Multi-Objective Optimization of EDM Process Parameters on Ti Alloy (BT20L) Using Taguchi Method and Grey Relational analysis

R. Swetha [1, a] **and** L. Siva Rama Krishna[2, b]

[1] Dept. of Mechanical Engineering, Methodist College of Engineering & Technology
Hyderabad, India - 500001

[2] Dept. of Mechanical Engineering, University College of Engineering, Osmania University, Hyderabad, India - 500007

[a]shwetagandra@gmail.com, [b] lsrkou@gmail.com

Abstract. EDM is an energy-based non-traditional technique extensively used in machining hard, high-strength and temperature-resistant materials in a contactless manner. The aim of this paper is to present multi-objective optimization of the EDM process parameters on Ti Alloy (BT20L) using Taguchi method and Grey relational analysis. The Performance characteristics considered are electrode wear rate, material removal rate and surface roughness. These are chosen to evaluate the machining effects on Ti alloy (BT20L). The process parameters selected are discharge current, pulse-on time, pulse-off time and flushing pressure. Experiments based on the appropriate orthogonal array according to Taguchi method are conducted first. The normalized experimental results of the performance characteristics are then introduced to calculate the coefficient and grades according to grey relational analysis. The optimized process parameters simultaneously lead to a lower electrode wear rate, higher material removal rate and better surface roughness. They are validated by conducting confirmation experiment.

Keywords: EDM, Orthogonal Array, Taguchi Method, Grey relational analysis.

Introduction

Electrical Discharge Machining (EDM) is the most extensively used non-traditional machining processes used for die-making, precision machining and manufacturing of prototypes. EDM is particularly used in aerospace industries when compared with the conventional machining process due to the intricacy involved. Titanium alloys are widely used due to their excellent corrosion resistance, light weight and mechanical properties. The aim of this paper is to find out the optimum values of the process parameters of the EDM process on Ti Alloy (BT20L) in order to increase the metal removal rate, decrease the electrode wear rate and reduce the surface roughness. The process parameters chosen in this work are discharge current, pulse-on time, pulse-off time, flushing pressure. Initially, by using orthogonal array (OA) technique of Taguchi method an appropriate OA is chosen. Three different levels are chosen for each process parameter and hence L9 orthogonal array (L9 OA) is chosen. Experimentation is carried out with the proposed L9 OA to find out the optimum values of process parameters and the grey relational analysis is used to find out the optimum values of process parameters.

The rest of this paper is organized as follows: Section 2 presents literature review concerned to the work. Problem definition is presented in Section 3. Section 4 describes the research methodology adopted to solve the problem. Results and Discussions are presented in section 5. Finally, Section 6 presents the Conclusions & Future scope of this work.

Literature Review

Ahmet Hascalk, Ulas caydas [1] presents a comparative study of surface integrity of Ti–6Al–4V alloy machined by EDM and AECG. This paper discusses the importance and very wide application areas of titanium alloys due to excellent corrosion resistance, light weight and mechanical properties. It also clearly explains Electrical discharge machining (EDM) as one of the most effective manufacturing processes available for creating complex or simple shapes and geometries within parts and assemblies. Sundaravel vijayan[2] et.al presented a paper on Multiobjective Optimization of Friction Stir Welding Process Parameters on Aluminum Alloy AA 5083 Using Taguchi-Based Grey Relation Analysis. N. Tosun, L. Ozler [3] presented a paper on 'Optimisation for hot turning operations with multiple performance characteristics'. This paper presents an investigation on the optimisation and the effect of cutting parameters on multiple performance characteristics (the tool life and the workpiece surface roughness) obtained by hot turning operations. P.J.Ross [4] in his book 'Taguchi techniques for quality engineering' discusses Taguchi methods and how ANOVA can be applied to multi objective problems.

Problem Definition

In this paper, the multi-objective optimization of EDM process parameters is done on Ti Alloy (BT20L) using Taguchi method and Grey relational analysis. The performance characteristics considered are electrode wear rate, metal removal rate and surface roughness. The process parameters chosen for the study are discharge current, pulse-on time, pulse-off time and flushing pressure. Following are objectives of this paper:

- To maximize material removal rate (MRR), minimize electrode wear rate (EWR) and surface roughness (R_a) by applying optimization techniques such as Taguchi method and to find the optimal values of EDM process parameters.
- To find the optimal process parameter set from Taguchi method.
- To find the optimal process parameter set using grey theory prediction design.
- To compare the values of MRR, EWR, R_a obtained from Taguchi method and Grey theory.

