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On Material Removal Rate and Overcut In Electric Discharge Machining Consisting Nickel Metallic Powder

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Abstract

Electric discharge machining (EDM) process with conductive metallic powderhas been widely used for machining of hard materials with acceptabledimensional and geometrical accuracy. However, low material removal rate (MRR)and poor surface quality limits the applications of this machining technique.In this article, effort has been made to identify the parameters that resulted in maximum MRR and minimum overcut (OC)duringEDM operation of various die steels having similar applications (EN8, EN19 & EN24) bycopper electrode with nickel powder-mixed dielectric fluid. Since the MRR in EDM process has been affected significantly by variation inpeak current, off and on time of pulse, so these three parameters along with concentration of conductive powder have been selected as input variables in the research work. The experiments were planned and analysed using response surface methodology (RSM) technique of design of experiments (DOE).

Keywords: Electric discharge machining; Material removal rate;Overcut;Die steels; Nickel powder; Response surface methodology

1. Introduction

EDM is an extensively used thermal energy process for machining of hard materials. The material removal mechanism in this process constitute successive electrical dischargebetween the tool (cathode) and the working surface (anode) causes the removal of material without any direct contact between them. The entire operation is performed under the dielectric liquid such as kerosene or deionised water. The process has found enormous applications in fabrication of complex and intricated shapes in dies, presses and moulds. However, the low machining efficiency of the process limits its domain [1]. To reduce the problem of low material removal rate, dielectric fluid is comprised with fine conductive metallic powder particles. Due to the introduction of theseconductive particles, the spark gap between the two electrodes increases

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whereasdielectric fluid insulating strength reduces. It ultimately improves the MRR and hence the process efficiency. EDM process with powder-mixed dielectric fluid has been named as PMEDM.

In PMEDM, the rapidly recurring electrical discharges causes the surface erosion of the conductive work piece and thus removes the material. A potential difference is created between the two electrodesthat generates the electric field between them. The conductive powder particles get energized as the tool electrode movesgradually towards the work piece.Further, this gradual movement increases the electric field between the two electrodes and ultimately spark occurs at a particular point known as fluid-ionization point. This point of spark occurrence varies with the dielectric type and depends upon its strength (dielectric)& the gap between two electrodes.Under the sparking area, the powder particles form chains and thus virtually reduces the gap. As a result, the explosion takes place much earlier due to reduction ingap voltage as well as dielectric insulating strength. This increases the frequency of discharging and ultimately more and more erosionoccurs from the surface and hence MRR increases.

Erden and Bilgin investigated that increase inconcentration of conductive powders into the dielectric fluid of EDM decreases the time lag between the successive sparks and thus increases the MRR [2]. Ming and He reported that with the incorporation of additives, surface quality as well as MRR improves with decrease in tool wear rate(TWR)[3]. The addition of aluminium (Al) powder in dielectric during machining of tungsten carbide results in higher discharge gap along with significant improvement in MRR [4]. Kansal et al. investigated significant improvement in themachining rate of AISI D2 die steel under the influence of silicon powder-mixed dielectric fluid [5]. Some of the researchers reported the effect of carbon nano tubes presence on the machining characteristics of EDM as well as its role for enhancing surface quality through EDM [6]. Further, researchers reported that better surface quality has been obtained when powder particles were present in dielectric fluid of EDM [7]. Material removal rate increases 60% along with decrease in wear rate of 15% when 4g/l of fine graphite powder was added in the dielectric fluid of EDM [8].

Mukund et al. analysed the MRR by inserting Al powder in EDM dielectric and highlighted that peak current & powder concentration affects the MRR significantly. However, there was hardly any influence of duty factor, gap voltage and pulse on-time on MRR [9]. Uno et

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al. examined that the EDMed surface with metal powder-mixed fluid shows better surface quality and improved corrosion resistance because of the electrode and/or powder materials diffusion into the machined surface [10]. Wang et al. examined the effect of mixture of copper (Cu) and Al powder in EDM dielectric on the MRR and reported that the metal powder presence in kerosene dielectric increases the gap &reduces the isolation and hence considerably enhanced the MRR [11]. Kansal et al. employed response surface methodology (RSM) technique for the parametric optimization for PMEDM processcontaining silicon powder in the dielectric fluid and concluded that better surface quality and higher MRR has been achieved with PMEDM process [12].

