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Experimental Analysis and Optimization of EDM Process Parameters

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Abstract. The paper presents the experimental analysis and multi-response optimization of EDM process parameters during machining of Nimonic 90 work material. The experiment has been conducted at different parametric setting considering discharge current, pulse-on-time and pulse-off-time as process parameters. Taguchi L9 orthogonal array has been used for experimental design. The effect of various parameters on response such as material removal rate and surface roughness has been studied with the help of suitable plots. The Grey Relational Analysis has been utilised for obtaining the optimal parametric combination.

1. Introduction

Electric discharge machining (EDM) is one of the most advanced method for precise machining of hard materials where the material is removed due to melting and vapourization. The voltage in pulsed form is applied within the small electrode gap immersed in dielectric fluid which generates a spark. The thermal energy of this spark melts and vapourizes the material which upon cooling, solidifies to form debris. The removed material is flushed away by the pressure of the dielectric fluid during pulse-off-time. Generally, the workpiece replicates the image of the tool electrode [1]. EDM machine in cooperates a servo- mechanism to control the movement of the tool and also to compensate for the tool wear. A small gap always exists between the electrodes in the machining zone which prevents their direct contact. Therefore, the process is advantageous in having less defects like mechanical stresses, clattering and vibration [2].

2. Literature survey

Chen.et.al [3] performed various experiments on EDM with discharge current, pulse-on-time (Ton) and pulse-off-time (Toff). The results revealed a factor (Fc) that showed MRR to vary directly to the discharge energy, which followed identical trend. Lonardo.et.al[4] studied the influence on wearing of the tool taking electrode material, dimension and depth of cut as parameters. The tool wear was found to be high with copper (Cu) electrode. However, the surface finish was observed to be better. The size of the electrode was noted to have significant effect wear on tool wear.Tzeng.et.al [5] investigated the powder characteristics in EDM machining. The machining was carried out using various powders mixed in dielectric with concentration of 0.5 cm^3/ltr. It was found that chromium (Cr) gave the highest material removal rate (MRR), followed be aluminum (Al) and silicon carbide (Sic).

Mohan.et.al [6] performed machining of aluminium - silicon carbide (Al-SiC) metal matrix using a tube electrode composed of brass with induced rotary motion. They concluded that the rotating tube type electrode produced high MRR compared to solid one. Better MRR was observed with smaller tube diameter of the tool electrode with an expense in surface roughness (Ra). Lauwers.et.al [7] performed a detailed investigation on MRR of ZrO_2, Si_3N_4 and Al_2O_3 based ceramic materials with addition of titanium carbide (TiN) and titanium carbonitride (TiCN) phase to make them electrically conductive. Chen.et.al [8] studied the machining characteristics of titanium superalloy (Ti-6Al-4V). The dielectric fluids were selected as kerosene and distilled water. MRR was found to be higher with less wearing of tool with distilled water. Khan.et.al [9] analyzed the wear process along the cross-section and length of Cu and brass tool electrode while machining Al and mild steel (MS). The tool wear increased with increase in current and voltage, showing more wear on the cross section than the length. M. L. Jeswani [10] studied the influence of graphite (Gr) powder of mean size 10, mixed with kerosene for machining of MS taking Cu tools of 4mm diameter. The concentration of the powder varied from 0.25 to 6.0 g/lit. The results showed that 4 g/lit of powder concentration produced highest MRR, lowest tool wear rate (TWR) leading to decreased wear ratio (WR). This effect was attributed to the fact that the powder lowered the dielectric strength of kerosene causing early discharge. Wong.et.al [11] used Al, Gr, silicon (Si), crushed glass, SiC and molybdenum sulphide (MoS_2) powders of size 40 μm with concentration of 2 g/l to investigate the effect of machining of AISI-01 and SKH-54 tool steel. They found that the powder added dielectric increased the gap between the electrodes in the machining zone. No such effect was observed with crushed glass. Very fine surface finish was produced by MoS_2 and Si powder on SKH-54 and by Al powder on AISI-01 tool steel. H.K.Hansal.et.al.[12] carried out powder mixed electrical discharge machining (PMEDM) of EN 31 tool with Si powder mixed dielectric. The size of powder in the range of 20-30 μm with concentration from 0-2 g/lit were used. MRR and Ra improved with increase in the powder concentration and more improvement was expected at higher concentrations. The peak current and concentration were found to be the most significant parameters affecting MRR and Ra [13]. Q.Y.Ming.et.al. [14] used iron (Fe), Cr and Si powders mixed with kerosene as dielectric fluid in electrical discharge machining of tempered high carbon steel using Cu electrodes. It was observed that the powder added could increase the MRR and lower the TWR with improved surface finish. Conductive and lipophilic powders could lower the Ra and resist cracking during semi-finish and finish operations. No such effect was rendered with inorganic oxide additive. Also, use of powder mixed dielectrics could lead to improvement of micro-hardness, decrease in the loss of alloy elements, thinner recast layer with less cracks. The increase in MRR and improved surface finish was that the powder lowered the discharge voltage and widened the spark gap which lead to uniform distribution of current in the discharge gap. The optimum concentration of different powders varied with the type. Best effect was noted when EWR was least. However, very high concentration of additives may hinder the machining stability. Furutani.et.al. [15] investigated the effect of EDM machining of stainless steel using MoS_2 powder mixed in EDM oil (EDF-K) as dielectric. Cu electrodes of 16 mm diameter were used as tool. It was found that MoS_2 could be deposited on metals whose melting point is lower than MoS_2. Also, it led to increase of gap length which improved the roughness of the machined surface. The high lubricity of MoS2 facilitated better dispersion of powder.

