depending upon the product selected. C. Wykes et al. [8] gave the technique to acquaint tungsten in the electrode that reduces

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the TWR and increases the MRR, instead of using pure copper electrode. L. Selvarajan et al. [9] carried out experimental work on Si3N4-TiN ceramics by using composite copper electrodes on EDM. They used L25 orthogonal array for designing experiment taking pulse on time, dielectric pressure, current, pulse off time and gap voltage as the input parameter. Using ANOVA, they confirmed that current, gap voltage and pulse on time are key players in machining. M. Kumar et al. [10] studied the changes in the surface roughness of EN 41 by relatively changing the values of input characters in EDM. The input parameters used were gap voltage, current, pulse on time, pulse off time. Grey taguchi path was introduced for configuring of the output parameters. Input parameters were arranged for the experiments in L27 orthogonal array for the experiments. RSM was used for the study of results and observed that surface roughness is mostly inclined by input current. Huali Hao [11] et al. studied the effects of trace elements on powder metallurgy of copper. It was observed that the green density of the compact can be simply increased by adding 1 wt. % of tin, hence helping the sintering process. Similar effects were observed when 1. wt.% of tungsten was added. H. O. Gulsoy [12] et al. reported that PM electrodes made greater composites than the conventional electrodes. Tool conductivity and the extent of attachment among the copper particles with the pelleted tools are an important function. Luo Laima [13] et.al in the year 2015 fabricated copper tungsten (W-15Cu) composites by electro-less plating PM method. The relative densities, hardness, compressive strength and electrical conductivity of the prepared composites were checked.

III. FABRICATION OF COMPOSITE

A. Material Procurement

The copper and tungsten metal powders of 325 mesh size and 99.97% pure were purchased. The chemical composition of EN-31 die steel is given in table 1.

B. Fabrication of The Die

For the preparation of a composite part by PM technique, it is required that the produced part must be of exact shape as that of the final desired product. Therefore, to fulfill the requirement, a die was manufactured. The shape of produced component by PM technique is chosen as cylindrical. Therefore, the die is prepared with dimensions of 80 mm outer dia., 16 mm inner dia., and 160 mm long. H11 Die-steel material was selected for the fabrication of die and after fabrication case-hardening was done in carbon atmosphere.

C. Fabrication of The Composite Electrode

Copper and tungsten composites are hard to fabricate through the conventional routes like that of casting. So, the components that are immiscible in each other in liquid state are fabricated through Powder Metallurgy techniques. The procedure adopted in the manufacture composite for our research purpose is:

- At first manual mixing of both the metal powders was carried out in the ratio of 90 wt.% copper and 10 wt.% tungsten.
- Compacting was done at 20 MPa pressure, followed by a holding time of 90 s at this pressure. The compact green product obtained after compacting is of 15 mm dia. and 25 mm length)
- Sintering was carried out in muffle furnace with increasing temperature gradually with the increasing rate of 300 ˚C per hour and to reach up to 850 ˚C. The sample was held for 25 minutes after reaching at 850 ˚C and thereafter furnace cooled to room temperature.

IV. EXPERIMENTAL SETUP

A. Workpiece Material

EN-31 die steel plate material (200 mm long, 50 mm wide and 5 mm thick) was purchased from the market. There after material preparation was done so that it becomes ready for machining. Firstly, carburizing of the metal plate was performed followed by surface grinding. This material was further used for machining on EDM.

Table 1. Theoretical chemical composition of EN-31 die steel.

S. No.	ELEMENTS	COMPOSITION (wt.%)
1.	Carbon	0.90-1.2
2.	Manganese	0.50
3.	Silicon	0.10-0.30
4.	Chromium	1.00-1.60
5.	Phosphorus	0.04
6.	Sulphur	0.04
7.	Iron	rest

Table 2. Physical and Thermal properties of EN-31 die steel work material.

S.No.	PROPERTIES	EN-31
1.	DENSITY	7.80 g/cm^3
2.	MELTING POINT	1100 ˚C
3.	COEFFICIENT OF THERMAL EXPANSION (α)	11.9×10^{-6}/˚C
4.	THERMAL CONDUCTIVITY (K) at 20 ˚C	44.5 W/m·K

B. EDM Used for Experimental Work

After selection of workpiece material, the machining has been carried out using EDM. For this purpose, the EDM machine of model ELEKTRA EMS 5355 was used.

