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Experimental Investigation of Geometrical Parameters in Wire-EDM Using RSM for Fabrication of Micro channels.

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Abstract

In Wire Electrical Discharge Machining or Wire-Cut EDM, a thin single-strand metal wire is fed through the work piece, typically occurring while in a submerged tank of dielectric fluid or deionised water. This fluid helps to cool the process and flush away the cut material. The Wire EDM process uses electric current to cut conductive materials leaving a smooth surface that requires no further finishing or polishing. Aluminium 6063 alloy Micro channels were fabricated using Wire Cut EDM. The performance of the micro-channels depends upon the machining parameters. In the given work, three input parameters of W-EDM were varied to get optimum values. The impact of various parameters of W-EDM like peak current (I_p), Pulse on time (T_{on}) and pulse off time (T_{off}) were studied. The parameters of WEDM are varied in the ranges of (I_p from 100 to 200 ampere, $T_{on}$from 105 to 115 µsec and T_{off} from 25 to 45 µsec). Two output parameters like material removal rate (MRR) and surface roughness (SR) were investigated for Micro channels. Response Surface Methodology (RSM) was used to correlate input and output parameters and mathematical equations have been generated for both responses. The variation of output responses because of variations in input parameters had also been studied and shown in the form of surface plots and contour plots. Mitutoyo Talysurf (SJ – 201) was used to measure the surface roughness of machined work piece. Each experiment was repeated three times for better results and the average was calculated.It has been found that T_{on}, T_{off} and I_p parameters were very significant in case of MRR and T_{on}(Maximum) was most significant in case of surface roughness.

Keyword : W-EDM(Wire Electrical Discharge Machining), Micro channel, RSM(Response Surface Methodology), MRR(Material Removal Rate),SR(Surface Roughness)

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1. Introduction

Fabrication of Micro channels is a difficult and challenging area. There are a lot of techniques but all these have certain merits and demerits over each other. Wire Cut Electric Discharge Machining (WEDM) is an efficient machining method which uses spark discharges to melt and vaporize material from work piece.

A spark is produced between wire and work piece having very small gap through dielectric fluid (generally deionised water) and material is eroded from work piece. It is a novel machining process used for fabrication of a micro-metal hole and can be used to machine hard electrically conductive materials. Micro channels are defined as flow passages that have hydraulic diameters in the range of 100 to 500 micrometers. These are used in the microelectronics cooling and other high heat-flux cooling applications. Due to their high area-to-volume ratio and also due to area enhancement Micro channel heat sinks are strong candidates for the effective dissipation of heat from devices, such as integrated circuits. Micro channel heat sinks are utilized generally with liquid coolants which provide higher heat transfer coefficients compared to gaseous coolants.

2. Literature Review

Literature has been reviewed to find some gaps in WEDM process and to find out the effect of different input parameters on SR and MRR in WEDM process. Some papers are discussed below:-

Habib.S (2009):-Four input parameters were taken in this study. Four responses were evaluated. RSM was used to design experiments and for mathematical modeling. ANOVA was used to find most significant input factor.[1]

Mohammad et al. (2009) compared the Micro end milling and micro electric milling for micro fluidic channels fabriction on polymers and metals.Micro-channels fabricated of dimensions 100-800 µm with aspect ratio of 1-2. Surface roughness measured were 100-200 nm for metals and 80-120 nm for polymers. Micro end milling formed large amount of burrs an metallic surface where as Micro ED milling produced high high aspect ratio micro channels without burr formation [2]

Mahendran et al. (2010) reviewed Micro EDM machining used to produce micro parts in a scale of 50µm - 100µm Micro metal holes made by Micro EDM with an advantage of non contact thermal process. Process of tool wear rate and MRR were most important response parameters in Micro-EDM process.[3]

