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Optimization of Material Removal Rate and Surface Roughness for EN31 Steel in Wire-EDM Process

R. Santosh Kumar[1], A. Balaram Naik[2]

[1, 2]Jawaharlal Nehru TechnologicalUniversity, College of Engineering, Kukatpally, Hyderabad 500085, India

Abstract: ***In the present work an attempt is been made to optimize the performance parameters of wire-cut electric discharge machining on EN31 alloy steel, this is achieved by adjusting the input parameters. Non-electrical input parameters are chosen in the experiment and they were wire feed-rate, wire tension, duty factor and dielectric pressure. Here fractional factorial method is used for design of experiment and trails were conducted based on it. The data obtained from the experimental trails is utilized to deduce optimum input parameters for best machining performance based on greys relational analysis.And finally the influence of each parameter chosen for the experimentation is also established.***

Keywords: WEDM, Alloy steel, MRR, Surface roughness, Fractional Factorial method, Grey relational Analysis(GRA)

1. Introduction

With the advancement in the field of material science many sophisticated materials with superior mechanical properties came in existence. Machining such exotic metal is difficult using the traditional techniques. This lead to development of advanced methods of machining which utilize the modern proficiencies of theory of metal cutting. Electric discharge machining is one among such process wherein thermal energy generated during electric spark in dielectric medium is used to cut the metal. There are two kinds of Electric discharge machine (EDM), and wire-cut EDM or WEDM is one of among those, it is generally used to cut intricate shapes on metals, in making dies and several other applications.

2. Past work in the field of WEDM

Enormous amount of work has been reported ever since the process isestablished.And the numerous researches carried out on Wire- EDM, referred from the papers, are classified into four major areas as shown in figure 1.

Vikas [1] et al. (2014) carried out the optimization of the Material removal rate for EN41 and EN19 based on the 4 input parameters namely the pulse on time, pulse off time, discharge current and gap voltage. He found out that the discharger current had a larger impact over the Material removal rate followed by some of the interaction plot, while the effect of the other parameters were minor.Not only for alloy steels, many researches were done on several other materials, say for instance B.H Yan [2] et al. studied the effect of multiple characteristics of WEDM on composite materials and found that abrasive reinforcements present in composite matrix effect machinability.

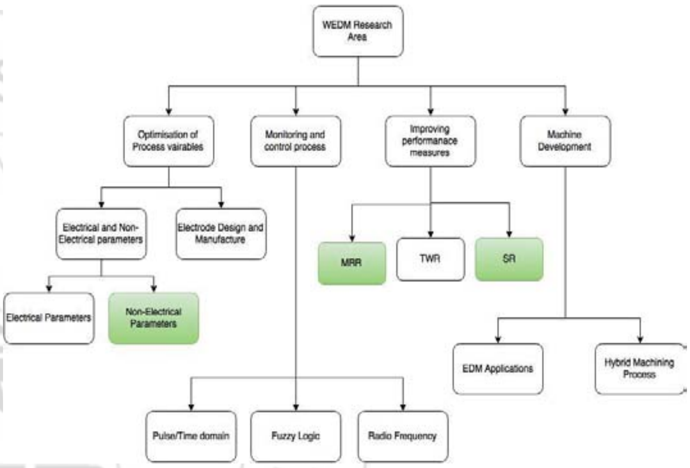

Figure 1: Research work in the field of WEDM

B. Bhattacharyya[3] etal. (2003) has investigated variation of geometric inaccuracy due to wire lag against parametric settings and optimised using taguchi method. Zahid [4] et al. (2014) and Mahdavinejad et al. (2009)have worked with grey analysis and controller model respectively on WEDM parameters using Taguchi methodology. K. L. Meena[6]et al. (2013) have studied the effect of wire feed rate and wire tension during machining of Pr-Al-SiC- material composite by wire-EDM and found optimal setting for it

From the extensive literature review done it seems that contribution done in the area of optimising non-electrical process variables to obtain better material removal rate and surface was very limited, hence this form the basis of the current paperwork.