C. Experimental Design

For the experimental work, three input machining parameters i.e. the peak current, gap voltage and pulse-on time (T-On) were selected to vary to investigate their effect in the machining of EN-31 die steels workpiece material. Each input parameter was planned to vary at three different levels. Based on the total number of input parameters and

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their levels, the Taguchi's L_9 orthogonal array (OA) [14] was selected to use for final experimentation work. The L_9 orthogonal array consists of three input parameters and three levels. The Material removal rate (MRR) of workpiece sample was selected as output response parameter. The quality characteristics of Material removal rate (MRR) was considered as higher the better type. Table 3 shows selected parameters and level chosen for the present experimental work.

Table 3. Input machining parameters and levels.

Parameter s	Unit	Level 1	Level 2	Level 3
Peak Current	A	6	9	12
Gap voltage	V	30	40	50
T-On	µs	50	100	150

A sample table of L_9 OA is shown in table 4, which enlists the nine experimental set of parameters.

Table 4. Sample L9 Taguchi orthogonal array.

Exp. Run	Random Exp. Run	A	B	C	D	Output Response
1.	**3.**	1	1	1	1	X1
2.	**5.**	1	2	2	2	X2
3.	**9.**	1	3	3	3	X3
4.	**1.**	2	1	2	3	X4
5.	**8.**	2	2	3	1	X5
6.	**2.**	2	3	1	2	X6
7.	**4.**	3	1	3	2	X7
8.	**6.**	3	2	1	3	X8
9.	7.	3	3	2	1	X9

D. Experimental Work

The experimental work was carried out based on the selected L_9 OA design. On the basis of L_9 OA, a total 9 number of experiments have been conducted, each with 2 replications. The machining parameters that were kept constant during operation are given in table 5. The weight of the workpiece material was measured using weighing balance before and after machining. After experimentation, MRR was obtained by calculating loss in the weight of workpiece divided by the time taken for each experiment respectively.

The average of output response of two replicated experiments conducted at each parametric setting is taken and which is given in table 6.

Table 5. Constant machining parameters used during operation.

S. No.	Parameters	Units	Value
1.	Duty Cycle	-----	8
2.	Flushing pressure	bar	0.1
3.	Machining time	min.	20
4.	Tool electrode diameter	mm	15

Table 6. L9 orthogonal array with actual values and output response MRR.

Exp. No.	Peak Current (A)	Gap voltage (V)	T-On (µs)	MRR (g/min)	S/N Ratio (dB)
1	6	30	50	0.0385	-28.2908
2	6	40	100	0.0440	-27.1309
3	6	50	150	0.0472	-26.5212
4	9	30	100	0.0480	-26.3752
5	9	40	150	0.0558	-25.0673
6	9	50	50	0.0521	-25.6632
7	12	30	150	0.0570	-24.8825
8	12	40	50	0.0559	-25.0518
9	12	50	100	0.0600	-24.4370

Figure 1: EDM machined workpiece sample using copper-tungsten electrode tool.

V. RESULTS AND DISCUSSIONS

After experimental work, the obtained results were analyzed using Minitab software.

A. Analysis of Mean of Means and Mean of S/N Ratio for MRR

The Optimized setting of machine parameters for higher MRR is determined after the analysis of mean of means and S/N ratio. The mean S/N ratio and mean of means response are given in table 7 and 8 respectively. From table 7 and 8, the optimum parametric setting for MRR is determined as Peak Current-3rd level (i.e. 12 A), Gap Voltage-3rd level (i.e. 50 V) and T-On-3rd level (i.e. 150 µs). The same parametric combinations can be observed from the mean results plotted in Figure 2 and 3 respectively.

Table 7. Mean S/N ratio response table for MRR.

Level	Mean S/N ratio (dB)		
	Peak Current (A)	Gap Voltage (V)	T-On (µs)
1	-27.31	-26.52	-26.34
2	-25.70	-25.75	-25.98
3	-24.79	-25.54	-25.49
Delta	2.52	0.98	0.84
Rank	1	2	3

Table 8. Mean of Means response table for MRR.

Level	Mean of Means		
	Peak Current (A)	Gap Voltage (V)	T-On (µs)
1	0.04323	0.04783	0.04883
2	0.05197	0.05190	0.05067

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3	0.05763	0.05310	0.05333
Delta	0.01440	0.00527	0.00450
Rank	1	2	3

Figure 2 shows the main effects plot of mean of means for MRR with respect to Peak Current, Gap Voltage, and Pulse-On Time. It can be observed that the MRR increasing drastically with variation in peak current from 6 A to 9 A. The MRR also increases with increase in pulse-on time, whereas the increase in MRR is significantly low with the increase of voltage. This may be because of low variations in voltage. A significant increase will hopefully be observed if the gap voltage varies over the large scale.

