INVESTIGATION AND OPTIMIZATION OF MICRO WEDM PROCESS PARAMETER FOR MICRO MACHINING OF INCONEL 601

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Abstract: The material used in this work is a Inconel 601. In this research work, experimentation was carried out with the parameters capacitance, voltage, pulse on time (PoT) and tool material on Inconel 601. The optimization of the material removal rate (MRR) and kerf width (KW) as a response variable was studied using grey relational analysis (GRA) and Taguchi method. From the result and analysis of experiments, it is observed that capacitance has a more significant effect on the response variable than voltage and pulse on time.

***Keywords* - Wire EDM; Taguchi method; ANOVA; INCONEL-601; Different tool material wire.**

1. Introduction

Wire electrical discharge machining (WEDM) is a advanced machining process which cuts the material by using spark energy in between tool and work piece. In which heat produced due to electrical spark between work piece and a wire. Dielectric fluid acts as a separating medium between tool and work piece. It flush away the debris and also acts as a coolant. WEDM use for tool making and also in machining sector. WEDM is process used for producing complicated cuts on metals. WEDM process is based on spark sense which utilizes the electric spark energy to remove material with accuracy. WEDM has a growing importance in industries due to its accuracy and precise cutting. The most important factor in EDM is to have proper flushing. For efficient cutting flushing is very important because small eroded particles are removed. Flushing important for fresh dielectric oil into the gap and also cools the electrode and work piece. It is a micro WEDM process have different p parameters such as wire speed, wire tension, voltage, current, wire feed, pulse on time, pulse off time, capacitance, different wire material and wire diameter. Takale and Chougule [1] carried out experiment on shape memory alloy for their research work Ti-Ni. Their result show that Ti49.4Ni50.6 is used for the medical sector for orthopaedic implant. Subrahmanyam et al. [2 found different process parameter like voltage, pulse on time and pulse off time assist to optimize the SR and material removal rate. Use INCONEL 625 alloy as work material. They conclude that pulse on time, pulse off time and MRR are signify factor. Highest 61.90 percent contribution of pulse off time. Dayakar et al. [3] used the maraging steel 350 and Taguchi optimization method for WEDM process. Also response variable used are MRR and surface roughness. The analysis of result is done by ANOVA. Kumar et al. [4] in this study pure titanium taken as material. In which found that pulse on time directly effect on MRR during machining. In addition to this MRR decrease due to pulse off time is increased. Increase in crater diameter and crater depth due to wire speed, voltage and voltage.

2. MATERIAL AND TOOL USED

2.1 Material used

For experimentation of WEDM on Inconel-601, the micro machining setup of synergy nano system is used. The experiments are performed on Inconel 601 material having dimension (L*B*T = 110mm*30mm*3mm).

2.2 Tool used

For carrying out experimentation on Inconel-601 by using WEDM process, the zinc coated brass hard EDM wire of 200 µm diameter and uncoated plain brass wire of 200 µm is used.

3. EXPERIMENTAL PROCEDURE AND METHOD

3.1 Experimental setup

For experimentation of WEDM on Inconel-601, the micro machining setup of synergy nano system is used. The experiments are performed on Inconel 601 material having dimension (L*B*T = 110mm*30mm*3mm). Zinc coated brass wire of 200 µm diameter (Zn coated) and uncoated plane brass wire of 200 µm diameter (Br) is used as tool in experiment. The Deionized water used as dielectric fluid for experiment. The micro WEDM machine setup shown in fig.1

3.2 Design of Experiment

Design of Experiment (DoE) is done by using Taguchi method. For this experimentation there are four process parameter are used i.e. voltage, capacitance, pulse on time and different tool material. The different level of parameters is state in Table 1. Taguchi design of experiment reduces the number of experiment result in saving of cost and time required for experimentation. Taguchi L8 array is state in Table 2

