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Multi- Objective Optimization of Process Parameters Using MOORA Method in Electrical Discharge Machining of Hastelloy

PRADEEP KUMAR J
Department of Production Engineering, PSG College of Technology, Coimbatore.

KAMPATI RAVI PRAKASH REDDY
Department of Production Engineering, PSG College of Technology, Coimbatore.

Abstract—

Hastelloy C-276 is widely used in fabrication of equipment components that are used in most hostile environments such as chemical processing, pulp and paper industry, industrial and municipal waste treatment. Machining of this alloy, pose a challenging requirement in all the applications. The features such as holes, slots can be effectively machined in this alloy by electrical discharge machining for achievingsignificantgeometrical and dimensional accuracy. The aim of this work is to optimize process parameters such as discharge current(I_P), pulse-on time(T_{ON}), pulse-off time(T_{OFF}) and electrode material (M) on response variables such as Metal Removal Rate (MRR) and Tool Wear Rate(TWR)while machining Hastelloy C-276 using MOORA method. The different electrode materials used in this work are copper, cryogenically treated copper, brass and phosphor bronze.The experiments are carried out based on Taguchi's L16 orthogonal array. The electrode material is found to have significant effect on both Metal removal rate (MRR) and Tool wear rate (TWR) when compared to other process parameters. The optimum combinations of process parameters for achieving the desired MRR and TWR is I_P=15v, T_{ON}=70μs, T_{OFF}=6μs and cryogenic treated copper electrode.

Keywords— Electrical Discharge Machining (EDM), Multi Objective Optimization by Ratio Analysis (MOORA) method, Cryogenic Treatment, Material Removal Rate (MRR), Tool Wear Rate (TWR).

I.INTRODUCTION

Technological development made us to use high strength and high hardness materials which are difficult to machine by traditional processes and are replaced by nontraditional processes like electrical discharge machining (EDM), electrical chemical machining (ECM) and laser machining [1]. EDM process involve erodingof the work piece material in the shape of electrode with continuous electrical sparks generated between work piece and tool. The heat produced due to this spark melts and vaporizes the work piece material [2]. Hastelloy C276 is one of the Ni-Cr-Mo alloys which have wide range of application in chemical processing equipments like heat exchangers, reaction vessels and evaporators [3]. Bhaskar et al. [4]reportedmulti-objective parametric optimization of electrical discharge machining (EDM) process by the Taguchi method with gray relation analysis. The experiments were carried out on Electronica make EDM machine using Inconel 718 alloy steel as work piece material and EDM oil as the dielectric medium. The investigation concluded that the utilization of optimal machining parameter combination resulted in achieving significant improvement of the machining characteristics. Prabhu et al. [5] studied the multi response optimization of process parameters like surface roughness (SR) and metal removal rate (MRR) while electrical discharge machining of carbon nano tubesmixed dielectric fluid using Gray relational analysiswith process parameters such as pulsed current, pulse-on duration, and pulse voltage. Taguchi's L9 orthogonal array was used to conduct experiments and analysis of variance (ANOVA) approach was used to find the influence of process parameters on the response variables. Kumar et al.(6) investigated evaluation of machining efficiency with additive powder mixed in dielectric fluid of EDM on Inconel 718 with copper and cryogenically treated copper electrodes. The experiments were conducted to study the effect of input parameters like polarity, type of electrode, peak current, pulse on time, duty cycle, gap voltage and concentration of fine graphite powder on machining efficiency. The results form experiments revealed that the cryogenically treated electrode has significant effect on tool wear rate and metal removal rate when compared with traditional electrode materials. Sahoo et al.[7] successfully employed MOORA technique in various machining process like wire EDM, milling for parameter optimization.Kathiravan et. al. [8] studied optimization of EDM process parameters for machining P20 mould steel. This study showed that both material removal rate and tool wear rate increase with increase in discharge current and the surface roughness increases with increase in pulse off time. Somasundaram [9] et. al. [9] identified optimum combination of process parameters using TOPSIS approach for electric discharge machining of bio compatible material. Somasundaram [10] et. al. adopted Taguchi L16 orthogonal array to study the effect of process parameters while machining AZ31 magnesium alloy using several types of electrode materials. Based on literature review, it was found that no works have been reported on electric discharge machining of Hastelloy C 276 with multi-objective optimization. Hence the relevance of this work.