Yan et al.investigated the effect of urea added in the dielectric fluid (distilled water) of EDM on the machining performance of titanium metals and concluded that the wear resistance improved dramatically after machining because of the existence of hard layer of TiN formed due to migration of nitrogen decomposed from the urea into the work surface [13]. Singh et al.analysed the MRR and surface roughness of SS-316L machined with tungsten electrode under the influence of TiO_2 nano-powder mixed dielectric fluid.The authors observed that addition of powdersignificantly enhancing the MRR [14]. Singh et al. highlighted the influence of pulse current on the MRR, overcut and roughnessof EN31 steel and observed that with the increase in pulsed current, the output parameters increases rapidly [15]. The conclusion came from the literaturereview indicated that the effect of metallic powders like nickel, chromium ormolybdenum in the EDM dielectric on the MRRis yet to be explored in detail. Further, researchers have made extensive efforts to study the influence of processing parameters on MRR but hitherto very less work has been reported on the OC. Basically, OCrepresents the difference between the electrode size and the machined hole.

2. Experimentation and Methodology

In this study, EN8, EN19 & EN24 steels were selected as the work materials. The electrode with 12mmdiameter made of high-grade copper has been used as tool electrode (Refer Figure 1). Commercially available kerosene oil mixed with nickel metallic powder acts as a dielectric fluid. Experimentation was executed with positive polarity. The chemical composition of the work piece materials has been shown in Table 1, 2 & 3:

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Table 1 Composition of EN-8 steel

P %	S %	Mn %	Si %	C %	Iron
0.06	0.06	0.70	0.09	0.40	Rest

Table 2 Composition of EN-19 steel

Mn %	Si %	Mo %	Cr %	C %	Iron
0.60	0.13	0.25	1.1	0.37	Rest

Table 3 Composition of EN-24 steel

Ni %	Mo %	Cr %	Mn %	Si %	C %	Iron
1.05	0.28	1.2	0.55	0.16	0.35	Rest

Figure 1 Fabricated copper electrode

An Ishikawa cause-effect diagram (refer Figure 2) was constructed with an aim to observe the factors that affect the PMEDM process.Since the MRRin EDM process has been affected significantly by variation in peak current, off and on time of pulse, so these three parameters along with concentration of conductive powder and work piece material have been selected as input variables. The levels of the parameters were decided by executing the pilot experimentation. The parameters along with their levels has been shown in Table 4.The experiments were planned and analysed using D-optimal design criterion of response surface methodology (RSM) technique. The reason for using D-optimal design criterion is that it allows the inclusion of categorical as well as numeric factors in the same experimental design. ‘Design Expert 8.0.4’ software was utilized for the formulation of experimental runs as well as data interpretation. Total number of 36 experiments were performed as per the Table 5. Each experiment was conducted for 15 minutes. For evaluation of the PMEDM process, “larger-the-better” characteristic criterion has been applied for the MRR whereas “smaller-the-better” characteristic criterion for the OC. The two responses have been calculated as follows:

$$\text{MRR (mm}^3\text{/min)} = \frac{\text{wear weight of work piece}}{\text{time of machining} \times \text{density of work piece material}} [16]$$

