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Research Article

EXPERIMENTAL STUDY OF MICRO CHANNELS FOR MATERIAL REMOVAL RATE BY USING WIRE-CUT EDM PROCESS

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A B S T R A C T

This study is based upon Experimental process about Material Removal Rate (MRR). All the data is based on Material removal Rate (MRR) using wire electro-discharge machining (WEDM) for fabrication of Micro Channels. Experiments were designed using DOE (Design of Experiments) and Response Surface methodology for optimization of Material removal Rate (MRR). DOE gave certain number of experiments to perform depending upon the number of parameters selected. The software used is MINITAB16.1. WEDM involves several machining parameters such as pulse-on time, pulse-off time, peak current, wire feed rate, servo reference voltage, wire tension, and dielectric flow rate. However for this work the variables such as pulse-on time, pulse-off time, wire tension, and dielectric flow rate were considered as the input (control) parameters. The experiments were conducted using brass wire of diameter 0.25 mm; on work piece material of Aluminum 6061 having dimensions 22mm×22mm×5mm. The micro channels of size 0.5x0.5 mm were fabricated. Micro channels were fabricated on CNC WIRE EDM EPULS40ADLX machine.

INTRODUCTION

Wire EDM, uses same principle as that of EDM, is a process of machining using erosive action on metals for material removal. In WEDM, an electric discharge takes place across the conductive work piece and the accurately positioned moving wire. Pulses of high frequency of AC or DC current are discharged from the wire through an insulated dielectric fluid to the work piece with very small gap between them.

Multiple discharges takes place with discharge sparks lasting for very small time in the range of 1/1000000 of a second or less. Desired cutting speed and the surface finish determines the volume of material removal during the sparking time. The high temperature of around 15000˚F to 20000˚F reaches due to heat provided by the electrical sparks that is sufficient to melt and vapourized the material work piece in the tiny bit of material. The wire material also eroded away during this process and the removed material that is suspended between the wire and work piece is flushed away by the stream of de-ionized water through the top and bottom nozzles. Water also helps in prevention of the built up of heat in the work piece as this would affect the positional accuracy due to thermal expansion of the work piece. In the process of material removal material is removed because of the current and the ON and OFF time for which the spark is repeated over and over.

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Micro channels are defined as flow passages that have hydraulic diameters in the range of 10 to 1000 micrometers.

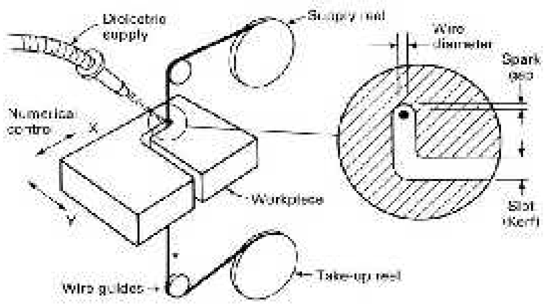

Figure 1 Principle of WEDM [Wikipedia]

Figure 2 WEDM Electronica Elpuls 40ADLX [Wikipedia]

These are used in the microelectronics cooling and other high heat-flux cooling applications [1]. Micro channels heat sink used for the heat dissipation from devices such as integrated circuits due to their high area-to-volume ratio. Liquid coolants are used in micro channel heat sinks that provide high heat transfer coefficients compared to gaseous coolants. The performance of the heat sink depends upon the surface roughness through which the heat gets convicted. The average heat transfer coefficient & the thermal resistance is affected a most if the surface roughness is not taken care of during the fabrication of the micro-channels. The principle of heat transfer in micro channels is heat transfer by convection.