Shandliya et al. (2012) experimented for Wire EDM process parameters optimization of metal matrix composites(MMC's).Optimization was done by Response Surface Methodology (RSM) and Genetic Algorithms (GA).Four process parameters of Wire EDM Pulse on Time (Ton),Pulse off Time (Toff),Servo Voltage and wire feed rate (WF) were varied to record their effect on SiCp/6061 Al MMC using surface roughness as response parameters. Response Surface Methodology develops a relationship between machining parameters and surface roughness. Genetic Algorithms was used to optimize the process parameters. [4]

Phipon et al. (2012) experimented on work piece of material (TI-6Al-4V).Single and multi objective optimization of micro EDM process using Genetic algorithms were taken. Response Surface Methodology (RSM) used to co relate the response and process parameters. Minimum Tool wear rate and minimum overcut while other independent control parameters considered were pulse on time, peak current and flushing pressure.[5]

Rajya lakshmi et al. (2013) used Inconel 825 for experimentation. Taguchi orthogonal array design of experiment and grey relational analysis were combined. The main objective of this study was to obtain improved material removal rate, surface roughness, and spark gap. Grey relational theory was adopted to determine the best process parameters that optimize the response measures.[6]

Daniel et al. (2013) discussed about current research trends in Wire EDM with process parameters and response parameters. These process parameters were servo voltage, peak current, pulse on time (Ton), pulse off time (Toff),dielectric flow, wire tension, wire feed rate. Response parameters were material removal rate (MRR), surface roughness (Ra), kerf width, wire wear rate, surface integrity factors, wire lag (LAG).[7]

Lin.Y.C et al (2006):-SKH 57 HIGH SPEEDSTEEL was used in the study as work material. Experiments were conducted with the L18 orthogonal array based on the Taguchi method. In this investigation 6 machining parameters (polarity, peak current, pulse duration, auxiliary current with high voltage, no-load voltage, servo reference voltage) were varied to find effects of these on MRR, EWR and SR.[8]

3. Design of Experiments

Parameters of WEDM are varied in a particular range to get optimal values of these parameters to achieve desired results. The parameters of wire-EDM which are varied in this work are peak current (Ip), pulse on time (T_{on}) and pulse off time (T_{off}).The variation of these parameters is also represented below in table 1. The desired output responses are material removal rate and surface roughness. Parameters are to be set in a way to get maximum material removal rate and minimum surface roughness.

The design of experiments technique used is response surface methodology(RSM). Mathematical modeling has been done by using response surface methodology and equations has been generated which show the relationship between input parameters and output responses. Two different equations have been generated for both responses.

Table1. Parameter Variations.

Parameters	Alpha	-1	0	1	Alpha	Units
Peak Current	65.91	100	150	200	230	Amp
Pulse On Time	101.5	105	110	115	118.4	µsec
Pulse Off Time	18.4	25	35	45	51.81	µsec

4. Experimental Setup and Metrology

The experimental runs(WEDM) are performed on Electronica ELPULS40ADLX.The wire used in experimental runs is of brass. The diameter of wire is 0.20mm. Taylor Hobson's Profilometer is used to get surface roughness (Ra) of microchannel after wire EDM experiment.

Material removal rate is calculated by the formula given below:-

$$\left(m_1 - m_2\right) / \left(\rho \text{ x } t\right) \text{ mm}^3 / \text{min}$$

m_1 is mass of workpiece before machining and m_2 is mass of workpiece after machining. ρ is density of Al-6063 and t is the time taken for fabrication.

5. Results and Discussion

The values of material removal rate and surface finish are tabulated in table 2.

Table 2.MRR and Surface Roughness.