$$\text{OC (mm)} = \frac{\text{Dh} - \text{Dt}}{2} [17]$$

Where D_h=Machined hole diameter
D_t=Electrode diameter

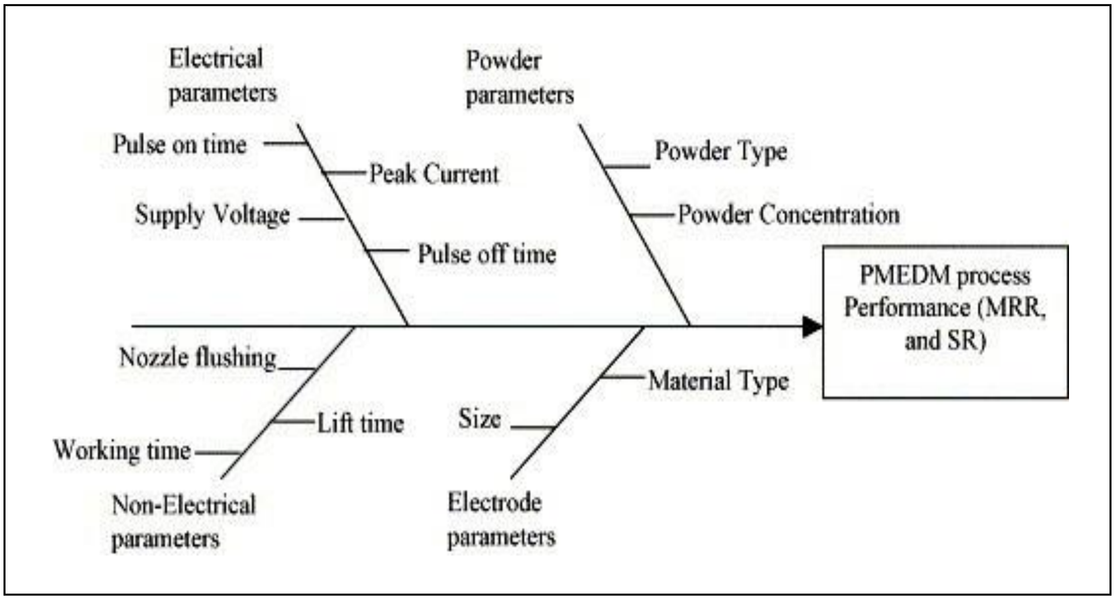

Figure 2 Ishikawa cause-effect diagram

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Table 4 Process parameters and their levels

Parameter	Symbol	Unit	Levels		
			-1	0	+1
Current	A	A	4	7	10
Pulse on time	B	µs	50	75	100
Pulse off time	C	µs	38	47	56
Powder Concentration	D	g/l	2	3	4
Work-piece	E		EN-8	EN-19	EN-24

3. Results and discussions

The three specimens die steels after experimentation were shown in Figure 3.The observations of the MRR and OC obtained for the experiments conducted has been shown in Table 5. For testing and analysing the results of MRR and OC, analysis of variance (ANOVA) and regression analysis were performed on the collected data. The F-valueof 72.83 and 127.94 after backward elimination for model in the ANOVA table of MRR and OC respectivelyindicates the significance of the model (Refer Table 6 & 7). The terms having value less than 0.05 in the column "Prob > F" are significant model terms. So, A, B, C, D, E, AB, AE, BC, DE, A^2 comes out to be the terms that effects the MRR significantly (Refer Table 6) and A, B, C, D, AB, BD, DE,$B^2$are the terms that effects the OC significantly (Refer Table 7).

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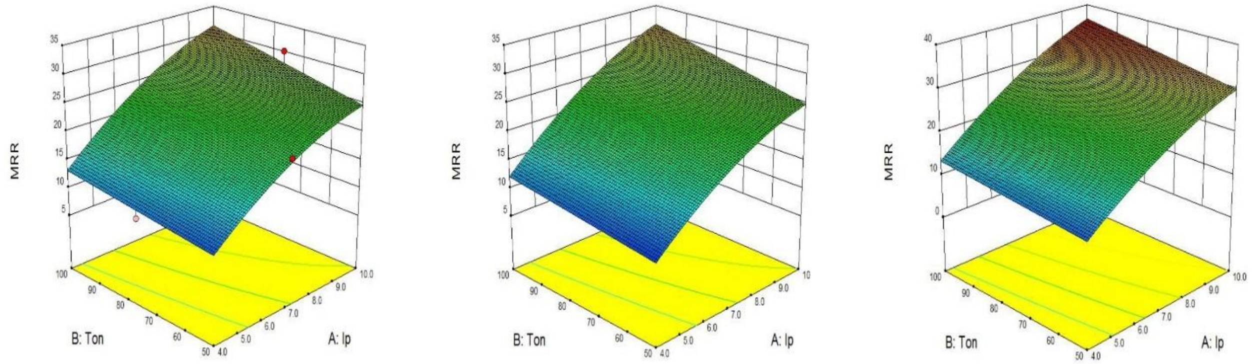
Figure 3 Die steels after experimentation

