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EFFECT OF MACHINING PARAMETERS ON THE MATERIAL REMOVAL RATE OF AISID3 DIE STEEL USING ELECTRIC DISCHARGE MACHINING (EDM)

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ABSTRACT

Electric discharge machining is a thermal energy method used to remove the material by melting & evaporation of tiny particles aided by cavitation and widely used in die making process. The area of research work is to study the effect of machining parameters like voltage, current, pulse on-time & pulse off-time on the material removal rate of AISID3die steel using kerosene as die-electric fluid and copper as an electrode by EDM. The experiment was designed using DESIGN EXPERT software, response surface methodology with Central composite design and analyzed using ANOVA analysis. It is found that as voltage increases MRR decreases, I_P *increases MRR increases slightly,* T_{ON} *increases MRR increases and* T_{OFF} *increases MRR decreases. And maximum MRR was 71.16mm*^{3}*/min at voltage of 37.50V, current value of 15.50A, pulse on-time of 200µs & pulse off-time of 56µs. we found that pulse on-time is most significant parameter to affect MRR within the range of 6-25A & 30-45V.*

KEY WORDS: *EDM, DESIGN EXXPERT, RSM, CCRD, MRR, pulse on/off*

1. INTRODUCTON

In the modern era, new materials which are having high strength- to-weight ratio, heat resistant, resist to corrosion, high hardness & toughness have been developed to meet the current demand of many industries like aerospace & public welfare industries.

Electric discharge machining was come to in existence in 1770s by English Scientist Joseph Priestly. Initially, it was used for metal working industry as a viable method. In the mid 1980s it was applied to machine tool which made it widely available and better compare to traditional machining process. Problem related to complexity of the products, their accuracy & finish can be resolved through this non conventional techniques. EDM is a non-conventional thermo-electric machining process used for all conductive materials & steels. It is widely used in die making. Generally, EDM oil and kerosene is used while machining by EDM but it provides glossy mirror like finish when fine powder like graphite, silicon, silicon carbide is mixed into the dielectric fluid (Wong et. al., 1997). Al or Sic powder mixed EDM increases material removal depth and surface finish. Sic powder mixed EDM provides better material removal depth than Al added to kerosene but Al powder mixed EDM is the best among the three to obtain superior surface finish while only kerosene gives lowest MRD and electrode wear rate (Chow et.al., 1998). Machining efficiency of the powder mixed EDM can be optimized by increasing peak current and reducing pulse width (Zhao et.al., 2002). Wire cut EDM can be used for cutting AISI4140 using brass electrode which shows crater size increases with the increase in pulse duration, open circuit voltage and wire speed while crater size decreases with the increase in die-electric flushing pressure (Tousun et.al., 2003). Material removal rate can be increased by increasing peak current and pulse on-time using Taguchi design when EDM is performed on Al-Sic mixed composites (Singh et.al., 2004). Material removal rate can be increased by mixing Sic powder in the dielectric fluid by the combination of high peak current and high concentration using response surface methodology (Kansal et.al., 2005). And this mixing gives maximum MRR for AISID2 die steel at 10A current, 4g/l powder concentration, 100µs pulse on-time, 15µs pulse off-time using Taguchi technique and ANOVA analysis (Kansal et.al., 2007). Sic mixed in water as die-electric fluid also provides higher MRR and surface finish on Ti alloy using Cu electrode in EDM (Chow et.al., 2007). MRR increases with peak current, pulse on-time and gap voltage for a certain value of Sic%, after that MRR decreases with the increase in Sic concentration (Habib et.al., 2009). 3D form tool is the best shape for the electrode for higher MRR (Ojha et.al., 2010). Copper, Al and brass are the tools used for electrode in EDM but Cu is best among three for highest MRR followed by Al and finally brass (Banker et.al., 2013).

We performed the experiment on AISID3 die steel using kerosene (dielectric fluid) and Copper (electrode) by electric discharge machining (EDM). The experiment was designed on DESIGN EXPERT software. Response surface methodology (RSM) with central composite rotable design (CCRD) is used with analysis of variance (ANOVA) to optimize the EDM parameters to achieve maximum value of material removal rate (MRR).

1.1 EDM PRINCIPLE

Electric discharge machining is a thermo-electric process which erodes the metal by melting and vaporization of tiny particles of the specimen aided by cavitation. In which both tool and work-piece are submerged in the dielectric fluid. Proper gap is maintained between tool & work-piece with the help of servo system. When the voltage across the gap becomes high enough it discharges spark through the gap which results in acceleration of ions & electrons producing the conductive discharge channel. A sudden drop of electric resistance creates powerful magnetic field due to increase in ionization. As the spark develops the sufficient pressure produced between work and tool, results in high pressure & temperature that removes metal by melting erosion. This cycle goes on working time and then electrode is raised for uplift time T for good flushing.

