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Optimization and Analysis of Process parameters on MRR in EDM of AISI D3 Die Steel using SiC as Dielectric

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ABSTRACT

In the manufacturing industries, various machining processes are adopted for removing the material from the work piece to obtain finished product. Due to demands for alloy materials having high hardness, toughness and impact in aerospace and automotive industries; it is very difficult to use conventional machining methods to remove the material from the work piece.

The unconventional methods of machining have several specific advantages over conventional methods of machining. These methods are not limited by hardness, toughness, and brittleness of the material and can produce any intricate shape on any work piece material by suitable control over the various physical parameters of the processes.

Among the various unconventional machining processes, electrical discharge machining (EDM) technology has grown tremendously. The EDM provides the best alternative or sometimes the only alternative for machining conductive, exotic, high strength and temperature resistive materials. In this research we have used RSM & DOE for optimization of MRR in EDM using AISID3 die steel.

Keywords—*Electrical discharge machining; Material Removal rate; Response Surface Methodology; ANOVA, Design of Experiments (DOE)*

1. INTRODUCTION

There has been tremendous progress over the decades in the field of materials and engineering. Innovation & creativity are the most important tools used for developing new technologies. The need for maximum efficiency & minimum losses has forced existing technologies to move towards development. The new era of growth demands much more from the materials field. As it is the soul of manufacturing industry. Enhanced properties or newly developed materials with high-performance capabilities are the requirement of industries [1]. Manufacturing industry has continuously faced challenges from these advanced and modern 'difficult-to-machine' materials, stringent design requirements (high precision, complex shapes and high surface quality) and very high machining cost. These materials play a progressively more vital role in modern manufacturing industries, especially in aircraft automobile, tool, die, and mould making industries. The improved thermal, chemical, and mechanical properties of the material have yielded enormous economic benefit to the manufacturing industries through improved product performance and product design. Tradition machining processes are not so efficient and are unable to machine the materials economically therefore they are increasingly being replaced by advance machining process.[2] EDM has put answers to all these questions it is one of its class machine and is one of the most extensively used nonconventional material removal processes. In this process the material is removed by a succession of electrical discharges, which occur between the electrode and the work piece. There is no direct contact between the electrode tool and the work piece. These are submersed in a dielectric liquid such as kerosene or deionized water. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage. The electrical discharge machining process is widely used in the aerospace, automobile, die manufacturing and moulds industries to machine hard metals and its alloy. The basic principle in EDM is the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in the dielectric fluid. It has now covered a vast literature and lots of research has been done on maximizing material removal rate.

2. LITERATURE REVIEW

Electrical discharge machining (EDM) is one of the most extensively used nonconventional material removal processes. In this process the material is removed by a succession of electrical discharges, which occur between the electrode and the work piece. There is no direct contact between the electrode and the work piece. Gopalakannan et al. (2012) investigated the effect of EDM parameters on MRR, EWR and SR during the machining of metal matrix composite of aluminium 7075 reinforced with 10 wt. % of B4C. The result shows that pulse current and pulse on time have been found most significant parameters that affect the MRR. The MRR initially increases with an increase in pulse on time and afterwards decreases with further increase in pulse on time. The pulse current and pulse on time have been found main influencing parameters for EWR and SR. The higher pulse off time offers lower the EWR value. The value of SR increases with increase in pulse current and pulse on time.[3] Laxman and Kumar (2013) employed RSM (response surface methodology) to optimize the material removal rate of the process on EN31 tool steel controlling the process variables like pulse on, pulse off time, current, voltage. Rotable type central composite design (CCRD) was used for RSM using Minitab software. Result revealed that the optimum parameters were pulse on 500µs, pulse off 1500µs, current 20A, voltage 60V for EN31 work-piece, Cu electrode, EDM oil as dielectric when machining was performed by CNC EDM.[4] Kamboj, A.et. al.(2013) studued Fabrication and characterization of Al6063/SiC composites showing the different aspects of machining with composites [5]. Chattopadhaya et. al. (2008) used linear regression analysis to develop empirical model in terms of peak current, pulse on time and rotational speed of tool electrode for prediction of surface roughness, MRR and TWR. The result shows that peak current and pulse on time have been found most significant parameters that affect the MRR and EWR. On the other hand, peak current and electrode rotation have been found most significance parameter that affects the surface roughness [7]. Kamboj,A.et. al.(2014) employed Multi Response Optimization in Drilling Al6063/SiC/15% Metal Matrix Composites[8]. On the basis of the previous researches the objective of the present research are-