Table 5 Design matrix along with output response MRR

Run no.	A:Ip	B:T_{on} us	C:T_{off} us	D:Conc g/l	E:Material	MRR mm^3/min	OC mm
1	4	50	38	2	EN19	8.417	0.135
2	10	50	38	2	EN8	20.387	0.18
3	4	75	56	2	EN24	9.493	0.12
4	4	100	38	3	EN24	16.877	0.135
5	10	50	56	2	EN19	21.399	0.175
6	4	50	47	4	EN24	10.759	0.125
7	10	50	38	3	EN24	33.755	0.19
8	4	100	38	4	EN19	14.814	0.15
9	10	100	56	2	EN19	26.748	0.19
10	10	50	38	2	EN19	23.045	0.185
11	7	100	56	4	EN24	24.472	0.165
12	7	50	47	3	EN8	20.387	0.16
13	4	50	56	2	EN19	6.978	0.115
14	10	100	38	4	EN8	36.697	0.225
15	4	50	38	4	EN8	12.232	0.145
16	10	100	56	4	EN19	30.452	0.215
17	10	75	38	2	EN24	32.067	0.18
18	10	50	56	3	EN24	29.535	0.18
19	10	75	38	4	EN24	35.443	0.185
20	4	50	56	4	EN19	10.735	0.115
21	10	50	56	4	EN8	27.726	0.18
22	10	100	38	2	EN19	37.037	0.21
23	4	100	56	2	EN19	9.994	0.125
24	10	100	47	2	EN24	33.755	0.2
25	7	75	38	3	EN8	24.464	0.16
26	4	75	38	2	EN24	12.658	0.125
27	10	50	47	2	EN24	29.535	0.18
28	4	100	38	2	EN8	12.232	0.135
29	10	75	47	3	EN8	30.173	0.175
30	10	100	56	2	EN8	24.464	0.195
31	4	100	56	4	EN8	14.391	0.145
32	4	75	47	3	EN8	10.193	0.12
33	4	50	56	2	EN8	8.807	0.115
34	7	75	47	3	EN19	20.576	0.155
35	7	50	38	2	EN24	22.784	0.165
36	10	50	38	4	EN19	26.337	0.19

Table 6 Results of ANOVA after backward elimination for MRR

Term	Sum of Squares	DOF	Mean Square	F-Value	Prob > F
Model	2962.83	13	227.91	72.83	< 0.0001
A-Ip	2433.43	1	2433.43	777.62	< 0.0001
B-Ton	161.51	1	161.51	51.61	< 0.0001
C-Toff	62.24	1	62.24	19.89	0.0002
D-Conc.	71.82	1	71.82	22.95	< 0.0001
E-Material	84.50	2	42.25	13.50	0.0001
AB	18.37	1	18.37	5.87	0.0241
AE	32.11	2	16.05	5.13	0.0148
BC	37.24	1	37.24	11.90	0.0023
DE	25.54	2	12.77	4.08	0.0311
A^2	22.47	1	22.47	7.18	0.0137
Residual	68.85	22	3.13		
Cor Total	3031.67	35			



(a) (b) (c)

Figure 4 Variation of MRR with current and pulse on time for a) EN8, b) EN19, c) EN24 die steel