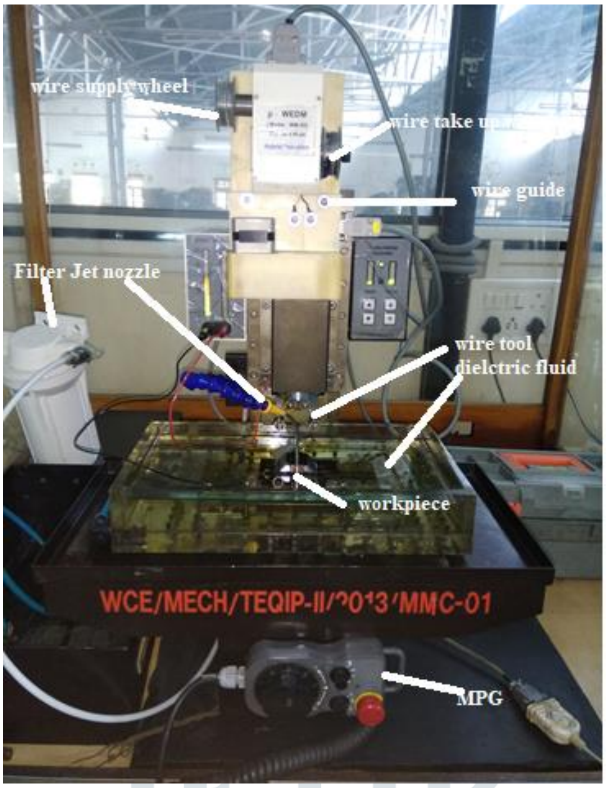


Fig.1: Experimental setup

Table 1. Process Parameter Levels L8 array

Parameter	Level1	Level2
Voltage, V (V)	150	175
Capacitance, C (pF)	1000	10000
Pulse on time ,Ton (μsec)	60	80
Tool material (wire)	Zn coated	Plain Brass

3.3 Statistical Analysis

The results of experimental work were used for the statistical analysis using the Minitab 17 statistical software, which gives the numerical value tables and graphs. Voltage, capacitance, pulse on time and tool material (wire) are the input parameters. Material removal rate and kerf width factor are the response variable. Optimal values of MRR and kerf width for experiments find out using an analysis of the signal to noise (S/N) ratio. Experiments were done based on the L-8 orthogonal array. Table 3 shows experimental observations. The outcomes of the experiments performed are done using an analysis of the signal to noise (S/N) ratio.

Table 2 Taguchi L8 array

Expri. No.	Tool Material (wire)	Voltage,V,(v)	Capacitance,C,(pF)	Pulse on time,Ton, (μsec)
1	Zinc coated	150	10000	80
2	Zinc coated	150	1000	60
3	Zinc coated	175	1000	80
4	Zinc coated	175	10000	60
5	Plain Brass	150	1000	80
6	Plain Brass	150	10000	60
7	Plain Brass	175	1000	60

8	Plain Brass	175	10000	80

When the response variable has to minimise the smaller the better characteristics is used. When it has to be maximized, the larger the better characteristic is used and when it is required to kept in between the maximum and minimum value then nominal the better characteristics is used. For optimization MRR and kerf width “smaller is better” signal to noise ratio are used.

3.4 Response variables

In this study, MRR for experiment is calculated by following formula.

MRR= (Thickness of W/P x Kerf width x Cut length) / Time in min, mm³/min.

The measurements of Kerf width and cutting length is done by using (dinolite) digital microscope setup shown in fig.2. Kerf width measurement magnification image shown in fig.3 and fig.4 for coated wire and uncoated wire.

