An Experimental Study on Parametric Optimization of High Carbon Steel (EN-31) by using Silicon Powder Mixed Dielectric EDM Process

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Abstract: ***Powder mixed electric discharge machining (PMEDM) is a recent innovation for enhancing the capabilities of electrical discharge machining process. The objective of present study is to realize the potential of silicon powder as additive in enhancing machining capabilities of PMEDM on EN31. Taguchi methodology has been adopted to plan and analyze the experimental results. L16 Orthogonal Array has been selected to conduct experiments. Peak current, Pulse on time, Pulse off time, gap voltage, and concentration of fine silicon powder added into the dielectric fluid were chosen as input process variables to study performance in terms of material removal rate & surface roughness. The ANOVA analysis identifies the most important parameters to maximize material removal rate & minimize surface roughness. The recommended best parametric settings have been verified by conducting confirmation experiments. From the present experimental study it is found that addition of silicon powder enhances machining rate & surface roughness appreciably.***

Keywords: Electrical discharge machining, Additive mixed electrical discharge machining, machining rate, Spark gap, Silicon powder concentration, Taguchi methodology

1. Introduction

Electrical discharge machining (EDM) is a common nonconventional material removal process. This technique has been widely used in modern metal working industry for producing complex cavities in dies and moulds, in press tools, aerospace, automotive and surgical components manufacturing industries which are otherwise difficult to create by conventional machining methods [1-2]. This machining process involves removal of material through action of electrical discharges of short duration and high current density between tool electrode and the work piece. However, its low machining efficiency and poor surface finish restricted its further applications [3]. To overcome these problems, one relatively new innovation used to improve the efficiency of EDM in the presence of powder particles suspended in the dielectric fluid. This new hybrid machining process is called powder mixed **e**lectrical discharge machining (PMEDM) [4-5]. Fig.1. depicts principle of PMEDM. The machining mechanism of PMEDM is different from.

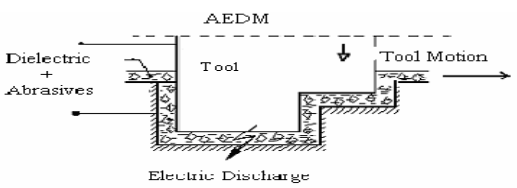


Figure 1: Principle of PMEDM

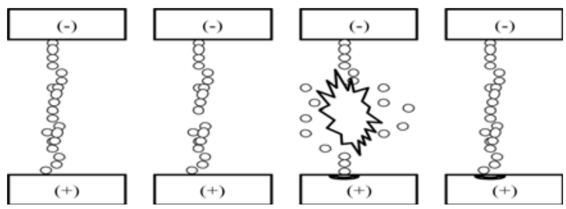


Figure 2: Particles arrangement

Mechanism of PMEDM.(a) Bridge formation, (b) Spark initiation because of breakage of chain, (c) Explosion leading to zigzag particle motion, (d) Re- bridging [4] Conventional EDM process [3-4]. In PMEDM when a voltage of 80-320V is applied across work piece and electrode electrical intensity in the range of 105 to 107V/m is generated [3]. Under the influence this electric intensity additives powder particles get energized and behave in a zigzag fashion. These additives particles arrange themselves in the form of chain at different places under the sparking area (Fig.2). The chain formation helps in bridging the gap between both the electrodes. This bridging effect results in lowering the breakdown strength of the dielectric fluid which causes early explosion in the gap. As a result, the series discharge starts under the electrode area. Due to increase in frequency of discharging, faster erosion takes place from the work piece surface. Therefore gap contamination facilitates ignition process and increases gap size thereby improving process stability. The absence of debris may results in arcing due to absence of precise feeding mechanism with highly position resolution. However excessive contamination may increase spark concentration i.e. arching leading to unstable and inefficient process [6].