Flow in micro channels has been widely investigated during the last two decades. The advantage of micro channels lies in their high heat transfer coefficient and ability to decrease the size of heat exchangers significantly, reduced weight, and reduced use of material. The decreased diameter of micro channels results in more compact heat exchangers. The main challenge of micro channels is the fabrication difficulty. Micro channels have been fabricated using processes such as micro EDM, lithography, wafer bonding etc. but these processes cannot be employed due to fabrication and cost constraints of the process. On the other hand wire cut EDM is easily available and also economical and literature review reveals that lots of work has been reported for the optimization of process parameters of wire cut electric discharge machining. Few researchers have worked on the fabrication of channels using wire cut EDM. So an attempt is made to fabricate the channels using wire cut EDM machine and to study the effect of wire cut EDM process parameters on the surface roughness to optimize the process parameters for fabrication of micro channels [2, 3]. After fabrication of the channels (Refer figure 4), process will be optimized using Response Surface Methodology (RSM) and ANNOVA will be used to obtain the best parameters that are affecting the responses.

Figure 3 Aluminium 6061 for fabrication

Figure 4 Micro channels on Al 6061

LITERATURE SURVEY

Wide-ranging study, analysis and work has been done in the field of EDM. Kandlkar and Grande (2002) discussed about classification of micro channels and advantages of using micro channels in high heat cooling applications. Tosun *et al*. (2004) studied the effect and optimization of machining parameters on the kerf and MRR in WEDM operations. Variables for input used were the Pulse duration, OCV, Wire speed and electric flushing. Taguchi and ANOVAs used to design the experiment to determine the level of importance of machining parameters on the surface. ESME *et al*. (2009) used factorial design and neural network for modelling and predicting the surface roughness of AISI 4340 steel. Input variables taken were the Pulse duration, OCV, wire speed and dielectric flushing pressure. Annova was used to determine the level of importance of the machining parameters. Mathematical model was established using Regression analysis method between the input variables and desired responses. It was found that with the increase in Pulse duration, OCV, and wire speed surface roughness increases whereas surface roughness decreases on increasing the flushing pressure. Kumar *et al*. (2010) carried out optimization of process parameters of WEDM. Material used was Incoloy 800 super alloy. Variables for input were taken as the voltage, pulse on time, pulse of time and wire feed and output variables were taken MRR, Ra and Kerf. Experiment designed using Taguchi’s L9 orthogonal array. GRA was used to optimize the input variables and annova was used to identify the level of importance. Result of confirmation experiments shows that established mathematical model can predict the output response with reasonable accuracy. Shabgard *et al*. (2011) studied the influence of EDM input parameters on the characteristics of EDM process. Material used was AISI H13. Full Factorial procedure was employed to design the procedure. Variables of input parameters are current and pulse on time. The result of study can be used to select the optimum process parameters to achieve desired surface roughness and surface integrity. Lakshmanan *et al*. (2013) presented the optimization process of material removal rate of electric discharge machining by RSM. The work piece material was EN31 steel. Variables for input taken were pulse on time, pulse off time, voltage and current. RSM method was used to design the experiment. Response model of process are validate with Annova.

Experimentation

First of all, the input parameters of the wire electric discharge machining for fabrication of micro channels are selected based on the data obtained from the literature survey which helped in deciding what are the parameters that will affect the desired response most in this case the response is material removal rate so depending upon the knowledge obtained from the literature survey [4,5,6,7] these parameters were selected which has the most effect on response parameters i.e. Pulse On Time (T_{ON}), Pulse Off Time (T_{OFF}) and Current (I_P). The levels of these parameters were decided keeping in mind the range of wire EDM for selected parameters. The selection of a particular parameter level for each parameter is made on the basis of earliest experimentation that is done to finally select the effective value of each level. The input parameters and the value of their levels are given in Table 1.

Table 1 Input Parameters and their Levels

Parameters	Peak current (Amp)	Pulse on time (μsec)	Pulse off time (μsec)
Symbol	I_p	T_{ON}	T_{OFF}
-α	65.91	101.5	18.4
-1	100	105	25
0	150	110	35
1	200	115	45
Α	230	118.4	51.81

Micro channels were fabricated on CNC WIRE EDM EPULS40ADLX machine. The selected design is a three-level, three factor central composite rotatable factorial design (CCD) consisting of 20 sets of coded conditions. As experiments were performed using different range of parameters so total of 20 experiments were performed. Material Removal Rate (MRR) were considered as the output responses.

