Analysis and Optimization of MRR in Powder-mixed EDM of AISI 5160 Steel

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Abstract

In electric discharge machining (EDM), dielectric mixed with powder plays very important role and helps to attain superior machinability of engineering materials. In this paper, analysis and optimization of material removal rate (that represents process productivity) during powder-mixed dielectric based EDM of AISI 5160 steel is discussed. Copper electrodes (as cathode) of 26 mm diameter and conductive copper powder 44 µm particle size have been used during machining. Taguchi L_9 orthogonal array based experimental study where voltage, peak current, and pulse duration have been varied at three levels each to analyze their effects on MRR. It is studied that MRR increased with increase in peak current and pulse duration. Optimum value of MRR (0.466 g/s) has been compared with the MRR obtained during normal EDM process.

Keywords
EDM, Optimization, Productivity, Steel

1. Introduction

Electrical discharge machining (EDM) is an advanced machining process used to machine conductive materials irrespective of their hardness (Gupta and Jain, 2017). It works on the principle of thermos-electric erosion where material removal or cutting takes place by sparks occur between two electrodes i.e. tool electrode (cathode) and workpiece (anode) under the influence of dielectric fluid. This process has many variants and has been used to cut many types of difficult-to-machine materials, and to machine typical features and shapes. In recent years, EDM has been extensively used as an alternate to conventional machining techniques. In normal or classical EDM, to obtain high material removal rate is a challenge, and it is always on the cost of poor surface quality. The possible solutions of this problem are to machine at optimum parameters with appropriate electrode material and using powder-mixed dielectric. Mixing of powder increases the insulating strength of the dielectric which reduces its frequent ionization and helps to obtain better productivity (Marashi et al, 2016). Al, SiC, Si, Ti and W are some of powder types used in powder-mixed EDM. After applying voltage and generation of electric field, the gap between tool electrode and workpiece is filled with powder particles and they increase the gap distance. The energized charged powder particles act as conductors and form clusters in the spark gap. Further, they bridge the gap between the tool electrode and workpiece and help to initiate early explosion. It consequently leads to faster sparking and erosion of work surface material. Power-mixed dielectric based EDM has potential and can be explored in machining of difficult-to-machine materials. Some past work on this process is discussed here as under.
Kansal et.al (2007) worked on the powder-mixed EDM and using silicon powder particle in deionized water as dielectric. Response surface methodology based analysis resulted in better surface finish and improved material removal rate. In a recent study, Singh (2018) successfully achieved over 40% improvement in MRR while machining D2 steel by powder-mixed EDM. Surface quality improvement in terms of reduction in crack density and recast layer thickness was achieved by Long et al. (2016) after fine machining of die steel by titan powder mixed EDM. Kolli and Kumar (2014) observed significant influence of boron carbide powder on material removal rate, surface roughness, and tool wear rate during powder mixed EDM of titanium alloys. An investigation on performance evaluation of various powders reveals the suitability and superiority of multi-walled carbon nanotube and Al powder to obtain higher MRR and better surface finish in EDM of EN-19 alloy steel (Mondal et al., 2018).