S.No	Peak Current(I_p)(Ampere)	Pulse On time(T_{on}) (µsec)	Pulse Off Time (T_{off}) (µsec)	M.R.R (mm^3/min)	R_a(µm)
1	150	102.5	35	1.530855	2.1142
2	150	110	35	3.326529	3.244133
3	150	110	35	3.326529	3.224133
4	150	110	35	3.326529	3.324133
5	100	115	45	4.228363	3.3382
6	100	105	45	3.191467	2.73267
7	150	117.4	35	2.950441	3.3977
8	230	110	35	4.28866	2.8493
9	200	115	25	4.124907	4.0286
10	200	115	45	3.500422	3.1794
11	150	110	35	3.226529	3.34133
12	100	105	25	2.961063	3.3152
13	150	110	35	3.226529	3.34133
14	150	110	35	3.226529	3.34133
15	200	105	45	2.490781	2.22
16	100	115	45	4.128363	3.3082
17	150	110	22.28	2.911937	3.082525
18	65.91	110	35	2.412243	2.71115
19	200	105	45	2.490781	2.1222
20	150	110	53.71	2.57765	6.1497

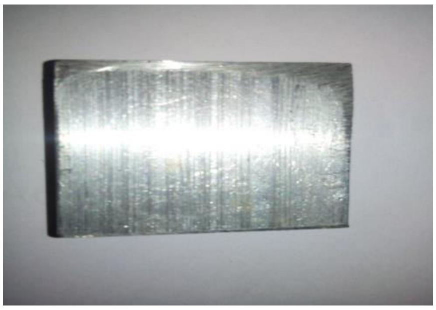

Fig 1. This figure shows the Microchannel substrate before WEDM

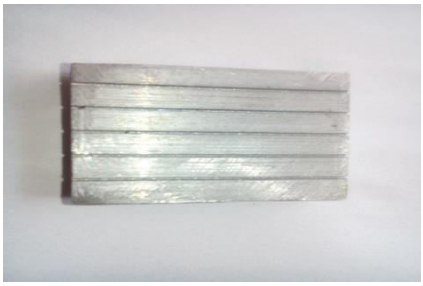

Fig 2. This figure shows Microchannel substrate after WEDM.

After getting the values of surface roughness and material removal rate, using MINITAB software equations for both responses have been generated as written below.

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$$MRR = -119.574 + Ip0.078 + Ton \times 0.878 - Ton \times Ton \times 0.012 - Toff \times Toff \times 0.001 - Ip \times Toff \times 0.002 + Toff \times Toff \times 0.011$$

$$Ra = -151.368 - Ip \times 0.139 + Ton \times 2.970 - Toff \times 0.179 - Ton \times Ton \times 0.014 + Toff \times Toff \times 0.004 + Ip \times Ton \times 0.002$$

These are equations which show relationship between input parameters and responses.

After generating these equations surface plots and contour plots are generated in MINITAB. These plots show variations in responses when input parameters are varied.

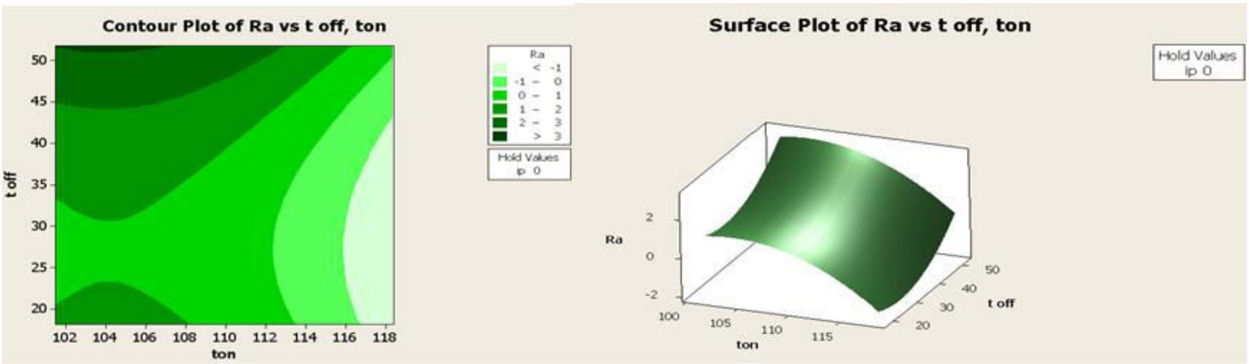

Fig 3. Contour Plot and surface plot between T_{on}, T_{off}(Ra).

