OPTIMIZATION OF MACHINING PARAMETERS IN WIRE EDM OF EN24 STEEL

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ABSTRACT

This objective of the research work is to obtain better surface finish and higher MRR for EN24 steel by optimizing various process parameters affecting the machining conditions with the assistance of Grey-Taguchi quality engineering. L_{18} orthogonal array (OA) was chosen and 18 experiments were conducted by varying the process parameters at various levels. Analysis of variance was used to find the contribution of each input parameter.

KEYWORDS: WEDM, MRR, R_a Grey-Taguchi & ANOVA

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INTRODUCTION

EDM is an unconventional machining process, metal removal is done by the erosion of the spark between the electrode and work piece. In wire EDM a conductive brass wire is used as the electrode and de-ionized water is used as the medium [1]. Intricate parts and difficult to machine materials can be machined easily using WEDM. The selection of input parameters for obtaining larger MRR and good surface finish is done using Taguchi - Grey Relational Analysis, which is a multi objective optimization technique [2].

Ko-Ta Chiang et al (2006), in their paper “modeling and analysis of the rapidly resolidified layer of SG cast iron in the edm process through the responsive surface methodology”, observed the changes occurring in spheroidal graphite due to wire edm. The rapidly re-solidified layer is formed by the re-solidification of residual molten metal on the machined surface, during the electric discharge machining process. The factors of second phase considered were quantity, diameter and area fraction of spheroidal graphite particle. The performance of rapidly re-solidified layer in terms of the layer thickness and ridge density were the response variables investigated. Experimental plan was performed by a standard rsm design called a central composite design (CCD). The results of analysis of variance (ANOVA) indicated that, the proposed mathematical model could adequately describe the performance within the limits of the factors being studied. Their conclusions reveal that, quantity and area fraction of graphite particle are the most influential factors, on layer thickness and ridge density [8].

Bert Lauwers et al (2006), described the influence of composition and grain size (coarse, micron) of WC-based cermets on manufacturability by wire-EDM. It was shown that, the cutting rate decreases with increasing WC-grain size, which can be explained mainly by the change in thermal conductivity of the material. Finally, the experiment showed that for all investigated materials, the WEDM material removal mechanism is mainly melting, while other mechanisms like spelling have not been recognized [4].

Juhr et al (2004), explored improved cemented carbide properties after wire edm, by pulse shaping. Their research was aimed at developing an optimal process energy source, that produces improved material properties after wedm. Their studies showed that, it was important to use the correct parameter selection for main-cut and post-cut. Deterioration in the material properties by processing with high energy pulses can be corrected only by a limited extent in post cut. The primary actuating variable of pulse was pulse duration i.e., with pulse duration less than 500ns higher current magnitudes can also be used without problems. Through the use of new process energy source increase of bending strength of average 30% could be achieved. Simulation of the pulse wave forms and how the thermal load of the cut surface can be reduced, and the technical conditions could be adapted to a particular application. A comparison of an is energetic equal pulse regimes with increasingly shortened discharge durations did not show an improvement of the bending fraction stress of a main cut, with a pulse energy of 3.6mJ[6].

Mu-Tian Yan et al (2004), explored about accuracy improvement of wire edm, by real-time wire tension control. A closed loop wire tension control system for a wire edm machine was presented, to improve the machining accuracy. Dynamic models of the wire feed control apparatus and wire tension control apparatus were derived, to analyze and design the control system. PI controller and one step adaptive controller were employed, to investigate the dynamic performance of the closed loop wire tension control system. Experimental results demonstrated that, the geometrical contour error of corner cutting and the wash out of cliff edge, measured along the thickness of the work piece could be reduced to 50 to 40%, respectively. This method contributed to better corner accuracy and vertical straightness [11].

TAGUCHI DESIGN OF EXPERIMENTS

Design of experiments was conducted by using Minitab software and the based on varying the process parameters, which affect the machining process, to obtain the required quality characteristics. The process parameters are known as factors, which influence the nature of these response variables.

The factors and levels can be tabulated as shown in Table 1

Table 1: Factors and Levels

Symbol	Control Factors	Level 1	Level 2	Level 3
A	Dielectric pressure	Low	High	
B	Wire feed rate(m/min)	5	6	7
C	Wire tension (g)	600	700	850
D	Pulse on time (μ s)	4	5	6
E	Pulse off time (μ s)	5	6	7
F	Gap current (amps)	5	3	1
G	Gap voltage (V)	45	55	65

RESULTS AND DISCUSSIONS

Experiments were conducted as per the $L_{18}(2^1 \times 3^7)$ orthogonal array, assigning various values of the levels to the process parameters. After individual experiments, for a set of values were conducted on EN24 steel for a size of $150 \times 100 \times 27 \text{ mm}^3$. The experimental results were tabulated in Table 2.