Research Methodology

The various steps involved for solving the problem described earlier are selection of the process parameters and performance characteristics, selection of the appropriate orthogonal array, conducting the experiment, calculation of MRR, EWR, R_a and S/N ratios by Taguchi method using the experimental values, applying ANOVA to calculate sum of squares and percentage contribution of each process parameter, determination of Grey relational grades, Applying ANOVA for the obtained Grey relational grade, Conducting a confirmation experiment to compare the results of the experimental run which has the highest value of Grey relational grade and the optimal grey theory prediction design.

Selection of process parameters. The process parameters chosen are discharge current, pulse-on time, pulse-off time and flushing pressure. Three levels are chosen for each process parameter.

Table 1 Process parameters

symbol	Process parameter	Level 1	Level 2	Level 3
A	Current (I) [Amp]	5	15	25
B	Pulse-on time (T_{on}) [µsec]	100	200	300
C	Pulse-off time (T_{off}) [µsec]	230	200	130
D	Flushing pressure[kgf/cm^2]	0.25	0.5	0.75

Selection of orthogonal array and conducting the experiments. Four process parameters are chosen and hence L_9 orthogonal array is chosen. The experimental runs are conducted with the EDM machine on TI alloy for time duration of 20 min. Two trials of experiments (T_1&T_2) are conducted inorder to account for the unknown or unaccounted errors.

Calculation of MRR, EWR, R_a and s/n ratios by Taguchi method. The weights of the electrode (material-copper) and the work piece (material-Ti alloy) are weighed before and after the experiments. After obtaining the MRR, EWR and R_a for both trials (T_1&T_2), the S/N ratio for MRR is calculated by the following formula. Table 2 shows the S/N ratios for MRR, EWR, SR.

$$\eta_{ij} = -10 \log(1/n \sum_{j=1}^{n} 1/y_{ij}^2). \quad (1)$$

The S/N for EWR and R_a is calculated with the following formula

$$\eta_{ij} = -10 \log(1/n \sum_{j=1}^{n} y_{ij}^2). \quad (2)$$

Table 2 Experimental results and s/n ratios for MRR, EWR, R_a

Exp. No.	A	B	C	D	Material Removal Rate (MRR) [mg/min]		S/N Ratio for MRR	Electrode Wear Rate (EWR) [mg/min]		S/N Ratio for EWR	Surface Roughness (R_a) [µm]		S/N Ratio for R_a
					T_1	T_2		T_1	T_2		T_1	T_2	
1.	1	1	1	1	1.045	0.91	-0.1977	-0.08	-0.015	29.7623	3.16	2.88	-9.60014
2.	1	2	2	2	1.18	1.145	1.3079	-0.1	0.02	27.9588	4.66	4.01	-12.74
3.	1	3	3	3	1.49	1.185	2.526	-0.115	0.095	40	4.33	3.91	-12.3
4.	2	1	2	3	6.99	7.07	16.94	2.25	1.92	-6.3821	5.53	6.11	-15.3
5.	2	2	3	1	9.325	8.95	19.2166	1.33	-0.13	4.4369	5.88	6.06	-15.52
6.	2	3	1	2	9.885	6.93	17.40	0.38	3.195	-5.0449	5.88	5.57	-15.155
7.	3	1	3	2	21.655	22.34	26.85	12.7	7.885	-20.2504	5.63	6.12	-15.38
8.	3	2	1	3	15.835	14.31	23.563	6.1	11.81	-19.0413	5.64	6.91	-15.9522
9.	3	3	2	1	15.865	14.7	23.684	3.435	1.02	-6.9563	7.68	6.42	-16.9637

ANOVA results. Table 3 shows performance of ANOVA to calculate sum of squares(S.S) and percentage contribution and to find the significance of each parameter on the performance characteristics.

Table 3 ANOVA results for MRR, EWR, R_a

Process parameter	ANOVA results for MRR		ANOVA results for EWR		ANOVA results for R_a	
	S.S	% Contribution	S.S	% Contribution	S.S	% Contribution
A	875.424	98.47	3692.5289	93.3	35.7055	84.6
B	0.06228	0.007	104.164	2.63	3.737	8.85
C	11.8967	1.34	57.1267	1.44	3.2877	7.79
D	1.6366	0.184	100.7219	2.54	0.526	1.246

Determination of Grey relational coefficient and Grades.