In first contour, it can be seen that value of surface roughness is minimum at lightest area and is maximum at darkest area. So, it shows that when T_{on} is maximum and T_{off} varies from 25 ampere to 45 ampere, surface roughness is minimum.

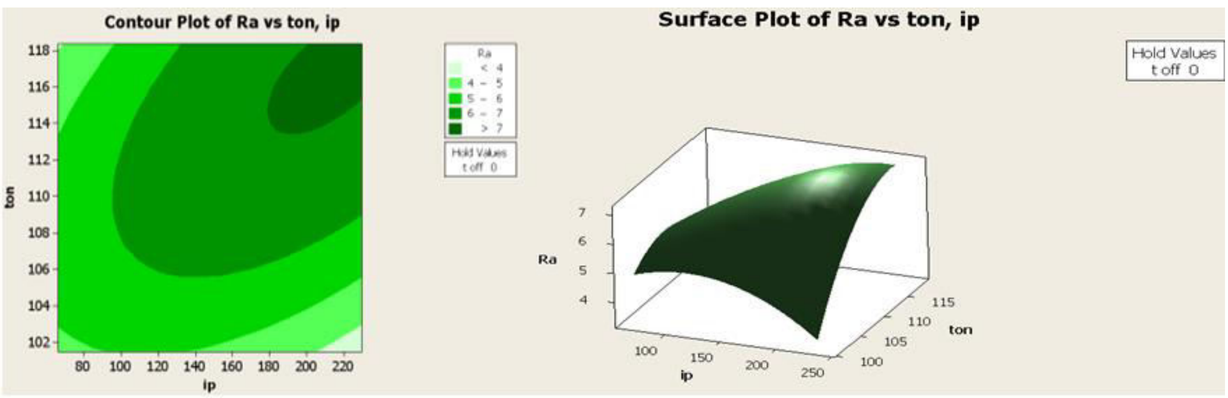

Fig 4. Contour plot and Surface plot between Ip and T_{on} (Ra).

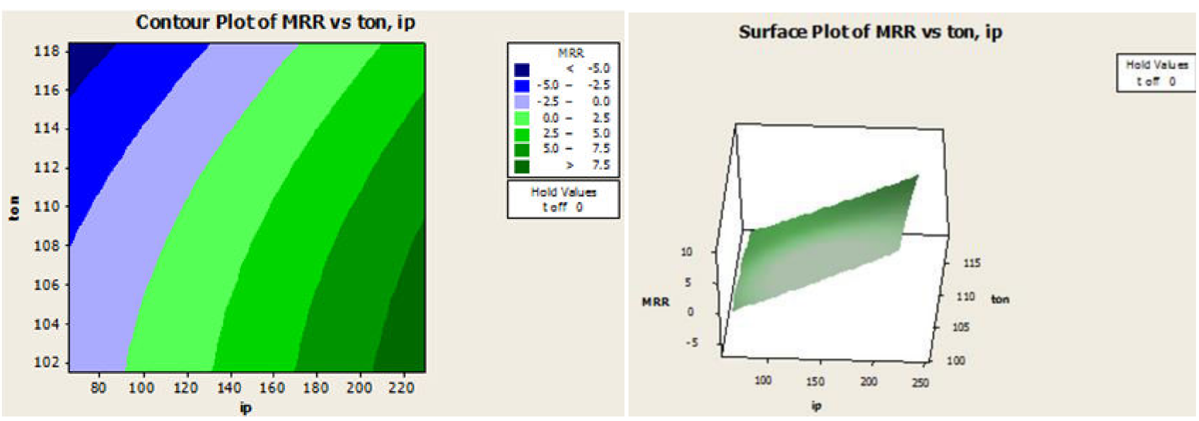

Fig 5. Contour and surface plot between $T_{on}$and Ip(MRR)

In second contour, it can be clearly understood that when T_{on} is minimum, surface roughness will be minimum and vice versa. Surface roughness is maximum when peak current and T_{on} are maximum. As indicated in these plots, MRR is greatly influenced by T_{on} and peak current. Material removal rate increases when both peak current (Ip) and Ton increase and MRR decreases when both input factors decrease.