3. Experimental Setup

3.1 Material

The material chosen for study is EN31 alloy steel. It is alloy steel with high percentage of carbon and chromium along with other minor alloying elements like Manganese, Silicon, Sulphur and Phosphorous. Possessing high hardness and ultimate tensile strength it best machined on WEDM, it is widely used in making dies, bearing and components which are subjected to high loads.

3.2 Experimental Parameters

Based on the Machine used for WEDM process and the mechanical properties of the material usedin the present study, input variables are chosen.Table-1 shows the control parameters and input settings used in the experiment.

Table 1: Control parameters and their settings

Control Parameters	Units	Symbol	Levels	
			Low	High
Wire Feed	m/min	A	5	7
Wire Tension	Kgf	B	7	10
Duty factor	%	C	0.6	0.7
Dielectric pressure	Kg/cm^2	D	2	4

Utilizing fractional factorial method, eight experiments were designed and conduction the material and input setting for each experiment is shown the table-2.

Table 2: Experimental inputs based on fractional factorial method

Trail	Wire Feed	Wire Tension	Duty factor	Dielectric Pressure
1	7	10	0.6	2
2	5	10	0.7	2
3	7	7	0.6	4
4	5	10	0.6	4
5	7	7	0.7	2
6	5	7	0.7	4
7	7	10	0.7	4
8	5	7	0.6	2

3.3 Experiment Process

Firstly the work-piece is sent for milling to remove tapered-ness. This gives the agility foreasy setting up of work-piece on the work-table.An electrolytic brass wire with a diameter of 0.25mm has been used as a toolelectrode (positive polarity) and work piece materials used is EN31 alloy steel of rectangular plates with dimensions 150 x 80 x 10 mm. De-ionised water is used as dielectric fluid with transverse flushing.

Figure 2(a): Electronica Ultracut S2 Wire-EDM

Figure 2(b):EN31 during wire EDM process

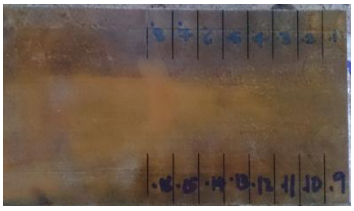

Figure2(c): Work-piece after 16 experiment were made

Figure2(d): Test-pieces whose surface roughness is measured

To reduce variability and reliability of experimental results, the experimentsare replicated twice. The mean of responses obtained from the replications are considered. After running the trails we obtain work-piece as shown in the figure 2(c). Now the material removal rate is measured as the volume of material removed in the machining time. So for determining the volume of material removed, the slot cut by the WEDM is measured on vertical profile projector at 20X magnification then value obtained is multiplied with thickness and length of cut to determine the volume of material removed. And “Taylor Hobson-Subtronic 3+” Surface tester is used to get the average surface roughness of the each test piece {fig 2(d)} which is separated from the work-piece shown in figure 2(c) by milling operation . The responses obtained from the experiments are enumerated in table 3.

Table 3:Responses obtained from the experiments

Trail No.	Cut Width (cm)	Thick-ness (cm)	Cut length (cm)	Time (mins)	MRR (mm^3/min)	Surface roughness (µm)
1	0.02	10.2	2	32	12.75	5.94
2	0.02	10.2	2	72	5.667	3.71
3	0.025	10.2	2	22	23.18	5.45
4	0.03	10.2	2	27	22.67	5.68
5	0.03	10.2	2	30	20.4	11.05
6	0.025	10.2	2	30	17	11.36
7	0.03	10.2	2	48	12.75	6.24
8	0.02	10.2	2	25	16.32	11.59

4. Grey Relation Analysis

Grey relational analysis is a part of Grey theory proposed by Professor J.L Deng [7]. GRA is a multivariate optimization techniques where in grades are calculated for the terms in the sequence and later there characteristics are determined based on the grey theory principles. It mainly consists of three steps which will be discussed in further sub sections.

