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OPTIMIZATION OF SURFACE ROUGHNESS IN ELECTRIC DISCHARGE MACHINING OF AISID3 STEEL USING SIC AS DIELECTRIC

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ABSTRACT

In manufacturing industries various processes are adopted for material removing due to increased demand for alloy materials. It is very difficult to progress with conventional machining processes as the direct contact between tool and workpiece often causes damages to the material. The solution to it is Non-conventional machining in which Electric Discharge Machining (EDM) also referred to as spark machining process is one of the most effective processes of machining. In today's era of global competition and technical growth where there is a strong need to of high quality and efficient products. Surface roughness is one of the critical and most effective parameter that affects several Mechanical properties, thus desired surface quality is of great importance for the functional behaviour of machines. It is also recognised that machining conditions affects the quality of the operation performed. Such parameters should be carefully selected so as to maximize the economics of manufacturing. D3 steel is widely used as a main material in die manufacturing industries where superior machinability is an important factor. in the present work the DOE(Design of Experiment) have been selected to optimize EDM parameters for minimizing surface roughness during machining of AISID3 steel with kerosene and kerosene with SiC.

KEYWORDS: Electrical Discharge Machining (EDM), ANOVA, DOE, RSM.

INTRODUCTION

Electrical discharge machining (EDM) is an electro thermal non-traditional process where material is removed with the help of electrical energy generating spark by a succession of electrical discharges occurring between the electrode and the work piece. The main advantage of this process is no direct contact between the electrode tool and the work piece. EDM is based on the principle 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 such as deionised water or kerosene

Mechanism of EDM:

The EDM process also known as spark erosion process as an electrical spark is created between the working electrode and work piece. The spark generated is visible evidence of the electricity flow. This flow produces intense heat and high temperature which can melt almost anything and almost every shape. The discharge created is with the help of dielectric liquid which spilled up of its molecules into ions and electrons. This discharge is created with the application of suitable voltage across the electrodes. The liberation of energy accompanying the discharge leads to continuous spark which is easily visible. This high temperature vaporization of metal. This leads to the formation of tiny crater at the point of discharge in the work piece.

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EDM Components:

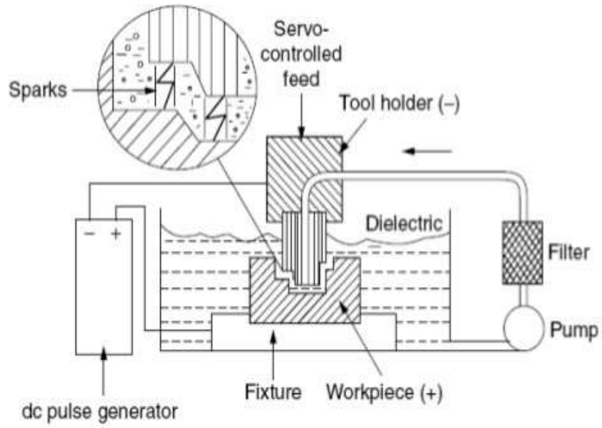

Figure 1.1 Schematic diagram of EDM Components

1. Servo controlled feed- It is a feed rate control device for controlling the feeding operation
2. Tool holder- It is used to hold the tool in position
3. DC pulse generator- It is used to supply the power in the form of pulse
4. Dielectric fluid tank- The dielectric used during the experiment is stored in it.
5. Fixture- Used to hold the work piece in position.
6. Filter- The dielectric after machine is again sent for the further process, filter cleans it from the residues.

EDM Parameters

Polarity:

It refers to the two opposite tendencies the polarity used in case of EDM is normal polarity which means the tool is set as negative and work piece as positive. Positive polarity can also be used depending upon the requirement i.e. where tool is positive and work piece is negative.

Pulse on Time:

The time period during which machining takes place. The pulse on time is the switch-on period of electrical charge to the capacitor bank and the charging current. Pulse on time is directly proportional to the material removed. Longer the pulse on time broader will be the crater and will give the better surface finish.

Pulse off Time:

Time during which re-ionization of dielectric takes place. As the medium must de-ionize before another spark can take place, and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low values of pulse off time may lead to short-circuits and arcing.

Peak Current:

Amount of power used in discharge machining, measured in Ampere.

Discharge Current:

It is the amount of power supplied to discharge gap. Higher current leads to a higher pulse energy and formation of deeper craters.

Electrode Material:

The shape of electrode will be basically same as that of the product is desired. The electrode materials are classified as metallic material (copper, brass, tungsten, aluminium), non-metallic material (graphite), combined metallic and non-metallic (copper-graphite), and metallic coating as insulators (copper on moulded plastic, copper on ceramic) etc [1]

LITERATURE REVIEW

A number of studies have been carried out to investigate and formulate the effect of machining condition for prediction of surface roughness and selection of optimal machining parameters during electric discharge machining. **Zhixin et. al. (1995)** proposed a technique (mechanical pulse electric discharge machining) to produce holes in the conductive hard and brittle materials. The ultrasonic vibration has been used to generate the spark in place of the conventional special pulse generator between the tool and work piece in mechanical pulse electric discharge machining (MPEDM). Ultrasonic vibration of the tool also acted as gap-flushing method.[2]. **Chow et. al. (1998)** studied the effect of studied the effect of different dielectric fluid on gap distance, expansion of slit, electrode wear, material removal depth, surface roughness for the micro-slit machining of Ti alloy by EDM[3]. **Pecas and Henriques, (2003)** investigated the effect of addition of powder particles in the dielectric fluid on the surface roughness of machined parts during the electrical discharge machining (EDM). The analysis is carried out varying the silicon powder concentration and the flushing flow rate over a set of different processing areas. The evaluation of process is done by surface morphologic analysis. The result revealed that with the addition of silicon powder in dielectric fluid there is reduction of crater dimensions (crater depth, crater diameter), white-layer thickness and surface roughness [4]. **Chow et. al. (2007)** employed SiC powder in water as dielectric for micro-slit EDM machining and Ti-6AL-4V (-) (Ti alloy) as work-piece and Cu Electrode. Results revealed higher MRR & low electrode wear. The dielectric pure water & SiC refines the surface roughness and high MRR[5]. **Chig (2008)** used response surface methodology to develop material removal rate, electrode wear and surface roughness prediction models in terms of EDM parameters and to investigate the effect of EDM parameters on material removal rate, electrode wear and surface roughness during the machining of Al2O3+Tic mixed ceramic[6]. **Saha and Choudhary (2009)** studied empirical modelling of the dry electric discharge machining using ANOVA technique to study the effect of gap voltage, discharge current, pulse on time & spindle speed on MRR, (Ra) surface roughness & tool wear[7].**krishna et. al. (2010)** used Taguchi parameter design to investigate the effect of WEDM parameters on surface roughness during the machining of titanium alloy[8].**Ashikur et. al. (2011)** used response surface methodology to develop first order surface roughness prediction model in terms of EDM parameters during the machining of Ti-6Al-4V using copper electrode retaining the negative polarity. The peak current, pulse on time and pulse off time have been considered as EDM parameters. The results revealed that as the pulse on time increases up to certain limit, the surface roughness decreases afterwards deteriorates in the surface finish has been appears[9].**Shashikant et. al. (2014)** investigated the parametric interactions and relationship between the controllable process variables to optimize the machining process for the response MRR (material removal rate) in die sinking EDM process on EN19 material using RSM (response surface methodology) and ANOVA technique. Result revealed that pulse off-time, discharge current, gap voltage and their interactions were significant whereas the pulse on-time had negligible effect for MRR and pulse on-time of 400μs, pulse off-time of 1600μs, current 15A and voltage of 40V will provide best MRR [10].