Table 2 Observations of Material Removal Rate

S.No.	I_p	T_{ON}	T_{OFF}	MRR
1	0	-1.68	0	2.7673
2	0	0	0	5.3255
3	0	0	0	5.1364
4	0	0	0	5.2403
5	-1	1	1	4.5764
6	-1	-1	1	2.1438
7	0	1.68	0	6.4744
8	1.68	0	0	4.7679
9	1	1	-1	6.5348
10	1	1	1	3.9923
11	0	0	0	5.0193
12	1	-1	-1	3.8979
13	0	0	0	5.3165
14	0	0	0	5.2741
15	1	-1	1	3.2714
16	-1	1	1	4.7185
17	0	0	-1.68	3.6973
18	-1.68	0	0	3.862
19	1	-1	1	3.173
20	0	0	1.68	3.5024

RESULTS AND DISCUSSION

Analysis of variance for MRR

The significance of each parameter can be determined using ANNOVA. Any parameter having p value less than or equal to α = 0.05 will be considered significant. It can be seen from Table 4.1 that the parameter having less value of p will be more significant. The parameters pulse on time, pulse off time and current have the p value less than α = 0.05 means all these parameters have come out to be significant. Lower value of S = S = 0.301612 means models better predicts the responses. With R-Sq = 96.47% predictor explain 96.47% variation in observed response and the value of R-Sq (adj.) = 93.28%.

Residual Plots

The result obtained after applying response surface methodology [8,9,10] are shown in terms of different plots and graphs which will depict the relationship and effect of different parameters and desired responses.

It can be seen from Figure 6 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

Surface Plots of Responses

Three dimensional graphs show the variation of response Surface finish with respect to two parameters. Surface plots are used to explore the relationship between three variables on a single plot and to view combinations of different input variable that produces desirable response values.

Surface Plot of MRR v/s T_{ON} and I_P

Surface plot of MRR for the combination of pulse off time and pulse on time is shown below in Fig. 6.

It can be seen that increasing I_P will result in increase material removal rate and increasing T_{ON} will also increase the material removal rate. The maximum material removal rate is achieved for the combination of I_P and T_{ON} when current is at 1(coded value) and T_{ON} is at 1(coded value).

Surface Plot of MRR v/s T_{OFF} and I_P

Surface plot of MRR for the combination of current and pulse off time is shown in Fig. 7. It can be seen that increasing current will result in increase in material removal rate but increasing T_{OFF} will decrease in the material removal rate. The maximum material removal rate is achieved for the combination of current and T_{OFF} when current is at 2(coded value) and pulse off time is at -2(coded value).

Surface Plot of MRR v/s T_{OFF} and T_{ON}

Surface plot of MRR for the combination of T_{OFF} and T_{ON} is shown in Fig. 8.

Table 3 Analysis of Variance for Material Removal Rate

Source	DF	SEQ SS	Adj SS	Adj MS	F	P
Regression	9	24.8300	24.8300	2.7589	30.33	0.000
Linear	3	17.5306	16.5387	5.5129	60.60	0.000
I_P	1	0.3229	1.4579	1.4579	16.03	0.003
T_{ON}	1	14.4210	13.9568	13.9568	153.42	0.000
T_{OFF}	1	2.7867	0.8551	0.8551	9.40	0.012
Square	3	5.6185	6.4728	2.1576	23.72	0.000
I_P*I_P	1	0.7928	1.7955	1.7955	19.74	0.001
$T_{ON}*T_{ON}$	1	0.2819	0.8829	0.8829	9.70	0.011
$T_{OFF}*T_{OFF}$	1	4.5437	5.1796	5.1796	56.94	0.000
Interaction	3	1.6809	1.6809	0.5603	6.16	0.012
I_P*T_{ON}	1	0.3056	0.7171	0.7171	7.88	0.019
I_P*T_{OFF}	1	0.4629	0.6699	0.6699	7.36	0.022
$T_{ON}*T_{OFF}$	1	0.9124	0.9124	0.9124	10.03	0.010
Residual Error	10	0.9097	0.9097	0.0910		
Lack-of-Fit	3	0.8237	0.8237	0.2746	22.35	0.001
Pure Error	7	0.0860	0.0860	0.0123		
Total	19	25.7397				