3. Experimental Setup and conditions.

The experiments were performed on EDM, Sparkonix MOS, 35A, ZNC coupled with normal controller as shown in figure 1. EDM oil is selected as dielectric. The material is selected as Nimonic 90 having dimension of 10 x 10 x 4.1 mm, Inconel 718 having dimension of 10 x 10 x 3.1 mm and Stainless Steel having dimension of 10 x 10 x 2.1 mm. Brass electrodes of 2 mm diameter was used as tool. Table 1 lists the process parameters and their respective levels considered for experimentation. The output responses were identified as material removal rate (MRR) and the surface roughness (Ra).

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Table 1. Parameters and their levels

Parameters	Unit	Levels		
		L1	L2	L3
Discharge Current	A	10	20	30
Pulse –on-time	µs	2	5	10
Pulse-off-time	µs	2	5	10

The MRR has been evaluated by taking the difference of initial and final weight of the work material and dividing the difference by time taken to machine the work material.

Table 2. Parametric combination and results

Parametric combination				Experimental results	
Expt. No	Discharge Current (A)	Pulse-on-time (µs)	Pulse-off-time (µs)	Material Removal Rate (gm/min)	Surface Roughness (µm)
1	10	2	2	0.2497	0.4355
2	10	5	5	0.7132	1.4405
3	10	10	10	1.1200	1.5040
4	20	2	2	20.00	0.3120
5	20	5	5	1.9910	0.4855
6	20	10	10	7.9730	0.4565
7	30	2	2	41.000	0.4060
8	30	5	5	3.4820	0.5095
9	30	10	10	23.000	0.4530

The surface roughness has been measured with the help of surface roughness measuring instrument. The design of experiment is based on Taguchi L9 orthogonal array. Table 2 shows the parametric combination and results.

4. Results and Discussion.

4.1. Analysis of Material Removal Rate (MRR).

The experiment was conducted at different parametric level and the material removal rate has been evaluated. Figure 1 shows the variation of MRR with different levels of process parameters. The figure depicts that the material removal increases with current. This is due to fact that with the increase in current the discharge energy increases removing more material.

The removal of material varied inversely with pulse-on-time. At higher values of pulse-on-time (Ton) more oxygen starts entering the machining zone which creates inefficient discharge within the electrode gap which resulted in lower MRR. MRR declined when Ton varied from 2 to 5 µs and then increased from 5 to 10 g/lit. This is due to increased duration for discharging removing more material. With increase of pulse-off-time (Toff), MRR also increased after which a slight decrease is observed with further increase of Toff.

