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Optimization of WEDM Process Parameters on Duplex 2205 steel using Grey Relational Analysis

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ABSTRACT:- *In this study, Grey Relational Analysis is used for multi response optimization of Wire Electrical Discharge Machining parameters, which converts the multi responses into a single Performance grey relational grade. Based on grey relational grade, optimal combination of parameters are determined. L9 orthogonal array is used for Design of experiments. Maximum Material removal rate and Minimum surface roughness were chosen as the objectives. In this study Duplex steel is considered as the target material for Wire Electrical discharge Machining, because of high corrosion resistance, good mechanical strength and relatively low cost. The process parameters viz., pulse on time, pulse off time, Peak Current and wire feed were optimized with consideration of Grey Relational Grade. The confirmation run, results shows that the better quality is achieved by the optimal combination of process parameters.*

Keywords:- *Duplex 2205 Steel, Grey relational Analysis, Multi objective optimization,*

I. INTRODUCTION

Duplex stainless steels are named as “Duplex” because, it is of two-phase microstructure consisting of grains of austenitic and ferritic stainless steel, possessing high corrosion resistance and excellent mechanical properties [1]. When this material is melted it then solidifies from the liquid phase to a ferritic structure. When the material gets cools to room temperature, half of the ferritic grains transform to austenitic grains. The result is a microstructure of roughly 50% austenite and 50% ferrite. Wire Electrical Discharge Machining (WEDM) is a non-conventional machining process, used to machine very hard materials with high precision, utilizing thermal energy to machine electrically conductive parts, which makes advantage in the manufacture of parts with complex shapes [2]. WEDM has been widely used in many industries for high precision and quality [3].

The research in WEDM processing has been focused on rapid machining with best quality. Material removal rate and surface roughness, which are the most important objectives in the manufacturing. To achieve best quality, it is important to select optimal process parameters [4]. Generally, Taguchi method is used to optimize the single response characteristics of process parameters to achieve high quality [e.g., 5-6], which is not suitable for present scenario in industries. At present, handling multi-response characteristics are an interesting and challenging research. Grey relational analysis is used to determine the optimal parameters by converting multi responses into single response (grey relational grade) [e.g., 7 - 8]. ANOVA is carried out to determine the percentage of contribution of each factor on the response of the system.

II. EXPERIMENTAL SETUP / OUTPUT MEASUREMENT

In this study, Duplex 2205 steel is the target metal. Experiments were conducted using Electronica Maxicut Wire EDM. A 0.25 mm diameter, brass wire was used as an electrode and distilled water is used as dielectric fluid. A small gap of 0.025 mm to 0.05 mm is maintained in between the wire and work-piece. The dimension of the work piece for experimentation is 1 * 1* 1 cm as shown in Fig.1. The process parameters were being set in the WEDM control panel and the experiments were conducted as per the design of experiments shown in Table 2. The time required for metal removal from work piece is determined by using stopwatch and the surface roughness is determined by using talysurf instrument and the results were tabulated in Table 2. In this study four process parameters with three levels are chosen for machining. The parameters and its levels are shown in Table 1. L9 (3^{3-1} = 9 runs) orthogonal array of experiments was chosen for experimentation, instead of L 27 array (3^3 = 27 runs) to reduce the experimentation cost.