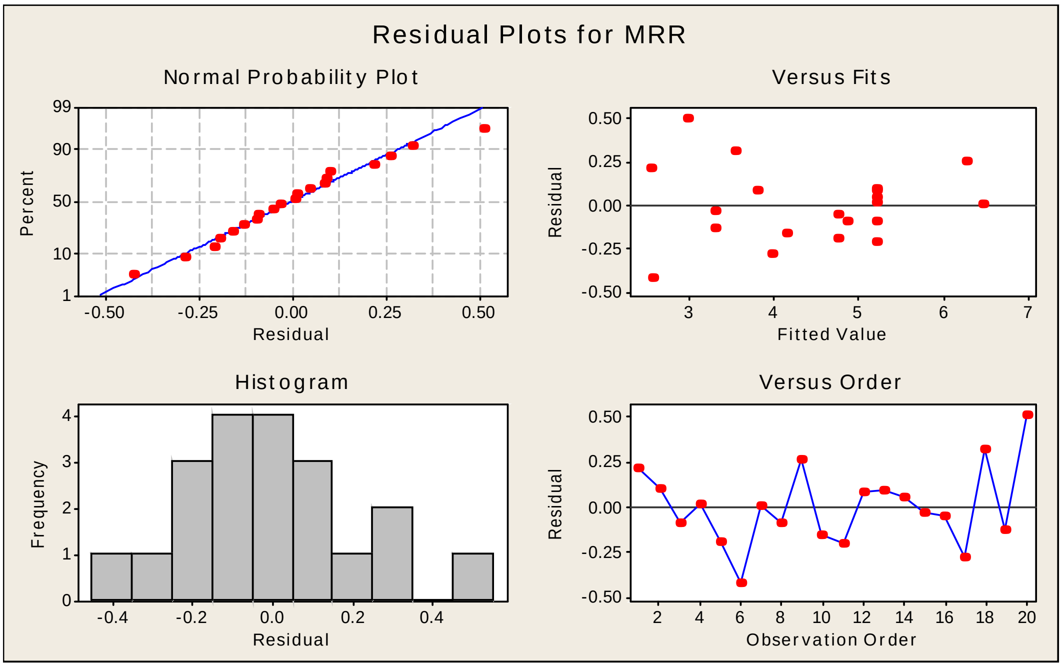

Figure 5 Residual Plots for MRR

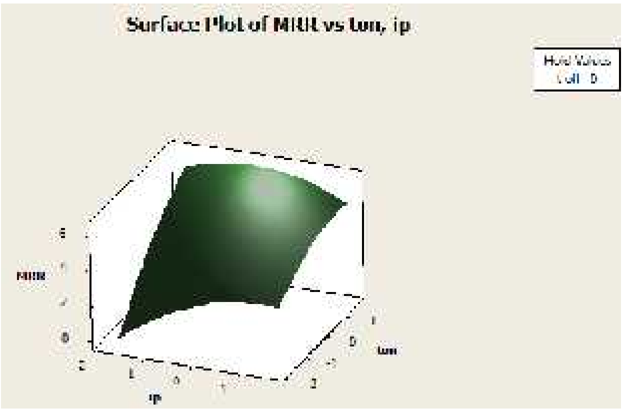

Figure 6 Surface Plot of MRR v/s T_{ON} and I_P

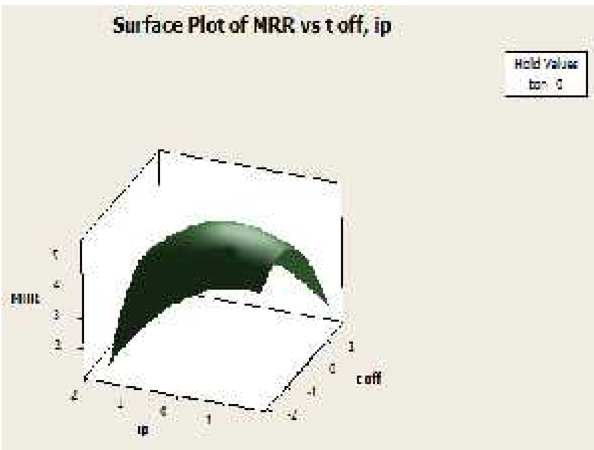

Figure 7 Surface Plot of MRR v/s T_{OFF} and I_P

It can be seen that increasing T_{OFF} will result in decrease in material removal rate but increasing T_{ON} will increase the material removal rate. The maximum material removal rate is achieved for the combination T_{OFF} and T_{ON} when T_{OFF} is at 2 (coded value) and T_{ON} is at 1 (coded value).

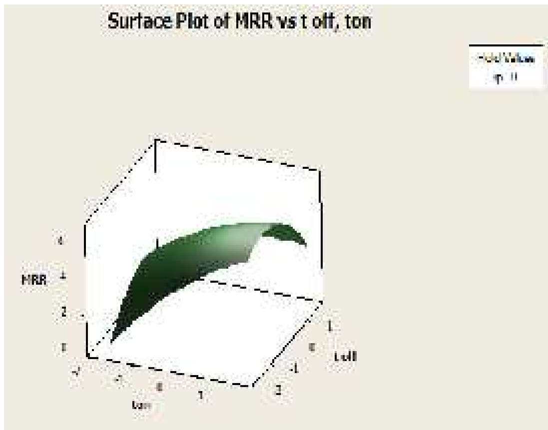

Figure 8 Surface Plot of MRR v/s T_{OFF} and T_{ON}

Contour plots

Contour Plots of MRR v/s T_{OFF} and T_{ON}

Contour plot for the combination of T_{ON} and I_P the maximum material removal rate range is shown by the dark green region of the plot the material removal rate increases as we move from right to left toward the upward region so selecting I_P and T_{ON} will result in higher removal rate. X axis represents the current and Y axis represents the T_{ON}. MRR will be maximum when keeping I_P at 0.5(coded value) and T_{ON} at 1.5(coded value).

Contour Plots of MRR v/s T_{OFF} and I_P

Contour plot of MRR is shown below in Fig. 10 for different combination of Pulse off time and current. For the combination of T_{OFF} and I_P the darker region showing maximum removal rate lies at the right side. X axis represents the I_P and Y axis represents the T_{OFF}. It can be seen that MRR will be maximum when keeping I_P at 1(coded value) and T_{OFF} at -1(coded value).

