Optimization of Process Parameters in Micro-EDM Through Mixed Flushing and GRA Technique

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1 Introduction

Among the non-traditional concepts of machining, EDM is widely used to produce dies and many other profiles on any kind of electrically conductive material. The surface workpiece is gradually sparked and eroded by thermal energies through a series of sparks in the gap between electrode and workpiece immersed in a dielectric liquid. Any kind of hard material can be machined with high precision and accuracy. Hence, it is commonly used in finishing parts for aerospace and automotive industry and surgical components. This technique was developed in the 1940s. As soon as the electrode is moved in, the vicinity of workpiece until the gap is too small to ionize the dielectric fluid. There happens continuous initiation of sparks having micro-second duration in the dielectric area between the tool and workpiece material [1]. The material is removed with spark and erosion phenomenon by electrical discharges from tool to workpiece via dielectric medium. In EDM machining, the tool and workpiece are separated by a very small distance known as the inter-electrode space containing the dielectric medium as shown in Fig. 1; thus, chances of mechanical stress and vibrations are reduced to a large extent.

2 Literature Review

Urso et al. [2] have fabricated holes using micro-EDM machining; the investigation focused on the effect of electrodes and workpiece materials on the process performance and was expressed in terms of tool and wear ratio. In particular, the influence of four workpiece materials (titanium, magnesium, SS and brass), three

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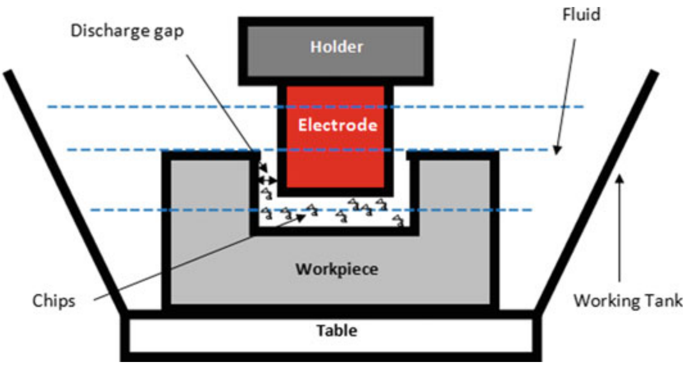

Fig. 1 Schematic of EDM process

electrode materials (tungsten carbide, brass and copper) and two electrode profile were investigated. Munz et al. [3] have found that too much flushing resulted in opposite process behaviour and reduced the speed of drilling; however, on the basis of supplied current to the gap, there was an optimal dielectric flow rate in order to obtain a higher drilling speed. It was also concluded that flow rate of dielectric and material removal was directly proportional in nature. Ayesta et al. [4] used different flushing arrangements inside the slots for this experimental study. A camera having high speed capture rate was used in the tests to observe and analyse the particle movement pattern within the slot. Trials done without flushing, intermittent flushing using a nozzle and a continuous arrangement for flushing were implemented inside the machining zone. In addition to this, electrode jump heights were programmed. The results highlighted the fact that the best debris removal was obtained along with application of continuous dielectric spray in the form of flushing.

Fu et al. [5] had machined the workpiece with different tool materials and further classified them as rough machining, semi-finish machining and finish machining conditions. As the tool feed had a great influence of the tool material, the time for machining was examined to get the detailed tool feed information. Since machining accuracy depends upon machining feed and side gap, their relationship was investigated. Similarly, machining feed and tool wear ration were also studied and investigated along with the investigation of tool material on the wear aspect. Niamat et al. [6] have discussed the effects of factors like pulse-on-time (μs) and current (A) for the response measurement while using fluid materials like water and kerosene as the dielectric medium. A study to compare the responses like MRR and TWR was performed while using water and kerosene separately as the dielectric mediums. Aluminium 6061 T6 alloy has been extensively used in the automobile and aviation industries. Natarajan and Arunachalam [7] used GRA to investigate the optimization of process parameters micro-EDM for SS 316 workpiece and concluded that current came out to be the most influential factor. Pradhan [8] used GRA along with principal component analysis (PCA) for the optimization of EDM machining. Chakravorty et al. [9] used two sets of past experimental data on EDM processes in order to compare four different optimization methods. It was found that utility theory method gave overall better optimization than GRA based and other methods. Dewangan and Biswas [10] used GRA based Taguchi technique to study the optimization process of various responses like MRR and TWR of EDM on a AISI P20 tool steel workpiece material; where a copper tool electrode of cylindrical geometry was used. Priyadarshini and Pal [11] investigated using GRA based PCA optimization resulted better feasible parametric setting which were also in accordance with the validation experiments. This research aims to study the effects of material density of electrodes (copper, aluminium and brass), current (ampere), T_{on} (μs), T_{off} (μs) which were evaluated for the performance measure and analysis by using a combination of through and side flushing. A comparison was performed for different electrode density material for responses like MRR (g/min), TWR (g/min) and micro-images of surface finish.