Erden and Belgin [7] were the first who studied the effect of impurities (copper, aluminum, iron and carbon) in electrical discharge machining of brass steel and copper steel pair and obtained increase in machining rates with increase in concentration of impurities. It was further observed that machining becomes unstable at an excessive powder concentration due to the occurrence of short-circuits. Thereafter Jeswani [8] investigated the effect of adding fine silicon powder in dielectric of EDM and reported that addition of about 4g of fine silicon powder (10 µm in average size) per liter of kerosene improved machining stability thereby increasing metal removal rate (MRR) by 60% and tool wear rate (TWR) by 15%. The WR was reduced by about 28%. This effect was attributed to increase in interspaces for electric discharge initiation and reduction in the breakdown strength of dielectric fluid. Later many researchers Kumar, Maheshwari, Sharma and Beri [10] investigated the process capabilities of additive powder mixed EDM. They reported that that machining efficiency of powder mixed EDM can be increased by selecting proper discharging parameters. Very little research work is reported on effect of machining parameters on machining characteristics in PMEDM of EN31. The electrical parameters (like pulse frequency, duty cycle, pulse on time, spark gap, current and gap voltage, polarity etc.), material properties of electrode, work piece and dielectric fluid, properties of additive powders (like melting point, specific heat, thermal conductivity, grain size and concentration etc.) are the main factors which influence additive mixed electrical discharge machining. Hence there is need to investigate machining parameters to obtain optimum machining rate. Therefore, promoting the quality of the process by developing a thorough understanding of the relationship between these parameters for better machined surfaces has become a major research concern [6]. The aim of the present research work was to identify the significant parameters affecting PMEDM process.

2. Experimental set up and procedure

In the present study experiments were carried out on Electronica make electrical discharge machine; model SMART ZNC (S50). The dielectric flow system was modified for circulation of silicon powder suspended dielectric medium in small quantities to prevent contamination of whole of dielectric fluid. EN31 (specimen 75mm X 50mm X 10mm) was selected as work piece. Cylindrical copper electrode (φ 30.0 mm) was used as an electrode. For conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. The effect of suspended powder on the phenomenon of surface modification should be studied in order to correctly understand its behavior. Hence, it was decided to conduct experiments with each combination of work material, electrode and powder. Out of the above listed design variables, the orthogonal array was to be selected for five design variables (namely peak current, pulse on-time, pulse off-time, gap voltage and dielectric concentration) which would constitute the orthogonal array. The machining process parameters set up as shown in Table 1 keeping all other parameters constant. Preliminary experiments were conducted in the given range of different input parameters to select their levels shown in Table 1. L16 orthogonal array has been used which contains 16 experimental runs at various combinations of five input variables [11]. Machining rate is measured in term of volume of material eroded from work piece per minute by weight loss method as per following equation.

$$\text{Machining rate} = \frac{\textit{weight loss from work piece (grms)}}{\textit{Density of work piece}\left(\frac{g}{mm3}\right) \textit{X machining Time} \text{ (min)}} \qquad (1)$$

Table 1: Fixed input process parameters

Sr. No	Machining Parameter	Fixed Value
1	Open Circuit Voltage	135 ± 5% Volts
2	Polarity	Straight
3	Machining Time	15min
4	Type of Dielectric	Kerosene
5	Electrode Quill Movement	14.4
6	Powder Concentration in Di-electric	2g/liter

3. Results and discussions

Taguchi methodology has been used for the design and analysis of the experiment [10, 11]. The Taguchi method uses signal-to-noise (S/N) ratio to quantify the variation in data. Higher response characteristics i.e. MR is desirable, so the selected response characteristic in the present work is machining rate and will be considered as 'higher the best'.

$$\text{HB: S/N} = -10\log_{10}\left[1/n \sum_{i=1}^{n} y_i^{-2}\right] \qquad (2)$$

The results are analyzed using MINITAB 1 5.1.1 software. The S/N ratios of the MR for each trial run through have been calculated. For calculating MRR and SR, both work pieces were taken to weighing machines, profilometer after unloading, and readings for their weight were noted. Following table gives all the response values at various values of responses:

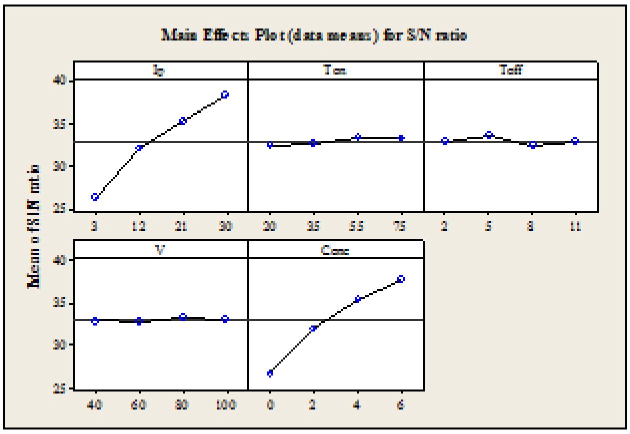
Table 2: Particle arranges

Sr. No	Current	Pulse-on time	Pulse-off time	Gap voltage	Dielectric concentration	MRR (grams)	SR (mg)
1	3	20	2	40	0	9.259	9.259
2	3	35	5	60	2	18.518	18.518
3	3	55	8	80	4	27.777	27.777
4	3	75	11	100	6	37.037	37.037
5	12	20	5	80	6	74.074	74.074
6	12	35	2	100	4	55.555	55.555
7	12	55	11	40	2	37.037	37.037
8	12	75	8	60	0	18.518	18.518
9	21	20	8	100	2	46.296	46.296
10	21	35	11	80	0	27.777	27.777
11	21	55	2	60	6	101.851	101.851
12	21	75	5	40	4	84.074	84.074
13	30	20	11	60	4	101.851	101.851
14	30	35	8	40	6	110.629	110.629
15	30	55	5	100	0	46.296	46.296
16	30	75	2	80	2	78.246	78.246

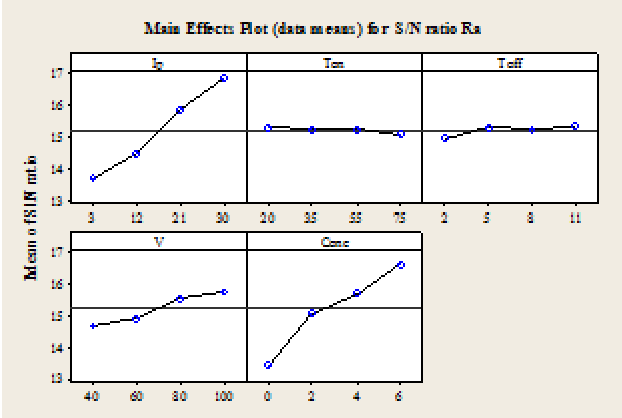
Table 3: SNR for MRR and SR

Sr. No	Current	Pulse on time	Pulse off time	Gap voltage	Dielectric concentration	MRR (grams)	SNR for MRR	SR (µm)	SNR For SR
1	3	20	2	40	0	9.259	19.3313	3.603	11.1332
2	3	35	5	60	2	18.518	25.3521	4.656	13.3602
3	3	55	8	80	4	27.777	28.8737	5.311	14.5035
4	3	75	11	100	6	37.037	31.3727	6.026	15.6000
5	12	20	5	80	6	74.074	37.3933	6.594	16.3829
6	12	35	2	100	4	55.555	34.1300	5.817	15.2939
7	12	55	11	40	2	37.037	31.3727	4.975	13.9358
8	12	75	8	60	0	18.518	25.3521	4.124	12.3063
9	21	20	8	100	2	46.296	33.3108	6.606	16.3987
10	21	35	11	80	0	27.777	28.8737	5.352	14.5703
11	21	55	2	60	6	101.851	40.1593	6.876	16.7467
12	21	75	5	40	4	84.074	38.4932	6.175	15.8127
13	30	20	11	60	4	101.851	40.1593	7.346	17.3210
14	30	35	8	40	6	110.629	40.8774	7.746	17.7815
15	30	55	5	100	0	46.296	33.3108	6.124	15.7407
16	30	75	2	80	2	78.246	37.8692	6.840	16.7011