Table 2: $L_{18}(2^1 \times 3^7)$ Orthogonal Array with Responses

EXPERIMENT NO	CONTROL FACTORS							RESPONSES	
	A	B	C	D	E	F	G	MRR (g/min)	Ra (μm)
1	Low	5	600	4	5	5	45	0.1011	3.0745
2	Low	5	700	5	6	3	55	0.0866	2.824
3	Low	5	850	6	7	1	65	0.0325	1.236
4	Low	6	600	4	6	3	65	0.0649	2.4935
5	Low	6	700	5	7	1	45	0.0397	2.2525
6	Low	6	850	6	5	5	55	0.0974	3.0085
7	Low	7	600	5	5	1	55	0.0469	2.433
8	Low	7	700	6	6	5	65	0.1046	3.298
9	Low	7	850	4	7	3	45	0.0686	2.4825
10	High	5	600	6	7	3	55	0.1119	3.518
11	High	5	700	4	5	1	65	0.0361	1.838
12	High	5	850	5	6	5	45	0.1227	3.789
13	High	6	600	5	7	5	65	0.1155	3.685
14	High	6	700	6	5	3	45	0.0794	2.7535
15	High	6	850	4	6	1	55	0.0289	1.1675
16	High	7	600	6	6	1	45	0.0433	2.2605
17	High	7	700	4	7	5	55	0.1083	3.1585
18	High	7	850	5	5	3	65	0.0938	2.9225

GRA converts the multiple response process optimization problems into a single response optimization situation, with the objective function of an overall grey relational grade. Table.3 shows the grey relation coefficient and grey relational grade for each experiment, using the $L_{18}(2^1 \times 3^7)$ orthogonal array. The higher grey relational grade reveals that, the corresponding experimental result is closer to the ideally normalized value. Experiment 12 has the best multiple performance characteristic, among 18 experiments, because it has the highest grey relational grade shown in Table 3 and Figure 4.

Table 4: Grey Relation Co-Efficient and Grey Relational Grades

EXP. NO	CONTROL FACTORS							GREY RELATION CO- EFFICIENT		GREY GRADE
	A	B	C	D	E	F	G	MRR	Ra	
1	Low	5	600	4	5	5	45	0.78874	0.73801	0.76338
2	Low	5	700	5	6	3	55	0.67478	0.66694	0.67086
3	Low	5	850	6	7	1	65	0.35241	0.34446	0.34844
4	Low	6	600	4	6	3	65	0.53164	0.58451	0.55808
5	Low	6	700	5	7	1	45	0.39049	0.53092	0.46071
6	Low	6	850	6	5	5	55	0.75791	0.71846	0.73819
7	Low	7	600	5	5	1	55	0.42913	0.57059	0.49986
8	Low	7	700	6	6	5	65	0.81916	0.80921	0.81419
9	Low	7	850	4	7	3	45	0.55424	0.58196	0.56810
10	High	5	600	6	7	3	55	0.88697	0.88804	0.88751
11	High	5	700	4	5	1	65	0.37143	0.44863	0.41003
12	High	5	850	5	6	5	45	1	1	1
13	High	6	600	5	7	5	65	0.92279	0.95484	0.93882
14	High	6	700	6	5	3	45	0.62420	0.64837	0.63629
15	High	6	850	4	6	1	55	0.33333	0.33333	0.33333
16	High	7	600	6	6	1	45	0.40971	0.53262	0.47117
17	High	7	700	4	7	5	55	0.85275	0.76381	0.80828
18	High	7	850	5	5	3	65	0.72913	0.69389	0.71151

Figure 1: Grey Relational Grades for Maximum MRR and Minimum Ra

Figure 1, shows the Grey relational grades for maximum MRR and Minimum Ra. Since, the experimental design is orthogonal; it is possible to separate out the effect of each machining parameter on the grey relational grade, at different levels. For example, the mean of the grey relational grade for the Dielectric pressure at levels 1 and 2 can be calculated by averaging the grey relational grade for the experiments 1 to 8, and 9 to 18, respectively. The mean of the grey relational grade for each level of the other machining parameters can be computed in a similar manner.