- To investigate the effect of EDM process parameters like current, voltage, pulse on time, pulse off time and SiC powder on MRR using response surface methodology based on two level full factorial design during the machining of D3 die steel.
- Development of material removal rate prediction model in terms of pulse on time, pulse off time, current, voltage for kerosene and for kerosene with SiC powder.
- Optimizations of EDM process parameters for maximize MRR.

3. EXPERIMENTAL SET-UP

In this experiment whole work was performed on electric discharge machine model TRESSMACH-330 SPARK GENERATOR (die sinking type) of 25 Ampere capacity with servo head system of constant gap. Negative polarity i.e. work-piece negative and tool positive was used to conduct the experiments. Experiment was conducted Rajasthan Udyog ltd. Jodhpur.

4. DESIGN OF EXPERIMENTS

Design of experiment procedure is a powerful approach to improve product design or improve process performance. This procedure constitutes a systematic method concerning the planning of experiments, collection and analysis of data with near-optimum use of available resources. It is possible to identify the process conditions that influence product quality and costs, which in turn enhance the product manufacturability, quality, reliability and productivity.

The advantages of design of experiments are as follows:

- Numbers of trials are significantly reduced.
- Important decision variables which control and improve the performance of the product or the process can be identified.
- The optimal setting of the parameters can be found out.
- Experimental error can be estimated.

On the basis of planning of experiments, design of experiment includes number of techniques like factorial design, Taguchi method, centre composite design etc. In the present work, 2 level full factorial design has been used to plan the experiments and subsequent analysis of the data collected.

EDM parameters and their levels

The levels of EDM parameters were decided on the basis of pilot experiment performed. The approach used for pilot experiment was varying the level of one factor & other remains constant. The values of the parameters are taken according to the nearby maximum & minimum values of pilot experiments.

Table 4.1 EDM parameters used & their level

Factor	Name	Units	Type	Subtype	Minimum (-1)	Maximum (+1)
A	Voltage	Volts	Numeric	Continuous	30	45
B	Current	Ampere	Numeric	Continuous	6	25
C	Pulse on	Microsecond	Numeric	Continuous	6	200
D	Pulse off	Microsecond	Numeric	Continuous	12	100
E	Dielectric medium		Categoric		Y	No

The results obtain after measurements of surface roughness indicators of machined work pieces have been shown in tables

Table 4.2 Design layout for Experiment

S.No.	A:Voltage (volts)	B:Current (Ampere)	C:Pulse on (Microsecond)	D:Pulse off (Microsecond)	E:type of dielectric	MRR (mm3/min.)
1	30	6	6	12	kero	52.74
2	45	6	6	12	kero	49.68
3	30	25	6	12	kero	60.93
4	45	25	6	12	kero	56.78
5	30	6	200	12	kero	75.1
6	45	6	200	12	kero	70.09
7	30	25	200	12	kero	79.46
8	45	25	200	12	kero	74.61
9	30	6	6	100	kero	41.26
10	45	6	6	100	kero	36.7
11	30	25	6	100	kero	48.36
12	45	25	6	100	kero	43.98
13	30	6	200	100	kero	58.8
14	45	6	200	100	kero	54.03
15	30	25	200	100	kero	62.94
16	45	25	200	100	kero	58.16
17	30	6	6	12	kero+ SiC	60.86
18	45	6	6	12	kero+ SiC	53.58
19	30	25	6	12	kero+ SiC	67.77
20	45	25	6	12	kero+ SiC	61.74
21	30	6	200	12	kero+ SiC	92.53
22	45	6	200	12	kero+ SiC	81.58
23	30	25	200	12	kero+ SiC	96.2
24	45	25	200	12	kero+ SiC	85.57
25	30	6	6	100	kero+ SiC	45.39
26	45	6	6	100	kero+ SiC	42.46
27	30	25	6	100	kero+ SiC	53.73
28	45	25	6	100	kero+ SiC	49.78
29	30	6	200	100	kero+ SiC	64.22
30	45	6	200	100	kero+ SiC	62.37
31	30	25	200	100	kero+ SiC	70.23
32	45	25	200	100	kero+ SiC	65.52
33	37.5	15.5	103	56	kero	59.5
34	37.5	15.5	103	56	kero+ SiC	64.77
35	37.5	15.5	103	56	kero	60.02
36	37.5	15.5	103	56	kero+ SiC	68.66
37	37.5	15.5	103	56	kero	58.42
38	37.5	15.5	103	56	kero+ SiC	69.87
39	37.5	15.5	103	56	kero	60.26
40	37.5	15.5	103	56	kero+ SiC	67.97