II.MOORA METHOD

Optimum process parameters for maximizing MRR and minimizing TWR are necessary for production purposes. In this work multi objective optimization by ratio analysis (MOORA) is employed. Steps in this optimization technique as follows [7].

Step 1 Decision matrix

$$X=\begin{bmatrix} x_{11} & \cdots & x_{1b} \\ \vdots & \ddots & \vdots \\ x_{a1} & \cdots & x_{ab} \end{bmatrix} \quad (1)$$

$X_{ij}$is the performance measures of i_{th} alternative in j_{th} criteria. Where 'a' is alternative and 'b' is number of criteria

Step 2 normalization of decision matrix as shown in Eq.2

$$X_{ij}^* = x_{ij}/\sqrt{\sum_{i=1}^{a} x_{ij}^2} \quad (2)$$

Step 3 calculation of overall performance as per Eq.3

$$Y_A = \sum_{j=1}^{k} x_{ij}^* - \sum_{j=k+1}^{b} x_{ij}^* \quad (3)$$

Where 'k' is the number of parameters to be maximized and 'b-k' is the number of parameters to be minimized. 'Y_A' is the assessment value of i_{th} alternative of overall parameters. For providing importance to certain parameters individual weightage value need to be multiplied and modified Eq3 as Eq4.

$$Y_A = \sum_{j=1}^{k} w_j \times x_{ij}^* - \sum_{j=K+1}^{b} w_j \times x_{ij}^* \quad (4)$$

Where 'w_j'is individual weight values which is calculated by shanon entropy process.

III.EXPERIMETAL DETAILS

Inthis work, Hastelloy C276 is selected as work piece material which is machined in the form of rectangular plate with length, width and thickness of 50mm, 30mm and 10mm respectively. Electrodes made ofcopper,cryogenic treated copper, brass and phosphor bronze are used in experiments. These electrodes are machined in the form of rod with diameter of 10mm and length of 35mm. The copper electrode of 10mm diameter is subjected to cryogenic treatment at slow cooling rate of 2.5ºc/min from ambient temperature. After reaching -196ºc the electrode is soaked for the time period of 48 hours. Then electrode is oil tempered to relieve stresses induced due to cryogenic treatment and brought it to room temperature slowly at a rate of 0.5ºc/min.

Machining is carried out with positive polarity which means work piece as anode and tool material as electrode as shown in Fig 1. Experimental trials are conducted by using ALTRA ZNC ORB 5530 EDM machine, based on Taguchi's L16 orthogonal array.The discharge current (I_p), pulse-on time (T_{ON}), pulse-off time (T_{OFF}) and electrode material(M) are selected as control factors and material removal rate (MRR) and tool wear rate (TWR) are selected as response variables. Table 1 shows the control factors and their levels.

Fig 1 Experimental setup

Table 1 Control factors and their levels

Factors	Level 1 (-1)	Level 2 (-0.333)	Level 3 (0.333)	Level 4 (1)
I_p(v)	9	12	15	18
T_{ON}(μs)	30	50	70	90
T_{OFF}(μs)	6	7	8	9
Electrode M	Copper	Cryogenic treated copper	Brass	Phosphor bronze

IV.RESULTS AND DISCUSSION

After finalization of work material, electrode material, process parameters and their levels and identification of response variables, the experiments are conducted based on Taguchi L16 orthogonal array. Table 2 shows Taguchi design matrix and the results of MRR and TWR obtained from experimental trials.