4.1 Data Preprocessing

The raw data obtained from the experimentation is normalized using the equations (1) and (2). If the target value of original sequence is infinite, then it has a characteristic of "the larger-the –better". The original sequence can be normalized as follows.

$$x_i^*(k) = \frac{x_i^0(K) - \min x_i^0(K)}{\max x_i^0(K) - \min x_i^0(K)} \rightarrow \quad (1)$$

If the expectancy is the smaller-the better, then the original sequence should be normalized as follows.

$$x_i^*(k) = \frac{\max x_i^0(K) - x_i^0(K)}{\max x_i^0(K) - \min x_i^0(K)} \rightarrow \quad (2)$$

For best performance of any machining process we require higher MRR and lower surface roughness, so we use the equation (1) for MRR and equation (2) for surface roughness. Values obtained from calculations are tabulated as shown in table 4.1

Table 4.1: The sequences of each performance characteristic after data processing

Trail Number	MRR (mm^3/min)	Surface roughness (µm)
Reference Sequence	1.0000	1.0000
1	0.4044	0.717
2	0.0000	1.0000
3	1.0000	0.7792
4	0.9706	0.75
5	0.8412	0.0685
6	0.6471	0.0292
7	0.4044	0.6789
8	0.6082	0.0000

4.3 Grey relational coefficient and grey relational grade:

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. They grey relational coefficient can be expressed as follows:

$$\zeta_i(k) = \frac{\Delta_{min} + \zeta.\Delta_{max}}{\Delta_{oi}(k) + \zeta.\Delta_{max}}$$

Where $\Delta_{oi}(k)$ is the deviation sequence of the reference $x_o^*(k)$ and the comparability sequence $x_i^*(k)$, derived as

$$\Delta_{oi}(k) = ||x_o^*(k) - x_i^*(k)||$$

$$\Delta_{max} = \mathbf{max}_{\forall j \in i} \mathbf{max}_{\forall k} ||x_o^*(k) - x_i^*(k)||$$

$$\Delta_{min} = \mathbf{min}_{\forall j \in i} \mathbf{min}_{\forall k} ||x_o^*(k) - x_i^*(k)||$$

ζ is distinguishing or identification coefficient $\zeta \in [0,1]$. $\zeta = 0.5$ is used when extent of influence of subjects in analysis is not known properly. Calculationsare performed for i=1 to 8 and the results of all for i=1 to 8 are presented in Table 4.2.

Table 4.2: Table showing deviation from reference sequence

Deviation Sequences	$\Delta_{oi}(1)$	$\Delta_{oi}(2)$
Exp. No. 1	0.595	0.283
Exp. No. 2	1	0
Exp. No. 3	0	0.22
Exp. No. 4	0.029	0.25
Exp. No. 5	0.159	0.931
Exp. No. 6	0.353	0.971
Exp. No. 7	0.596	0.321
Exp. No. 8	0.392	1

4.4 Grey relational grade

After obtaining the grey relational coefficient, we normally take the average of the grey relational coefficient as the grey grade. The grey relational grade is defined as follows.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \zeta_i(k)$$

Table 4.3: The calculated grey relational coefficients and grey relational grade

Trail	Grey relational coefficient		Grey Relational Grade
	MRR (mm^3/min)	Ra (µm)	
1	0.4564	0.639	0.548
2	0.333	1	0.667
3	1	0.694	0.847
4	0.944	0.667	0.806
5	0.759	0.349	0.554
6	0.586	0.34	0.463
7	0.456	0.609	0.533
8	0.561	0.333	0.447

5. Results and Discussion

According to Grey Relational Analysis, higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized values. Trail 3 has the higher Grey relational grade which implies it has strong correlation with the ideal/reference sequence; hence it is the optimal setting from the set of experiments performed. So optimal setting is $A_H B_L C_L D_H$. A graph is drawn between grey relational grade against trail number to demonstrate the variation and for identifying the highest grey relational grade.