5. ANOVA FOR MRR PREDICTION MODEL

The ANOVA was carried out for a significance level of α = 0.05, i.e. for a confidence level of 95%. The ANOVA for MRR is summarized in Table.

Table 5.1 Resulting ANOVA table for MRR

Source	Sum of squares	Degree of freedom	Mean square	F-Value	p-value Prob > F
Model	6811.97	9.00	756.89	212.98	< 0.0001
A-Voltage	219.92	1.00	219.92	61.88	< 0.0001
B-Current	278.30	1.00	278.30	78.31	< 0.0001
C-Pulse on	3314.40	1.00	3314.40	932.64	< 0.0001
D-Pulse off	2133.51	1.00	2133.51	600.35	< 0.0001
E-type of dielectric	664.06	1.00	664.06	186.86	< 0.0001
BC	21.83	1.00	21.83	6.14	0.0190
CD	99.58	1.00	99.58	28.02	< 0.0001
CE	50.38	1.00	50.38	14.18	0.0007
DE	29.97	1.00	29.97	8.43	0.0068
Residual	106.61	30.00	3.55		
Lack of Fit	90.38	24.00	3.77	1.39	0.3616
Pure Error	16.24	6.00	2.71		
Cor Total	6918.58	39.00			

Std. Dev.	1.885	R-Squared	0.985
Mean	62.166	Adj R-Squared	0.980
C.V. %	3.032	Pred R-Squared	0.973
PRESS	185.205	Adeq Precision	59.386

The R^2 value is equal to 0.985 or close to 1, which is desirable. The adjusted R^2 value is equal to 0.98. The result shows that the adjusted R^2 value is very close to the ordinary R^2 value. Adequate precision value is equal to 59.386; a ratio greater than 4 is desirable which indicates adequate model discrimination.

Assumptions for ANOVA

To check the assumption of normal distribution, the normal probability plot of the residuals is shown in figure. The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally. The figure. represents residuals versus the predicted response plot for surface roughness. The figure shows that there is no obvious pattern and it shows unusual structure. This implies that there is no reason to suspect any violation of the independence or constant variance assumption.