EXPERIMENTAL WORK

Selection of EDM Parameters and the Range Of EDM Parameters*:*

The process parameters that were chosen for experimentation are given as under:

1) Peak current
2) Pulse on time (μs)
3) Pulse off time (μs)
4) Voltage
5) Kerosene
6) Kerosene + SiC

Table 3.1 shows the levels of EDM parameters used and their levels

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

Table 3.1 EDM parameters used & their level

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.

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

Formation of Design Matrix:
In the present work two levels full factorial design has been used to plan the experiments. Total 40 numbers (20 with kerosene and 20 with kerosene + SiC powder) of experiments has been finalized according to two level full factorial design. Out of each 20 experiments, 16 are the factorial points and 4 are the centre points. The table 3.2 shows the design layout for experimentation.

S.No.	A:Voltage (volts)	B:Current (Ampere)	C:Pulse on (Microsecond)	D:Pulse off (Microsecond)	E:type of dielectric	Surface roughness (Microns)
1	30	6	6	12	kero	3.830
2	45	6	6	12	kero	3.537
3	30	25	6	12	kero	4.252
4	45	25	6	12	kero	3.684
5	30	6	200	12	kero	7.715
6	45	6	200	12	kero	6.476
7	30	25	200	12	kero	7.920
8	45	25	200	12	kero	7.307
9	30	6	6	100	kero	3.765
10	45	6	6	100	kero	2.316
11	30	25	6	100	kero	4.399
12	45	25	6	100	kero	2.863
13	30	6	200	100	kero	6.290
14	45	6	200	100	kero	4.777
15	30	25	200	100	kero	6.741
16	45	25	200	100	kero	5.140
17	30	6	6	12	kero+ SiC	4.852
18	45	6	6	12	kero+ SiC	4.212
19	30	25	6	12	kero+ SiC	5.247
20	45	25	6	12	kero+ SiC	4.569
21	30	6	200	12	kero+ SiC	9.723
22	45	6	200	12	kero+ SiC	8.059
23	30	25	200	12	kero+ SiC	10.237

24	45	25	200	12	kero+ SiC	9.198
25	30	6	6	100	kero+ SiC	4.840
26	45	6	6	100	kero+ SiC	2.836
27	30	25	6	100	kero+ SiC	5.499
28	45	25	6	100	kero+ SiC	3.520
29	30	6	200	100	kero+ SiC	7.855
30	45	6	200	100	kero+ SiC	5.958
31	30	25	200	100	kero+ SiC	8.320
32	45	25	200	100	kero+ SiC	6.342
33	37.5	15.5	103	56	kero	4.843
34	37.5	15.5	103	56	kero+ SiC	5.618
35	37.5	15.5	103	56	kero	4.494
36	37.5	15.5	103	56	kero+ SiC	5.524
37	37.5	15.5	103	56	kero	5.051
38	37.5	15.5	103	56	kero+ SiC	6.055
39	37.5	15.5	103	56	kero	4.739
40	37.5	15.5	103	56	kero+ SiC	6.170

Table3.2 Experimental work

DEVELOPMENT OF SURFACE ROUGHNESS PREDICTION MODEL

ANOVA for Surface roughness 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 surface roughness is summarized in Table 4.1. it shows that the value of "Prob. > *F*" for model is less than 0.0001 which is less than 0.05, that indicates the model is significant, which is desirable as it indicates that the terms in the model have a significant effect on the surface roughness.

Source	Sum of squares	Degree of freedom	Mean square	F-Value	p-value Prob > F
Model	139.52	8	17.44	185.69	< 0.0001
A-Voltage	13.38	1	13.38	142.45	< 0.0001
B-Current	2.10	1	2.10	22.35	< 0.0001
C-Pulse on	90.59	1	90.59	964.54	< 0.0001
D-Pulse off	11.71	1	11.71	124.68	< 0.0001
E-type of dielectric	15.00	1	15.00	159.75	< 0.0001
AD	1.63	1	1.63	17.36	0.0002
CD	3.83	1	3.83	40.75	< 0.0001
CE	1.28	1	1.28	13.62	0.0009
Residual	2.91	31	0.09		
Lack of Fit	2.45	25	0.10	1.26	0.4148
Pure Error	0.46	6	0.08		
Cor Total	142.43	39			

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Std. Dev.	0.306	R-Squared	0.98
Mean	5.619	Adj R-Squared	0.974
C.V. %	5.454	Pred R-Squared	0.968
PRESS	4.47	Adeq Precision	52.317

Table 3.3 Resulting ANOVA table for surface roughness

The value of "Prob. > *F*" for lack-of-fit is 0.4148 which is greater than 0.05 and it indicates the insignificant lack of fit. If the model does not fit the data well, this will be significant. The insignificant lack of fit is desirable.

The R^2 value is equal to 0.98 or close to 1, which is desirable. The adjusted R^2 value is equal to 0.974; it is particularly useful when comparing models with different number of terms. The result shows that the adjusted R^2 value is very close to the ordinary R^2 value. Adequate precision value is equal to 52.317; a ratio greater than 4 is desirable which indicates adequate model discrimination. Adequate precision value compares the range of the predicted values at the design points to the average prediction error.

Assumptions for ANOVA

The analysis of variance (ANOVA) is based on two assumptions: (1) the variables are normally distributed and (2) homogeneity of variance. Significant violation of either assumption can increase the chances of error.

To check the assumption of normal distribution, the normal probability plot of the residuals is shown in figure.3.1.The normal probability plot indicates whether the residuals follow a normal distribution or not, if the residuals follow a normal distribution majority of points will follow a straight line except some moderate scatter even with normal data. The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally.