Table 4 values of Grey relational coefficient for MRR, SR, EWR

Exp.	S/N Ratio			Normalisation			Deviation sequence			Grey relational coefficient		
	MRR	SR	EWR	MRR	SR	EWR	MRR	SR	EWR	MRR	SR	EWR
1	-.1977	-9.600	29.7623	0	1	0.83	1	0	0.17	0.333	1	0.7462
2	1.3079	-12.74	27.9588	0.0556	0.5736	0.8001	0.9444	0.4264	0.1999	0.3461	0.5397	0.7144
3	2.526	-12.3	40	0.1007	0.633	1	0.8933	0.3667	0	0.3573	0.577	1
4	16.94	-15.3	-6.3821	0.6336	0.226	0.23	0.3664	0.774	0.77	0.5771	0.3924	0.3937
5	19.216	-15.52	4.4369	0.7178	0.196	0.4097	0.2822	0.804	0.5903	0.6392	0.3834	0.4585
6	17.4	-15.15	-5.0449	0.6506	0.2456	0.2523	0.3494	0.7544	0.7477	0.886	0.3986	0.4007
7	26.85	-15.38	-20.25	1	0.2151	0	0	0.7849	1	1	0.3891	0.333
8	23.563	-15.95	-19.041	0.8785	0.1373	0.0201	0.1215	0.8627	0.9799	0.8045	0.367	0.3378
9	23.684	-16.96	-6.9563	0.8829	0	0.2206	0.1171	1	0.7794	0.8102	0.333	0.3908

The S/N ratio's of MRR, EWR, SR are normalised and the deviation sequence is calculated from these normalized values. Finally, the Grey Relational coefficient is calculated and the values are given in the Table 4 above. For normalisation, the following formula is used

$$x_i^*(k) = \frac{x_i^{(o)}(k) - \min x_i^{(o)}(k)}{\max x_i^{(o)}(k) - \min x_i^{(o)}(k)} \quad (3)$$

The Grey Relational Coefficient is given by

$$\gamma\,(x_o^*(k), x_i^*(k)) = \frac{\Delta_{min} + \zeta\,.\,\Delta_{max}}{\Delta_{oi}\,(k) + \zeta\,.\,\Delta_{max}} \quad (4)$$

The Grey relational grades and their order is calculated and the values are shown in the Table 5 below.

Table 5 Grey relational grades and their order

Exp. No.	A	B	C	D	Grey Relational Grade	Order
1.	1	1	1	1	0.6925	1
2.	1	2	2	2	0.53286	4
3.	1	3	3	3	0.6441	2
4.	2	1	2	3	0.45	9
5.	2	2	3	1	0.4932	7
6.	2	3	1	2	0.46217	8
7.	3	1	3	2	0.5734	3
8.	3	2	1	3	0.5026	6
9.	3	3	2	1	0.5108	5

ANOVA is performed for the obtained values of Grey relational grades and the results are shown in Table 6 below.

Table 6 ANOVA Results for Grey relational grades

Process Parameter	S/N Ratio			S.S	Variance	% Contribution
	Level 1	Level 2	Level3			
A	0.62315	0.4684	0.529	0.0366	0.0183	67
B	0.572	0.51	0.539	0.007415	0.003707	13.58
C	0.5524	0.4978	0.5702	0.008236	0.004118	15.08
D	0.5655	0.5228	0.532	0.0024	0.0012	4.4

Confirmation tests

After the optimal EDM process parameter set is obtained, the confirmation tests are processed to verify the performance characteristics improvement. The results of confirmation experiment are compared with the outcome of the orthogonal array and grey theory prediction of the design operating parameters. Table 7 shows the comparison of the experimental results using the initial (orthogonal array, $A_1B_1C_1D_1$) and optimal (grey theory prediction design, $A_1B_1C_3D_1$) EDM parameters on BT20L Alloy. The corresponding improvement in EWR is 16%, MRR 17% and surface roughness 12%, respectively.

