Multi-objective optimization in WEDM of Incoloy 800® Using Taguchi method and Grey Relational Analysis

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Abstract
This research work addresses multi objective optimization based on Taguchi method and grey relational analysis for wire electro discharge machining of Incoloy 800®superalloy material. Influence of peak current, pulse on time and pulse off time are investigated for MRR, surface roughness and kerf width, during machining of Incoloy 800®superalloy. Taguchi L27 array is been selected for experimental design. Grey relational analysis is used along with Taguchi method to optimize the multiple performance characteristics. Through grey relational analysis, grey relational grade is obtained which is used as performance index of process parameters. ANOVA is also performed to determine significance of the all process parameters.

Keywords: *WEDM, grey relational analysis, Taguchi method, optimization*

INTRODUCTION

In machining process whether it is conventional or unconventional, it has multiple process parameters which affect multiple performance characteristics in the work. It has also seen for some process parameter its lower value and for some process parameters its higher value is desirable to get optimum individual performance characteristics. But at the same time for other performance characteristics value of process parameter differ. Hence, investigation to find best relation between multiple process parameter and multiple performance characteristics is quite complex to learn. In this study, the effort has been made to use grey relational analysis to optimize wire electro discharge machining of Incoloy 800® superalloy.

LITERATURE REVIEW

Muthu Kumar et al. [1] investigated effect of machining parameters on Incoloy-800 material on wire EDM. The process parameters considered in the work are gap voltage, pulse on-time, pulse off-time and wire feed to see multiple performance characteristics of material removal rate, kerf width and surface roughness based on Grey–Taguchi Method. Durairaj et al. [2]investigated effect of parameters which are gap voltage, wire feed, pulse on time, and pulse off time to attain the minimum kerf width (KW) and the best surface quality on wire EDM for SS304 Using Grey relational analysis and Taguchi technique. Lahane et al. [3] investigated machining of high speed steel through wire EDM using Taguchi method. Parameters were selected pulse on time, pulse off time, upper flush and wire feed to optimize process parameter MRR and wire wear rate [WWR]. They reported that pulse on time is most significant factor affecting MRR and WWR. Azhiri et al. [4] applied Taguchi, grey analysis and Adaptive neuro-fuzzy inference system (ANFIS) on wire EDM to optimize process parameter while using gaseous medium on silicon carbide and aluminium carbide metal matrix composite material. Kulkarni and Rodge [5] uses Taguchi orthogonal array for designing runs and evaluate optimum multiple performance characteristics such as Material removal rate, surface finish and kerf width. Lin [6] applies Taguchi method and gray relational analysis to find optimum process parameter for multiple performance characteristics in turning operation on lathe machine. In the study three process parameters speed, feed rate and depth of cut are selected for optimization tool life, cutting force and surface roughness as performance characteristics and get improved result for the same.

Vinod Kumar et al. [7] investigated effect of machining parameters on Nimonic-90 material which is a nickel based super alloy. The machining parameters selected were discharge current, pulse on time, pulse off time, servo voltage and wire feed to optimize cutting speed as machinability attribute. It is investigated that at low pulse duration the cutting speed increases slowly with increase in peak current but at high pulse duration cutting speed sharply increases with increase in peak current. Sivakiran et al. [8] revealed effect of machining parameters of EN-31 tool steel material on CONCORD DK7720C four axis CNC WEDM machine. The machining parameters selected were Pulse-on, Pulse-off, Bed speed and Current to optimize material removal rate. In this study, the settings of machining parameters were determined by using Taguchi experimental design method.

EXPERIEMENTAL DETAILS

Experiments were performed on NC controlled Electra Elcut-334 wire electro discharge machine. The brass wire of size Ø0.25mm was used as electrode material. The work material selected in this investigation was Incoloy 800® superalloy. Chemical composition of the work material is shown in Table 1.

Table 1: *Chemical Composition of Incoloy 800®.*

Element	Ni	Cr	Mn	Al	C	Si	Ti	Cu	Iron
% composition	30-35	19-23	1.5 max	0.15-0.6	0.1 max	0.015 max	0.15-0.6	0.75 max	Balance

The experiments were performed according to Taguchi Design of Experiments. Taguchi's L27 orthogonal array has been implemented to conduct the experiments. Among various parameters pulse on time, pulse off time, peak current is selected as process parameters. Each parameter with their three levels decided for experimentation. The machining parameters used and their levels chosen are presented in Table 2.