In our case, material is AISID3 die steel, electrode (tool) is Cu & die-electric fluid is kerosene. die sinking type EDM is used in our experimental work.And the gap of 0.025mm is maintained. Then, current is supplied by the power unit and machining parameters which are voltage (V), current (I_P), pulse on-time (T_{ON}) & pulse off-time (T_{OFF}) in our case are optimized to achieve maximum material removal rate. We have work-piece of width 50mm and depth 15mm.Cylindrical Cu electrode of diameter 12mm.

Our objective is to make the holes in the work-piece of 12mm diameter and up to 8mm depth by electric discharge machining and to achieve maximum MRR by optimizing machining parameters. EDM working principle can be shown by the diagram below-

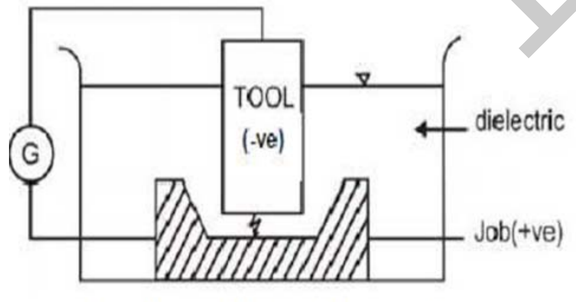

Figure 1.1: working principal of electric discharge machining

1.2 METHODOLOGY

We used DESIGN EXPERT software to design the experiment which designs the experimental runs according to the range of the factors and provides different design like Full Factorial, Taguchi-design, response surface methodology (RSM), etc. to achieve your objective i.e. to maximize or minimize the response.

We used response surface methodology (RSM) which is the best method among others because it tells us % contribution of each factor on the response and their interaction effect on the response by the help of interaction curves, contour plots, 3D-surface and CUBE very precise & accurately. Central composite rotable design (CCRD) is used to design the experiment as the point are equally spaced around the circle in the rotable design and it gives perfect idea of the system. According to CCRD design, if the number of factors is K then 2^K is the corner points, 2K axial points and centre point to allow the turning parameters of second order polynomial.

2. EXPERIMENTAL WORK

From the DESIGN EXPERT software, we designed the experimental runs according to the CCRD design and RSM approach. Machining parameters which are taken into account are voltage (V), current (I_P), pulse on-time (T_{ON}), pulse off-time (T_{OFF}) and the objective is to optimize these parameters to achieve maximum MRR.

CCRD design involves 2^N factorial points, 2N axial points & 1centre points where N denotes number of factors.

Thus, we had 30 experiments or runs in the design matrix with 6 repeatable values to check the errors.

After getting design matrix, we performed the experiment on electric discharge machine (EDM) according to the run order of the matrix which can be easily seen by the diagram below-

Figure 2.1: electric discharge machine

2.1 WORK-PIECE, ELECTRODE & DIE-ELECTRIC FLUID PROPERTIES

In this experiment, work-piece used was AISID3 die steel having following chemical composition –

Table 2.1: chemical composition of work-piece

C%	Si%	Mn%	Cr%	Cu%	W%	V%	Fe%
1.88	0.5	0.38	11.5	0.16	1	1	rest

Figure 2.2: work-piece after machining by EDM

In this experiment cylindrical shaped Cu tool of 12mm diameter was used that has following chemical composition-

Table 2.2: chemical composition of electrode or tool

Cu	Zn	Al	Bi	Pb
99.8%	0.057%	0.15%	0.0011%	0.0008%

While die-electric fluid was kerosene having following property shown below by the table

Table 2.3: property of kerosene used

Surface tension (N/m)	Density (kg/m^3)	Dynamic viscosity
0.028	820	2400

Figure 2.3: kerosene used as dielectric fluid in EDM

2.2 DESIGN MATRIX & MRR CALCULATION

Factors and their ranges used to build the design matrix are as follows-

Table 2.4: Factors and range

S.N.	FACTORS	RANGE
1	Voltage (V)	30-45V
2	Current (I_P)	6-25A
3	Pulse on-time (T_{ON})	6-200μs
4	Pulse off-time (T_{OFF})	12-100μs

From the design matrix, we performed the experiment according to run order and time was calculated for each & every run to drill the hole of size 12*8mm into the work-piece by EDM.
Material removal rate is calculated by-
MRR= volume of the material removed / time taken
Design matrix after taking observations of time taken and calculating material removal rate is shown below by the table.