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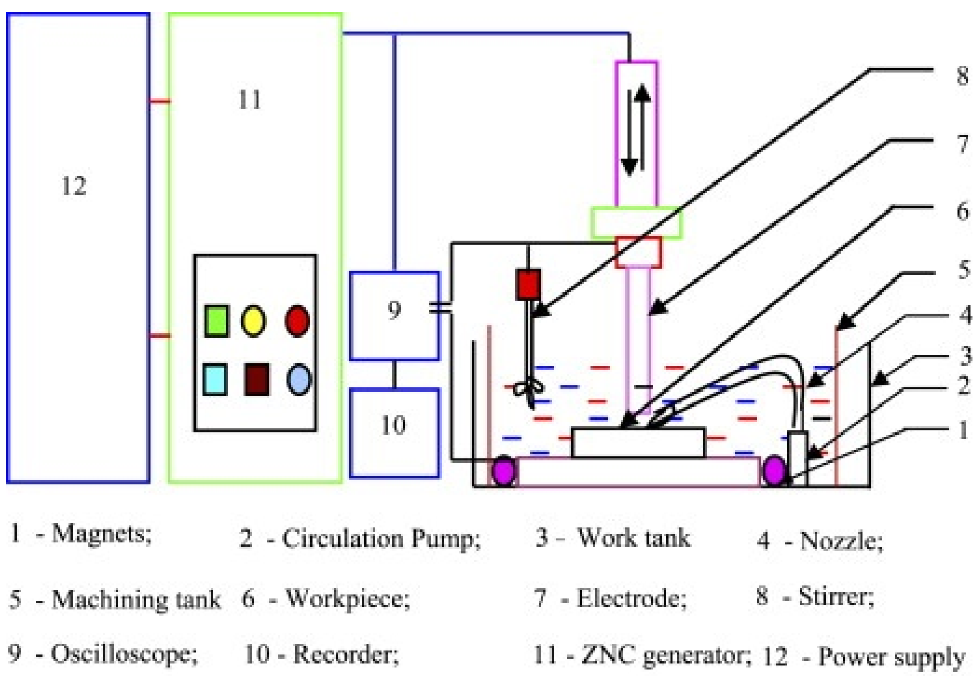
Graphene nano powder based EDM of Inconel superalloy performed by Kumar et al. (2018) found better surface characteristics compared to classical EDM.
Literature review indicates towards the potential of powder-mixed EDM. It also shows that some more future research is required to be conducted on machining of other materials. This work fulfills the research gap and presents the investigation on analysis and optimization of material removal rate while machining AISI 5160 steel (a candidate material for automotive and heavy duty applications) by powder-mixed EDM.

2. Experimentation

In this research work, experiments have been performed on Electra make Electrical Discharge Machine. Figure 1 depicts schematic and pictorial representation of the experimental setup. In this experiment setup a separate tank is fitted for dielectric fluid and work piece. Here we are using kerosene oil as dielectric fluid because of better corrosive resistant and easy availability. The dielectric fluid supplied at a pressure of 0.5 kg/cm^2 to completely flush out the eroded material from the working area. As shown in the experimental setup, a separate pump is used to circulate the dielectric fluid. In this setup side flushing is used to flush the eroded material and a magnetic is put inside working tank to collect the eroded materials (debris). The copper powder is mixed in the dielectric fluid which is constantly stirring by separate motor so that powder is completely mixed with dielectric fluid. The properties of copper electrode and copper powder are given in Table 1 and Table 2 respectively.
For process productivity evaluation, material removal rate (MRR) has been considered a response parameter. It has been calculated by dividing the machining time (in seconds) from the weight difference of the un-machined and machined samples. A weighing balance was used to measure the weight of the work piece before and after EDM process. A stop watch was used to record the machining time. Three important input EDM parameters namely voltage, peak current, and pulse duration (or pulse-on time) and their levels are depicted in Table 3. Taguchi robust design of experiment based nine experimental combinations of machining parameters are shown in Table 4.



(a)

(b)

Fig. 1 Experimental Set-up

Table 1 Properties of copper electrode

Property	Value
Density	8.94 g/cm^3
Young's Modulus	118GPa
Modulus of Rigidity	44GPa
Thermal conductivity	395 W/mK
Coefficient of thermal expansion	0.0000168/°C
Melting Point	1083°C

Table 2 Characteristics of powder material

Powder	Size (m)	K (Wcm^{-1}K^{-1})	R (cm^{-1})	ρ (g cm^{-3})
Copper	300	4.16	0.596	8.96

Table 3 Details of input EDM parameters

Input Parameters	Level 1	Level 2	Level 3
Voltage 'V' (Volts)	30	60	90
Peak current 'P' (Amp)	5	25	45
Pulse duration 'PD' (µs)	10	80	150

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3. Results and Discussion

Table 4 presents the nine experimental combinations of EDM parameters and corresponding values of MRR.

Table 4 Experimental array and MRR values

Run	V	P	PD	MRR (g/s)
1	30	5	10	0.0005
2	30	25	80	0.097
3	30	45	150	0.2425
4	60	5	80	0.05
5	60	25	150	0.455
6	60	45	10	0.33
7	90	5	150	0.0025
8	90	25	10	0.001
9	90	45	80	0.048

3.1 Analysis of MRR

Analysis of variance (ANOVA) has been conducted to evaluate the significance of EDM input parameters (See Table 5). According to ANOVA analysis, voltage was identified as the most significant parameters affecting MRR.