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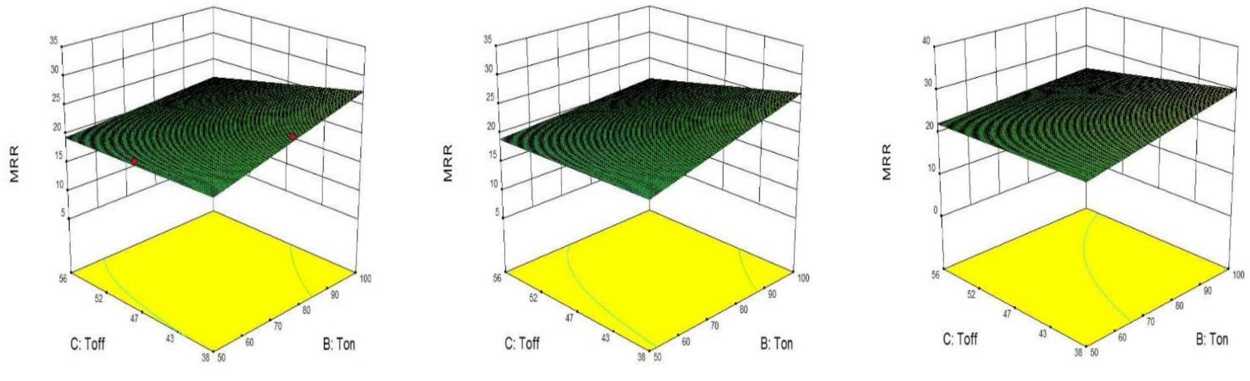

Figure 5 Variation of MRR with pulse on and off time for a) EN8, b) EN19, c) EN24 die steel

Figure 4 shows the MRR variation with change in peak current and pulse on-time in the form of response surface for the three selected die steels. With increase in any of the peak current and pulse on time,the MRR for all the three die steels increase significantly. Itwas basically due to increase in input energy with increase in peak current and pulse on time. So, highest values of peak current and pulse on time yields maximum MRR. Further, the MRR tends to decrease for all the three materials as the pulse off time increases as shown in Figure 5. It was basically due to reduction in frequency of the pulse as the off time increases. Further, MRR improves with the addition ofpowder concentration because of the fact that these powder particles resulted in bridging effect between the two electrodes which ultimately increases the dispersion of discharge several times.

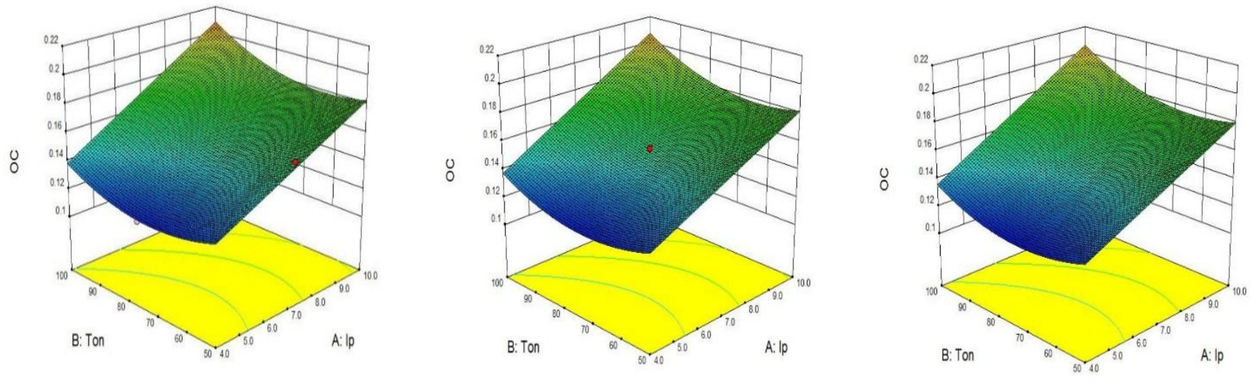

Figure 6 Variation of OC with current and on-time for a) EN8, b) EN19, c) EN24 die steel

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Table 7 Results of ANOVA after backward elimination for OC