3 Experimental Set-up and Procedure

Diesinking (SPARKONIX 35A) EDM was used for the experimentation. In micromachining, removal of debris is a major issue with increase in depth of the hole, as soon as the sparking starts and the material starts to erode; there is an urgent requirement to flush-off the machining area, otherwise the eroded material again sticks to the machined surface. The impulse flushing which is the default flushing method fails to remove the debris inside the hole; however, it flushes off the debris in the initial machining time. To rectify this problem, one of the impulse nozzles had been modified to allow the dielectric to pass through the tool electrode, and hence, debris accumulated just beneath the tool electrode gets removed to a certain extent. A mixed flushing arrangement was employed for the micromachining task as shown in Fig. 2 Mild steel plate with thickness 5 mm was used as the workpiece material

Fig. 2 Mixed flushing arrangement

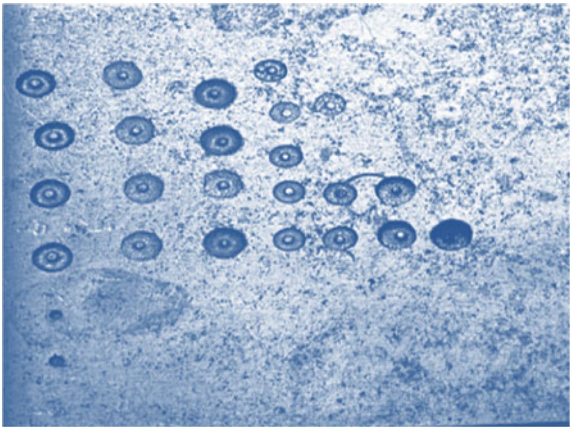

Fig. 3 Mild steel workpiece

Table 1 Electrode materials and density

S. No.	Electrode material	Density (g/cm^3)
1	Copper	8.96
2	Aluminium	2.7
3	Brass	8.73

as shown in Fig. 3 with kerosene oil as dielectric medium. Three different materials (copper, brass and aluminium) were used as the tool electrode, Table 1 shows the density corresponding to each electrode material. The tool electrodes were hollow in geometry with internal diameter 0.8 mm. For each electrode material and workpiece, based on the pilot studies, best machining process parameters were identified and a set of parameters were selected. The effects of material density of electrode (copper, aluminium and brass), current (ampere), pulse-on-time (μs) and pulse-of-time (μs) were evaluated for performance measures using mixed flushing arrangement.

Electrode and workpiece were weighted using digital weight balance prior and post each experimental run. Machining time was obtained by using a stopwatch for a constant 10 min run. The obtained weight differences in electrode and workpiece were divided by time to get MRR and TWR in the unit of mg/min, where "*n*" shows number of experiments and "*y*" shows observed values of MRR and TWR.

All the parameters were set at three levels based on the pilot studies performed in order to get the range as given in Table 2. The experiments were performed by taking in consideration the Taguchi's *L*9 orthogonal array. Further the experimental design is given in Table 3. After getting the output in the form of MRR and TWR, S/N ratio was calculated in order to analyse the overall effects of parameters on responses. *S*/*N* ratio was calculated for MRR using higher the better *S*/*N* ratio as shown in Eq. (1). On the contrast note, lower the better *S*/*N* ratio was employed for TWR as shown in Eq. (2) [11].

Table 2 Factors and levels

Factors	Symbol	Unit	Levels		
			I	II	III
Density	ρ	g/cm^3	8.96	2.7	8.73
Current	I	A	3	6	9
Pulse-on-time	T_{on}	μs	30	50	70
Pulse-off-time	T_{off}	μs	40	60	80