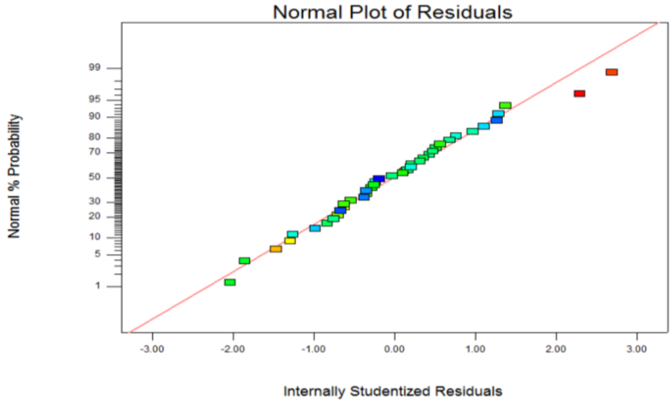

Figure 5.1 : Normal probability plot of residuals of MRR

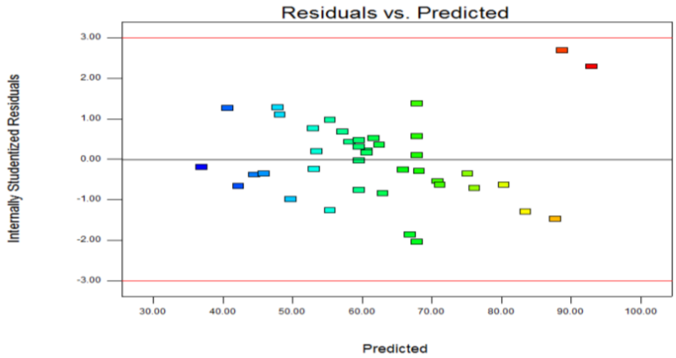

Fig 5.2: Plot of residuals v/s predicted MRR

A graph of the actual response values versus the predicted response values is shown in. The figure reveals that all the data points split evenly by the 45 degree line.

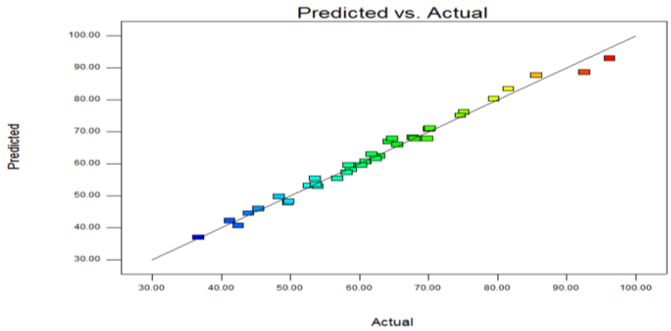

Figure 5.3: Plot of predicted v/s actual MRR

MRR prediction model

The regression model for MRR in terms of coded factors is shown as follows:

$$(MRR) = 62.17 - 2.62 * A + 2.95 * B + 10.18 * C - 8.17 * D + 4.07 * E - 0.83 * B * C - 1.76 * C * D + 1.25 * C * E - 0.97 * D * E$$

$$(MRR) = 62.25 - 0.35 * Voltage + 0.4 * Current + 0.13 * Pulse\ on - 0.121 * Pulse\ off - 0.0009 * Current * Pulse\ on - 0.0004 * Pulse\ on * Pulse\ off$$

The empirical models in terms of actual factors are shown by equation 4.5 and 4.6. Equation represented the relation between the EDM parameters and MRR with kerosene while equation represented the relation between the EDM parameters and MRR with kerosene +Si-C powder.

$$MRR) = 70.2 - 0.35 * Voltage + 0.4 * Current + 0.15 * Pulse\ on - 0.165 * Pulse\ off - 0.0009 * Current * Pulse\ on - 0.0004 * Pulse\ on * Pulse\ off$$

CONTRIBUTION OF EDM PARAMETERS ON MRR

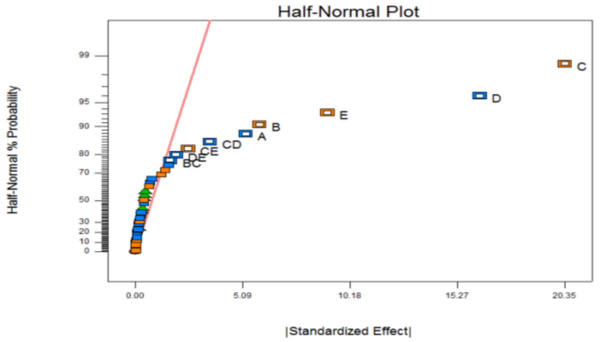

Figure 5.4: A half normal plot shows the effectiveness of the factors

The figure 5.4 shows the half normal plot, the extreme right side factor has the highest effect on the response, however as the dots corresponding to the particular factor comes nearer and nearer to the line, it shows these value affects the least. The value at the right extreme has the strongest effect on the surface roughness and keeps on decreasing as it comes nearer and nearer to the line.

