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PARAMETRIC OPTIMIZATION OF TOOL WEAR RATE IN MICRO DRILLING OF MARAGING STEEL 300 ALLOY

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Abstract: Micro EDM, a variant of Electrical Discharge Machining (EDM) process, is used to drill micro holes in hard and electrically conducting materials. Since Maraging Steel 300 alloy has not been studied on micro EDM process, an attempt has been made in this research paper to investigate the effect of various process parameters on tool wear rate (TWR) in micro EDM drilling of holes in Maraging Steel 300 alloy using Taguchi Methodology. Process parameters taken up for study are Pulse-on time, Pulse-off time, Tool diameter and current. Brass electrode of 300 µm, 400 µm and 500 µm diameter is used as tool material. The experiments were carried out using L_9 ($3^{4)}$ orthogonal array. Based on eroded length of tool and volume measurements, the tool wear rate is calculated for various combinations of factors and levels. The results of experiments are thoroughly discussed and the effect of process parameters on tool wear rate is presented.

Keywords: Micro EDM, Maraging Steel 300 Alloy, Tool Wear Rate, Taguchi Method

1. INTRODUCTION

Micro-EDM is a modified process of Electrical Discharge Machining (EDM) process. It uses the principle of Electrical Discharge Machining i.e., the material is removed by a sequence of frequently recurring electric spark discharges between the tool electrode and the workpiece [1,2]. Micro-EDM is differentiated from the conventional EDM by parameters like Type of pulse generator, the resolution of the axes of movement and diameter of the tool. In micro-EDM, pulse generator produces very small pulses within pulse duration of a few micro seconds or nano seconds. Because of this reason, micro-EDM utilizes low discharge energies (~ 10^{-6} - 10^{-9} Joules) to remove small volumes (~0.05 - 500µm^3) of material. Micro-EDM is characterized by its ability to machine any type of conductive and semi-conductive materials with high surface accuracy irrespective of material hardness [3]. It is preferred especially for the machining of difficult-to-cut material due to its high efficiency and precision. Small volumetric material removal of micro-EDM provides substantial opportunities for manufacturing of micro-dies and micro-structure such as micro holes, micro slot, and micro gears etc. [4].

The main advantage of micro-EDM is that it can machine complex shapes into any conductive material with very low forces. The forces are very small because the tool and the workpiece do not come into contact during the machining process. This property provides advantages to both the tool and the workpiece. In addition, micro-EDM is a contactless material removal process thereby eliminating mechanical stress, chatter and vibration problems during machining. Therefore, micro-EDM is very effective to machine any kind of micro holes with high aspect ratio. Despite a very efficient process in micro-hole machining and having many advantages, micro-EDM is rather a slow machining process with the tool electrode wear at a rather significant rate. This tool-wear leads to shape inaccuracies. Another drawback is the formation of a heat affected layer on the machined surface. Since it is impossible to remove all the molten part of the workpiece, a thin layer of molten material remains on the workpiece surface, which re-solidifies during cooling [5]. Micro-EDM is generally used to manufacture micro and miniature parts and components like holes, nozzles, and gears in micro-electro-mechanical systems (MEMS), biomedical applications, automotive industry, and defense industry. It can be used as variant machining processes like micro-ED drilling, micro-ED milling, micro-ED die sinking, micro-ED contouring, micro-ED dressing, and micro wire electrical discharge grinding (micro-WEDG). All of these processes are integrated in today’s sophisticated micro-EDM machines [6].

This paper studies the effect of various process parameter combinations on tool wear rate (TWR) in micro EDM drilling of Maraging Steel 300 alloy using Taguchi methodology. Based on volumetric measurements and eroded length of the electrode, tool wear rate is calculated. The influence of the various process parameters and the behaviour of the electrode on a hard to cut material like Maraging Steel 300 alloy are studied and discussed elaborately.