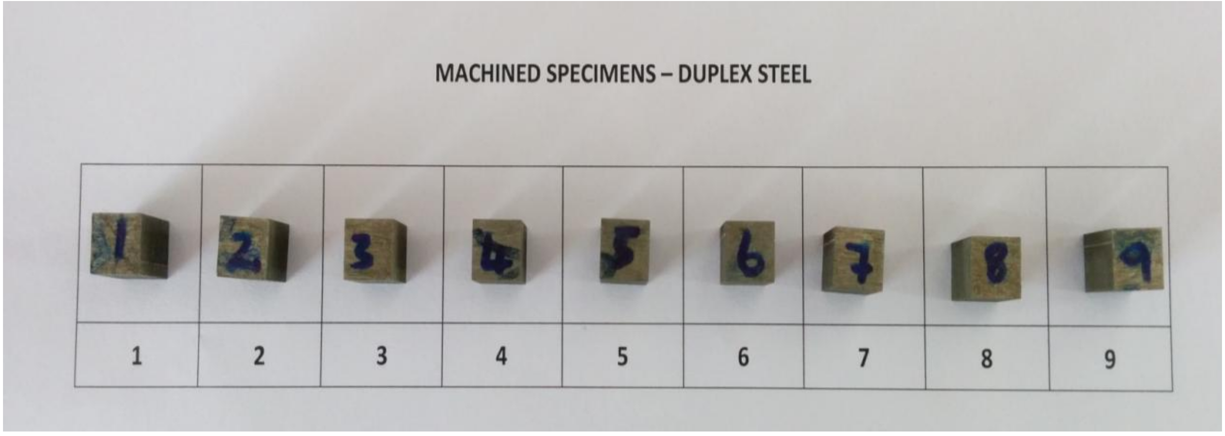

Fig. 1 Machined Specimens

TABLE 1. Process parameters and levels

Process parameters	Levels		
	Level-1	Level-2	Level-3
Pulse-on (µs)	32	36	38
Pulse-off (µs)	4	6	8
Peak Current (Amps)	1	2	3
Wire feed (m/min)	1	2	3

TABLE 2. Design of experiments and responses

Expt. No	Input --- Process parameters				Output Responses	
	Pulse On (µs) A	Pulse Off (µs) B	Peak Current (Amp) C	Wire Feed (m/min) D	MRR (mm^3/sec)	SR (µm)
1	3	3	1	7	17.56	2.70
2	3	6	2	8	18.50	2.93
3	3	9	3	9	19.00	2.69
4	6	3	2	9	25.00	2.85
5	6	6	3	7	29.36	2.99
6	6	9	1	8	27.56	2.85
7	9	3	3	8	21.00	3.10
8	9	6	1	9	27.00	2.95
9	9	9	2	7	33.10	2.76

III. GREY RELATIONAL ANALYSIS

The grey relational analysis includes the following steps:
1. Conduct the experiments as per design of experiments.
2. Transform the experimental results into signal-to-noise ratio.
3. Normalize the values of signal-to-noise ratio.
4. Perform grey relational generating and calculate grey relational coefficient.
5. Calculate the grey relational grade by averaging the grey relational coefficient.

3.1 Normalization: Convert the original sequences to a set of comparable sequences by normalizing the data. Depending upon the response characteristic, three main categories for normalizing the data is as follows:

‘Larger the better’

$$a_i^{(*)}(k) = \frac{b_i^{(*)}(k) - \min\ b_i^{(*)}(k)}{\max\ b_i^{(*)}(k) - \min\ b_i^{(*)}(k)} \quad (1)$$

'Smaller the better' $$a_i^{(*)}(k) = \frac{\max b_i^{(*)}(k) - b_i^{(*)}(k)}{\max b_i^{(*)}(k) - \min b_i^{(*)}(k)} \quad (2)$$

'Nominal the better' $$a_i^{(*)}(k) = 1 - \frac{b_i^{(*)}(k) - OV}{\max\{\max b_i^{(*)}(k) - OV, OV - \min b_i^{(*)}(k)\}} \quad (3)$$

Where $b_i^{(*)}(k)$ is the experimental result in i[th], $a_i^{(*)}(k)$ is the normalized result in the i[th] experiment and OV is the optimum value. The original reference sequence $a_0^{(*)}$ (k) = 1 and normalized data $a_i^{(*)}$ (k) (comparability sequence) where i = 1,2,….,m; k =1,2,.....,n respectively, where m is the number of experiments and n is the total number of observations of data.