Table 3 Experiment results

Run No.	ρ	I	T_{on}	T_{off}	MRR (g/min)	TWR (g/min)
1	8.96	3	30	40	0.021094	0.000837
2	8.96	6	50	60	0.053069	0.003515
3	8.96	9	70	80	0.061272	0.006361
4	2.70	3	50	80	0.02	0.003333
5	2.70	6	70	40	0.007222	0.010555
6	2.70	9	30	60	0.013889	0.031666
7	8.73	3	70	60	0.001718	0.005326
8	8.73	6	30	80	0.001031	0.013573
9	8.73	9	50	40	0.001546	0.016323

$$\text{Higher the better} \quad \left(\frac{S}{N}\right) = -\log\left(\frac{1}{n}\left(\sum\left(\frac{1}{y^2}\right)\right)\right) \tag{1}$$

$$\text{Lower the better} \quad \left(\frac{S}{N}\right) = -\log\left(\frac{1}{n}\left(\sum\left(y^2\right)\right)\right) \tag{2}$$

MRR resulted out to be minimum for brass; however, it increased for aluminium and the highest obtained MRR resulted while using copper electrode. As far as the effect of current is concerned, maximum MRR was seen at the highest level of current while minimum MRR came out to be at the intermediate level. T_{on} and T_{off} had similar effect on MRR, and the intermediate levels of T_{on} and T_{off} resulted in highest MRR. So the optimum set of factors for MRR came out to be $\rho = 8.96$ (Copper), $I = 9$ A, $T_{\text{on}} = 50$ μs and $T_{\text{off}} = 60$ μs. While analysis the effects of factors on the TWR, it was found that lowest TWR was seen in case of copper electrode while highest TWR came out while using the brass electrode. Minimum TWR was found at 9 A while maximum at 6 A current. T_{on} and T_{off} had similar effect on TWR as the intermediate levels yielded lowest TWR (Figs. 4 and 5).

Figures 6, 7 and 8 shows the machined surface with copper, brass and aluminium electrode, respectively. Figure 6 shows the machining through copper electrode; it has yielded better material removal and good surface finish than that of brass and aluminium electrodes. This has been achieved due to proper debris removal

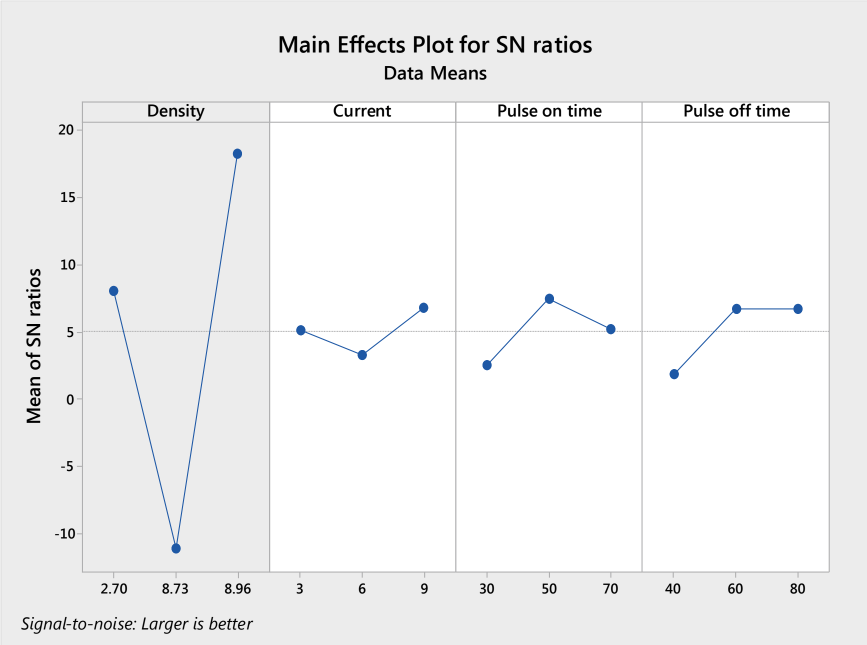

Fig. 4 *S*/*N* ratio for MRR

which has been achieved due to mixed flushing arrangement and the better electrical conductivity of copper. Figure 7 shows the machining through aluminium electrode; it has yielded significant material removal while surface finish was not as good as that obtained in case of using copper electrode. This could be related to the relatively lower electrical conductivity of aluminium as compared to copper. Figure 8 shows the machining through brass electrode; it has yielded the lowest material removal, and surface finish is not as good as that obtained in case of using copper and aluminium electrodes. This could be related to the low value of electrical conductivity of brass as compared to the other two electrodes. It can be clearly seen that brass debris have sticked in the hole depth.