2. PRINCIPLE OF MICRO-EDM

Fig.1 shows schematic of the experimental setup used in the micro drilling process. It consists of single-discharge RC circuit with one end connected to the tool (electrode) and the other to the workpiece. Dielectric medium is used for insulation as well as for flushing out the debris after machining [6].

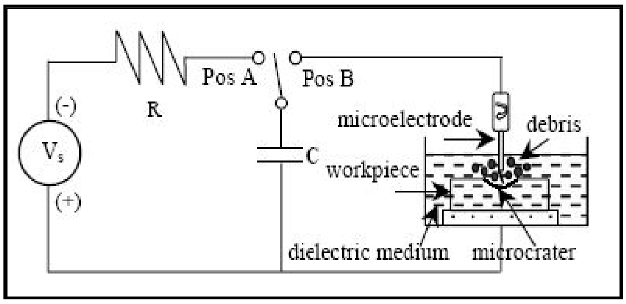

Fig.1 Schematic of EDM micro drilling process

Tool and workpiece are separated with a very small gap, called as interelectrode gap. Discharging of the pulsed arc occurs in the interelectrode gap. The electrode shape is copied with an offset equal to the gap size and the liquid will be selected to minimize the gap in order to obtain precise machining. To make sure it is safe, a certain gap width is needed to avoid short circuiting especially for electrodes that are sensitive to vibration or deformation is used. Initially, a high voltage current is needed to discharge in order to overcome the dielectric breakdown strength of the small gap. Formed between the electrodes is a channel of plasma (ionized and electrically conductive gas with high temperature) and its further development depends on the discharge durations. Discharge occurs at high frequencies between 10^3 Hz and 10^6 Hz since the metal removal per discharge is very small. For every pulse, discharge occurs at a particular location where the electrode materials are evaporated or ejected in the molten phase then a small crater is generated both on the tool electrode and workpiece surfaces. The removed material are then cooled and re-solidified in the dielectric liquid forming several hundreds of spherical debris particles which will be flushed away from the gap by the dielectric flow. At the end of the discharge duration, the temperature of the plasma and the electrode surfaces that is in contact of the plasma rapidly drops, resulting in the recombination of ions and electrons also the recovery of the dielectric breakdown strength. To obtain stable condition in EDM, it is important that the next pulse discharge occur sufficiently far away from the previous discharge location. This is because the previous location will result in having a small gap and it is contaminated with debris particles which may weaken the dielectric breakdown strength of the liquid. The time interval for the next discharge pulse should be long so that the plasma that is generated by the previous discharge can be fully de-ionized and the dielectric breakdown strength around the previous discharge location can be recovered by the time the next voltage charge is applied. If discharges occur at the same location, it results in thermal overheating and non-uniform erosion of the workpiece [6].

3. TOOL WEAR RATE (TWR)

Wear ratio is defined as the ratio of amount of electrode eroded to the amount of workpiece removal. There are four methods to evaluate the tool wear ratio by means of measuring weight, shape, length, and total volume respectively. A common one is by calculating the volumetric wear ratio (υ). Usually the weight differences are measured and converted into the volumes by the density of materials. However this method is unsuitable for micro-EDM because the weight change is so small making it difficult to measure it accurately. Therefore, it is important to measure and analyze removed material directly [7].

Tool Wear Rate (TWR) is calculated by [7]:

$$\boldsymbol{TWR} = \frac{\boldsymbol{V_e}}{\boldsymbol{t}}\text{, mm}^3\text{/min} \qquad (1)$$

$$\boldsymbol{V_e} = \frac{\boldsymbol{\pi D_e^2 L_e}}{\boldsymbol{4}}\text{, mm}^3 \qquad (2)$$

where,

V_e= eroded volume of the tool/ electrode

D_e= eroded diameter of the tool/ electrode

L_e= eroded length of the tool/ electrode

T = machining time of hole (micro drilling)

4. TAGUCHI METHODOLOGY

Taguchi's robust design methodology is used not only to optimize the process parameters for micro-EDM drilling but also to know the wear trend of electrode. Phadke [8] defined the steps to be used in Taguchi's Robust Design Methodology as under:

- Identifying the main function, side effects and failures modes.
- Identifying the testing conditions for evaluating the quality loss and noise factors.
- Identifying the quality characteristic to be observed and the objective function to be optimized.
- Selection of control factors and their levels.
- Design of matrix experiment.
- Conducting the matrix experiment.