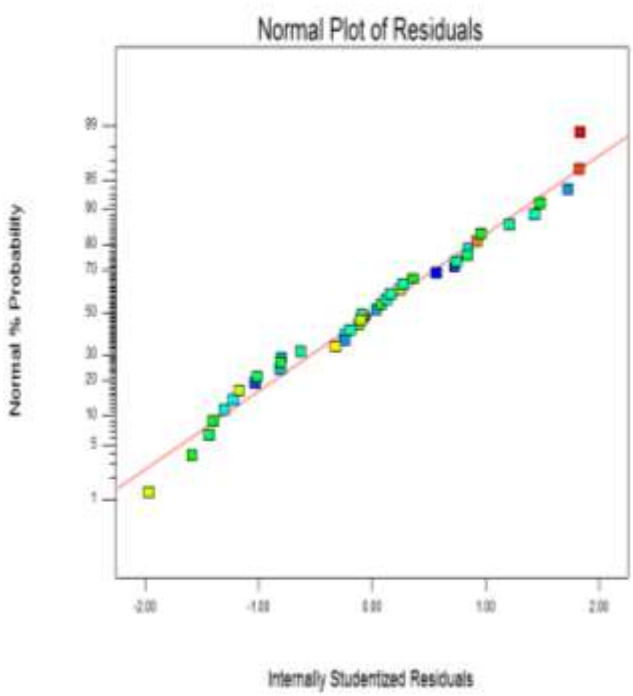

Figure 3.1 Normal probability plot of residuals for surface roughness

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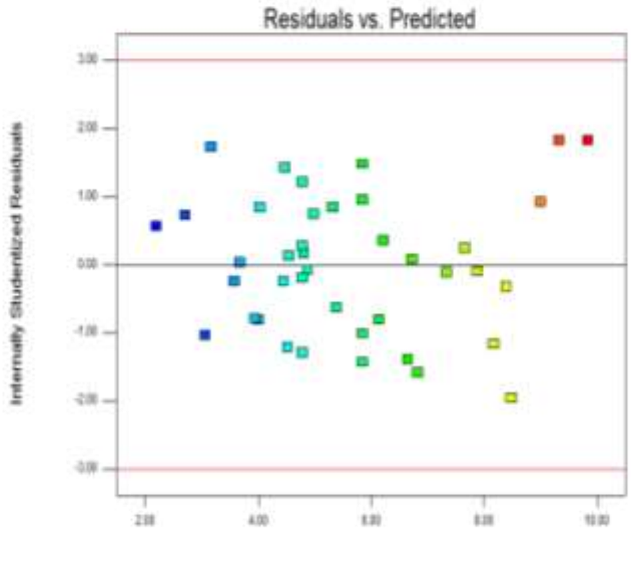

Figure 3.2 Plot of residuals v/s predicted surface roughness

A graph of the actual response values versus the predicted response values is shown in figure 3.3. The figure reveals that all the data points split evenly by the 45 degree line.

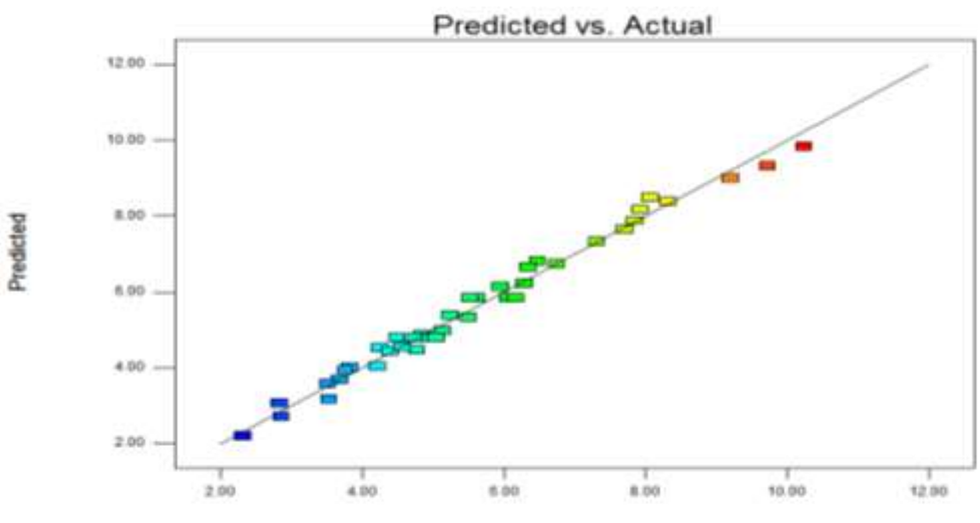

Figure 3.3 Plot of predicted v/s actual response

CONTRIBUTION OF EDM PARAMETERS ON SURFACE ROUGHNESS

The figure 3.4, 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.

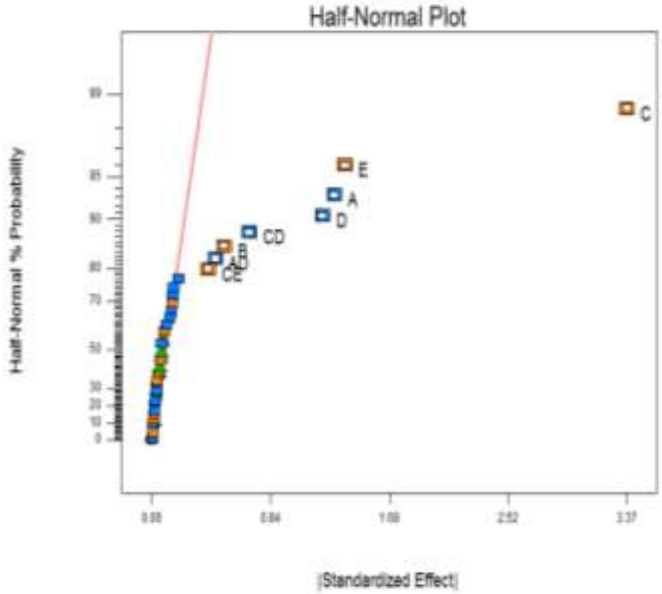

Figure 3.4: A half normal plot shows the effectiveness of the factors

EFFECT OF EDM PARAMETERS ON SURFACE ROUGHNESS

The effect of voltage on surface roughness at constant current (15.5 A), constant pulse on time (103 microseconds) and constant pulse off time (56 microseconds) with kerosene and kerosene +SiC powder are shown in figure 3.5 and 3.6respectively.

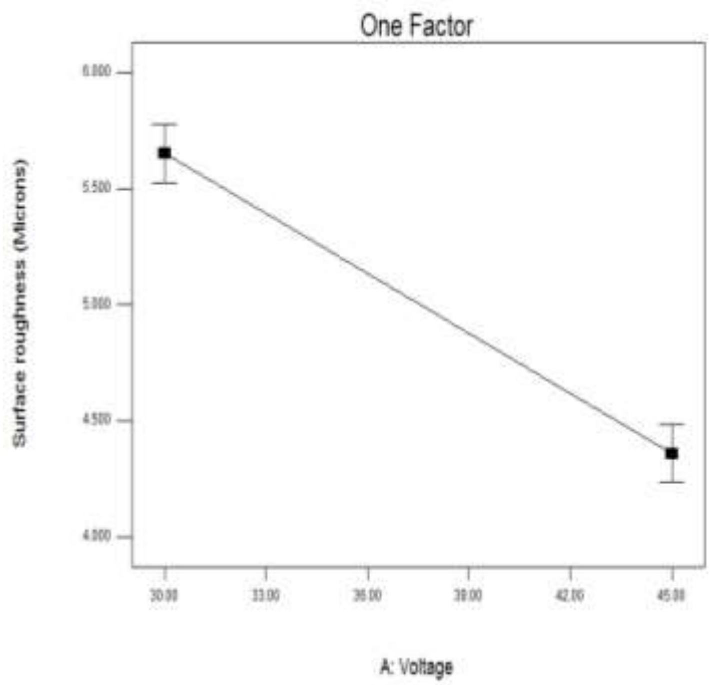

Figure 3.5. Plot between roughness & voltage at current (15.5 A), pulse on time (103 microseconds) and pulse off time (56 microseconds) with kerosene