4. Experimental results for MRR & SR



Graph 1: Effect of various factors on the MRR



Graph 2: Effect of various factors on the SR

In the Graph 4.1, effect of various factors i.e. current, pulse on-time, pulse off-time and Dielectric is shown on the Material removal rate. It is clear from the graphs that as the current increases, MRR goes on increasing. Same is the effect of pulse on-time and pulse off-time, but the rate of increase is comparatively lower than that of current, whereas in case of dielectric powder suspended kerosene gives better results than that of simple kerosene and the silicon suspended kerosene gives higher material removal rate. Reason for the better results with powder mixed dielectric is that that due to much loss of discharge energy in the discharge gaps and reduction of the ejecting force on the melted materials, machining efficiency is better Graph 4.2 represents the effect of all the factors upon MRR. First graph of the six shown graphs give the interactive effect of current and pulse on-time. Second one gives the effect of current and pulse off-time, third one gives the effect of pulse on-time and pulse off-time and so on. These graphs indicates that Silicon as additive gives the best result for hardness for a particular value of the current, pulse on-time and pulse off time. Maximum MRR is at highest combination level of current and pulse on-time. Same the results for current and pulse off-time. For combination with dielectric, silicon with highest level value of current, pulse on-time and pulse off-time gives the higher MRR.

Table 4: Optimum values of process parameter for MRR & SR

Process parameters	units	Optimum values	Optimum values
Discharge current (Ip)	A	30	30
Spark on time (Ton)	µs	55	20
Spark off time (Toff)	µs	5	11
Voltage (V)	volt	80	100
Conc. of dielectric(C)	g/lit	6	6

The table shown above gives the optimal values for all the levels of the factors current, pulse on-time and pulse off-time for the silicon powder Mean value of SNR for Material Removal Rate is 115.829 & Surface roughness 3.532.

Table 5: ANOVA table of Material Removal Rate

Source	DF	SS	MS	F	P
Regression	5	18649.9	3730.0	462.09	0.000
Residual error	10	80.7	8.1		
Total	15	8730.6			

Source	DF	Seq. SS
Ip	1	9355.1
Ton	1	44.5
Toff	1	193.3
V	1	827.6
C	1	8229.3

Table 6: ANOVA table of Surface roughness

Source	DF	SS	MS	F	P
Regression	5	19.5149	3.9030	91.60	0.000
Residual error	10	0.4261	0.0426		
Total	15	19.9409			

Source	DF	Seq. SS
Ip	1	10.4250
Ton	1	0.1252
Toff	1	0.0464
V	1	0.6692
C	1	8.2491

From the results of the ANOVA table, it is clear that all the five factors current, pulse on time, pulse off time and dielectric have effect on the material removal rate individually. The interaction between current and dielectric also has the significant effect upon the material removal rate. This interaction is important because current is directly proportional to the energy at discharge and by adding dielectric machining efficiency improves too. So, the combined effect of both becomes important. The other two interactions are not so much of importance as the F-test value is less than the F-critical, so they are non-significant. Out of all factors, current and dielectric has most significant effect on the Material removal rate. From these results, it is clear that the material removal rate increases with the addition of the powder in the dielectric and the increase in the current amperage.

Grey Relational Analysis

Data Analysis: Normalized data:

Table 7: Normalized data

Sr. No.	MRR	Surface roughness (Ra)
Ideal Sequence	**1.0000**	**1.0000**
1	0.08369	1
2	0.16738	0.7732
3	0.25108	0.67783
4	0.33478	0.5974
5	0.66957	0.5459
6	0.50217	0.61887
7	0.33478	0.7236
8	0.167388	0.8729
9	0.418479	0.5449
10	0.25108	0.6726
11	0.92065	0.5236
12	0.75996	0.5829
13	0.920653	0.49
14	1	0.4647
15	0.418479	0.5878
16	0.70728	0.5263

Check for correlation between the responses:

Table 8: Check for correlation between the response calculation of the principal component score

Sr. No.	Correlation between responses	Pearson Correlation coefficient	Comment
1	MRR and Ra	-0.82952	Both are correlated

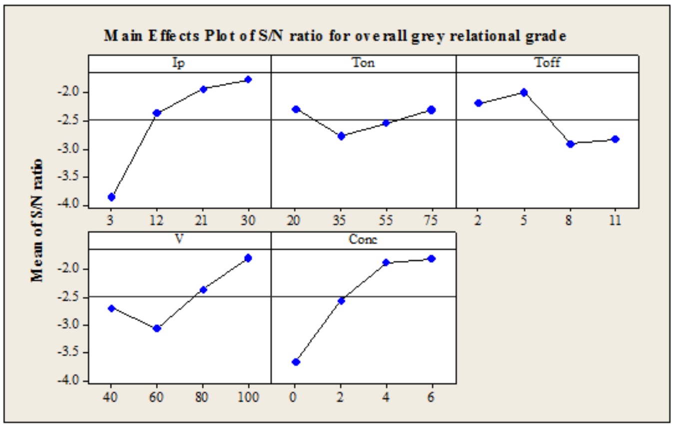
Table 9: Eigen values, eigenvectors, accountability proportion (AP) and Cumulative accountability proportion (CAP) computed for the responses