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Table 2.5: design matrix for material removal rate

STD	RUN	VOLTAGE	CURRENT	PULSE ON-TIME	PULSE OFF- TIME	MRR
21	1	37.5	15.5	6	56	31.64
16	2	41.25	20.25	151.5	78	52.73
19	3	37.5	6	103	56	39.36
7	4	33.75	20.25	151.5	34	66.37
5	5	33.75	10.75	151.5	34	64.08
24	6	37.5	15.5	103	100	30.84
13	7	33.75	10.75	151.5	78	55.23
10	8	41.25	10.75	54.5	78	30.84
4	9	41.25	20.25	54.5	34	42.21
18	10	45	15.5	103	56	36.36
17	11	30	15.5	103	56	58.39
23	12	37.5	15.5	103	12	46.65
29	13	37.5	15.5	103	56	42.86
25	14	37.5	15.5	103	56	43.22
2	15	41.25	10.75	54.5	34	36.59
8	16	41.25	20.25	151.5	34	51.93
6	17	41.25	10.75	151.5	34	50.78
3	18	33.75	20.25	54.5	34	47.23
12	19	41.25	20.25	54.5	78	31.75
27	20	37.5	15.5	103	56	41.93
15	21	33.75	20.25	151.5	78	57.49
11	22	33.75	20.25	54.5	78	35.87
28	23	37.5	15.5	103	56	45.53
20	24	37.5	25	103	56	44.54
22	25	37.5	15.5	200	56	71.16
30	26	37.5	15.5	103	56	42.46
9	27	33.75	10.75	54.5	78	30.77
1	28	33.75	10.75	54.5	34	45.98
26	29	37.5	15.5	103	56	46.52
14	30	41.25	10.75	151.5	78	48.54

From this matrix, we found material removal rate in the range of 30.77mm^3/min to 71.16mm^3/min at two different settings.

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3. ANALYSIS FOR RESPONSE (MRR)

After calculating MRR, result was analyzed using analysis of variance (ANOVA) which tells us about the significance of the model. For this, ANOVA table which is formed by the DESIGN EXPERT software for our response (material removal rate) is analyzed where analysis of significant and non-significant term is carried out. Lack of fit is checked as it is the undesirable points for the model so non-significant lack of fit is desirable and good for fitting the model.

Table 3.1: Reduced ANOVA for material removal rate

ANOVA for Response Surface Reduced Quadratic model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3272.85	10	327.2845604	84.3519	< 0.0001	significant
A-Voltage(V)	431.039	1	431.0385042	111.093	< 0.0001	
B-Current(Ip)	45.7332	1	45.73320417	11.7869	0.00279	
C-Pulse-on Time(Ton)	2108.44	1	2108.437604	543.413	< 0.0001	
D-Pulse-off Time(Toff)	364.806	1	364.8060375	94.0224	< 0.0001	
AC	26.8583	1	26.85830625	6.92226	0.01646	
AD	44.3889	1	44.38890625	11.4405	0.00313	
CD	34.8395	1	34.83950625	8.97928	0.00742	
A^2	43.2079	1	43.20793951	11.1361	0.00346	
C^2	141.559	1	141.5588145	36.4843	< 0.0001	
D^2	23.456	1	23.45602701	6.04538	0.02371	
Residual	73.7198	19	3.879990163			
Lack of Fit	56.8291	14	4.059219983	1.20161	0.45206	not significant
Pure Error	16.8907	5	3.378146667			
Cor Total	3346.57	29				
Std. Dev.	1.96977		R-Squared		0.97797	
Mean	45.6617		Adj R-Squared		0.96638	
C.V. %	4.31384		Pred R-Squared		0.92951	

For getting best model & R- Squared value, we applied backward elimination. Reduced ANOVA for material removal rate (response) shown above is the final analysis which indicates that voltage (V), current (I_P), pulse on-time (T_{ON}), pulse off-time are significant as probability > F (p-value) for all factors is less than 0.05 and lack of fit is non-significant which is good for our model.
And R-Squared values are also good as their difference is less than 0.2.

