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Optimization of Electro-Discharge Machining Parameters Using Taguchi Method and ANOVA during Fabrication of Microchannels

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Abstract
In this paper, optimization of electro-discharge machining (EDM) process parameters has been done during fabrication of microchannels. The process parameters selected for the study were current, voltage, pulse-on time, and pulse-off time. The response parameter taken was electrode wear rate. The settings of EDM parameters were determined by using the Taguchi experimental design method. The level of importance of the EDM parameters on the electrode wear rate is determined by using analysis of variance (ANOVA). The optimum EDM parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio. Microchannels were fabricated using EDM process on D3 Die-steel plate using copper electrodes.

Keywords: ANOVA, die-sink EDM, EDM, electro-discharge machining, microfluidic channel

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INTRODUCTION

Constantly expanding space, vitality and efficiency necessities are impelling products towards scaling down in several areas such as biomedicine, electronics, dies-molds, optics, energy, micromechanics, microfluidics, aerospace, and aeronautics to name a few. [1, 2] Microchannels have been distinguished to be one of the significant components to transport fluid inside of a miniature region. In addition to interfacing distinctive chemical chambers, microchannels are additionally utilized for reactant conveyance, physical particle partition, fluid control, PC chips cooling and chemical mixing. [3]

This paper endeavors to examine the optimization of the die-sinking electro-discharge machining process parameters for optimum tool wear rate of copper sheet electrode while fabricating microchannels on D3 Die-steel plate workpeice. We utilized Taguchi Method for optimization of EDM procedure parameters for minimum device wear rate of copper sheet electrodes.

The main disadvantage of this method is that the results obtained are only relative in nature and do not exactly indicate which parameter has the highest effect on the performance characteristic value. Hence, ANOVA is used for finding the most significant parameters. The schematic of the workpiece and electrode sheet is shown in Figure 1. This is a fast process for cutting microchannels using electrode sheets as the complete microchannel is made using only the vertical movement of the electrode.