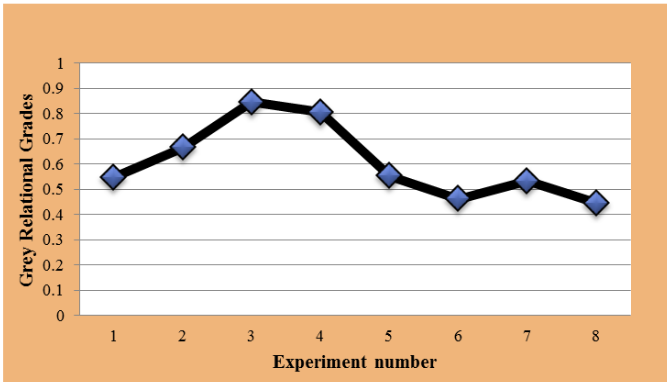

Figure 3: Graphs showing GRG vs. Experiment No.

5.1 Influence of each factor

Since the experimental design is fractional factorial, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels. Table 5 show the average of grey relational grade at each level and the asterisk mark above them shows that they possess dominant role in experiment, so they are used in confirmation test to validate the experiment.

Table 5: Grey Relation Grade for each WEDM parameter

Symbols	Machining Parameters	Grey Relational Grade		Main Effect	Rank
		Low	High		
A	Wire Feed	0.667*	0.548	0.118	1
B	Wire Tension	0.658*	0.558	0.1	2
C	Duty Factor	0.640*	0.576	0.063	3
D	Dielectric Pressure	0.595	0.620*	0.025	4

A graph is drawn between average GRG values of each factor at low and high levels and its deviation is measured against the mean of total mean grade value.This can be seen in figure 4, the orange line shows the total mean of grey relational grade for whole process and the blue line indicates the variation of each factor with change in their level.

It is found the wire feed has major influence on the machining process as it shows larger deviation for given change in the level. It is also observed that dielectric pressure doesn't have much influence on machining process in chosen level as it doesn't intercept the total mean of the process. This is again restated in table 5 by the means of "main effect column", the column with highest deviation is known to have major influence.

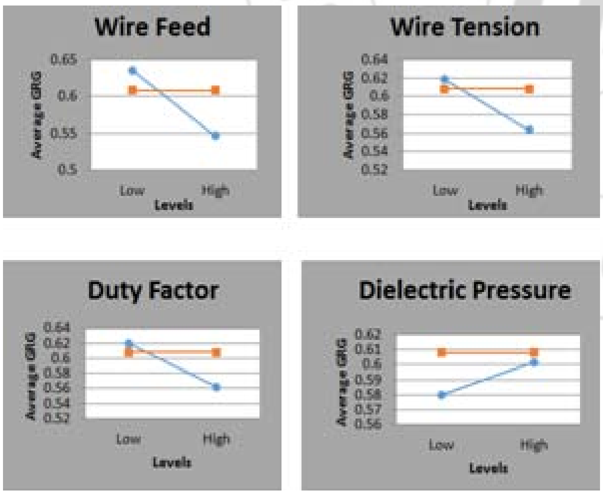

Figure 4: Graph showing Average Grey Relation grade for each factor

5.2 Confirmation Test

After identifying the most influential parameters, the final phase is to verify the surface roughness and the cut width by conducting the confirmation experiments**.** The test settings are selected via the grey relational analysis table 5which shows the levels with dominant effect. Therefore, the condition $A_LB_LC_LD_H$forms the parameter combination during WEDM. The result of the confirmation test gives the surface roughness average and the MRR as 4.08µm and 23.18mm^3/min respectively. This shows and improvement of 8.33% in MRR and 19.25% in Surface roughness.

6. Conclusion

In this study, Fractional factorial method with grey relational analysis has been used to optimize material removal rate and surface roughness. It is found that wire feed-rate is most significant factor among the chosen process variables in WEDM process. Confirmation test shown an improvement of 8.3% and 19.25% improvement in MRR and surface roughness.

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Author Profile

R. Santosh Kumar B. Tech (Mechanical), M. Tech (Manufacturing systems), He is a member of Society of Automotive Engineers India and He is currently working Hyundai Mobis.

A. Balaram Naik B.E (Mechanical), M.Tech (Manufacturing Technology), PhD (Manufacturing Technology) -Welding. Member of International Institute of Welding. He is now a professor at Jawaharlal Technological University Hyderabad.