In this plot, it is clear that material removal rate is minimum when T_{off} is at lowest level and when the value of T_{off} is increased material removal rate increases.

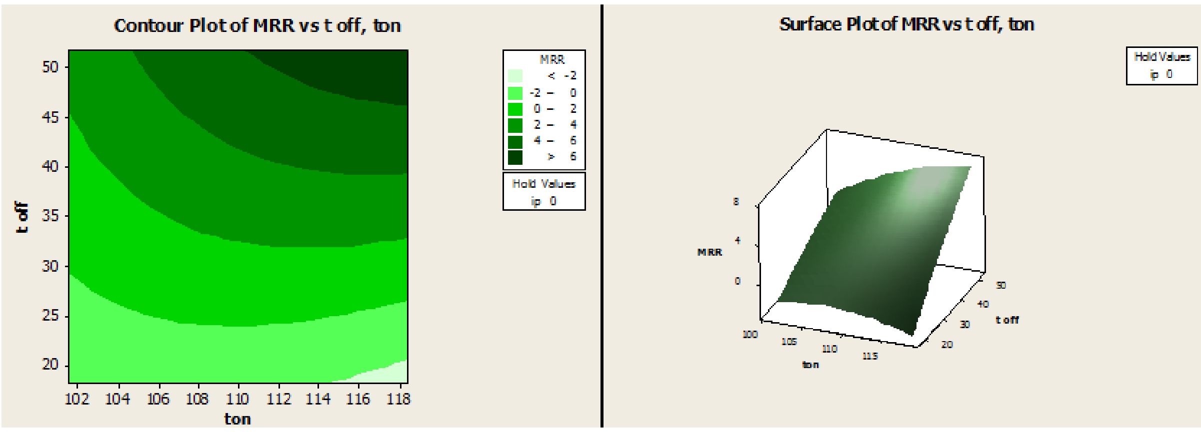

Fig 6. Contour and surface plots between $T_{on}$and T_{off} (MRR).

Table 3. Analysis of Variance for Ra.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	9.4383	9.42829	1.05759	2.25	0.111
Linear	3	2.9389	2.59076	0.86459	1.85	0.201
I_P	1	0.0547	0.63436	0.63436	1.36	0.270
T_{on}	1	2.6281	1.61004	1.61204	3.46	0.093
T_{off}	1	0.3570	0.03280	0.03380	0.07	0.796
Square	3	5.3038	5.39440	1.79713	3.86	0.045
I_P x I_P	1	1.2339	1.29899	1.29889	2.79	0.126
T_{on} x T_{on}	1	2.1553	1.83124	1.83224	3.93	0.076
T_{off} x T_{off}	1	1.9445	1.78703	1.78723	3.84	0.079
Interaction	3	1.1947	1.19467	0.49822	0.85	0.495
I_P x T_{on}	1	1.1504	1.14998	1.15998	2.47	0.147
I_P x T_{off}	1	0.0442	0.03439	0.03339	0.07	0.791
T_{on} x T_{off}	1	0.0002	0.00016	0.02016	0.00	0.986
Residual Error	10	4.6589	4.65894	0.46689		
Lack of Fit	3	4.6589	4.65894	1.56298		
Pure Error	7	0.0000	0.0000	0.0000		
Total	19	14.0872				

It is clear from tables 3 and 4 that T_{on} andT_{off} are parameters are very important in case of MRR and T_{on} is most significant in case of surface roughness. Main effect plots are also generated for both responses which are discussed figure7 and 8. The graph depicted above shows that with increase in Ip the MRR increases first then remains constant and then increases again. MRR increases sharply with T_{on} and then decreases after 115.00µm. MRR remain almost constant in beginning due to increase in T_{off} and then decreases slightly.