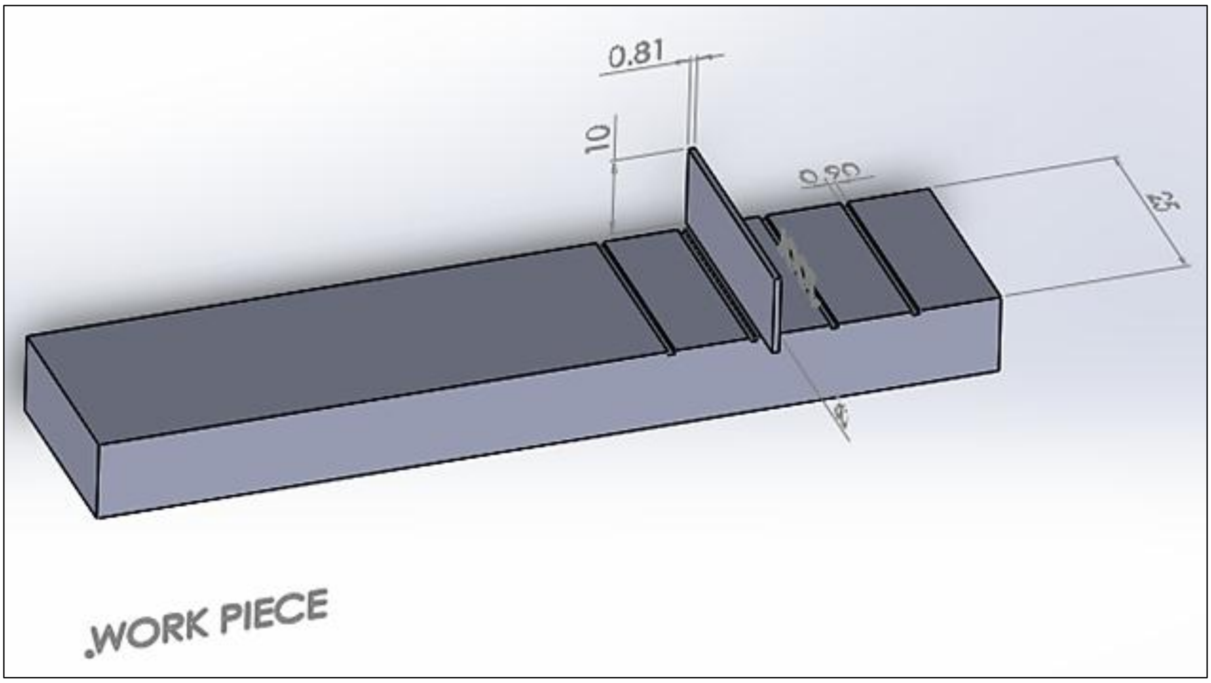

Fig. 1. *Schematic of Workpiece and Electrode Sheet During Cutting Operation.*

EXPERIMENTS

The experiments were performed on EDM Die Sink ECOCUT by Electronica. The four different levels of Current (Ip), Pulse-on Time (Ton), Pulse-off Time (T_{off}), and Voltage (V_g) kept in the experiments are shown in Table 1. Most of these ranges were selected in light of the data available in the literature, and machine technical data. The values of all other factors were kept constant. Sixteen numbers of rectangular microchannels of size 0.5 mm × 0.9 mm × 25 mm were cut on the workpiece of AISI D3 Die steel of 25 mm × 200 mm × 10 mm size. AISI D3 die steel is one of the most extensively used materials in mold and dies manufacturing industry. The electrode used was copper sheet. The measured values of tool wear rates for each of the 16 experiments are shown in Table 2.

Table 1. *Levels of Parameters.*

Sl. no.	Machining parameter	Symbol	Level 1	Level 2	Level 3	Level 4
1	Current (A)	I_p	5	7	9	11
2	Pulse-on Time (μs)	T_{on}	10	20	30	40
3	Pulse-off Time (μs)	T_{off}	5	10	15	20
4	Voltage (V)	V_g	30	40	50	60

METHODOLOGY

The experiment was designed using Taguchi's design of experiments. [4, 5] L16 orthogonal array was chosen. The quality engineering method proposed by Taguchi is commonly known as the Taguchi method or Taguchi approach. His approach provides a new experimental strategy in which a modified and standardized form of design of experiment (DOE) is used. As such, the Taguchi methodology is a form of DOE with unique application principles. By examining the impact of individual factors on the outcomes, the best factor combination can be resolved. [6, 7]

Taguchi method is one of the simple and compelling solutions for parameter outline and experimental arranging. [4] Taguchi method is a capable technique for the design of a high quality framework. It gives an effective, as well as a precise way to optimize designs for performance and quality. [8]

Taguchi method can be utilized for optimization of process parameters to get optimum condition with most reduced expense and least number of experiments which prompts generation of high quality products. Attributable to the advantages offered by the Taguchi method, researchers have extensively utilized this technique to plan experiments with the purpose of improvement of process and design parameters. [9]

In this paper, the experiments were conducted with four control factors with four levels. Sixteen experimental runs based on the orthogonal array L16 were carried. Table 1 shows the four controlled factors, i.e., current [A (Ampere)], pulse ON time [B (μs)], pulse OFF time [C (μs)], and voltage [D (volts)] with four levels for each factor. Table 3 shows the experimental trials according to the selected orthogonal table. The values of all the parameters namely Current, Pulse ON, Pulse OFF and Voltage were kept at four levels as shown in Table 1.

Table 2. *Tool Wear Rate for Each Trial.*

Sl. no.	Tool wear rate (in g/second)
1	2.515×10^{-5}
2	4.189×10^{-5}
3	7.425×10^{-5}
4	1.384×10^{-4}
5	5.371×10^{-5}
6	6.075×10^{-5}
7	2.853×10^{-4}
8	2.040×10^{-4}
9	1.540×10^{-4}
10	1.852×10^{-4}
11	2.073×10^{-4}
12	1.852×10^{-4}
13	4.000×10^{-4}
14	5.513×10^{-4}
15	2.670×10^{-4}
16	3.488×10^{-5}

Table 3. *Experimental Trials.*

Sl. no.	Current (I_p)	Pulse-on time (T_{on})	Pulse-off time (T_{off})	Voltage (V_g)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

RESULTS

Analysis of Experiments

The experiments were conducted based on varying the process parameters, which affect the machining process to obtain the required quality characteristics. Quality characteristics are the response values or the output values expected out of the experiments. As the objective is to obtain optimum tool wear rate, we are concerned with obtaining smaller value of tool wear rate. Hence, the required quality characteristic for tool wear rate is smaller the better, which states that the output must be as low as possible. Table 4 shows the signal to noise ratios for the experiments.

Table 4. *S/N Ratios for Each Trial.*

Sl. no.	Current (I_p)	Pulse-on time (T_{on})	Pulse-off time (T_{off})	Voltage (V_g)	Tool wear rate (in g/second)	S/N ratio
1	1	1	1	1	2.515×10^{-5}	91.9892
2	1	2	2	2	4.189×10^{-5}	87.5577
3	1	3	3	3	7.425×10^{-5}	82.5860
4	1	4	4	4	1.384×10^{-4}	77.177
5	2	1	2	3	5.371×10^{-5}	85.3988
6	2	2	1	4	6.075×10^{-5}	84.3290
7	2	3	4	1	2.853×10^{-4}	70.8939
8	2	4	3	2	2.040×10^{-4}	73.80739
9	3	1	3	4	1.540×10^{-4}	76.2495
10	3	2	4	3	1.852×10^{-4}	74.6471
11	3	3	1	2	2.073×10^{-4}	73.6680
12	3	4	2	1	1.852×10^{-4}	74.6471
13	4	1	4	2	4.000×10^{-4}	67.9588
14	4	2	3	1	5.513×10^{-4}	65.1722
15	4	3	2	4	2.670×10^{-4}	71.4697
16	4	4	1	3	3.488×10^{-5}	89.1484

Analysis of variance (ANOVA) was performed and the effects of individual parameters are shown in Table 5. And the Main Effect plots are shown in Figures 2–5.