- Analyzing the data, determining optimum levels for the control factors and predicting performance under these levels.
- Conducting the verification experiment and future plan.

5. EXPERIMENTAL SETUP

GRACE make micro-EDM machine was used to drill micro-holes of 300 µm (0.3 mm), 400 µm (0.4 mm), and 500 µm (0.5 mm) diameter on Maraging Steel 300 alloy using brass wire electrodes. Literature review suggested that Maraging Steel 300 alloy was not tested on Micro EDM process. Also it was found to be a hard to cut material. Composition of Maraging Steel 300 alloy is given in Table 1.

Table 1 Workpiece Composition of Maraging Steel 300 alloy

Element	Fe	Ni	Co	Mo
%	67.50	18.21	8.34	5.12
Element	Ti	Al	Si	Mn
%	0.61	0.069	0.056	0.061
Element	C	P	S	
%	0.026	0.005	0.004	

Dimensions of the two workpieces were 55 mm (length) x 20 mm (width) x 5 mm (thickness) each. 5 mm thickness was used to for microdrilling of holes so as to test the drilling operation for a higher aspect ratio. Fig.2 shows the workpiece specimen. Dielectric used was deionised water [9].

Fig.2 Maraging Steel 300 specimen

Table 2 Process Parameters and their levels

Factors	Levels		
	1	2	3
Pulse on time [T_{On}] (µs)	1	5	9
Pulse off time [T_{Off}] (µs)	3	6	9
Tool Diameter [D] (µm)	300	400	500
Current [I] (A)	3	4	5

Machining parameters along with their levels used in the experimentation are listed in Table **2**. L_9 (3^4) orthogonal array **was** selected for carrying out the experimentation.

6. RESULTS AND DISCUSSION

Experiments were conducted as per the L_9 Orthogonal Array experimental design shown in Table 3. Nine microholes drilled on the two Maraging Steel 300 alloy specimens are shown in Fig.3.

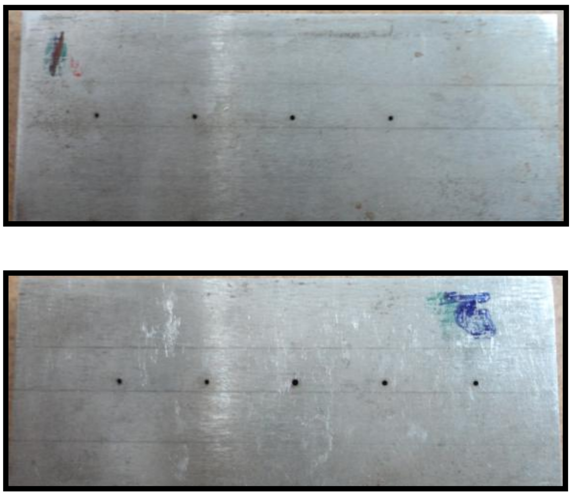

Fig.3 Microholes on Maraging Steel 300 alloy specimens

After each experiment, eroded length and eroded diameter of the tool were noted. Tool Wear Rate (TWR) was then calculated using Equation (1) and (2) respectively. Since wear rate of a tool should be as small as possible, the output characteristic belonged to “Smaller-the-better” (S-Type) quality characteristic. Signal to Noise ratio (S/N) ratio for a S-Type characteristic is calculated by