Table 2: *Process Parameters And Their Levels.*

Sr. No.	Parameters	Unit	Level 1	Level 2	Level 3
1	Peak current (Ip)	Amp	4	6	8
2	Pulse on time (Ton)	machine unit	3	5	7
3	Pulse off time (Toff)	machine unit	3	5	7

The response parameters measured in this work were material removal rate, surface roughness and kerf width. MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material. Surface roughness weas measured with HOMMEL surface roughness tester. Scanning electron microscope was used to measure the Kerf width of samples. The findings of present study of WEDM machining of Incoloy 800® alloy with different parameters and experimental runs are tabulated in Table 3.

Table 3: *Experimetal Design Using L27Array And Response Parameters*

Experiement No.	Control parameters			Response parameters		
	Peak current	Pulse on time	Pulse off time	Surface roughness (Ra)	MRR (mm^3/min)	Kerf width (mm)
1	4	3	3	3.323	0.0247	0.288
2	4	5	3	3.430	0.0247	0.288
3	4	7	3	3.018	0.0224	0.28
4	4	3	5	3.460	0.0201	0.296
5	4	5	5	3.493	0.0207	0.28
6	4	7	5	3.505	0.0225	0.28
7	4	3	7	3.785	0.0178	0.296
8	4	5	7	3.628	0.0196	0.288
9	4	7	7	3.808	0.0218	0.288
10	6	3	3	3.095	0.0168	0.288
11	6	5	3	3.125	0.0323	0.272
12	6	7	3	3.528	0.0277	0.272
13	6	3	5	3.713	0.0322	0.304
14	6	5	5	3.725	0.0307	0.264
15	6	7	5	3.905	0.0352	0.288
16	6	3	7	3.473	0.0303	0.304

17	6	5	7	3.880	0.0316	0.288
18	6	7	7	3.793	0.0358	0.296
19	8	3	3	3.418	0.0366	0.304
20	8	5	3	3.925	0.0411	0.336
21	8	7	3	3.908	0.0531	0.315
22	8	3	5	3.603	0.0446	0.305
23	8	5	5	3.838	0.0502	0.33
24	8	7	5	3.860	0.0474	0.312
25	8	3	7	3.855	0.0429	0.298
26	8	5	7	3.755	0.0528	0.322
27	8	7	7	4.063	0.0538	0.328

GREY RELATIONAL ANALYSIS (GRA)

It includes the modeling, prediction and decision making of a system in which the model is unsure or the information is incomplete. This method is used for solving the inter relationship among the multiple performing characteristics. In GRA, data pre-processing is done because the range and unit in one data sequence may differ from the others. In GRA measured responses are first normalized in the range of 0 to 1. Depending on the characteristics of data sequence, there are various methodologies of data pre-processing available for the GRA. Normalization can be done by using following equations [9].

When the "Higher is better" is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$X_{ij} = \frac{\max(Y_{ij}) - Y_{ij}}{max(Y_{ij}) - \min(Y_{ij})} \tag{1}$$

When the "Smaller is better" is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$X_{ij} = \frac{Y_{ij} - \min(Y_{ij})}{max(Y_{ij}) - \min(Y_{ij})} \tag{2}$$

Where, X_{ij} & Y_{ij} are normalized value and experimental observed value of i^{th} experiment and j^{th} response respectively, while $\max(Y_{ij})$ & $\min(Y_{ij})$ are maximum and minimum experimental observed value of j^{th} response respectively.

$$\Delta_{ij} = \left| X_0 - X_{ij} \right| \tag{3}$$

Δ_{ij} is the difference of the absolute value called deviation sequence of the reference sequence X0 and comparability sequence X_{ij} . After data pre-processing grey relational coefficient (GRC) is calculated. This provides the relational degree between ideal and normalized experimental results. GRC can be calculated as:

$$GRC_{ij} = \frac{\Delta_{\min} + \varphi\, \Delta_{max}}{\Delta_{ij} + \varphi\, \Delta_{max}} \tag{4}$$

Δ_{max} and Δ_{min} are maximum and minimum absolute differences, which are the deviations from target value and can be treated as quality loss. φ is the distinguishing coefficient which varies from 0 to 1. Since multi response characteristics consist of both larger the better and smaller the better, is assumed to 0.5 in this study. The grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristic. Higher grey relational grade indicates the stronger correlation between performance characteristics. It can be expressed as;

$$G_i = \frac{1}{n} \sum_{j=1}^{n} GRC_{ij} \tag{5}$$

Where, Gi represents the GRG of the i^{th} experiment for performance characteristics and n is the number of performance characteristics.