EFFECT OF EDM PARAMETERS ON MRR

The figures shows the effect of voltage on metal removal rate at constant current (15.5 A), constant pulse on time (103 microseconds) and constant pulse off time (56 microseconds) with kerosene and with kerosene + SiC powder. From the figures, it is clear that the metal removal rate decreases as the voltage increases from 30 V to 45 V. With the higher voltage, the discharge time gets longer. This will lead to a wider average discharge gap. Therefore, MRR decreases as voltage increases.

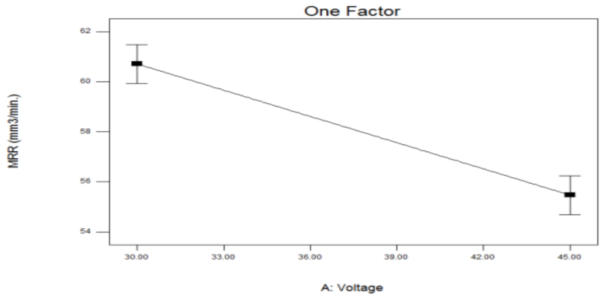

Figure 5.5: Plot between metal removal rate & voltage at current (15.5 A), pulse on time (103 microseconds) and pulse off time (56 microseconds) with kerosene

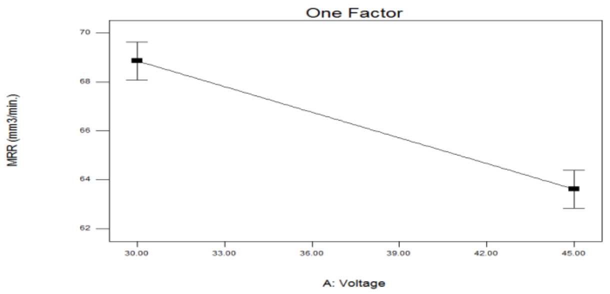

Figure 5.6: Plot between metal removal rate & voltage at current (15.5 A), pulse on time (103 microseconds) and pulse off time (56 microseconds) with kerosene + SiC powder

The effect of current on metal removal rate at constant voltage (37.50 Volts), constant pulse on time (103 microseconds) and constant pulse off time (56 microseconds) with kerosene and with kerosene + Si-C powder is shown in figures respectively. It has been revealed from the figures that as the current increases, the MRR also increases. The higher is the peak current, the larger is the discharge energy. This leads to increase in MRR.

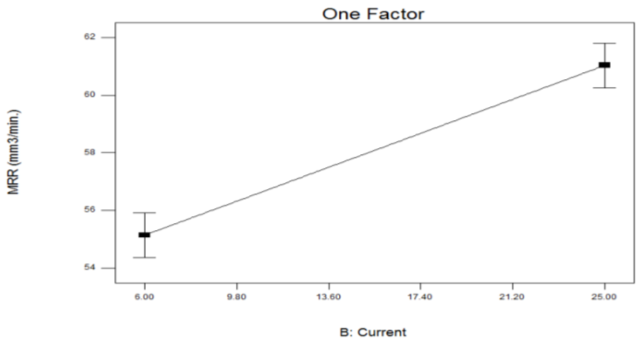

Figure 5.7: Plot between current and metal removal rate at voltage (37.50 Volts), pulse on time (103 microseconds) and pulse off time (56 microseconds) with kerosene

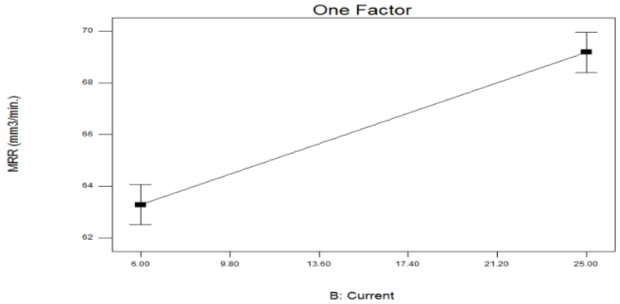

Figure 5.8: Plot between current and metal removal rate at voltage (37.50 Volts), pulse on time (103 microseconds) and pulse off time (56 microseconds) with kerosene + SiC powder