	Ψ_1	Ψ_2
Eigen value	1.82952	0.17048
Eigen vector	-0.707107	-0.707107
	0.707107	-0.707107
AP	0.91476	0.085241
CAP	0.91476	1.0000

Calculation of the individual grey relational grades:

Table 10: Individual grey relational coefficients for the principal components

Sr. No.	**Grey relational coefficients for individual principal components**	
	Ψ_1	Ψ_2
1	0.418239	0.738038
2	0.540289	0.671928
3	0.649623	0.667057
4	0.797551	0.668413
5	0.988015	0.811575
6	1	0.757497
7	0.678715	0.72542
8	0.494003	0.716653
9	0.98337	0.681655
10	0.653485	0.664895
11	0.67218	0.981306
12	0.904977	0.898072
13	0.646768	0.952061
14	0.578645	1
15	0.916138	0.700748
16	0.89943	0.822836



Graph 3: S/N Ratio plot of overall grey relational grade

Confirmatory experiments

Table 11: Reflects the satisfactory result of confirmatory experiment

	Optimal setting	
	Prediction	**Experiment**
Level of factors	$Ip_4, Ton_4, Toff_2, Vg_4, C4$	$Ip_4, Ton_4, Toff_2, Vg_4, C4$
S/N ratio	-0.22882	-0.33604
Overall grey relational grade	0.974	0.96205

5. Conclusions

From the study it has been concluded that the PMEDM (Powder Mixed Electric Discharge Machining) has significant effect on the material removal rate and surface roughness. With the addition of the powders in the dielectric, material removal rate has been increased to a great extent and the surface roughness has been reduced. Silicon gives better results in terms of Material removal rate and surface roughness. So, it is concluded and suggested to use silicon as an additive for PMEDM. While machining the material EN31, the industrialist can directly use the optimum values so that the material removal rate will be maximum and Ra value will be minimum. This will save the time required for machining, improve surface roughness save the electrical power consumption, reduce labor cost, etc

References

[1] N.M. Abbas, D.G. Solomon and M.F. Bahari, "A review on current research trends in electrical discharge machining (EDM)".International Journal of Machine Tools and Manufacture, vol. 47, no. (7-8).

[2] K.H. Ho and S.T. Newman, "State of the art electrical discharge machining (EDM)". International Journal of Machine Tools and Manufacture, vol. 43, pp. 1287-1300, 2003

[3] H.K. Kansal, S. Singh and P. Kumar, "Technology and research developments in powder mixed electric discharge machining (PMEDM)", Journal of Materials Processing Technology, vol. 184, pp. 32-41, 2007.

[4] A. Kumar, S. Maheshwari, C. Sharma and N. Beri, "Research Developments in Additives Mixed Electrical Discharge Machining (AEDM): A State of Art Review", Materials and Manufacturing processes,
[5] Y.F. Tzeng and C. Lee, "Effects of Powder Characteristics on Electro discharge Machining Efficiency." International Journal of Advanced Manufacturing Technology, vol. 17(8), pp. 586–592, 2001.
[6] A. Erden and S. Bilgin, "Role of impurities in electric discharge machining", Proceedings of the 21th International Machine Tool Design and Research Conference, Macmillan, London, pp. 345-350, 1980.
[7] M.L. Jeswani, "Effect of the addition of graphite powder to kerosene used as the dielectric fluid in electrical discharge machining" Wear, vol.70, no.2, pp.133-139, 1981.
[8] A. Kumar, S. Maheshwari, C. Sharma and N. Beri, "Performance evaluation of silicon additive in electrical discharge machining of EN 24 steel based on Taguchi method", Journal of Mechanical Engineering,vol.60, no.(5- 6), pp. 289-304, 2009. Montgomery, D.C. (2001).Design and analysis of experiments, Fifth edition, John Wiley & Sons, New York

Author Profile

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