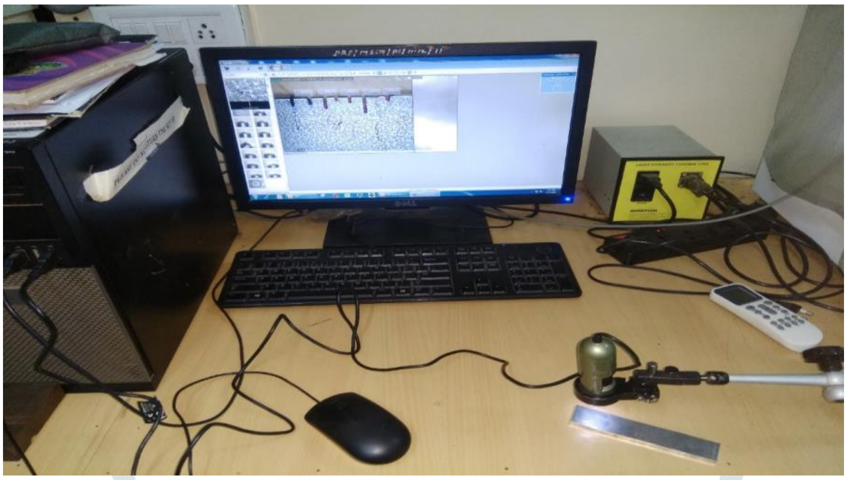


Fig. 2: Kerf width measurement by dinolite setup

Fig. 3: Kerf width measurement image by using dinolite for zinc coated wire

Fig. 4: Kerf width measurement image by using dinolite for uncoated plain brass wire

4. EXPERIMENTAL RESULT AND DISCUSSION

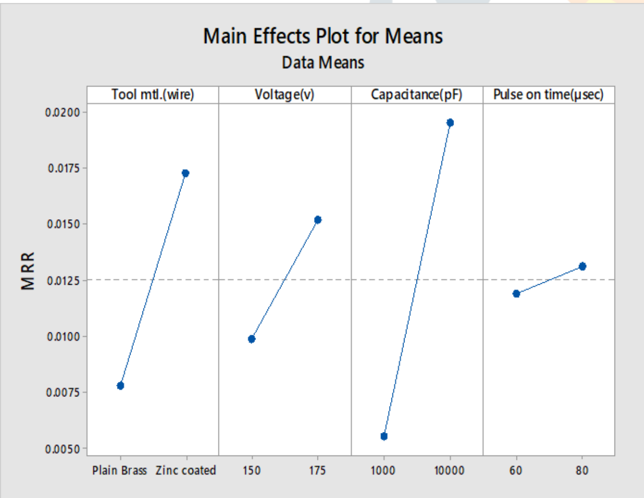
4.1 Result table

The measured values of variables are state in Table 3.

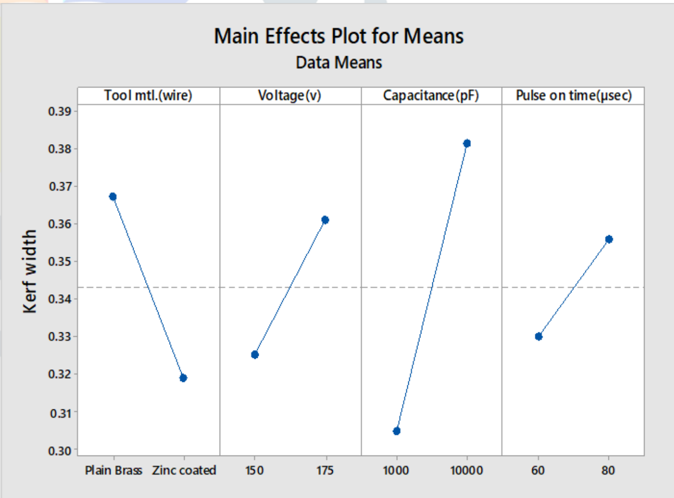
Table 3 Measured values

Expri. No.	Tool Material (wire)	Voltage V,(v)	Capacitance,C, (pF)	Pulse on time,Ton, (μsec)	KW (mm)	MRR (mm^3/min)
1	Zinc coated	150	10000	80	0.344	0.0228
2	Zinc coated	150	1000	60	0.304	0.0055
3	Zinc coated	175	1000	80	0.304	0.0102
4	Zinc coated	175	10000	60	0.324	0.0306
5	Plain Brass	150	1000	80	0.286	0.0030
6	Plain Brass	150	10000	60	0.367	0.0082
7	Plain Brass	175	1000	60	0.326	0.0034
8	Plain Brass	175	10000	80	0.490	0.0166

Graph 1 and Graph2 shows the mean effect plot for MRR and KW factor respectively.