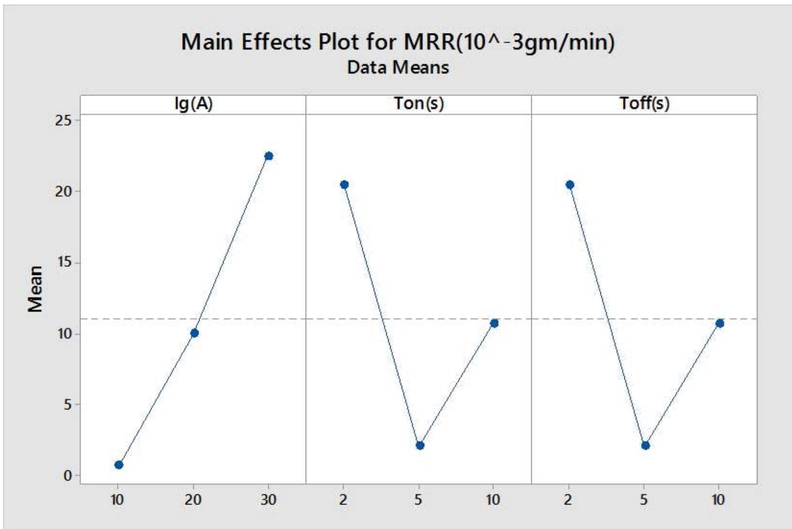

Fig. 1 Effect of process parameters on material removal rate

4.2. Analysis of Surface Roughness (Ra).

The surface roughness was measured with the help of surface roughness measuring instrument. Fig 2 depicts the effect of process parameters on surface roughness. Figure 2 shows that with increase in discharge current the surface roughness decreases. This effect is due to the effect of powders which widened the discharge gap leading to uniform current density. With further increase of current (Ig), Ra starts to increase as with increase in current more energy is available for removing material causing deep cracks and irregularities.

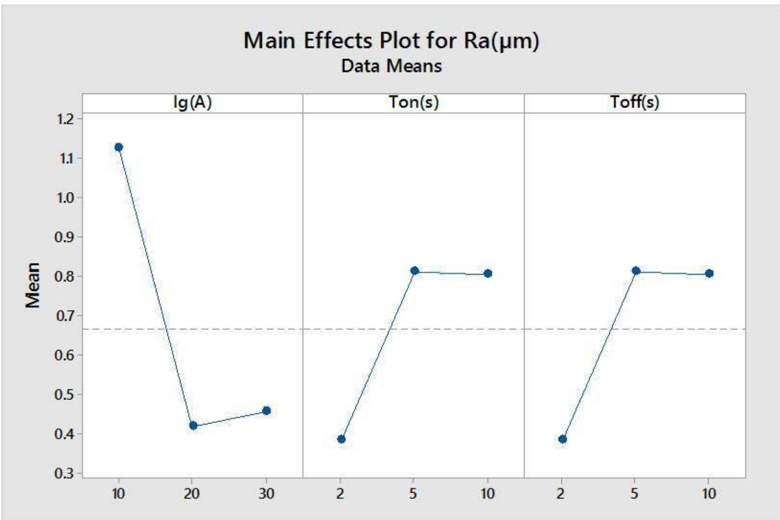

Fig. 2 Effect of process parameters on surface roughness

The surface roughness increased with increase in pulse-on-time due to more duration available for discharging. It is seen that further increase in Ton does not yield significant effect on Ra. The pulse-off-time (Toff) also showed the similar trend as that of pulse-on-time.

5. Multi-Response Optimization using Grey Relational Analysis (GRA).

The Grey Relational Analysis (GRA) has become an efficient multi-objective optimization technique used for handling the data where the information is partially provided and partially unavailable. Therefore, the situation is considered as Grey (neither black nor white). The grey relational analysis involves following steps [16][17].

5.1. Normalization of experimental data.

Normalization is carried out in order to evenly place the data in the range between 0 to 1. The normalization of response having higher the better type is calculated using equation 1 and the response of lower the better type has been calculated using the equation 2 [18]. Table 3 shows the normalized value of the experimental results.