3. 2 Grey relational coefficient and grey relational grade: Grey relation coefficient (α_{ij}) is calculated for each of the performance characteristics, which expresses the relationship between ideal and actual normalized experimental results, as shown in "Eq.(4)."

$$\alpha_{ij} = \frac{\Delta\min + \xi\Delta\max}{\Delta oi(k) + \xi\Delta\max} \quad (4)$$

i =1,2,….,m; k =1,2,.....,n respectively, where m is the number of experiments and n is the total number of observations of data. Where $\Delta oi(k)$is the deviation sequence of the reference sequence $a_0^{(*)}(k)$ and comparability sequence $a_i^{(*)}(k)$.

i.e.; $\Delta oi(k) = |a_0^{(*)}(k) - a_i^{(*)}(k)|$, and

$$\Delta\min = \min|a_0^{(*)}(k) - a_i^{(*)}(k)|, \quad \Delta\max = \max|a_0^{(*)}(k) - a_i^{(*)}(k)|$$

'ξ' is the distinguishing coefficient and the value lies between 0 and 1 i.e. $0 \leq \xi \geq 1$. The distinguishing coefficient ξ value generally chosen to be 0.5. Grey relational grade can be calculated by taking the average of is the weighted grey relational coefficient and defined as follows:

$$\Sigma\beta_k\gamma(x_0^{(*)}(k), x_i^{(*)}(k)) = 1 \quad (5)$$

where β_k is the weighting factor of each response. In the present study, all process parameters influence the responses, so equal weights are assigned to parameters.

TABLE 3. S/N RATIOS, NORMALIZED AND GREY RELATIONAL COEFFICIENTS

Expt No	S/N ratios		Normalized values		Grey Relational coefficients	
	MRR	SR	MRR	SR	MRR	SR
1.	24.89	-8.62	0.10	0.15	0.31	0.37
2.	25.34	-9.33	0.00	0.80	0.33	0.72
3.	25.57	-8.59	0.04	0.12	0.34	0.36
4.	27.95	-9.09	0.53	0.58	0.51	0.54
5.	29.35	-9.51	0.81	0.97	0.73	0.10
6.	28.80	-9.09	0.70	0.58	0.62	0.54
7.	26.44	-9.82	0.22	1.00	0.39	0.65
8.	28.62	-9.39	0.66	0.86	0.60	0.78
9.	30.39	-8.81	1.00	0.33	0.10	0.42

TABLE 4. GREY RELATIONAL GRADES

Expt. No	Grey Relational grade	Order
1	0.342	9
2	0.528	6
3	0.353	8
4	0.532	5
5	0.839	1
6	0.589	4
7	0.524	7
8	0.693	2
9	0.683	3

Table 4. Shows the order of grey relational grades obtained.. The larger grade value among all possible combinations of the process parameters indicates the optimal combination of parameters and confirmed that the experiment number 5 has the optimal combination of process parameters for machining. The averages of grades for each level of the machining factors are then computed and tabulated in Table 5. The darkened number in each column of factors indicates the best level for each factor. The delta, indicates the difference between maximum and minimum, of grades. Rank 1 represents the largest delta among their levels and have more influence on the machining process.

TABLE 5. RESPONSE TABLE FOR GREY GRADE

LEVEL	PULSE ON	PULSE OFF	PEAK CURRENT	WIRE FEED
1	-7.970	-6.805	-5.701	**-4.719**
2	**-3.868**	**-3.419**	**-4.780**	-5.253
3	-4.037	-5.651	-5.394	-5.904
DELTA	4.102	3.386	0.921	1.185
RANK	1	2	4	3