Figure 6.2: Response Graph of Average Grey Relational Grade

ANALYSIS OF VARIANCE (ANOVA)

The results of the ANOVA are shown in Table 3 and from the graphical representation it is clear that, average gap current is the major influencing factor, contributing 90.007% to MRR, followed by pulse-on time contributing 4.361%, pulse-off time contributing 0.277% and Wire Feed contributing 1.654%, Dielectric pressure contributing 1.013%, Wire tension contributing 1.552% and gap voltage contributing 0.108%.

Table 3: Influence of Various Parameters on MRR

PARAMETERS	SUM of SQUARES	VARIANCE	DOF	F Test Values	CONTRIBUTION %
DIELECTRIC PRESSURE	3.101	3.101	1	4.924	1.013
WIRE FEED	5.061	2.5305	2	4.018	1.654
WIRE TENSION	4.747	2.3735	2	3.769	1.552
PULSE ON TIME	13.343	6.6715	2	10.593	4.361
PULSE OFF TIME	0.847	0.4235	2	0.6724	0.277
AVERAGE GAP CURRENT	275.422	137.711	2	218.658	90.007
GAP VOLTAGE	0.331	0.1655	2	0.263	0.108
ERROR	3.149	0.6298	5		1.029
TOTAL	306.001				100

The results of the ANOVA are represented in graphical form and from the graphical representation it is clear that average gap current is the major influencing factor contributing 90.007% to MRR, followed by pulse-on time contributing 4.361%, pulse-off time contributing 0.277% and Wire Feed contributing 1.654%, Dielectric pressure contributing 1.013%, Wire tension contributing 1.552% and gap voltage contributing 0.108%.

Table 4: Influence of Various Parameters on Surface Roughness

PARAMETERS	SUM of SQUARES	VARIANCE	DOF	F Test Values	CONTRIBUTION %
DIELECTRIC PRESSURE	0.141	0.141	1	0.0536	0.0994
WIRE FEED	3.428	1.714	2	0.6509	2.4165
WIRE TENSION	15.179	7.589	2	2.8823	10.704
PULSE ON TIME	15.893	7.947	2	3.0182	11.2034
PULSE OFF TIME	0.815	0.408	2	0.1549	0.5745
AVERAGE GAP CURRENT	92.78	46.390	2	17.6187	65.403
GAP VOLTAGE	0.458	0.229	2	0.0869	0.3228
ERROR	13.165	2.633	5		9.2803
TOTAL	141.859				100

CONFIRMATION EXPERIMENT

Table 5 shows the comparison of the experimental results using the initial (A2B1C3D2E2F1G3) and optimal (A2B1C1D2E3F1G1) WEDM parameters on EN24 steel. The response values obtained from the confirmation experiment are MRR = 0.1316 g/min and Ra = 3.347µm. The Material Removal Rate shows an increased value of 0.1227 g/min to 0.1316 g/min and the Surface Roughness shows a reduced value of 3.789µm to 3.347µm respectively. The corresponding improvement in Material Removal Rate and Surface Roughness were 7.25% and 11.66% respectively.

Table 5: Optimization Results of OA L₁₈ (2¹*3⁷) Vs Grey Theory Design

	Optimal Process Parameters	
	Orthogonal Array	Grey Theory Design
Level	A2B1C3D2E2F1G3	A2 B1C1D2E3F1G1
MRR(g/min)	0.1227	0.1316
Ra (µm)	3.789	3.347

The results of the ANOVA are represented in graphical form and from the graphical representation it is clear that, average gap current is the major influencing factor contributing 65.403% to MRR, followed by pulse-on time contributing 11.2034%, pulse-off time contributing 0.5745% and Wire Feed contributing 2.4165%, Dielectric pressure contributing 0.0994%, Wire tension contributing 10.704% and gap voltage contributing 0.3228%.

CONCLUSIONS

- The optimal 'process parameters' based on Grey Relational Analysis for the Wire-Cut EDM of EN24 steel include a high Dielectric pressure with a wire feed rate of 5m/min and wire tension of 600g, 5µs pulse on time, pulse off time of 7µs, Average Gap current of 5A and Gap voltage of 45V.
- While applying the Grey-Taguchi method, The Material Removal Rate shows an increased value of 0.1227 g/min to 0.1316 g/min and the Surface Roughness shows a reduced value of 3.789µm to 3.347µm respectively, which are positive indicators of efficiency in the machining process.

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