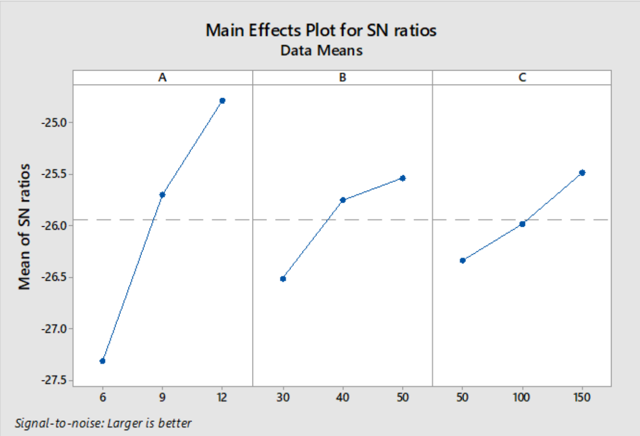

Figure 2. Main effects plot of S/N ratio for MRR.

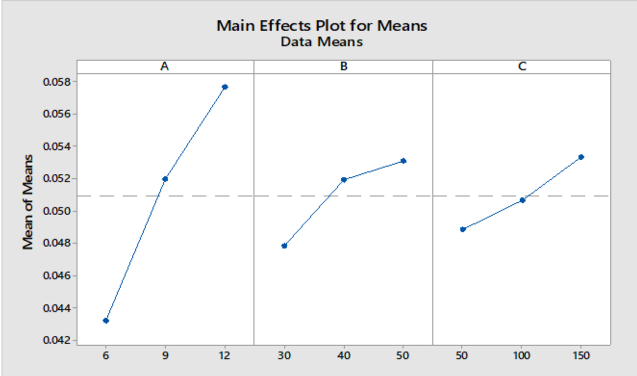

Figure 3. Main effects plot of Mean of Means for MRR.

The current has the dominating effect on the MRR because the heat generation equation has current squared term. Similarly, the case with the pulse on time if machine is on for longer duration then surely the MRR will increase. A similar trend can be observed from the S/N ratio curve as the higher S/N ratio values corresponds towards better results.

B. ANOVA FOR MRR

In order to find out the significant parameter for MRR, ANOVA analysis was carried out. The obtained results are presented in Table 9.

Table 9. ANOVA results for MRR.

Source	**DOF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-ratio**	**P-value**	**Percent contribution**	**Remarks**
Peak Current (A)	2	0.000316	0.000316	0.000158	181.23	0.005	80.15%	Significant
Gap Voltage (V)	2	0.000046	0.000046	0.000023	26.24	0.037	11.61%	Significant
T-On (µs)	2	0.000031	0.000031	0.000015	17.63	0.049	7.80%	Significant
Error	2	0.000002	0.000002	0.000001	------	------	0.44%	------
Total	8	0.000394	------	------	------	------	100.00%	------

From table 9, It can be seen that the peak current has the maximum effect on the MRR i.e. 80.15%. It can also be seen that the second major contributing factor is gap voltage with contribution of 11.61% and the very least effect has been observed for pulse-on time.

VI. OPTIMIZATION

After obtaining significant parameters and their optimum level, the estimated MRR at optimal parametric combinations can be calculated as:

$$MRR = \overline{T} + (\overline{A_3} - \overline{T}) + (\overline{B_3} - \overline{T}) + (\overline{C_3} - \overline{T}) \quad \ldots(1)$$

Here $\overline{T}$ = Overall mean of output response i.e. MRR

$\overline{A_3}$ = Mean MRR at 3rd level of Peak current

$\overline{B_3}$ = Mean MRR at 3rd level of Gap voltage

$\overline{C_3}$ = Mean MRR at 3rd level of Pulse-on time

The estimated MRR using equation (1) is calculated as 0.0622 g/min and the C.I$_{CE}$ is obtained as ±0.0057. After this confirmation experiment was carried out using the optimal setting of peak current, gap voltage and pulse-on time.

The MRR at confirmation experiment is obtained as 0.0665 g/min, which shows a good agreement with the estimated value.

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VII. Conclusion

In the present research, copper-tungsten composite tool has been prepared and used in EDM as a tool electrode for machining of EN-31 die steel work material. The effect of EDM parameters i.e. peak current, gap voltage and pulse-on time has been investigated on the output response characteristic (i.e MRR) of work material. After analysis of results, it was found that maximum MRR is observed for higher values of peak current whose contribution was found to be 80.15%, which is pretty high as compared to rest of the two contributing parameters considered in the present work. The second contributing parameter was gap voltage which is followed by pulse on time.

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