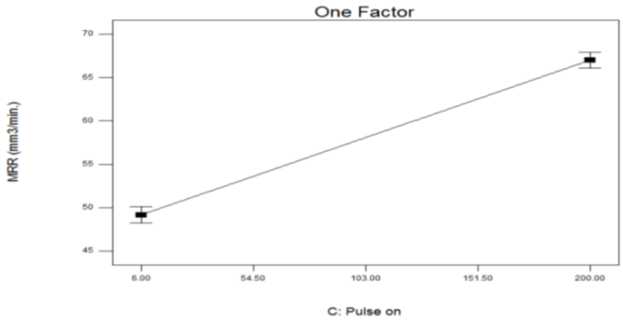

Figure 5.9: Plot between pulse on and surface roughness at voltage (37.50 Volts),current (15.5 A) and pulse off time (56 microseconds) with kerosene

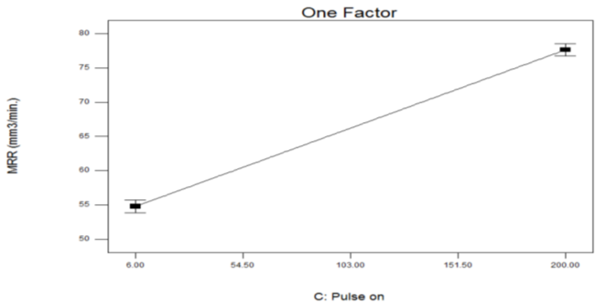

Figure 5.10 : Plot between pulse on and surface roughness at voltage (37.50 Volts), current (15.5 A) and pulse off time (56 microseconds) with kerosene + SiC powder

The figures shows the effect of pulse on time on metal removal rate at constant voltage (37.50 Volts), constant current (15.5 A) and constant pulse off time (56 microseconds) with kerosene and with kerosene+ SiC powder respectively. It is clear from the plots that as the pulse on time increases, the value of metal removal rate also increases. The metal removal rate is most affected by the amount of discharge energy which increases with increase in pulse on-time. Furthermore, greater discharge energy will produce a larger crater, causing a high metal removal rate.

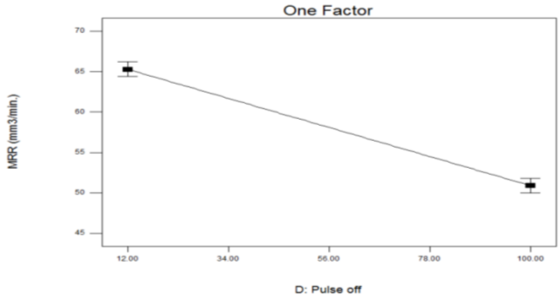

Figure 5.11: Plot between pulse on and metal removal rate at voltage (37.50 Volts), current (15.5 A) and pulse on time (103 microseconds) with kerosene

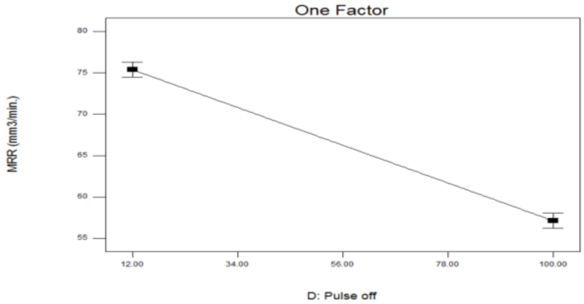

Figure 5.12: Plot between pulse on and metal removal rate at voltage (37.50 Volts),current (15.5 A) and pulse on time (103 microseconds) with kerosene + SiC

The effect of pulse off time on metal removal rate at constant voltage (37.50 Volts), constant current (15.5 A) and constant pulse on time (103 microseconds) with kerosene and with kerosene+ SiC powder is shown in figures respectively. The amount of discharge energy decreases with increase in pulse off-time. Further as the discharge energy decrease, the metal removal rate also decreases.