Table 7 EDM performance results using initial and optimal process parameters

	Optimal Process Parameters	
	Orthogonal array	Grey theory prediction design
Level	$A_1B_1C_1D_1$	$A_1B_1C_3D_1$
EWR [mg/min]	-0.0325	-0.038
MRR [mg/min]	0.9775	1.125
SR [µm]	3.02	2.65

Results and discussions

Fig. below shows that discharge current significantly affect material removal rate, Electrode wear rate and surface roughness. $A_3B_2C_3D_2$ parameter set is optimal for the performance characteristic of the MRR. $A_1B_3C_3D_1$ parameter set is optimal for the performance characteristic of the EWR. The optimal parameter set for the performance characteristic of Surface roughness is $A_1B_1C_1D_1$.

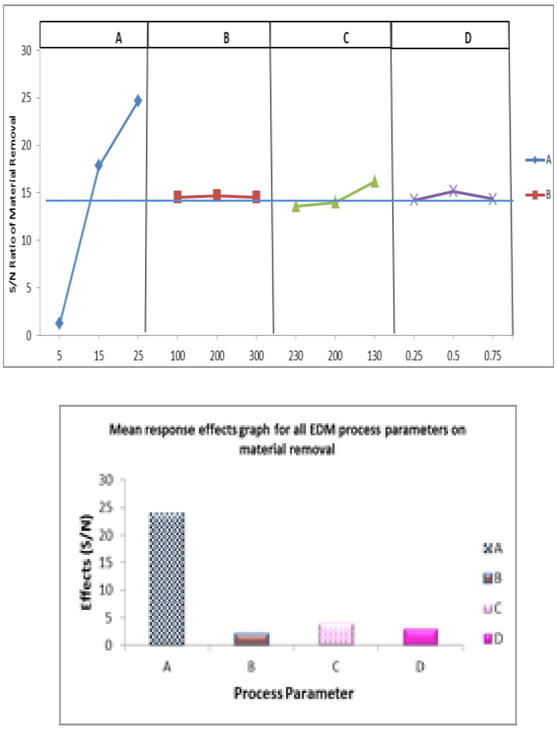

Fig. 3 S/N and mean response effects graph for all parameters on MRR

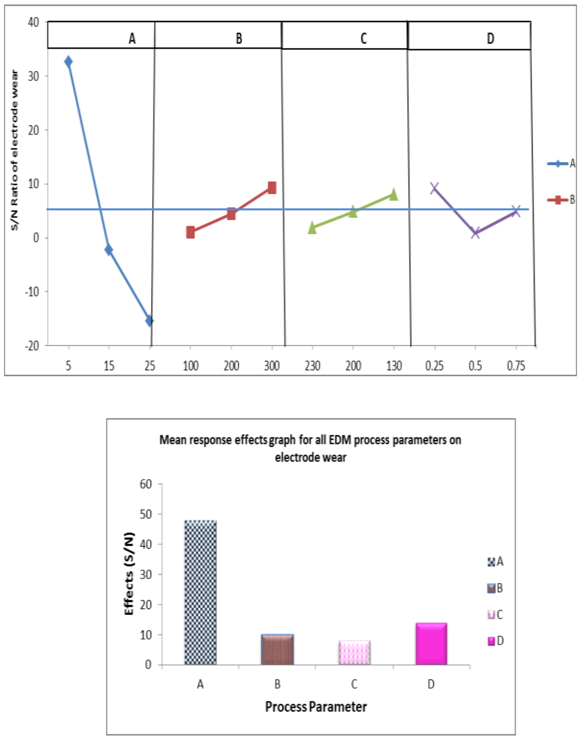

Fig. 4 S/N and mean response effects graph for all parameters on EWR

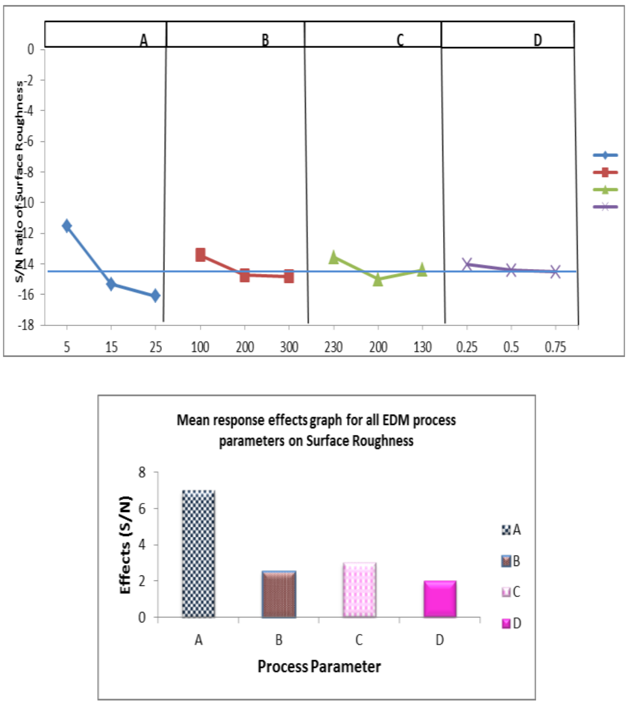

Fig. 5 S/N and mean response effects graph for all parameters on SR

Fig. 6 below shows the S/N response effects graph for Grey relational grade.

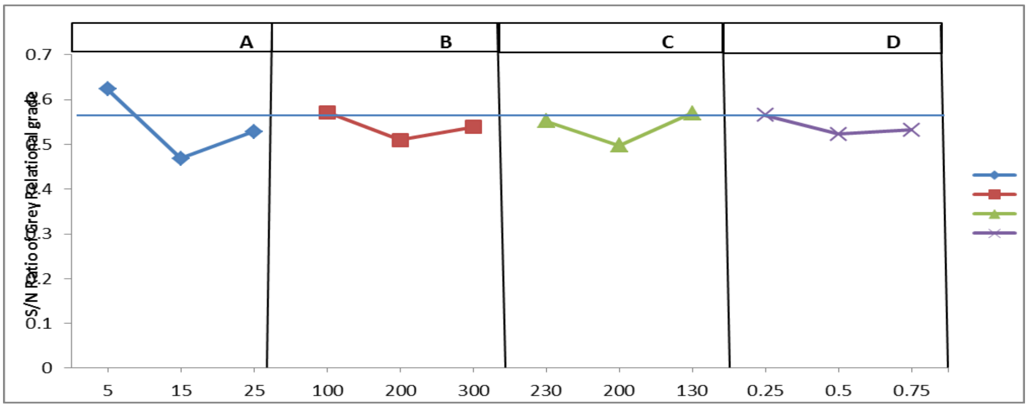

Fig. 6 S/N response graph for Grey relational grade

Conclusions and future scope of work

Taguchi method is effectively used to improve the multiple performance characteristics of the electrode wear rate, material removal rate and surface roughness in the Electrical Discharge Machining of Ti alloy (BT20L). The future scope of this work is to do the SEM Analysis and to acquire the relationship of the EDMed parameters to the EWR, MRR, SR and to generate linear regression expression by using software 'SPSS'