The mathematical model found from the analysis was quadratic in nature. Final equation in coded and actual factors is shown below-

Final equation in terms of coded factors-

$$MRR = 43.60 - 4.24 * A + 1.38 * B + 9.37 * C - 3.90 * D - 1.30 * AC + 1.67 * AD + 1.48 * CD + 1.24 * A^2 + 2.25 * C^2 - 0.92 * D^2$$

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Where A denotes voltage (V), B denotes current (I_P), C denotes pulse on-time (T_{ON}) & D denotes pulse off-time (T_{OFF}).

Final equation in terms of actual factors-

MRR = 222.78790 – 8.15221 * voltage (V) + 0.29061 * current (I_P) + 0.18604 * pulse on-time (T_{ON}) – 0.86497 * pulse off-time (T_{OFF}) – 7.12371E-003 * voltage (V) * pulse off-time (T_{OFF}) + 1.38297E-003 * pulse on-time (T_{ON}) * pulse off-time (T_{OFF}) + 0.088337E-004 * voltage^2 (V)^2 + 9.55886E-004 * pulse on-time^2 (T_{ON})^2 – 1.89105E-003 * pulse off-time^2 (T_{OFF})^2.

Variation of each factor with the response i.e. material removal rate can be seen from the one factor curves.

3.1 ONE FACTOR PLOTS

From the Figures, it is clear that pulse on-time is the most significant parameter which affects the material removal rate (response) while current has least influence while voltage and pulse off-time have negative influence on material removal rate means material removal rate decreases either voltage increases or pulse off time increases.

3.1.1 One Factor Plot of Voltage & Pulse on Time for Mrr

It is clear from the plots below that material removal rate decreases when voltage increases from 33.75V to 41.25V and material removal rate increases when pulse on-time increases from 54.50µs to 151.50µs.

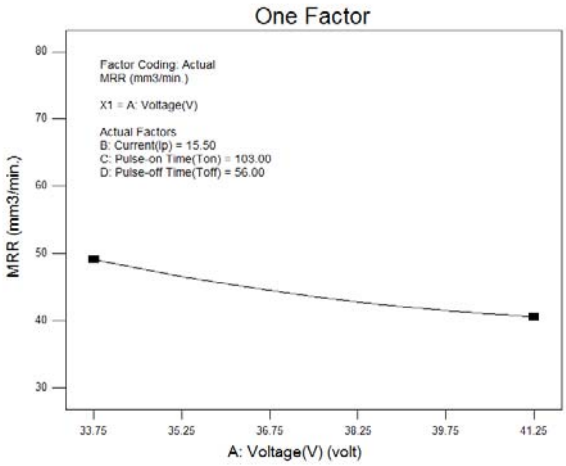


Figure3.1: one factor plot of voltage v/s MRR

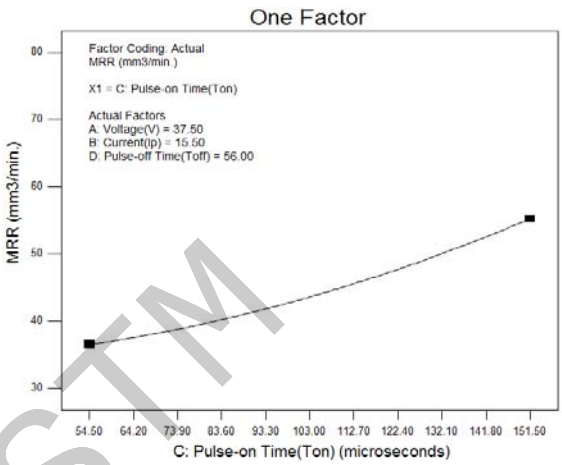


Figure 3.2: plot of pulse on time v/s MRR

Interaction effect of input parameters can be best seen in interaction curves, contour curves and 3D surface which is shown below-

3.2 Interaction effects of voltage (V) and pulse on-time (T_{ON}) on MRR

From the interaction plot, we found that when voltage increase material removal rate decreases but if compare the MRR for pulse on-time (T_{ON}) then, at higher value of pulse on-time, we got higher value of MRR at constant voltage which is shown below by the figure below-