As shown in this graph, surface roughness (Ra) varies to some extent when I_p increases with increase in T_{on} roughness value increases and then become constant. Roughness value increase with increase in T_{off} in the starting, then decreases and then again increases.

Table 4. Analysis of Variance for MRR.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	12.7678	12.76878	1.40654	64.38	0.000
Linear	3	8.2798	2.2104	0.74447	33.55	0.000
I_P	1	0.4131	0.1886	0.18857	9.08	0.013
T_{on}	1	7.7145	0.9602	0.98116	44.83	0.000
T_{off}	1	0.0623	0.7868	0.78684	35.99	0.000
Square	3	1.68282	1.6477	0.54933	25.12	0.000
I_P x I_P	1	0.2211	0.1544	0.15338	7.02	0.024
T_{on} x T_{on}	1	1.1334	1.2438	1.24377	56.85	0.000
T_{off} x T_{off}	1	0.2137	0.2158	0.20579	9.41	0.012
Interaction	3	2.9198	2.9198	0.97328	44.52	0.000
I_P x T_{on}	1	0.0354	0.0263	0.02530	1.20	0.298
I_P x T_{off}	1	1.5555	2.6167	2.61671	129.70	0.000
T_{on} x T_{off}	1	0.0012	0.00016	0.00016	0.00	0.986
Residual Error	10	4.6789	4.65794	0.46589		
Lack of Fit	3	4.6689	4.65794	1.55398		
Pure Error	7	0.0000	0.0000	0.0000		
Total	19	14.0772				

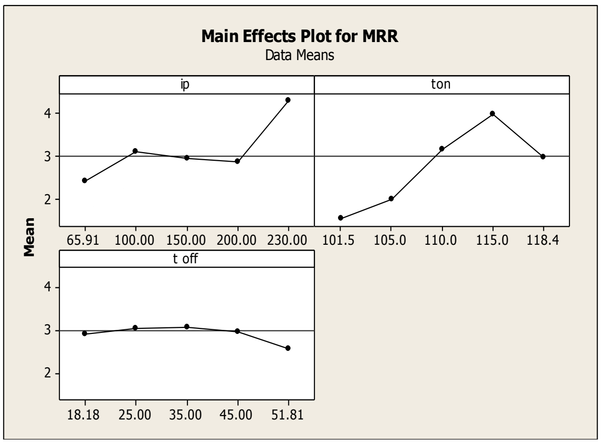

Fig 7. Main Effects Plots for MRR.

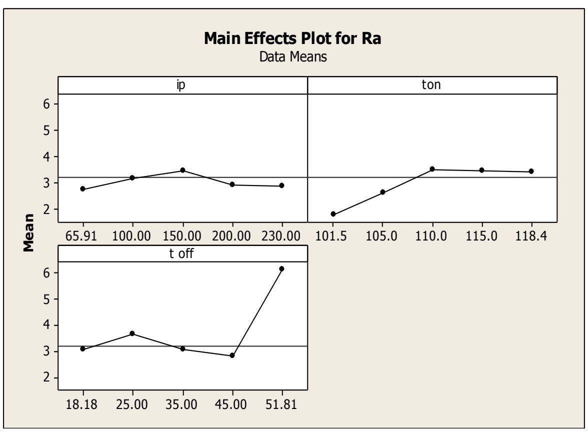

Fig 8. Main Effects Plots for Roghness.

6. Conclusion

In this work, experimental investigations were done to find out significant factor of WEDM machining process while machining micro channels. Mathematical models for material removal rate and surface roughness were developed for peak current, pulse on time, and pulse off time using RSM. Major findings in this work, based upon 0ptimisation results, are:

1 The number of experiments was reduced by using central composite factorial design in RSM.

2 It is concluded that T_{on} and T_{off} parameters were found to be very significant, using ANOVA, in case of MRR.(p-value was minimum in ANOVA table)

3 The most important factor, in case of surface roughness, was found out to be T_{on} .(p-value was minimum in ANOVA table).

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