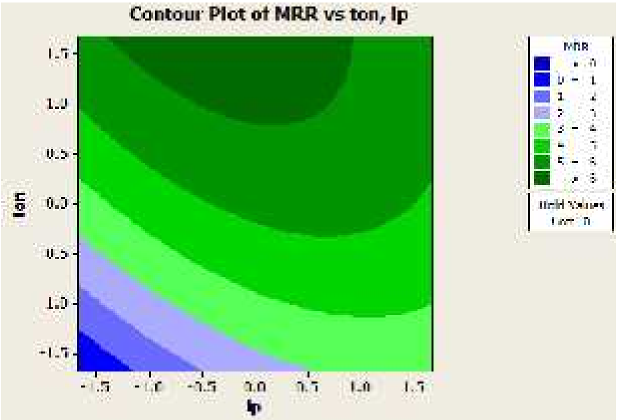

Figure 9 Contour Plots of MRR v/s T_{on} and I_P

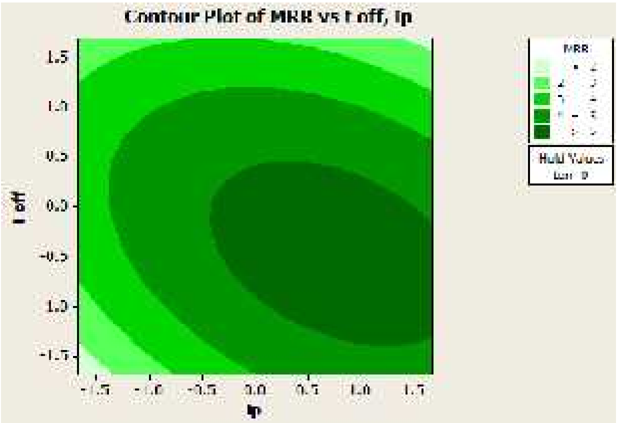

Figure 10 Contour Plots of MRR v/s T_{OFF} and I_P

Contour Plots of MRR v/s T_{OFF} and T_{ON}

Contour plot of MRR is shown in Fig. 12 for different combination of pulse off time and pulse on time. For the combination of T_{OFF} and T_{ON} the darker region showing maximum removal rate lies at the right side. X axis represents the T_{ON} and Y axis represents the T_{OFF}. It can be seen that MRR will be maximum when keeping T_{ON} at 1.5(coded value) and T_{OFF} at -0.5(coded value).

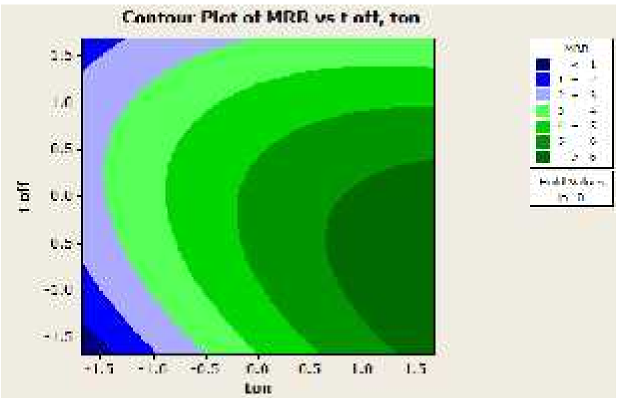

Figure 11 Contour Plots of MRR v/s T_{off} and T_{on}

Main Effects Plot of MRR

It can be seen from the main effect plot for MRR that MRR is increasing with increasing in current and T_{ON} and decreases with increase in pulse off time. The reason for this is that discharge energy increases with the increases in T_{ON} and decreases with increase in pulse off time

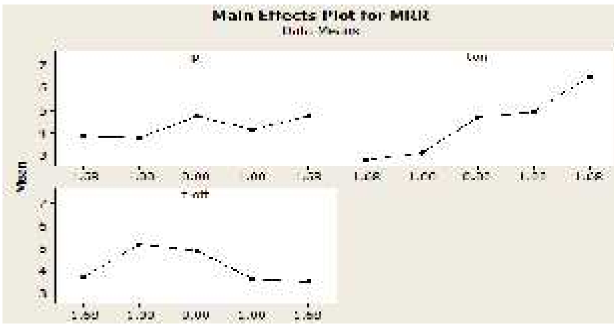

Figure 12 Main Effect plot For MRR

CONCLUSIONS

For material removal rate T_{ON} and I_P are the most significant process parameter. MRR increases with the increase in T_{ON} and I_P and decreases with the increase in T_{OFF}

The maximum value of material rate comes out to be 6.534 mm^3/min when the levels of parameters were at (I_P =200, T_{ON} =115, T_{OFF} =25) which are coded as (I_P =1, T_{ON} =1, T_{OFF} =-1) and the minimum value of material removal rate comes out to be 2.1438 mm^3/min. when the levels of parameters were at (I_P =100, T_{ON} =105, T_{OFF} =45) which are coded as (I_P =-1, T_{ON} =-1, $T_{OFF\ f}$=1).

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