Table 5. *Analysis of Variance (ANOVA).*

Symbol	Process Parameter	D.O.F	SS	MS	F	%Contribution
A	Current	3	311.87	103.95	4.017	32.89
B	Pulse-on	3	69.58	23.17	0.89	7.33
C	Pulse-off	3	359.92	119.97	4.610	37.96
D	Voltage	3	129.32	43.107	1.66	13.67
Error		3	77.63	25.87		8.18
Total		15	948.14			

DOF, degree of freedom; SS, sum of square; MS, mean of square.

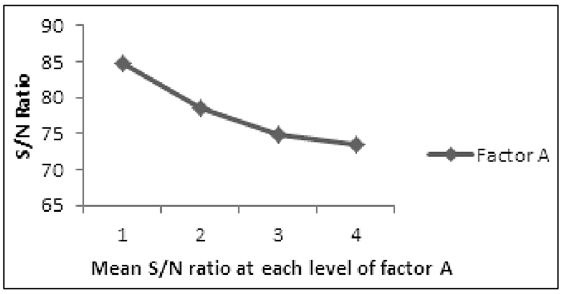

Fig. 2. *Main Effect Plot for Factor A.*

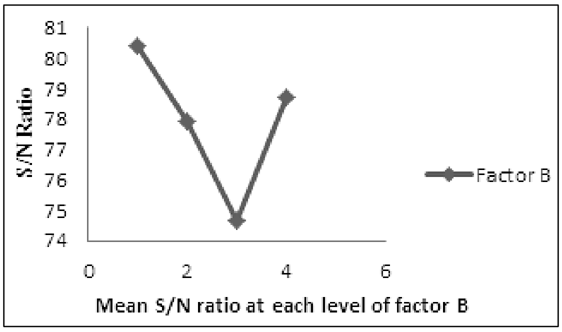

Fig. 3. *Main Effect Plot for Factor B.*

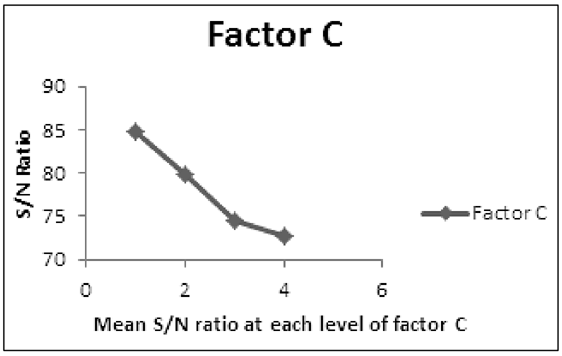

Fig. 4. *Main Effect Plot for Factor C.*

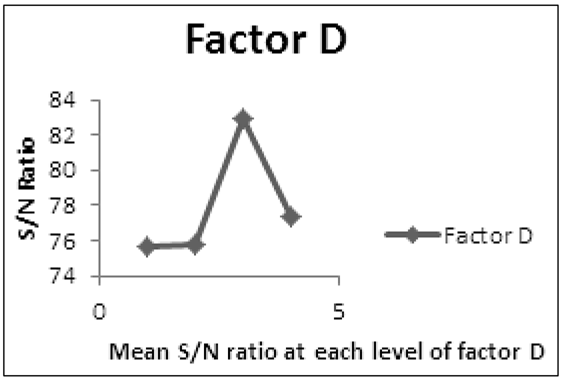

Fig. 5. *Main Effect Plot for Factor D.*

CONCLUSION

Microchannels were fabricated on AISI D3 Die-steel using copper electrodes in the form of sheets. The effects of current, pulse on time, pulse off time, and voltage were experimentally investigated using Taguchi method and ANOVA. The combination of machining parameters $A_1B_1C_1D_3$ i.e. current at 5 A, pulse on time at 10 µs, pulse off time at 5 µs and voltage at 50 V was found to be optimum for minimum tool wear rate. In addition, it was also found that pulse-off time was the most dominant factor for tool wear rate, its percentage contribution is maximum i.e. 37.96%. The level of importance of current, pulse-on time and voltage, indicated by percentage contribution, on the tool wear rate was observed to be 32.89, 7.33, and 13.67%, respectively.

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