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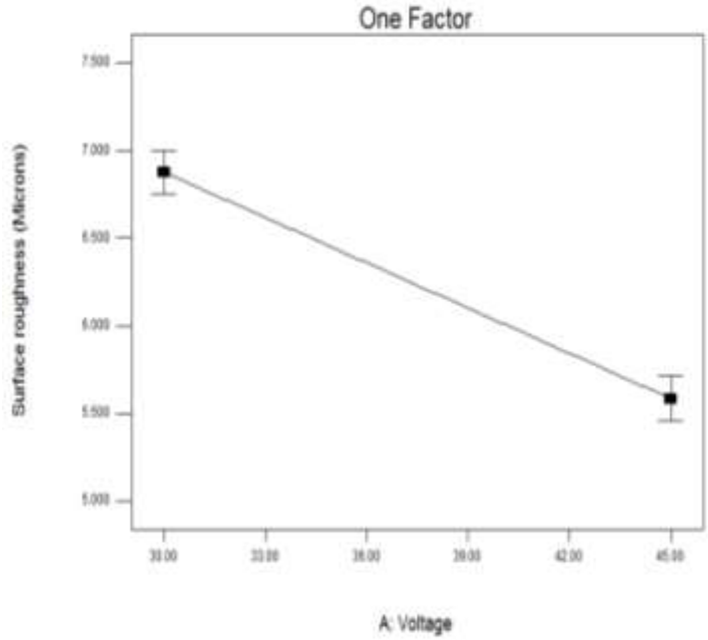

Figure 3.6. Plot between roughness & voltage at current (15.5 A), pulse on time* (103 microseconds) *pulse off time (56 microseconds) with kerosene +SiC powder

The plots show that the surface roughness decreases as the voltage increases. With the higher voltage, the discharge time gets longer. This will lead to a wider average discharge gap. Therefore, the discharge condition becomes more stable but the number of discharge cycles decreases within a given period. Owing to this stable machining, surface accuracy becomes better and surface roughness value decreases.

Figure 3.7 and 3.8 shows the effect of current on surface roughness at constant voltage (37.50 Volts), constant pulse on time (103 microseconds) and constant pulse off time (56 microseconds) with kerosene and kerosene +SiC powder respectively.

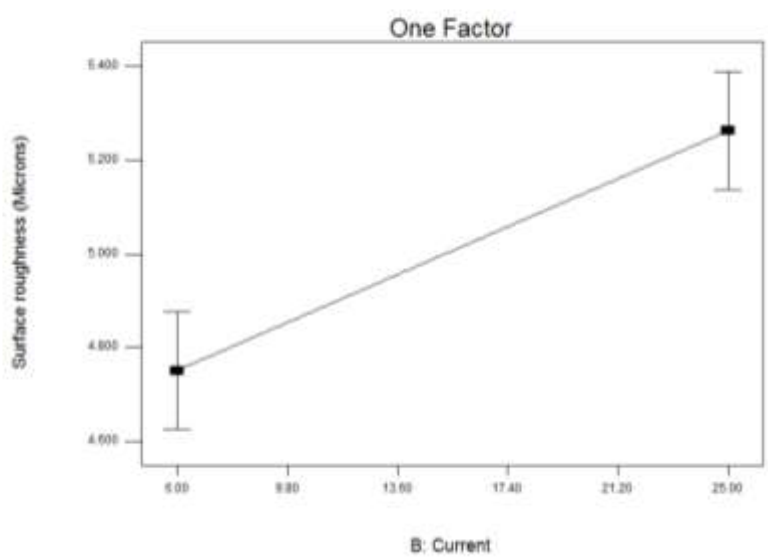

Figure 3.7 Plot between current and surface roughness at voltage (37.50 Volts), pulse on time (103 microseconds) and pulse off time (56 microseconds) with kerosene

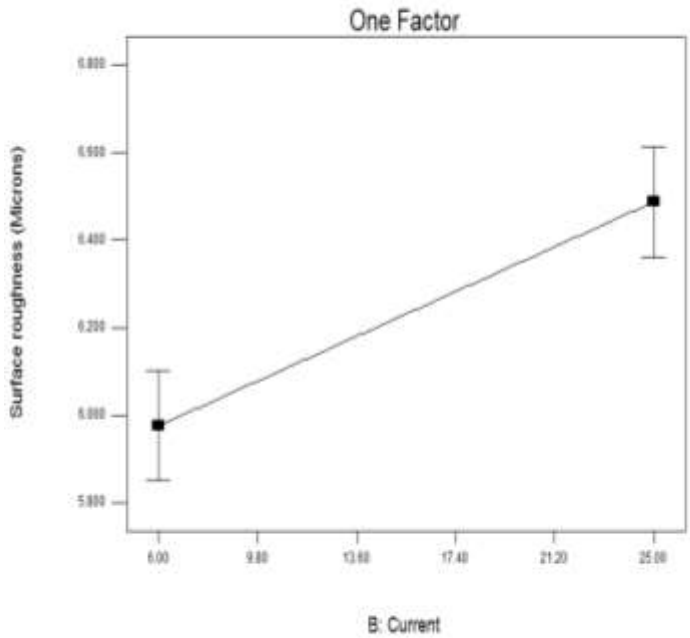

Figure 3.8 Plot between current and surface roughness at voltage (37.50 Volts) Pulse on time (103 microseconds) and pulse off time (56 microseconds) with kerosene +SiC powder

From the figures it is clear that as the current increases the surface roughness also increases. The higher is the peak current, the larger is the discharge energy. Large discharge energy creates craters, this leads to increase in surface roughness.