RESULTS AND DISCUSSIONS

In the present study, typically lower values of surface roughness and kerf width, higher value of MRR as the target values are desirable. Therefore the data sequences have the smaller the better characteristics for surface roughness and Kerf width, Higher-the-better characteristics for MRR.

Table 4 : *Grey Relational Coefficient of Each Performance Characteristic.*

Experiment No.	Grey Relational Coefficient			Grey Relational Grade	Rank
	MRR	Surface Roughness	Kerf Width		
1	0.3886	0.6314	0.6	0.5400	9
2	0.3886	0.5591	0.6	0.5159	16
3	0.3707	1	0.6923	0.6876	2
4	0.3544	0.5417	0.5294	0.4751	22
5	0.3585	0.5238	0.6923	0.5248	13
6	0.3714	0.5175	0.6923	0.5271	11
7	0.3394	0.4051	0.5294	0.4246	27
8	0.3510	0.4613	0.6	0.4708	23
9	0.3663	0.3980	0.6	0.4548	24
10	0.3333	0.8715	0.6	0.6016	4
11	0.4625	0.8300	0.8181	0.7035	1
12	0.4147	0.5060	0.8181	0.5796	7
13	0.46134	0.4291	0.4736	0.4547	25
14	0.4447	0.4249	1	0.6232	3
15	0.4986	0.3706	0.6	0.4897	18
16	0.4404	0.5345	0.4736	0.4828	19
17	0.4545	0.3773	0.6	0.4773	21
18	0.5068	0.4026	0.5294	0.4796	20
19	0.5182	0.5663	0.4736	0.5194	14
20	0.5929	0.3655	0.3333	0.4305	26
21	0.9635	0.3699	0.4137	0.5824	5
22	0.6678	0.4717	0.4675	0.5357	10
23	0.8371	0.3891	0.3529	0.52641	12
24	0.7429	0.3829	0.4285	0.51815	15
25	0.6292	0.3843	0.5142	0.5092	17
26	0.9487	0.4148	0.3829	0.5821	6
27	1	0.3333	0.36	0.5644	8

The grade in Grey analysis is used to evaluate the experimental data for multi-response characteristics. The highest grade corresponds to the optimal level of experimental set where optimization of any complicated multiple performance characteristics can be converted into a single Grey relational grade. According to the grey relational grades from Table 4, experiment no. 11 has the highest grey relational grade. Thus the optimized process parameters are 3 Ip, 6 Ton and 5 Toff respectively in the present experimental set.

Table 5 gives the average response table for the grey relational grade values. Delta is the difference between the maximum and minimum grade values of the each input parameter and the significance row gives the order of influence of the process parameter.

Table 5: *Average Grey Relational Grade for Factor and Levels*

Process parameters	Level 1	Level 2	Level 3	Delta (max- min)	Rank
Pulse on time	0.5135	0.5436	0.5299	0.0302	3
Pulse of time	0.5048	0.5394	0.5426	0.0378	2
Peak Current	0.5734	0.5195	0.4940	0.0794	1

The results obtained through grey relational analysis are in agreement with the results obtained from ANOVA analysis. ANOVA for grey relational grade at 5% significance level is presented in Table 6. Results of the ANOVA indicate that peak current is the most significant cutting factor for affecting the multiple performance characteristics.

Table 6: *ANOVA of Grey Relational Grade*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pulse on time	2	0.004101	0.002051	0.48	0.625
Pulse off time	2	0.007906	0.003953	0.93	0.412
Peak Current	2	0.029611	0.014805	3.47	0.051
Error	20	0.085297	0.004265		
Total	26	0.126915			

CONCLUSIONS

The grey relational analysis has been applied for the optimization of Wire EDM process parameters for machining of Incoloy 800® super alloy material along with Taguchi orthogonal experimental design. The following conclusions can be drawn from this study:

1. The experiment number 11 which has highest grey relational grade is said to be best choice of all the runs. The optimized process parameters are found to be 3 Ip, 6 Ton and 5 Toff.
2. It was also found that peak current is most influencing factor, followed by pulse off time and pulse on time is least significant factor.

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