Graph 1: Mean effect plot for MRR



Graph 2: Mean effect plot for KW

4.2 Analysis of Variance

ANOVA used to search the percentage contribution of input variables and their interactions with the selected response variables.

Table 4 state the response table for S/N ratio of MRR and graph 3 state the mean effect plot for MRR

Table 4 Response Table for Signal to Noise Ratio (MRR)

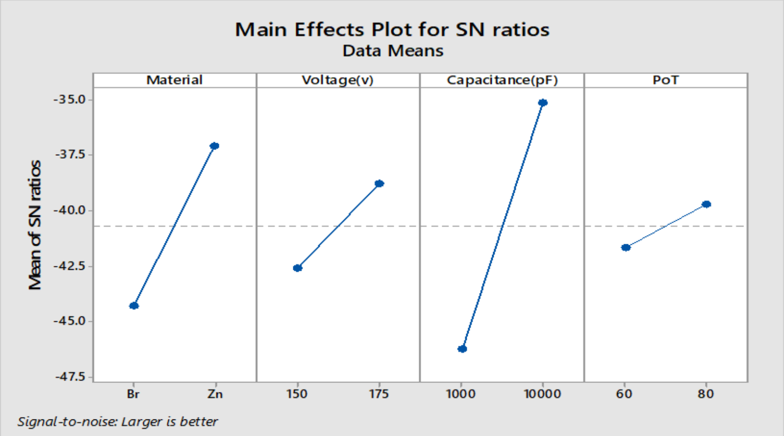
Larger is better

Level	Material	Voltage	Capacitance	PoT
1	-44.29	-42.55	-46.21	-41.64
2	-37.04	-38.77	-35.11	-39.68
Delta	7.25	3.78	11.10	1.96
Rank	2	3	1	4

4.2.1 Analysis of variance for MRR

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Mtl(wire)	1	1.39359	27.05%	1.39359	1.39359	431.54	0.000
V	1	0.37946	7.37%	0.37946	0.37946	117.50	0.002
C	1	3.26628	63.41%	3.26628	3.26628	1011.43	0.000
PoT	1	0.10204	1.98%	0.10204	0.10204	31.60	0.011
Error	3	0.00969	0.19%	0.00969	0.00323		
Total	7	5.15105	100.00%				

If capacitance is at level 1 more MRR observed, and the optimal value of MRR observed at 1000pF. Also MRR observed at voltage 150 V.



Graph 3: Main effect plot for S/N ratio of MRR

ANOVA result shows that capacitance is the most significant factor, which contributes 63.41%, followed by tool wire material and voltage with a contribution of 27.05% and 7.37%, respectively

4.2.2 Analysis of variance for kerf width

Table 5 shows the response table for S/N ratio of kerf width and graph 4 shows the mean effect plot for kerf width. If capacitance is at level 1 more kerf width observed, and the optimal value of kerf width observed at 1000 pF. ANOVA result shows that capacitance is the most significant factor, which contributes 59.65%, followed by tool wire material and voltage with a contribution of 7.79% and 6.66%, respectively