The effect of pulse on time on surface roughness at constant voltage (37.50 Volts), constant current (15.5 A) and constant pulse off time (56 microseconds) with kerosene and kerosene +Si-C powder is shown in figure 3.9 and 3.10

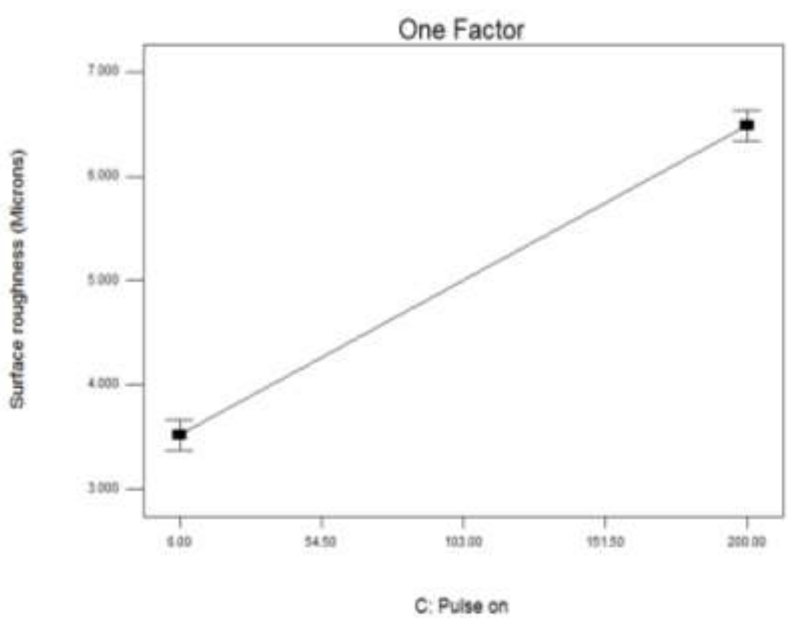

Figure 3.9 Plot between pulse on and surface roughness at voltage (37.50 Volts), Current (15.5 A) and pulse off time (56 microseconds) with kerosene

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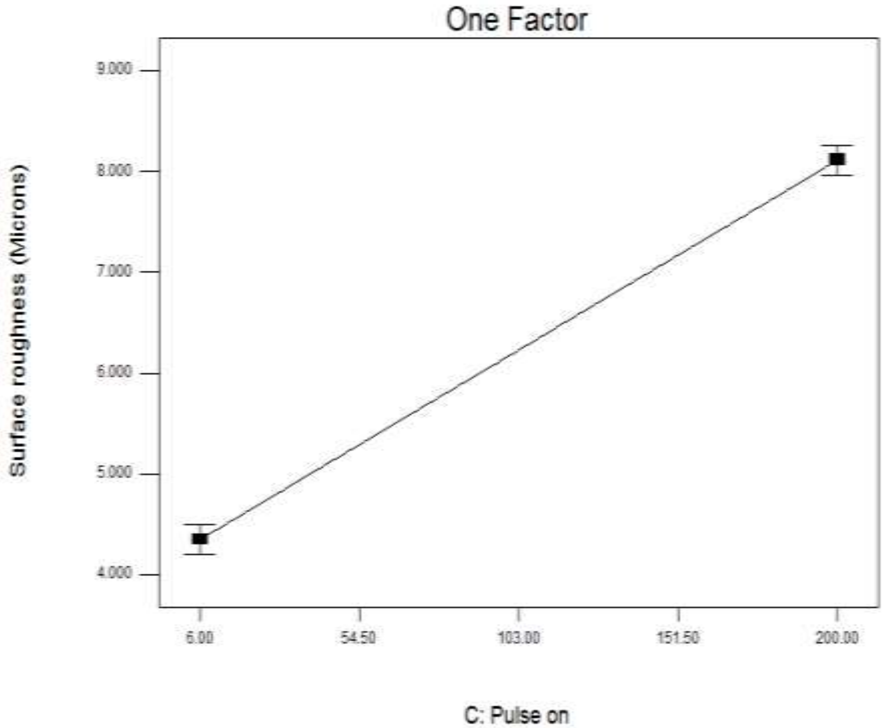

Figure 3.10 Plot between pulse on and surface roughness at voltage (37.50 Volts), current (15.5 A) and pulse off time (56 microseconds) with kerosene + SiC powder

It is clear from the plots that as the pulse on time increases from 6 microseconds to 200 microseconds, the value of surface roughness also increases. The surface roughness is most affected by the amount of discharge energy which increases with increase in pulse on-time. The surface roughness depends on the size of spark crater. A shallow crater together with a larger diameter leads to a better work piece surface roughness. To obtain a flat crater, it is important to control the electrical discharging energy at a smaller level by setting a small pulse-on time. A large discharging energy will cause violent sparks resulting in a deeper erosion crater on the surface. Accompanying the cooling process after the spilling of molten metal, residues will remain at the periphery of the crater to form a rough surface. Furthermore, greater discharge energy will produce a larger crater, causing a larger surface roughness value on the work piece.

The Influence of pulse off time on surface roughness at constant voltage (37.50 Volts), constant current (15.5 A) and constant pulse on time (103 microseconds) with kerosene and kerosene +SiC powder is shown in figure 3.11 and 3.12. The plots show that as the pulse off time increases, the surface roughness decreases. The amount of discharge energy decreases with increase in pulse off-time. Further as the discharge energy decrease, the roughness also decreases.

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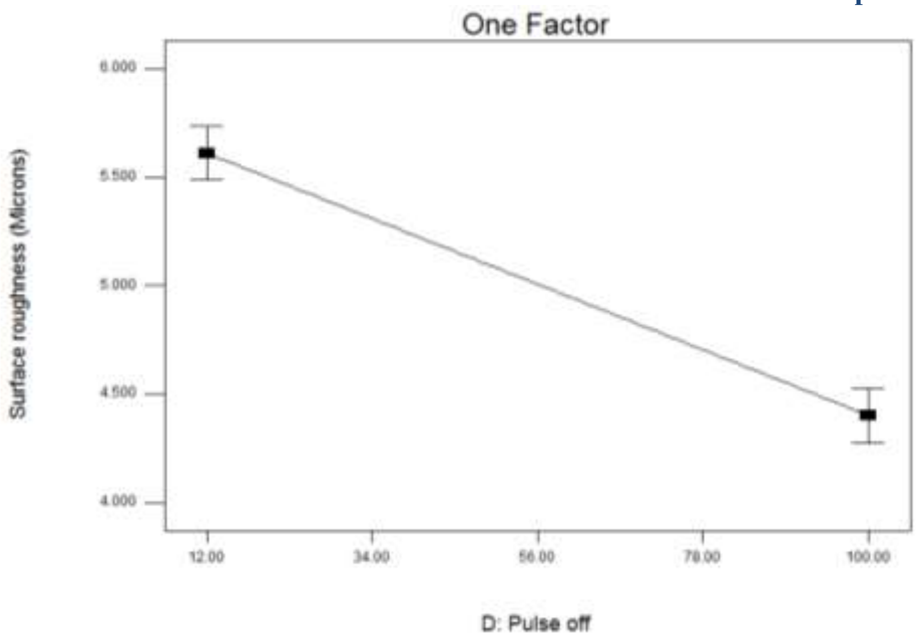

Figure 3.11 Plot between pulse on and surface roughness at voltage (37.50 Volts), current (15.5 A) and pulse on time (103 microseconds) with kerosene