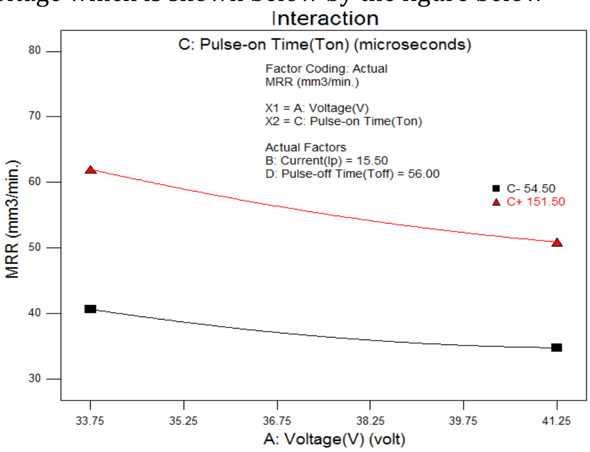


Figure 3.3: Interaction plot of voltage and pulse on-time with MRR

3.3 INTERACTION PLOT OF PULSE ON-TIME & PULSE OFF-TIME ON MATERIAL REMOVAL RATE

As we know that from previous discussion that material removal rate increases with pulse on time but from the interaction of pulse on-time (T_{ON}) & pulse off-time (T_{OFF}), we found that for a pulse on-time T_{ON} = 54.50µs, we got maximum MRR at lower value of pulse off-time of 34µs (D-) and minimum MRR at higher value of pulse off-time = 78µs (D+). Gap between 2 curves (D- & D+) was greater on low pulse on-time and goes decreasing at higher pulse on-time =151.50µs which is shown below by the figure-

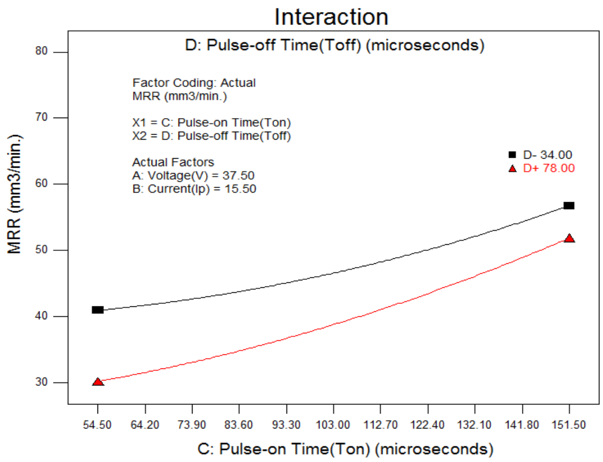


Figure 3.4: Interaction plot of pulse on-time & pulse off-time with MRR

3.4 3D SURFACE VIEW OF VOLTAGE & PULSE ON-TIME ON MRR (RESPONSE)

3D surface is a 3D view which gives complete details of the variation of parameters and their combine effect on the response. In which, MRR decreases when voltage increases at any constant value of pulse on-time (T_{ON}) similarly for any constant value of voltage (V), MRR increases when pulse on-time (T_{ON}) increases. In this case following machining parameters are constant-

Current (I_P) =15.50A, Pulse off-time (T_{OFF}) =56µs

Design range of voltage (V) = 33.75V to 41.25V & design range of pulse on-time (T_{ON}) = 54.50 to 151.50µs is taken in the 3D surface below-

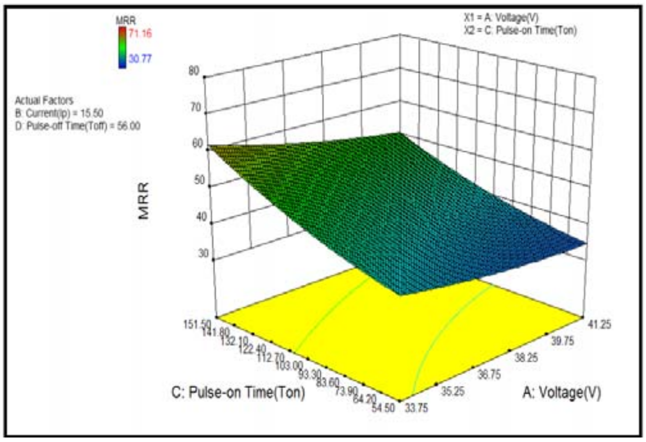


Figure3.5: 3D surface for material removal rate with voltage & pulse on-time

3.5 3D SURFACE VIEW OF PULSE ON-TIME & PULSE OFF-TIME ON MRR

From the 3D surface shown below, we found that material removal rate (MRR) increases when pulse on-time (T_{ON}) increases at any constant value of pulse off-time range shown in the diagram. Similarly, material removal rate (MRR) decreases when pulse off-time (T_{OFF}) increases at any constant value of pulse on-time (T_{ON}) range shown in the diagram.