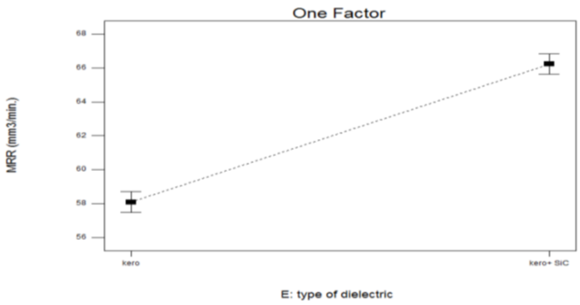

Figure 5.13 Plot between type of dielectric medium and metal removal rate at voltage (37.50 Volts), current (15.5 A), pulse off time (56 microseconds) and pulse on time (103 microseconds)

Figure shows the effect of SiC powder on MRR. From the figure it is clear that higher MRR obtained with SiC powder as compare to without SiC powder. Due to applied voltage, the powder particles become energized and behave in a zigzag fashion. These charged particles are accelerated due to the electric field and act as conductors promoting breakdown in the gap. This increases the spark gap between tool and the work piece. Under the sparking area, these particles come close to each other and arrange themselves in the form of chain like structures. The interlocking between the powder particles occurs in the direction of flow of current. The chain formation helps in bridging the discharge gap between the electrodes. Because of bridging effect, the insulating strength of the dielectric fluid decreases resulting in easy short circuit. This causes early explosion in the gap and 'series discharge' starts under the electrode area. The faster sparking within a discharge causes faster erosion from the work piece surface and hence the material removal rate increases.

Below are the 3d plots shown for the clear picture of MRR

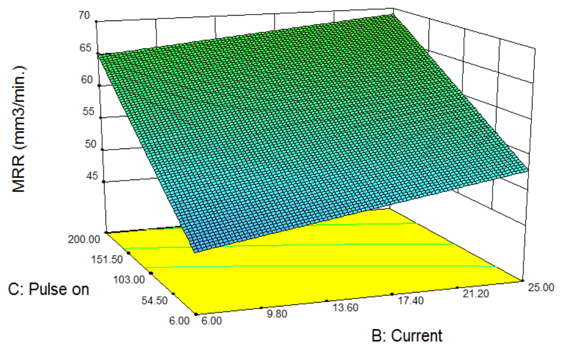

Figure 5.14: 3D plot between current and pulse on time for MRR with kerosene

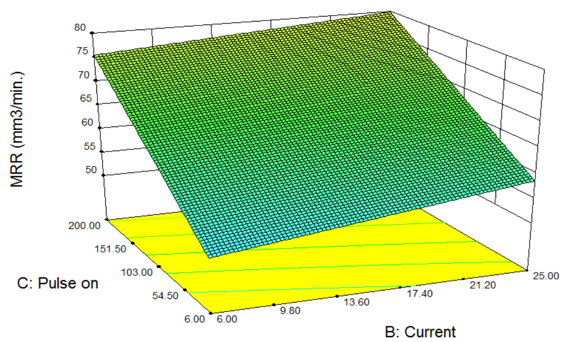

Figure 5.15 : 3D plot between current and pulse on time for MRR with kerosene +SiC powder

The figures show the 3 D plot for MRR between pulse on and current with kerosene and with kerosene +SiC powder respectively. From the 3D plots it is clear that MRR increase with increase in pulse on time, as well as with increase in current. The maximum MRR is achieved at maximum pulse on time, maximum current and with SiC powder.

The figures show the 3 D plot for MRR between pulse on and pulse off with kerosene and with kerosene+SiC powder respectively. From the 3D plots it is clear that MRR increase with increase in pulse on time, as well as with decrease in pulse off time. The maximum MRR is achieved at maximum pulse on time, minimum pulse off time and with SiC powder.