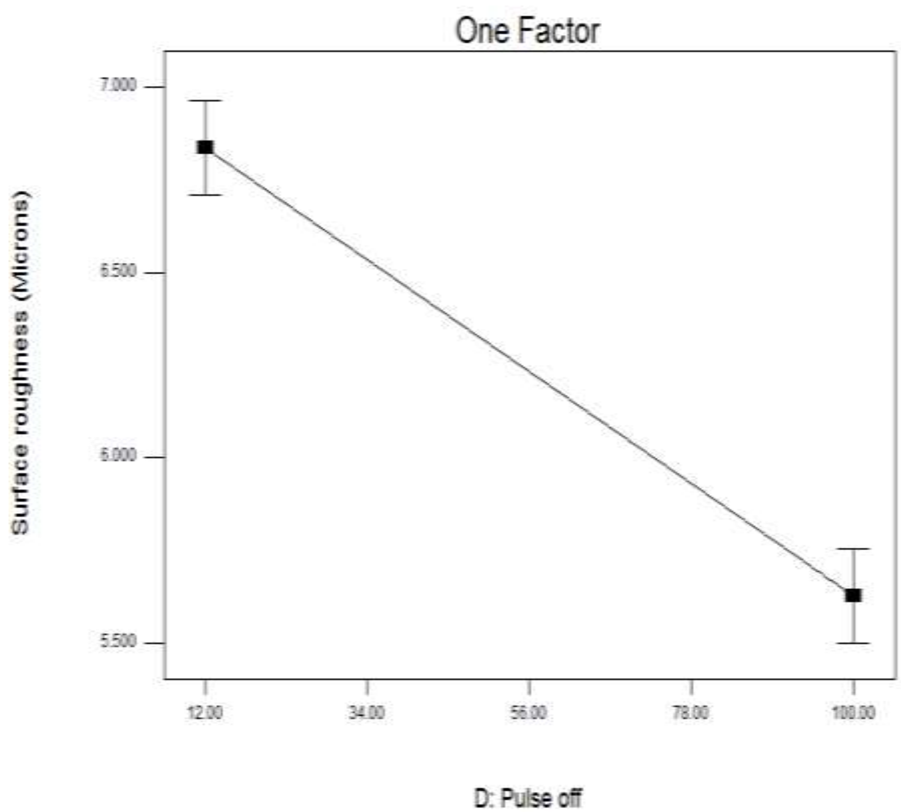

Figure 3.12 Plot between pulse on and surface roughness at voltage (37.50 Volts), current (15.5 A) and pulse on time (103 microseconds) with kerosene +SiC powder

Figure 3.13 shows the effect of SiC powder on surface roughness. From the figure it is clear that higher surface roughness obtained with SiC powder as compare to without SiC powder. Due to applied voltage, the powder particles become energized. These charged particles are accelerated due to the electric field and act as conductors promoting breakdown in the gap. the sparking area, these particles come close to each other and arrange themselves in the form of chain like structures. 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 a deeper erosion crater on the surface. Accompanying the cooling process after the spilling of molten metal, residues will remain at the periphery of the crater to form a rough surface.

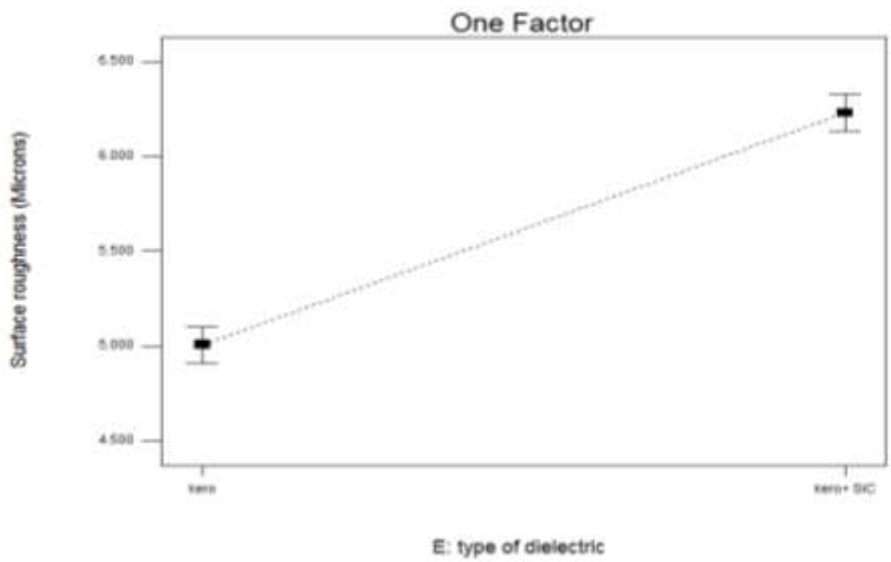

Figure 3.13 Plot between type of dielectric medium and surface roughness at voltage(37.50 Volts), current(15.5 A), pulse off time (56 microseconds) and pulse on time(103 microseconds)

The figure 3.14 and 3.15 shows the contour plot for surface roughness at constant current 15.5 A and pulse on time 103 microsecond with kerosene and with kerosene + SiC powder. The figures show the cumulative effect of voltage and pulse off time on surface roughness. From the contour plot it is clear that as the voltage increases the surface roughness decreases for any value of pulse off time. It is also visible that as the pulse off time increases the surface roughness decreases for any value of voltage.

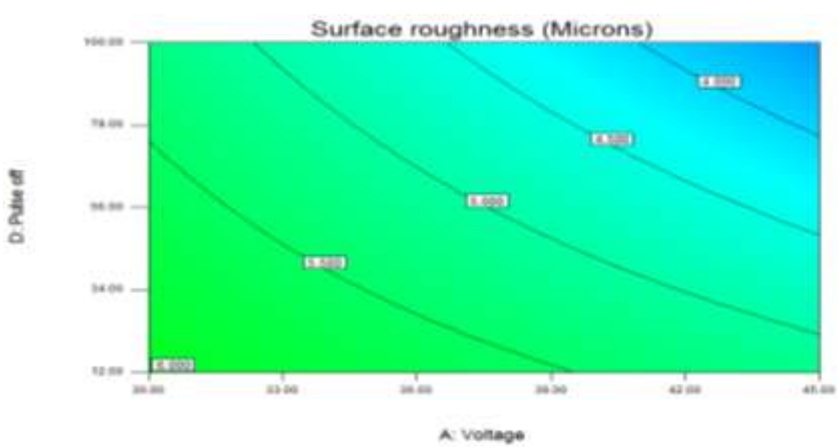

Figure 3.14 Contour plot between voltage and pulse off time for surface roughness at constant current 15.5 A and pulse on time 103 microsecond with kerosene