$$\eta = -10\log_{10}\left[\frac{1}{n}(y_i^2)\right] \qquad (3)$$

where,
η = signal to noise ratio
y_i = observations
n = number of observations

The obtained results along with S/N ratios are shown in Table 3. The objective of Taguchi’s methodology is always to maximize S/N ratio. TWR falls under S-Type category. Hence maximum S/N ratio value in Fig.4 or in Table 4 indicates minimum wear (S-Type). The optimum combination of process parameter was selected as per Taguchi’s S/N analysis and is shown in Fig.4 and Table 4. As shown in Fig.4a, TWR is increasing with increase in pulse on time. This may be attributed to the transfer of more energy during discharging process. Fig.4b shows that TWR decreases with the increase in pulse-off time. Too short pulse-off time does not produce stable discharge, hence less machining of workpiece takes place amounting to less wear. However as seen in Fig.4c, TWR increases with increase in diameter of the tool i.e., least wear is observed with smallest diameter of the electrode. Also, TWR is showing an increasing trend with increase in current as shown in Fig.4d. Initially the wear is less due to low setting of input current and thereafter increases.

Table 3 Experimental Design with Tool Wear Rate and S/N results

Exp. Nos.	T_{On} (µs)	T_{Off} (µs)	D (µm)	I (A)	L_e (mm)	T (min.)	TWR (mm^3/min)	η (dB)
1	1	3	300	3	7.67	360	0.001507	56.43773
2	1	6	400	4	6.30	330	0.002399	52.3994
3	1	9	500	5	5.07	270	0.003688	48.66418
4	5	3	400	5	6	328	0.002301	52.76167
5	5	6	500	3	4.92	274	0.003529	49.04697
6	5	9	300	4	6.60	331	0.00141	57.01562
7	9	3	500	4	5	271	0.003621	48.82343
8	9	6	300	5	7.65	363	0.001487	56.55378
9	9	9	400	3	5.11	269	0.002386	52.44659
Total							0.022328	474.1494
Average							0.002481	52.68326

Table 4 Average S/N ratio at different levels of process parameters

Factor	Average S/N (η) as per factor level		
	1	2	3
Pulse on time (µs)	52.50	52.94	52.61
Pulse off time (µs)	52.67	52.67	52.71
Tool Diameter (µm)	52.67	52.54	48.84
Current (A)	52.64	52.75	52.66