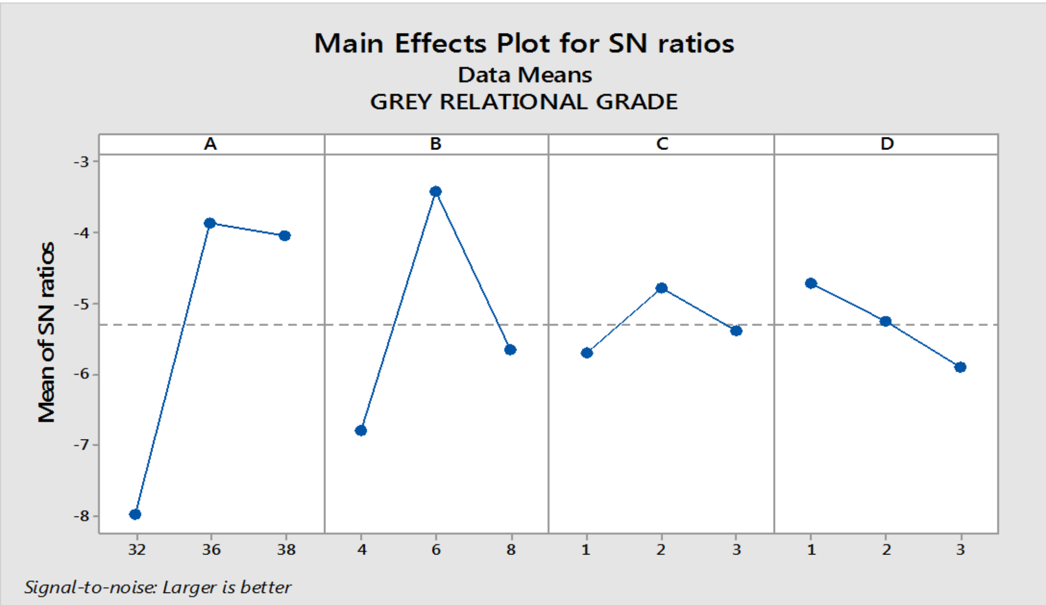

Fig. 2. Main effect plot for Grey relational grades

IV. ANALYSIS OF VARIANCE (ANOVA)

ANOVA is performed to identify the contribution of process parameters of WEDM on Grey Relational Grades. An ANOVA table as shown in Table. 6 consists of degrees of freedom, sums of squares and the percentage of contribution.

TABLE 6. ANALYSIS OF VARIANCE

Source	DF	Seq SS	Adj SS	Seq MS	% Contribution
Pulse on	2	0.15254	0.15254	0.0762	72.73
Pulse off	2	0.02463	0.02463	0.0123	11.74
Peak Current	2	0.01428	0.01428	0.0071	6.81
Wire feed	2	0.01828	0.01828	0.0091	8.72
Error	0	--	--	--	--
Total	8	0.20975	--	--	100.00

From Table 6, it shows that the process parameters Pulse on and Pulse off have the most influence on the grades, which coincides with the results of Table 5. It is observed that the Pulse On (72.73%) is most significant factor followed by Pulse off (11.74%), Wire feed (8.72%) and Peak Current (6.81%). The percentage of error is 0% indicating the selection of the process parameters are highly reliable.

V. CONFIRMATION TEST

Table 7. Confirmation test results

Type	Initial	Optimal / Predicted	Optimal/Experimental
Level combination	$A_1B_1C_1D_1$	$A_2B_2C_2D_1$	$A_2B_2C_2D_1$
MRR (mm^3/sec)	17.56	29.33	29.1967
SR (□m)	2.70	2.94	2.93
Grey Relational Grade	0.342	0.939	0.935

From the table 7. It shows that $A_2B_2C_2D_1$ is an optimal parameter combination of the machining process obtained by grey relational analysis. The confirmation experiment is carried out to validate the optimal level of parameters for maximum Metal removal rate and minimum surface roughness. After confirmation test, it is clear that the MRR and SR increased greatly with the optimal parameters and the fuzzy grade is increased by 43.8%.

VI. CONCLUSION

- In this paper, Grey Relational analysis is applied for optimizing the process parameters of WEDM process,
- The optimal combination of parameters are: pulse on -- 36 µs, pulse off – 6 µs, Peak Current – 2 Amps and Wire feed – 1 m/min.
- From the ANOVA, it shows that Pulse on and Pulse off are the predominant factors for machining.
- Increase of grades from 0.342 to 0.935 confirms the improvement in performance characteristics at optimal level of process parameters.

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