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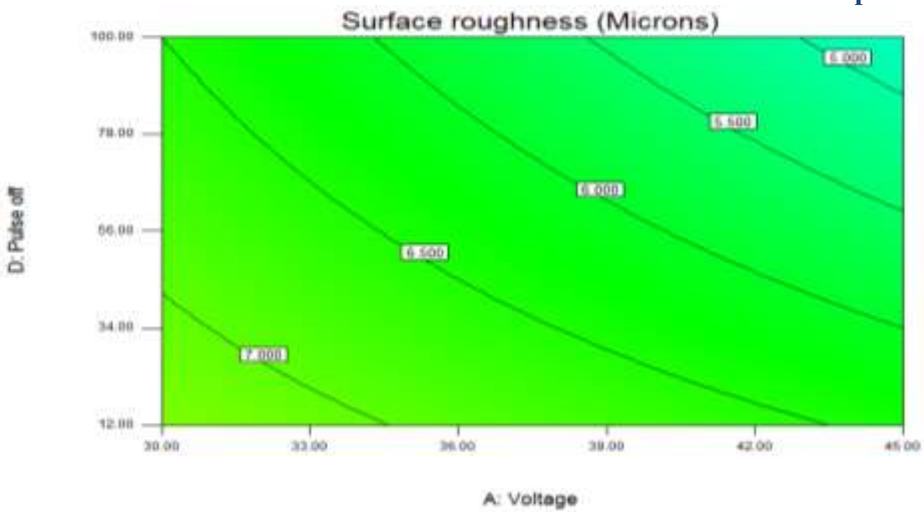

Figure 3.15 Contour plot between voltage and pulse off time for surface roughness At constant current 15.5 A and pulse on time 103 microsecond with kerosene + SiC Powder

The figure 3.16 and 3.17 shows the contour plot between pulse on time and pulse off time for surface roughness at constant voltage 37.5 V and constant current 15.5 A with kerosene and with kerosene + SiC powder respectively. The figures show the cumulative effect of pulse on time and pulse off time on surface roughness. From the contour plot it is clear that as the pulse on time increases the surface roughness also increases for any value of pulse off time. It is also visible that as the pulse off time increases the surface roughness decreases for any value of pulse on time.

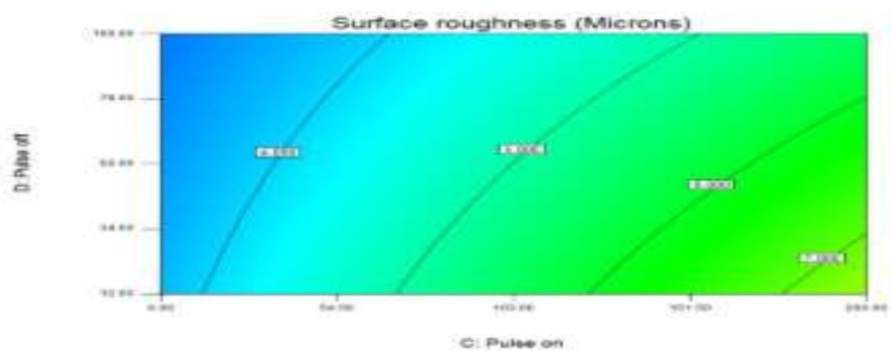

Figure 3.16 Contour plot between pulse off time and pulse on time for surface roughness at constant voltage 37.5 V and constant current 15.5 A with kerosene

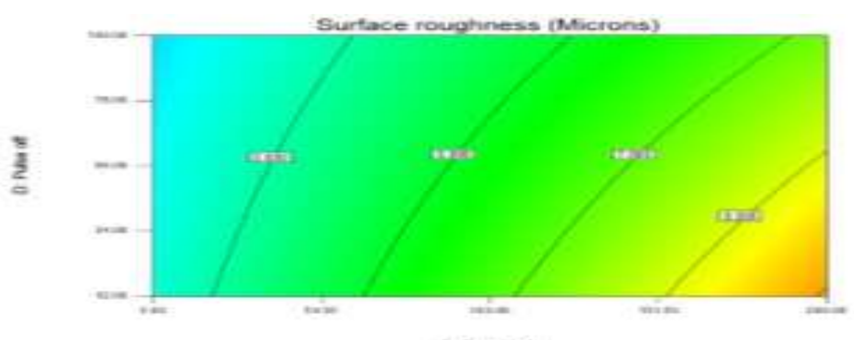

Figure 3.17 Contour plot between pulse off time and pulse on time for surface roughness at constant voltage 37.5 V and constant current 15.5 A with kerosene + SiC powder

Figure 3.18 shows the Interaction plot between type of dielectric medium and pulse on time for surface roughness at constant voltage 37.5 V, constant pulse off time 56 microsecond and constant current 15.5 A. The red line shows the graph between pulse on and surface roughness when dielectric medium is kerosene while green line shows the graph between pulse on and surface roughness when dielectric medium is kerosene with SiC powder. From the interaction plot it is clear that as the pulse on time increases the surface roughness also increases at both dielectric medium i.e kerosene and kerosene with SiC powder. It is also visible from the plot that for every value of pulse on time, the surface roughness is higher with kerosene with SiC powder as compare to kerosene.

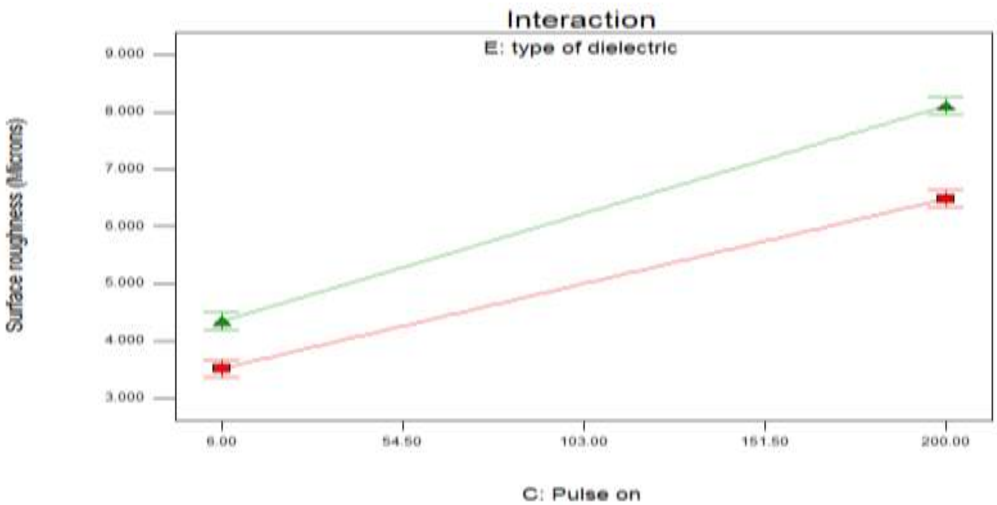

Figure 3.18 Interaction plot between type of dielectric medium and pulse on time for surface roughness at constant voltage 37.5 V, constant pulse off time 56 microsecond and constant current 15.5 A

The figures 3.19 and 3.20 show the 3 D plot for surface roughness between voltage and pulse off time with kerosene and with kerosene +SiC powder respectively. From the 3D plots it is clear that surface roughness decreases with increase in voltage as well as with increase in pulse off time. The minimum surface roughness is achieved at maximum pulse off time, maximum voltage and without SiC powder.