If the response is of higher-the-better type, then normalized value z_{ij} is expressed as

$$z_{ij} = \left(a_{ij} - \min\left(a_{ij} \right) \right) / \left(\max\left(a_{ij} \right) - \min\left(a_{ij} \right) \right) \text{..................} \quad (1)$$

If the response is of smaller-the-better type, then normalized value z_{ij} is expressed as

$$z_{ij} = \left(\max\left(a_{ij} \right) - a_{ij} \right) / \left(\max\left(a_{ij} \right) - \min\left(a_{ij} \right) \right) \text{..................} \quad (2)$$

The material removal rate is considered as higher the better type and the surface roughness has been considered as lower the better type.

5.2. Grey Relational Coefficient.

This coefficient determines the closeness of *xij* to *x0j* is determined. The higher grey relational coefficient depicts that the *xij* is closer to *x0j.* The distinguish coefficient ξ is taken as 0.5. The grey relational coefficient is shown in table 3 and is calculated using equation 3.

$$\gamma\left(x_{0j}, x_{ij} \right) = \left(\Delta_{\min} + \xi\Delta_{\max} \right) / \left(\Delta_{ij} + \xi\Delta_{\max} \right) \text{ for i = 1,2,3,…..,m and j = 1,2,3,….,n} \text{ ....} \quad (3)$$

ξ = distinguishing coefficient, $i \in (0,1)$

5.3. Grey Relational Grade.

It is the weighted sum of grey relational coefficient. In this work the average of grey relational coefficient is calculated by taking the average of grey relational coefficient considering the equal weightage for all the responses. The grey relational grade is depicted in table 3.

Table 3. Normalized Value, Grey relational coefficient and Grey relational grade

Sl No	Material Removal Rate (gm/min)	Surface Roughness (µm)	Grey relational coefficient For Material Removal Rate	Grey relational coefficient for Surface Roughness	Grey Relational Grade	Rank
1	0	0.8981	0.3334	0.8307	0.5820	5
2	0.0114	0.0533	0.3359	0.3456	0.3408	8
3	0.0213	0	0.3381	0.3334	0.3357	9
4	0.4850	1	0.4926	1	0.7463	2
5	0.0427	0.8544	0.3431	0.7745	0.5588	6
6	0.1810	0.8788	0.3788	0.8049	0.5918	4
7	1	0.9211	1	0.8637	0.9318	1
8	0.0793	0.8343	0.3519	0.7511	0.5515	7
9	0.550	0.8817	0.5263	0.8087	0.6675	3

Table 4. Response table

Levels	Discharge Current (Amp)	Pulse-on-time (μs)	Pulse-off-time (μs)
1	0.4195	**0.7533**	**0.7533**
2	0.6323	0.4837	0.4837
3	**0.7169**	0.5316	0.5316

The highest rank or order of Grey relational grade represents the strong correlation with respect to the reference sequence. The highest value obtained is 0.9318, corresponding to experiment number seven. The response table for Grey relational grade is shown in table 3. The highest value in response table corresponding to different levels of process parameters were selected as the optimal parametric combination. The optimal parametric combinations are 30 Amp discharge current, 2 μs Ton and 2 μs Toff.

6. Conclusion

The paper presents the experimental analysis and multi-response optimization of EDM process parameters. The experiment was conducted and the effect of process parameters on process response has been analyzed through suitable plots. The plots revealed that the process parameters have significant effect on the process response. The optimal selection of process parameters always leads to an efficient machining. For machining of Nimonic 90, optimal parametric combination yielded by GRA is 30 Amp discharge current, 2 μs pulse-on-time and 2 μs pulse-off- time.

References

[1] E.C. Jameson, "Description and development of electrical discharge machining (EDM), Electrical Discharge Machining," Society of Manufacturing Engineers, Dearbern, Michigan,2001, pp. 16.

[2] W.S. Zhao, Q.G. Meng, Z.L. Wang, "The application of research on powder mixed EDM in rough machining." Journal of Material Processing. Technol, Vol 129, 2002, pp. 30–33.