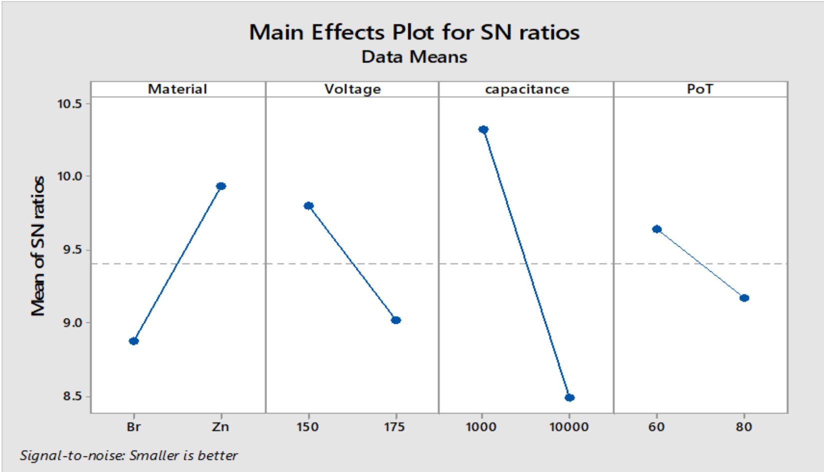
Table 5 Response Table for Signal to Noise Ratio kerf width (KW)

Smaller is better

Level	Material	Voltage	Capacitance	PoT
1	8.878	9.798	10.323	9.643
2	9.936	9.016	8.490	9.170
Delta	1.058	0.782	1.833	0.473
Rank	2	3	1	4

Analysis of variance for kerf width

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Wire mtl	1	0.001140	7.79%	0.001140	0.001140	0.90	0.412
V	1	0.000974	6.66%	0.000974	0.000974	0.77	0.444
C	1	0.008728	59.65%	0.008728	0.008728	6.91	0.078
PoT	1	0.000002	0.02%	0.000002	0.000002	0.00	0.969
Error	3	0.003787	25.88%	0.003787	0.001262		
Total	7	0.014631	100.00%				



Graph 4: Main effect plot for S/N ratio of kerf width

5. OPTIMISATION USING GREY RELATIONAL ANALYSIS (GRA)

GRA is used to optimise problems involving multiple factors and responses. The experimental result is used as a data for grey relational generation. Taguchi method is used to find optimum parameters for a single response variable. If the responses are two or more then we have to use multi-objective optimisation techniques in order to find single parameter level for the all responses

5.1 Normalised values

The first step in GRA is to calculate the normalised data within the range of zero and one. This can be done by using two quality characteristics larger-the-better or smaller-the-better. For smaller-the-better following equation is used

$$X_i^*(k) = \frac{max y_i(k) - y_i(k)}{max y_i(k) - min y_i(k)}$$

Where $X_i^*(k)$ denotes the normalised data after calculation for i^{th} experiment and $y_i(k)$ denotes the value of result for response variable for i^{th} experiment. The normalised values shown in table 6

Table 6 Normalised values

Experiment No.	Normalisation	
	KW	MRR
1	0.911765	0.09058
2	0.715686	0.717391
3	0.813725	1
4	0.911765	0.26087
5	1	0
6	0.602941	0.188406
7	0.803922	0.014493
8	0	0.492754

5.2 Deviation sequence

After normalisation, next step is to calculate deviation sequence shown in table 7 which is calculated by using following equation

$$\Delta_{0i}(k) = X_0^i(k) - X_i^*(k)$$

Where $X_0^i(k)$ is maximum of normalised value of response variable which is always 1 and $X_i^*(k)$ is the normalised value of i^{th} term.