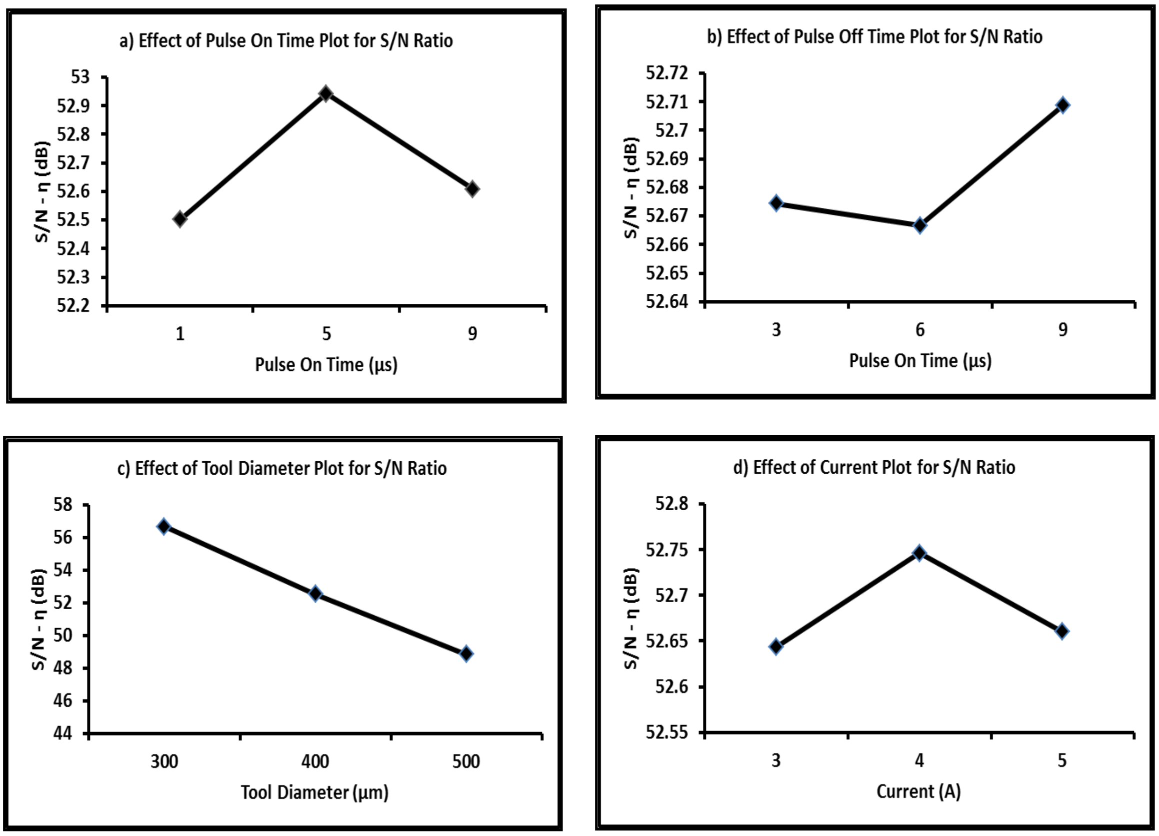

Fig.4 S/N plots of factor effects

The optimum combination of process parameters is pulse ON time of 5 µs, pulse OFF time of 9 µs, tool diameter of 300 µm and current of 4 A. Theoretical S/N ratio for this optimum combination was predicted as 57.01562 dB. A verification experiment was carried out with optimum settings of factors and levels in order to validate the experimentation. The tool wear rate was obtained using Equation (1) and (2) respectively and is shown in Table 5. S/N ratio value for the conformation experiment was calculated and compared with the predicted one. The predicted S/N ratio, shown in Table 6, was found to be in close proximity with the actual one, thus validating the research study.

As shown in Table 7, the optimum combination of factor and levels gave an improvement of 0.000137 mm^3/min in the tool wear rate. Also, the objective function of maximizing the S/N ratio was achieved i.e., from 56.43 dB to 57.26 dB.

Table 5 Optimum condition for conformation experiment and obtained TWR

T_{On} (µs)	T_{Off} (µs)	D (µm)	I (A)	Output
				TWR (mm^3/min)
5	9	300	4	0.00137

Table 6 Predicted and Conformed S/N ratio

S/N Ratio	η (dB)
Predicted	57.01562
Conformation	57.265589

Table 7 **Results of Verification Experiment**

Output	Starting Condition	Optimum Condition	Improvement
TWR (mm^3/min)	0.001507	0.00137	0.000137
η (dB)	56.43773	57.26559	0.827859

Fig.**5** shows the SEM image of 300 µm diameter microhole drilled under optimum condition on Maraging Steel 330 Alloy.

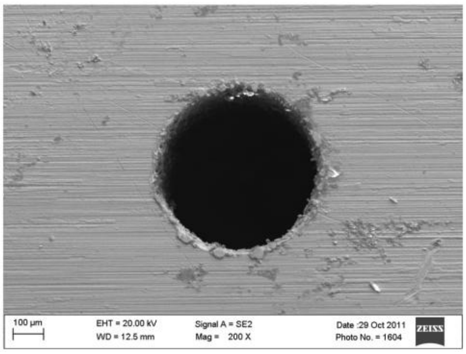

Fig.5 SEM micrograph of 300 µm diameter hole under optimum condition (at 100 µm and 200X)

7. CONCLUSIONS

The effect of machining parameters like pulse on time, pulse off time, tool diameter and pulse current on tool wear rate in micro drilling holes on Maraging Steel 300 alloy using brass wire electrodes of 300 µm, 400 µm, and 500 µm diameter is studied. Following are the observations.