4 Grey Relational Analysis

There is a limitation in case of Taguchi technique of optimization, and it can either analyse the response with *S*/*N* ratio as larger is better or smaller is better. In this case, MRR should be analysed with *S*/*N* ratio as larger is better and TWR with *S*/*N* ratio smaller is better. To obtain multi-objective optimization, GRA had been used on the response data. GRA technique analysed the optimization by taking into consideration of different response parameters having dissimilar characteristics. Thus, applying

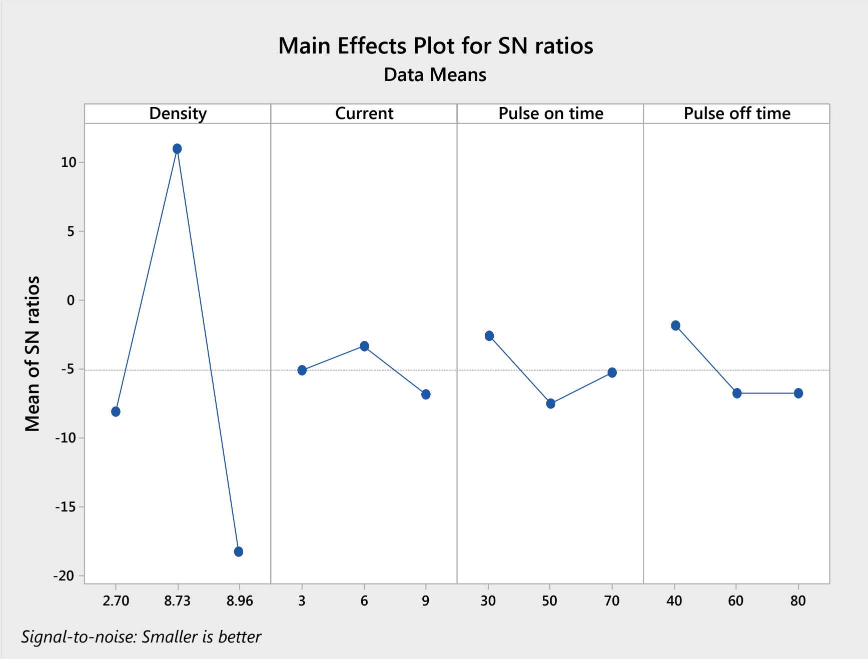

Fig. 5 *S*/*N* ratio for TWR

Fig. 6 Hole with copper tool

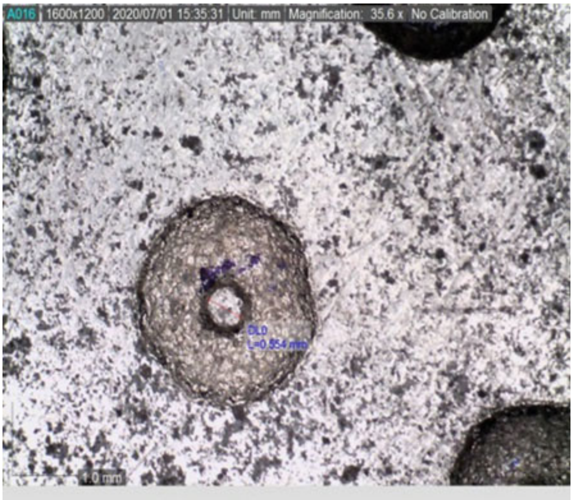

Fig. 7 Hole with aluminium tool

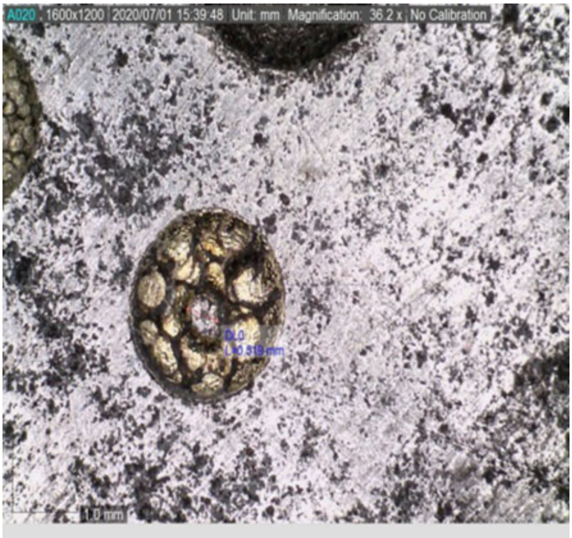

Fig. 8 Hole with brass tool

GRA converts the multi-objective into a single objective as given in Table 4. Steps performed in GRA analysis are listed below [11]:

1. Normalize the response values MRR and TWR in the range 0 to 1 by taking into consideration the nature of response measure (like higher is better or smaller is better). In case of higher the better, the response normalization is done by Eq. (3); while in case of smaller the better, the response normalization is done by Eq. (4) [12].