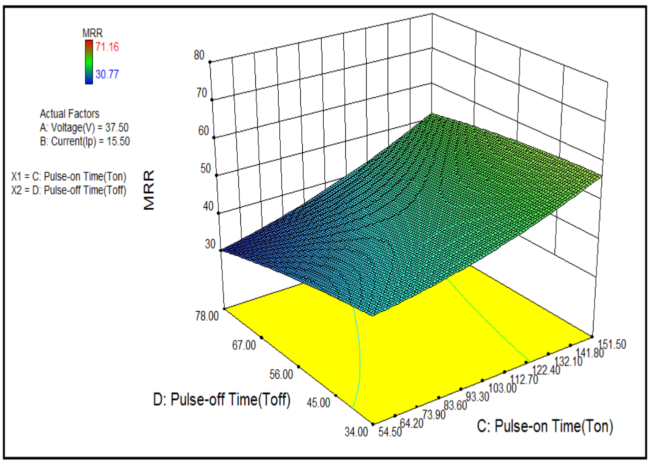


Figure 3.6: 3D surface for material removal rate with pulse on-time & pulse off-time

4. CONCLUSION

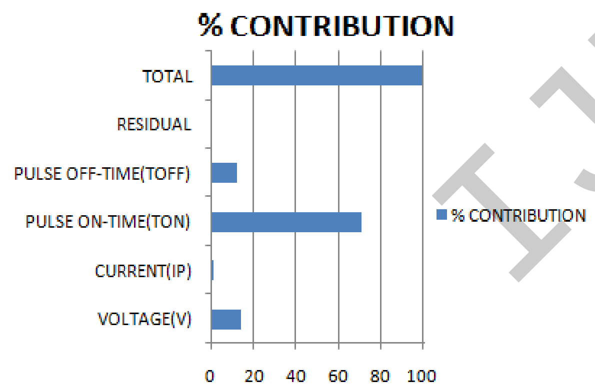
In this experimental study, we performed the experiment on AISID3 die steel (work-piece) using Cu electrode (tool) and kerosene as a dielectric fluid by electric discharge machining with the input parameters-voltage (V), Current (I_P), Pulse on-time (T_{ON}) & Pulse off-time (T_{OFF}) to calculate and statistical study the material removal rate (MRR) as our response. We used response surface methodology (RSM) & central composite rotable design (CCRD) in DESIGN EXPERT software; we found different effects on material removal rate (MRR) of the input parameters. The following conclusions are found from this experimental study-

- We found that material removal rate decreases non-linearly when voltage increases so voltage should be not high.
- Similarly, material removal rate decreases when pulse off-time increases as pulse off time is like setting time between two sparks so it should be as low as possible.
- We observed that material removal rate increases slightly when current increases within the range of 6-25A.
- We found material removal rate increase when pulse on-time increases.
- Thus, material removal rate increases whether current or pulse on-time increases as in both the case, pulse discharge energy increases which results greater crack size (diameter and depth) and finally increased material removal rate but pulse on time is most significant parameter.
- Thus, higher current, higher pulse on-time, low voltage & low pulse off-time result maximum material removal rate.
- From the table below, we can easily say that pulse on time (T_{ON}) is the most significant factor for material removal rate (MRR) while current (I_P) has very less effect on the response. Voltage (V) and pulse off-time pulse on time (T_{OFF}) has negative effect on the response as when their values increases material removal rate decreases.
- ANOVA table showing the significance and contribution of each factor is shown below where contribution % is calculated on the basis of F-value is shown below-

Table 4.1: table of % contribution of each factor on response (material removal rate)

SOURCE	SUM OF SQUARES	DEGREE OF FREEDOM	MEAN SQUARE	F- VALUE	% CONTRIBUTION
voltage(v)	431.03	1	431.03	111.09	14.61
current(I_p)	45.733	1	45.73	11.78	1.5
Pulse on-time(T_{on})	2108.44	1	2108.43	543.41	71.47
pulse off-time(T_{off})	364.80	1	364.80	94.02	12.36
residual	73.71	19	3.88		
total	3346.57	29		760.3	99.94

- Above table shows that pulse on-time (T_{ON}) has the maximum contribution equal to 71.47% on material removal rate while current has the minimum contribution equal to 1.5% and both have positive effect on material removal rate i.e. material removal rate increases whether current or pulse on-time increases. While voltage has a negative effect on material removal rate with 14.61% contribution and pulse off time also has the negative effect on material removal rate i.e. material removal rate decreases with increase in pulse off-time and the decrement is 12.36%. It can be seen by bar chart below-



BAR CHART: bar chart for % contribution of each factor on MRR

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