(i) Optimum combination of factor levels for minimizing Tool Wear Rate while micro drilling holes on Maraging Steel 300 alloy include a pulse on time of 5 µs, pulse off time of 9 µs, tool diameter of 300 µm and current of 4 A. The least tool wear is attributed to the long pulse off time (9 µs) associated with medium pulse ON time (5µs) and current (4 A).

(ii) A trend of low tool wear is seen in experiment numbers 1, 6 & 8 respectively where the diameter of electrode is the least in experimentation i.e., 300 µm. It is observed that as the tool diameter decreases, tool wear decreases.

(iii) It is found that the tool wear is increasing with increased diameter of electrode (500 µm) as shown in experiments numbers 3, 5 & 7 respectively.

(iv) TWR is seen to be increasing with increasing pulse on time and current due to more energy generated during the pulse.

(v) Less TWR is observed at low pulse off time and increases further as pulse off time is increased. This is because at low pulse off time a stable discharge is not generated so less machining is done thereby reducing the wear rate.

(vi) Confirmation experiment shows that the tool wear rate has indeed reduced i.e., 0.00137 mm^3/min with optimum combination of factors and levels in micro-EDM drilling of Maraging Steel 300 alloy. The tool wear rate obtained at the start of experimentation is 0.001507 mm^3/min. Therefore, an improvement in tool wear rate of 0.000137 mm^3/min is obtained using the optimal parameters.

(vii) The objective function of maximising the S/N ratio is also achieved at the end of conformation experiment. The S/N ratio is maximized by an amount of 0.8278. Thus, it can be concluded that with the set of process parameters taken up for study, tool diameter seems to influence the tool wear rate. However, there are other parameters like spark gap, discharge location and precipitation of carbon which needs to be studied for knowing their effect on tool wear rate.

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REFERENCES

[1] Kuneida, M., Lauwers, B., Rajurkar, K.P. and Schumacher, B.M., Advancing EDM Through Fundamental Insight into the Process, CIRP Annals–Manufacturing Technology, Vol. 54, pp.64-87, 2005.

[2] Zarepur, H., Fadaei Tehrani, A., Karimi, D. and Amini, S., Statistical Analysis on Electrode Wear in EDM of Tool Steel DIN 1.2714 Used in Forged Dies, Journal of Materials Processing Technology, Vol. 187-188, pp.711-714, 2007.

[3] Murali, M., Yeo, S.H., Rapid Biocompatible Micro Device Fabrication by Micro Electro-Discharge Machining, Biomedical Micro Devices, Vol.6, pp.41-45, 2004.

[4] Bleys, P., Kruth, J. and Lauwers, B., Investigation of Material Removal Mechanisms in EDM of Composite Ceramic Materials, Journal of Materials Processing Technology, Vol. 149, pp.139-146, 2004.

[5] Liu, K., Lauwers, B. and Reynaerts, D., Process Capabilities of Micro-EDM and its Applications, The International Journal of Advanced Manufacturing Technology, Vol. 47, Issue 1-4, pp. 11-19, 2010.

[6] Mahendran, S., Devarajan, R., Nagarajan, T. and Majidi, A., A Review of Micro EDM, International Multiconference of Engineers and Computer Scientists, Hong Kong, Vol. II, pp.981-986, 2010.

[7] Yao, Y.T. and Masuzawa, T., An Index to Evaluate the Wear Resistance of the Electrode in Micro-EDM, Journal of Materials Processing Technology, Vol.149, pp.304-309, 2004.

[8] Phadke, M.D., Quality Engineering Using Robust Design, Prentice Hall, New Delhi, 1989.

[9] Kunieda, M. and Kobayashi, T., Clarifying Mechanism of Determining Tool Electrode Wear in EDM Using Spectroscopic Measurement of Vapour Density, Journal of Materials Processing Technology, Vol. 149, pp.284-288, 2004.