Term	Sum of Squares	DOF	Mean Square	F-Value	Prob > F
Model	0.034	11	3.059E-03	127.94	<0.0001
A-Ip	0.028	1	0.028	1175.20	<0.0001
B-Ton	1.853E-03	1	1.853E-03	77.52	<0.0001
C-Toff	9.902E-04	1	9.902E-04	41.41	<0.0001
D-Conc.	4.547E-04	1	4.547E-04	19.02	0.0002
E-Material	1.649E-05	2	8.245E-06	0.34	0.7118
AB	3.784E-04	1	3.784E-04	15.82	0.0006
BD	1.589E-04	1	1.589E-04	6.65	0.0165
DE	3.236E-04	2	1.618E-04	6.77	0.0047
B2	9.476E-04	1	9.476E-04	39.63	<0.0001
Residual	5.739E-04	24	2.391E-05		
Cor Total	0.034	35			

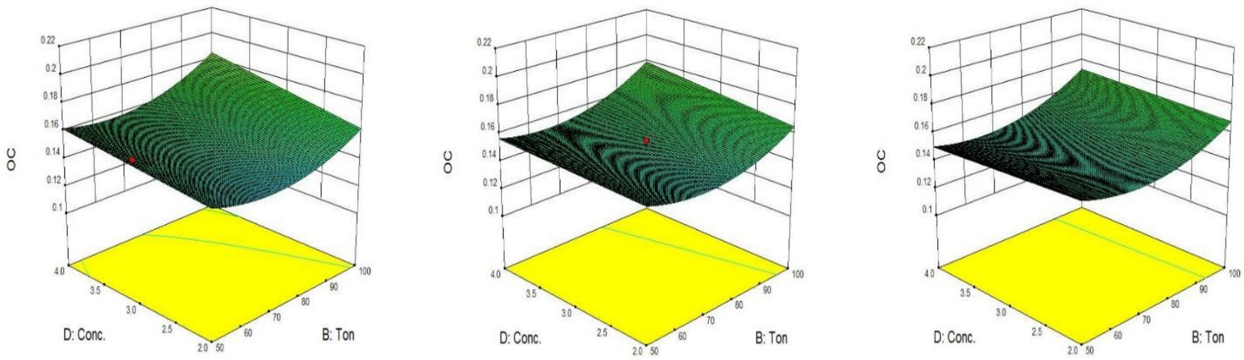

Figure 7 Variation of OC with on-time and powder concentration for a) EN8, b) EN19, c) EN24 die steel

Figure 6indicates the OCvariation with change in peak current and pulse on-time in the form of response surface for the three selected die steels. The OC for all the three die steels increase significantly with increase in current value. Itwas basically due to increase in input

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energy with increase in peak current. With increase in pulse on time, the OC initially decreases up to a minimum level and after that it start increasing for all the three die steels as shown in Figure 6. OC reduces significantly with increase in pulse off-time due to reduced pulse frequency.Increase in powder concentration shows different effects on OC for the three materials (Refer Figure 7). For EN8, increase in powder concentration increases OC. For EN19, increase in powder concentration increases OC but much lower than EN8. For EN24, increase in powder concentration decreases OC.

4. Conclusions

MRR: The most influencing parameter affecting MRR have been found to be as peak current having F-value 777.62 (Refer Table 6). In all the work pieces, the MRR increased linearly with peak current. The second influencing factor (F-value 51.61) was identified as pulse on time followed by powder concentration (F-value 22.95) affecting the MRR. The MRR was found to increase for all the materials with increase in pulse on time and powder concentration. Thus, the maximum MRR was found at highest level of current, pulse on-time and powder concentration. The MRR decreasesas the pulse off time increased. EN24 exhibit maximum MRR whereas EN19 exhibit minimum MRR for similar process settings.

OC: Peak current was the most influencing parameter (F-value 1175.20) affecting OC. The amount of overcut increases linearly with peak current for any settings of other design variables. The second influencing factor (F-value 77.52) was identified as pulse on timeand OC initially decreases up to a minimum level with increase in pulse on-time and after that it start increasing for all the three die steels. Also, the interaction between pulse on time and current was significant showing minimum OC for intermediate value of pulse on-time (70-80 µs). Pulse off-time has little effect on OC as compared two other parameters. OC was found to increase a bit for EN-8 and EN-19 steels with increase in powder concentrationbut it decreases for EN-24 die steel. EN-24 exhibit minimum OC whereas EN-8 exhibit maximum OC for similar process settings.

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