5.3 Grey relational coefficient (GRC) and grade (GRG)

After the deviation sequence grey relational coefficient state in table 8 is calculated by following equation

$$\in_i(k) = \frac{\Delta_{min} + \delta\,\Delta_{max}}{\Delta_{0i}(k) + \delta\,\Delta_{max}}$$

Then grey relational grade is calculated by averaging the GRC of each response variable

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n} \epsilon_i\ (k)$$

Table 7 deviation sequence

Experiment no.	Deviation Sequence	
	KW	MRR
1	0.088235	0.90942
2	0.284314	0.282609
3	0.186275	0
4	0.088235	0.73913
5	0	1
6	0.397059	0.811594
7	0.196078	0.985507
8	1	0.507246

Table 8 grey relational coefficients (GRC)

Experiment no	GRC	
	KW	MRR
1	0.967213	0.879808
2	0.901528	0.480315
3	0.933216	0.398693
4	0.967213	0.717647
5	1	1
6	0.867647	0.778723
7	0.929947	0.97861
8	0.722449	0.573668

$\epsilon_i\ (k)$ Is the grey relational coefficient of the individual response variables δ - is the identification coefficient which is in the range of 0 to 1 and is generally set at 0.5 tp allocate equal weights to every parameter
From Table 9 it is confirmed that experiment number 5 gives the minimum fitness value of MRR and KW with the combination of optimum machining conditions capacitance – 1000 pF, voltage – 150 V and pulse on time – 80 microsecond.

γ - represent the grey relational grade

By using the GRG, rank was defined to each experiment run.

Table 9 grey relational grades(GRG)

Experiment no	GRG	Rank
1	0.92351	3
2	0.690921	6
3	0.665954	7
4	0.84243	4
5	1	1
6	0.823185	5
7	0.954279	2
8	0.648058	8

Analysis of parameter like tool material, voltage, pulse on time and capacitance on response variable that is kerf width and MRR by using GRA. In this analysis we find the best possible combination of parameter as shown in table 10.

Table 10 Analysis by using GRA (whole table)

						Normalisation		Deviation		GRC		GRG	Rank
Mtl.	V	Pot	C	KW	MRR	KW	MRR	KW	MRR	KW	MRR		
Zn	150	60	1000	0.304	0.0055	0.911765	0.09058	0.088235	0.90942	0.967213	0.879808	0.92351	3
Zn	150	80	10000	0.344	0.0228	0.715686	0.717391	0.284314	0.282609	0.901528	0.480315	0.690921	6
Zn	175	60	10000	0.324	0.0306	0.813725	1	0.186275	0	0.933216	0.398693	0.665954	7
Zn	175	80	1000	0.304	0.0102	0.911765	0.26087	0.088235	0.73913	0.967213	0.717647	0.84243	4
Br	150	80	1000	0.286	0.003	1	0	0	1	1	1	1	1
Br	150	60	10000	0.367	0.0082	0.602941	0.188406	0.397059	0.811594	0.867647	0.778723	0.823185	5
Br	175	60	1000	0.326	0.0034	0.803922	0.014493	0.196078	0.985507	0.929947	0.97861	0.954279	2
Br	175	80	10000	0.49	0.0166	0	0.492754	1	0.507246	0.722449	0.573668	0.648058	8
Max	175	80	10000	0.49	0.0306								
Min	150	60	1000	0.286	0.003								

6. CONCLUSION

From the result and analysis of the experiment, it is observed that capacitance is a more influencing effect on the response variable than tool wire material and voltage. The outcomes of the project are as following

1. As the capacitance increases from 1000 pF to 10000 pF, the MRR goes on increasing.
2. When voltage is increased from 150V to 175V, the MRR increases gradually.
3. On the other hand, as Ton is increased from 60 µsec to 80µsec, a vigorous increase in MRR is observed.
4. Capacitance, Tool wire material and voltage is found to be most influencing parameter for MRR in Micro WEDM process carried out in experimental work.
5. As the capacitance increases from 1000 pF to 10000 pF, the Kerf width goes on increasing.
6. The capacitance, tool wire material, voltage is found to be most influencing parameter for KW in Micro WEDM process carried out in experimental work.
7. The Ton is found to be least affecting parameter on Kerf width.

By the GRA technique the optimal parameter level found at capacitance at level- 1000 pF, voltage at level- 150 V and pulse on time 80 microsecond.

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