Table 2 Results of Metal Removal Rate (MRR)and Tool Wear Rate (TWR)

Ex. No.	I_p (V)	T_{ON} (μs)	T_{OFF} (μs)	M	MRR (mm^3/min)	TWR (gm/min) $\times 10^{-4}$
1	-1	-1	-1	-1	16.1100	6.06
2	-1	-0.333	-0.333	-0.333	19.1960	0.78
3	-1	0.333	0.333	0.333	7.3449	365.00
4	-1	1	1	1	15.4115	457.00
5	-0.333	-1	-0.333	0.333	8.0780	458.00
6	-0.333	-0.333	-1	1	15.2140	733.00
7	-0.333	0.333	1	-1	24.6700	0.34
8	-0.333	1	0.333	-0.333	26.6900	0.13
9	0.333	-1	0.333	1	12.5826	790.16
10	0.333	-0.333	1	0.333	8.0334	725.00
11	0.333	0.333	-1	-0.333	34.6890	1.61
12	0.333	1	-0.333	-1	31.6700	0.85
13	1	-1	1	-0.333	36.8210	45.90
14	1	-0.333	0.333	-1	35.1640	13.90
15	1	0.333	-0.333	1	23.5200	1301.90
16	1	1	-1	0.333	13.8900	761.31

A. Material Removal Rate

Table 3 shows ANOVA table acquired from experimental data as shown in Table 2. It reveals that electrode material is the most influencing factor with contribution of 33.41% followed by interaction between discharge current and pulse-on time with contribution of 28.33% and discharge current with contribution of 22.51% respectively. Other factors are comparatively less, in case of MRR.

Table 3 ANOVA table for Material Removal Rate

Source	DF	Seq SS	Adj SS	Contribution
I_P	1	345.80	15.287	22.51%
T_{ON}	1	37.56	20.192	2.45%
T_{OFF}	1	2.60	309.355	0.17%
Electrode M	1	513.33	408.416	33.41%
I_P*I_P	1	2.12	0.924	0.14%
T_{ON}*T_{ON}	1	2.70	2.705	0.18%
T_{OFF}*T_{OFF}	1	0.02	0.691	0.00%
M*M	1	24.01	0.022	1.56%
I_P*T_{ON}	1	435.29	401.464	28.33%
I_P*T_{OFF}	1	8.30	0.0092	0.54%
I_P*M	1	77.34	77.338	5.03%
T_{ON}*T_{OFF}	1	4.38	1.481	0.29%
T_{ON}*M	1	0.67	0.669	0.04%
Error	2	82.10	41.050	5.34%
Total	15	1536.22		100%

Figure 2 shows the main effect plot for S-N ratios of MRR. The Taguchi quality characteristic larger-the-better is used for calculating S-N ration for MRR. Therefore optimal combination of process parameter for MRR is

I_P=18,T_{ON}=90,T_{OFF}=6 and the cryogenic treated copper electrode.

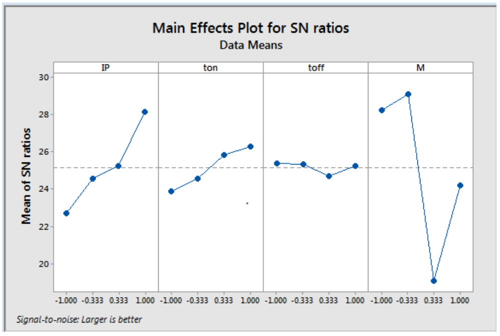

Fig 2 Main effect plot for SN ratios of MRR

B. Tool Wear Rate

Table 4 shows ANOVA table acquired from experimental data shown in Table 2. It reveals that the electrode material is the most influencing factor with contribution of 72.13% followed by interaction between discharge current and pulse-on time with contribution of 12.90% and discharge current with contribution of 8.81% respectively. Other factors are comparatively less, in case of TWR.

Table 4 ANOVA for Tool Wear Rate

Source	DF	Seq SS	Adj SS	Contribution
I_P	1	0.002214	0.000080	8.81%
T_{ON}	1	0.000000	0.000077	0.00%
T_{OFF}	1	0.000250	0.001103	0.99%
Electrode M	1	0.018128	0.012011	72.13%
I_P*I_P	1	0.000037	0.000001	0.15%
T_{ON}*T_{ON}	1	0.000242	0.000242	0.96%
T_{OFF}*T_{OFF}	1	0.000025	0.000000	0.10%
M*M	1	0.000559	0.000010	2.22%
I_P*T_{ON}	1	0.003243	0.001503	12.90%
I_P*T_{OFF}	1	0.000118	0.000093	0.47%
I_P*M	1	0.000009	0.000009	0.03%
T_{ON}*T_{OFF}	1	0.000056	0.000004	0.22%
T_{ON}*M	1	0.000000	0.000000	0.00%
Error	2	0.000250	0.000250	0.99%
Total	15	0.025131		100%

Figure 3 shows the main effect plot for S-N ratios of TWR. The Taguchi quality characteristic smaller-the-betteris used for calculating S-N ratio for TWR. Therefore, theoptimal process parameters for TWR is I_P=12,T_{ON}=90.T_{OFF}=7 and M=cryogenic treated copper.