[3] Chen, S.M. Mahdivia., "Analysis of electro-discharge machining process and its comparison with experiments" Journal of Materials Processing Technology,Vol 104, 2000, pp.150-157.

[4] P. M. Lonardo, A.A.Bruzzone., "Effect of Flushing and Electrode Material on Die Sinking EDM", International Journal of Machine Tools & Manufacture, Vol 45, 2005, pp. 194–200.

[5] Y.-F. Tzeng, C.-Y. Lee., "Effects of Powder Characteristics on Electro discharge Machining Efficiency" International Journal Advance ManufacturingTechnology, Vol 17,2001, pp. 586–592.

[6] B. Mohan, A.Rajadurai, K.G.Satyanarayana, "Electric Discharge Machining of Al-SiC metal matrix composites using rotary tube electrode, Journal of Materials Processing Technology, Vol 124, 2002, pp. 297-304.

[7] B. Lauwers, J.P. Kruth, W. Liu, W. Eeraerts, B. Schacht, P. Bley., "Investigation of material removal mechanisms in EDM of composite ceramic materials", Journal of Materials Processing Technology,Vol 149, 2004, pp. 347–352.

[8] S.L. Chen, B.H. Yan , F.Y. Huang., "Influence of kerosene and distilled water as dielectrics on the electric discharge machining characteristics of Ti–6A1–4V", Journal of Materials Processing Technology, Vol 87, 1999, pp. 107–111.

[9] A.A.Khan, "Electrode wear and material removal rate during EDM of aluminum and mild steel using copper and brass electrodes" International Journal of Advanced Manufacturing Technology,

Vol 39, 2008, pp. 482-487.

[10] Jeswani, M.L., “Effect of the addition of graphite powder to kerosene used as the dielectric fluid in electrical discharge machining.” Wear,Vol 70, 1981, pp. 133 – 139S.

[11] Wong, Y.S., Lim, L. C., Rahuman, I., Tee, W. M., “Near mirror finish phenomenon in EDM using powder mixed dielectric.”.Journal of Material Processing Technology, Vol 79, 1998, pp. 30-40.

[12] H.K.Kansal,., Singh, S., Kumar, P., “Parametric optimization of powder mixed electrical discharge machining by response surface methodology.” Journal of Materials Processing Technology, Vol. 169, 2005, pp. 427–436.

[13] Ragavendran, U., Ranjan K. Ghadai, Akash Bhoi, Manickam Ramachandran, and Kanak Kalita. "Sensitivity Analysis and Optimization of EDM Process Parameters." Transactions of the Canadian Society for Mechanical Engineering (2018) Doi: 10.1139/tcsme-2018-0021.

[14] Ming, Q.Y., and He, L.Y., “Powder-suspension dielectric fluid for EDM.” Journal of Materials Processing Technology, Vol 52, 1995, pp. 44 –54.

[15] Furutania, K., Sanetoa , A., Takezawaa, H., Mohria , N., and Miyake, H., “Accretion of titanium carbide by electrical discharge machining with powder suspended in working fluid.” Journal of the International Societies for Precision Engineering and Nanotechnology, Vol 25, 2001, pp. 138– 144.

[16] Ghadai, R. K., Das, P. P., Shivakoti, I., Mondal, S. C., & Swain, B. P. (2017, July). Grey fuzzy logic approach for the optimization of DLC thin film coating process parameters using PACVD technique. In IOP Conference Series: Materials Science and Engineering (Vol. 217, No. 1, p. 012034). IOP Publishing.

[17] I.Shivakoti, P.P Das, G. Kibria, B.B. Pradhan, Z. Mustafa ,R.K. Ghadai, Multi Response Optimization of Laser Micro Marking Process:A Grey- Fuzzy Approach, IOP Conference Series: Material Science & Engineering, Vol 217, 2017, pp. 1-6.

[18] Xiao, Y., Shao, D., Wu, Y., “Ex-Post Evaluation Analysis of Flood Control Engineering System Based on Grey Relation Projection Method.” Proceedings of 2007 IEEE International Conference on Grey Systems and Intelligent Services, pp. 221-225, 2007,