The figures 3.21 and 3.22 show the 3 D plot for surface roughness between pulse on and pulse off time with kerosene and with kerosene +SiC powder respectively. From the 3D plots it is clear that surface roughness decreases with increase in pulse off time as well as with decrease in pulse on time. The minimum surface roughness is achieved at maximum pulse off time, minimum pulse on time and without SiC powder.

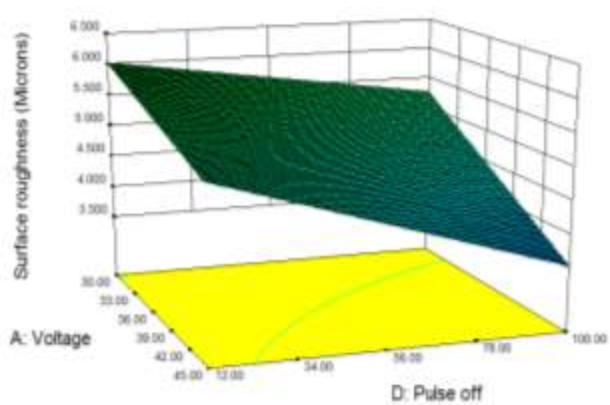

Figure 3.19 3D plot between voltage and pulse off time with kerosene

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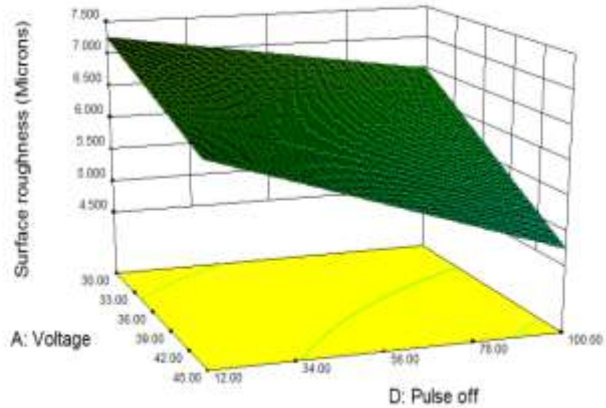

Figure 3.20 3D plot between voltage and pulse off time with kerosene +SiC powder

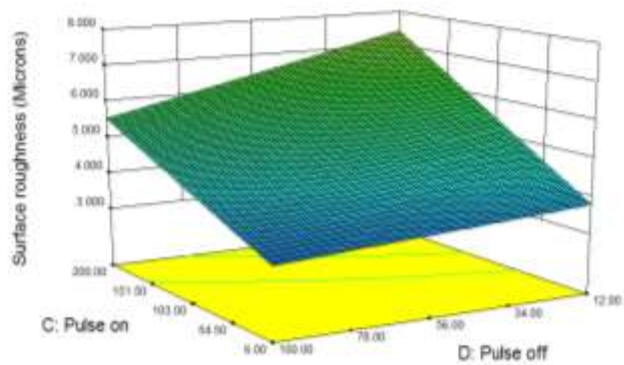

Figure 3.21 3D plot between pulse on time and pulse off time with kerosene

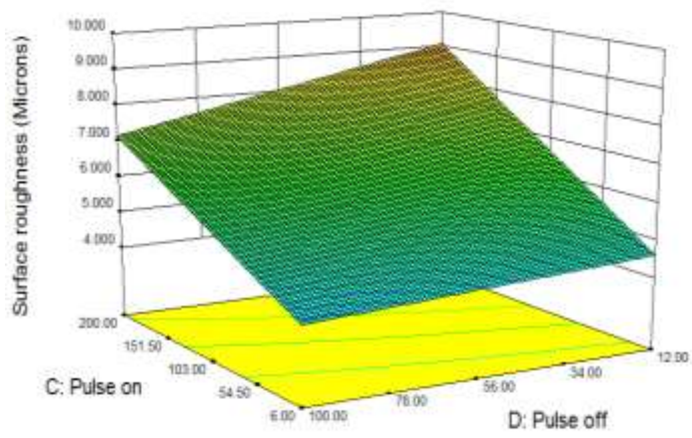

Figure 3.22 3D plot between pulse on time and pulse off time with kerosene +SiC

From all the 3D plots it is clear that minimum surface roughness is achieved at low level of current, low level of pulse on time, high level of voltage, high level of pulse off time and without SiC powder.

OPTIMIZATION OF EDM PARAMETERS FOR MINIMUM SURFACE ROUGHNESS

In the present study, the aim is to obtain the optimal values of EDM parameters for minimum surface roughness and maximum metal removal rate. The constraints used during the optimization process are summarized in Table 3.4

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 3.4 Constraints for optimization of EDM parameters

Solution No.	A:Voltage (Volts)	B:Current (Ampere)	C:Pulse on (Microseconds)	D:Pulse off (Microseconds)	Surface roughness (Microns)
1	45.00	6.00	6.00	100.00	2.137

Table 3.5 Optimization results for surface roughness

Multi response optimization based on desirability

Table 3.6 shows the constraints of input parameters. Table 3.6 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.

Exp. No	Voltage	Current	Pulse on	Pulse off	Type of dielectric	Surface roughness	Desirability	
1	31.54	25	6	12	Kero+ SiC	5.199	0.579	selected

Table 3.6 Solutions for optimum settings of process inputs for confirmation of

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 surface roughness & were compared with the optimal response values. Table 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 surface roughness within 5.8%. Obviously it confirms the excellent reproducibility of the experimental conditions.

Parameters	Values of parameter	Predicted	Experimental	% Improvement
Voltage	45	2.137	2.011	5.8
Current	6			
Pulse on	6			
Pulse off	100			
Dielectric	kerosene			

Table 3.7 Experimental validation of % improvement in Surface roughness

CONCLUSION AND FUTURE SCOPE

Following are the conclusions yielded fro, the research done

1) The minimum surface roughness 2.137 microns has been obtained at voltage 45 V, current 6 A, pulse on time 6 microseconds pulse off time 100 microseconds and with kerosene as dielectric medium
2) The two models for Surface Roughness & MRR are then optimized for minimum surface roughness and maximum MRR which resulted in the third model.

3) From the multi response optimization, the optimal combinations of parameter settings are Voltage -31.54 V, Current- 25 A, pulse on 6(microseconds), pulse off 12(microseconds), dielectric Kero + SiC for achieving the required minimum surface finish
4) The surface roughness prediction model clearly shows that the pulse is the most significant factor that affects the surface roughness.

In the present research only two parameters have been studied in accordance with their effects. In view of future scope, the further researches can be carried out as:

1) Effect of SiC as dielectric in EDM can be analyzed by varying its concentration in dielectric.
2) Performance characteristics on same work piece after different heat treatment processes can be analyzed.
3) To study the effect of output factors like power consumption, tool life etc. can be studied.
4) Optimization and analysis of other EDM parameters.

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