References

[1] Ahmet Hascalk, Ulas caydas, "A comparative study of surface integrity of Ti–6Al–4V alloy machined by EDM and AECG", Journal of Materials Processing Technology, 190, 173–180, 2007.

[2] Sundaravel Vijayan, R. Raju, S. R. K Rao, "Multiobjective Optimization of Friction Stir Welding Process Parameters on Aluminum Alloy AA 5083 Using Taguchi-Based Grey Relation Analysis", Journal of Materials and Manufacturing Processes, vol 25, page no. 1206–1212, 2010.

[3] N.Tosun, L.Ozler, "Optimisation for hot turning operations with multiple performance characteristics", International journal of Advance Manufacturing Technology, vol 23, page no. 777-782, 2004.

[4] P.J.Ross in his book 'Taguchi techniques for quality engineering' discusses taguchi methods and how ANOVA can be applied to multi objective problems. The author explains how taguchi's s/n ratio can be combined with ANOVA inorder to solve multi objective problems and also to find out the contribution of each process parameter to the performance characteristics under consideration.

[5] J.L. Deng, "Introduction to Grey system", Journal of Grey system, vol 1, page no. 1-24, 1989.

[6] TR Lin, "Optimization technique for face milling stainless steel with multiple performance characteristics", International journal of manufacturing technology, vol 19, page no. 330-335, 2002.

[7] H.S. Lu, C.K. Chang, N.C. Hwang, C.T. Chung, "Grey relational analysis coupled with principal component analysis for optimization design of the cutting parameters in high-speed end milling", journal of materials processing technology, 209, 3808-3817, 2009.