Table 4 GRA normalizing and deviation sequence

Run No.	Output/response		Normalizing		Deviation sequence	
	MRR	TWR	MRR	TWR	MRR	TWR
1	0.021094	0.000837	0.333041	1	0.66695941	0
2	0.053069	0.003515	0.863829	0.913134	0.13617054	0.086866262
3	0.061272	0.006361	1	0.820818	0	0.179181939
4	0.02	0.003333	0.314884	0.919037	0.68511554	0.08096273
5	0.007222	0.010555	0.102775	0.684777	0.89722522	0.31522268
6	0.013889	0.031666	0.213441	0	0.78655928	1
7	0.001718	0.005326	0.011409	0.85439	0.98859115	0.145609653
8	0.001031	0.013573	0	0.586882	1	0.413117519
9	0.001546	0.016323	0.008557	0.497681	0.99144336	0.502319245

$$X_i^*(k) = \frac{X_i(k) - \min X_i(k)}{\max X_i(k) - \min X_i(k)} \tag{3}$$

$$X_i^*(k) = \frac{\max X_i(k) - X_i(k)}{\max X_i(k) - \min X_i(k)} \tag{4}$$

where $X_i^*(k)$ and $X_i(k)$ are the set of normalized data and the initial observed data for the ith experiment and kth response.

2. Deviation sequences are calculated from the normalized values as obtained in the previous step.
3. Grey relational coefficient (GRC) values $\zeta_i(k)$ are generated which can be used to compare the theoretical and experimental data [12].

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_i(k) + \zeta \Delta_{\max}} \tag{5}$$

$\Delta_{\max}$ and $\Delta_{\min}$ refer to the highest and lowest values in the different data series, respectively. The coefficient ζ always ranges in between 0 to 1.

4. Grey relational grade (GRGs) is obtained by taking the mean of the grey relational coefficient values.
5. Based on the GRGs, ranking is done by assigning the highest GRG with rank 1.

Table 4 demonstrates the results of GRA normalizing and deviation sequence calculation, while Table 5 shows the GRCs along with GRGs and the ranks calculated on the basis of these GRGs. Table 6 has been summed up by taking the mean value of GRGs of each factor at level I, II and III, respectively. The difference between maximum and minimum values has been used to predict the rank of the factors in the experiment.

Table 5 GRA rank calculation for experiment run

Run No.	GRCs		GRGs	Rank
	MRR	TWR		
1	0.428463917	1	0.714231958	3
2	0.785952776	0.851982866	0.818967821	2
3	1	0.736179765	0.868089882	1
4	0.421899793	0.860640406	0.6412701	4
5	0.357852116	0.613329354	0.485590735	6
6	0.388633473	0.333333333	0.360983403	9
7	0.335888065	0.774461778	0.555174922	5
8	0.333333333	0.547574643	0.440453988	7
9	0.335245719	0.498843061	0.41704439	8

Table 6 GRA rank for factors

Factors	Level			Range	Rank
	I	II	III		
Density	0.80043	0.495948	0.470891	0.329539	1
Current	0.636892	0.581671	0.548706	0.088186	3
Pulse-on-time	0.505223	0.625761	0.636285	0.010524	4
Pulse-off-time	0.538956	0.578375	0.642135	0.103179	2

5 Conclusion

Based on the above experimental study performed on the mild steel workpiece using different tool electrodes, following observations were noted:

1. Without proper flushing arrangement, the debris could accumulate on the machining area, resulting in poor surface finish inside the hole.
2. The optimum set of factors for MRR came out to be $\rho = 8.96$ g/cm^3 (Copper), $I = 9$ A, $T_{\text{on}} = 50$ µs and $T_{\text{off}} = 60$ µs.
3. Better hole quality in terms of surface finish and depth was seen in case of machining with the hollow copper tool.
4. Hole quality as obtained by machining with the hollow brass tool resulted in poor surface finish; accumulation of debris damaged the finish of the surface and shortened the hole depth.
5. Tool wear was observed the maximum in case of copper followed by aluminium and brass.
6. Based on GRA, it was observed that experiment number 3 with electrode density 8.96 g/cm^3, current 9 A, T_{on} 70 µs and T_{off} 80 µs was the overall best run in terms of MRR and TWR.

7. GRA study also concluded that density was the most dominant factor followed by T_{off}, current and T_{on}.

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