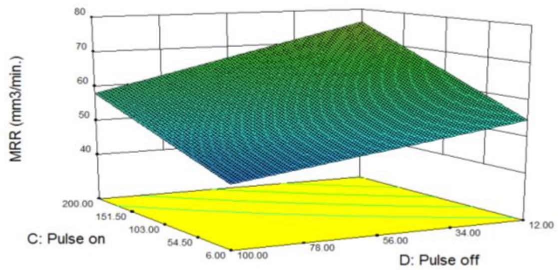

Figure 5.16 : 3D plot between pulse on time and pulse off

time for MRR with kerosene

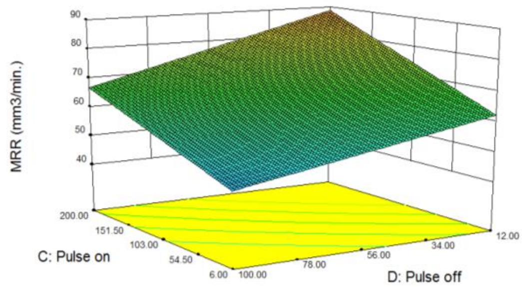

Figure 5.17 3D plot between pulse on time and pulse off time for MRR with kerosene + SiC powder

From all the 3D plots it is clear that maximum MRR is achieved at high level of current, high level of pulse on time, low level of voltage, low level of pulse off time and with SiC powder.

6. Optimization of EDM Parameters For Maximum Metal Removal Rate

In the present study, the aim is to obtain the optimal values of EDM parameters for maximum metal removal rate. The constraints used during the optimization process are summarized in Table 6.1.The optimal solutions are reported in table 6.2.

Table 6.1 Constraints for optimization of EDM Parameters.

Condition	Units	Goal	Lower limit	Upper limit
A:Voltage	Volts	Is in range	30	45
B:Current	Ampere	Is in range	6	25
C:Pulse on	Microseconds	Is in range	6	200
D:Pulse off	Microseconds	Is in range	12	100
E:type of dielectric		Is in range	Kerosene	Kerosene+SiC
Surface roughness	Microns	Minimize	2.315	10.237
MRR	mm3/min	Maximize	36.7	96.2

Table 6.2 Optimization results for MRR

Solution No.	A:Voltage (Volts)	B:Current (Ampere)	C:Pulse on (Microseconds)	D:Pulse off (Microseconds)	MRR (mm3/min)
1	30	25	200	12	93.31

Multi response optimization based on desirability Table 6.3 shows the constraints of input parameters. Table 6.3 gives the optimal input process parametric settings for multi response optimization. In which an optimal solution is obtained for the maximize MRR and minimized surface roughness which is desirable.

Table 6.3 Solutions for optimum settings of process inputs for confirmation of experiments

Voltage	Current	Pulse on	Pulse off	Type of dielectric	MRR	Desirability	
31.54	25	6	12	Kero+ SiC	68.03	0.579	selected

Once the optimal level of parameters is selected, the final step is to perform the experiments on the basis of these values & verify the improvements of the performance characteristics using the machining parameters. Experiments performed on machine for MRR & were compared with the optimal response values. Table 6.4 shows the percentage improvement for experimental validation of the developed model for the response of optimal parametric setting during machining of AISI D3 Die steel. From the analysis of the Table it can be clearly observed that the calculated error is small. The improvement between experimental & predicted values for MRR within 3.6%. Obviously it confirms the excellent reproducibility of the experimental conditions.

Table 6.4: Experimental validation of % improvement in MRR

Parameters	Values of parameter	Predicted	Experimental	% Improvement
Voltage	30	93.31	96.81	3.6
Current	25			
Pulse on	200			
Pulse off	12			
Dielectric	Kerosene + SiC			

7. CONCLUSION

The objective of the present work is to optimize EDM parameters for maximum MRR. An attempt has also been made to investigate the effects of the EDM parameters on surface roughness and MRR. Design of experiment using 2 level full factorial designs has been used to develop relationship for predicting MRR.

The maximum MRR 93.31 mm^3/min has been obtained at voltage 30 V, current 25 A, pulse on time 200 microseconds pulse off time 12 microseconds and with kerosene +SiC

Experiments were performed with predicted parametric values, predicted results are compared with experimental results shown in table 7.1

Table 7.1 Percentage improvement of the MRR

No. of Models	Predicted	Experimental	% Improvement
Model 2(MRR)	93.31	96.81	3.6

- The MRR prediction model clearly shows that the pulse on seems to be the most significant factor that affect the MRR.
- MRR increases with increase in pulse on time and current but decreases with increase in pulse off time and voltage.
- The addition of SiC powder in dielectric medium (Kerosene) increase MRR.

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