Table 5 ANOVA for MRR mean values

Source	DF	SS	MS	F	%
V	2	0.104681	0.052341	13.84	47.19
P	2	0.064068	0.032034	8.47	28.89
PD	2	0.045494	0.022747	6.01	20.51
Residual Error	2	0.007564	0.003782		3.41
Total	8	0.221807			

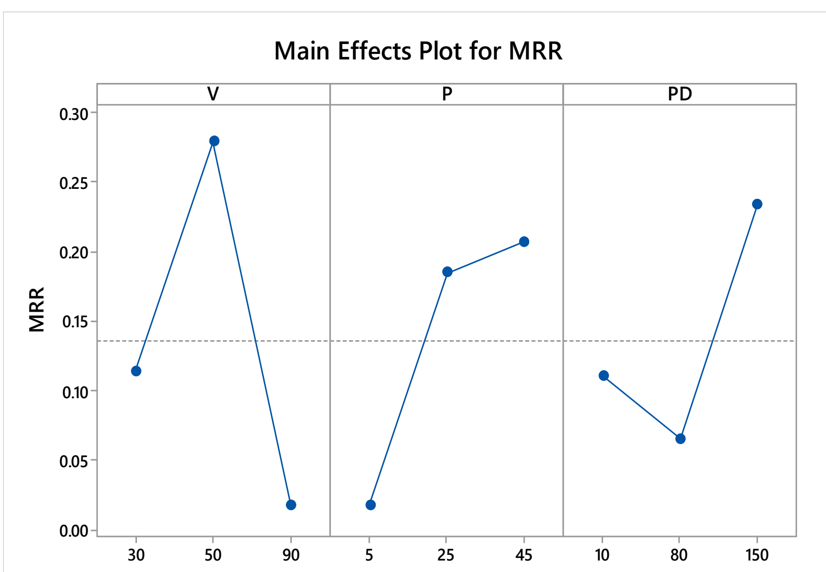

Fig. 2 Variation of MRR with EDM input parameters

Larger-the-better type characteristic formula has been used in Taguchi analysis of MRR. From Fig. 2, it is observed that MRR first increases with increase in voltage and then decreases. Increase in peak current increases MRR. The reason is the increase in the spark energy between the tool electrode and work-piece. With pulse duration, MRR first decreases and then starts increasing rapidly. Further increase in pulse duration after 10 μs, is first used to remove the deposited material and then after complete removal, it removes fresh material from the worksurface (Kumar et al, 2018).

Table 6 Response Table for MRR mean values

Level	**V**	**P**	**PD**
1	0.11333	0.01767	0.11050
2	**0.27833**	0.18433	0.06500
3	0.01717	**0.20683**	**0.23333**
Delta	0.26117	0.18917	0.16833
Rank	1	2	3

3.2 Optimization and validation

It is evident from the analysis of the experimental results that second level of V, third level of P and PD result in maximum MRR (See Table 6). Therefore, mean value of MRR can be calculated using Equation 1.

$$\mu_{MRR} = (V)_2 + (P)_3 + (PD)_3 - 2\,(T) \quad (1)$$

where, T- mean of the all experimental values.
All other values of V, P and PD can be found from Table 6.
$\mu_{MRR} = 0.71849 - 2\,(0.136278)$
$\mu_{MRR} = 0.445934$ g/min

The validation experiments are performed at the suggested optimal setting for MRR. Table 7 shows the optimal setting suggested for MRR and the values of MRR predicted at optimal setting along with its experimental value.

Table 7 Results of optimization

Sr. No.	**Response Variable**	**Parametric Setting by ANOVA**	**Predicted**	**Experimental**
1	MRR	$(V)_2(P)_3(PD)_3$	0.4459	0.466

The parametric setting suggested by ANOVA is V: 60 V; P: 45A; PD: 150 μs. The results at the optimized setting exhibit a good results reproducibility which is verified by the predicted and experimental values.

4. Conclusions

The results of investigation on material removal rate while powder-mixed EDM of AISI5160 steel is reported in this paper. Voltage was found as the most significant parameter. Optimum process parameters i.e. 60 Volta voltage, 45 Amp peak current, and 150 μs pulse duration produced the best value of MRR 0.466 g/s. A detailed investigation on analysis of all machinability indicators, comparison of powed-mixed EDM performance with classical and other variants of EDM, and softcomputing technique based process optimization etc. can be possible avenues for future research.

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Biographies
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