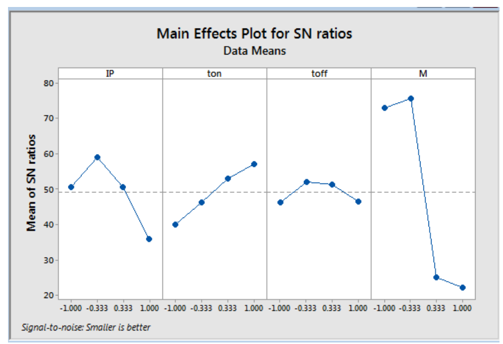

Fig 3 Main effect plot for SN ratios of TWR

V.MUTLI OBJECTIVE OPTIMIZATION

Table 5 shows the calculated results of Eq 2 and Eq 4 of MOORA method for the experimental results in Table 2. The optimal process parameters from this optimization technique are I_P=15,T_{ON}=70.T_{OFF}=6 and M=cryogenic treated copper. Table 6 shows the individual weightage values calculated by shanon entropy process.

Table 5 Results of MOORA method

Ex. No.	MRR (mm^3/min) $X^*_{ij}\times10^{-2}$	TWR (gm/min) $X^*_{ij}\times10^{-3}$	Y_A	Rank
1	17.6780	2.8516	0.0222	8

2	21.0643	0.3670	0.0291	7
3	8.0598	171.7579	-0.1364	9
4	16.9115	215.0503	-0.1613	10
5	8.8642	215.5208	-0.1729	11
6	16.6948	344.9275	-0.2733	12
7	27.0711	0.1599	0.0377	6
8	29.2877	0.0611	0.0409	4
9	13.8072	371.8252	-0.3004	15
10	8.8153	341.1629	-0.2811	13
11	38.0652	0.7576	**0.0526**	**1**
12	34.7524	0.3999	0.0482	3
13	40.4047	21.5991	0.0379	5
14	38.5865	6.5409	0.0483	2
15	25.8092	612.6345	-0.4908	16
16	15.2419	358.2493	-0.2868	14

Table 6 Weightage values of Entropy process

S.No.	MRR w_j	TWR w_j
1	0.139899	0.860101

VI.CONCLUSION

The aim of this work is to optimize process parameters and perform multi objective optimizationusing MOORA method while electric discharge machining of Hastelloy C276. Apart from process parameters such as discharge current, pulse on time and pulse off time four electrode materials namely copper, cryogenic treated copper, brass and phosphor bronze areusedin experiments. The effect of discharge current, pulse on time, pulse off time and electrode material on material removal rate and tool wear rate were analyzed. The confirmation experimental trials are carried out to ensure the accuracy of the optimum combination of process parameters. Based on the results from experiments the following conclusions are made.

- The most influencing factor is electrode material for both MRR and TWR. It is observed that cryogenic treated copper material is best material for both MRR and TWR when compared with copper, brass and phosphor bronze electrodes.
- The discharge current is also a key influencing factor comparatively less than electrode material for both MRR and TWR. As discharge current increases MRR also increases but TWR decreases with initial increase up to a threshold level.
- Pulse on time shows less significance but with increase of pulse on time result in increase of both MRR and TWR.
- Optimum solution in case of material removal rate is I_P=18v,T_{ON}=90μs, T_{OFF}=6μs and cryogenic treated copper electrode.
- Optimum solution in case of tool wear rate is I_P=12v, T_{ON}=90μs, T_{OFF}=7μs and cryogenic treated copper electrode.
- Multi objective optimization (MOORA) yields optimum solution for MRR and TWR simultaneously is I_P=15v,T_{ON}=70μs, T_{OFF}=6μs and cryogenic treated copper electrode.

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