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Experimental Investigation of MRR and Surface Roughness of Stainless Steel 410s in Wire EDM Using Grey Taguchi Method

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Abstract: ***Wire electrical discharge machining (WEDM) has become an important non-traditional machining process which is used to manufacture complex contours with great accuracy and excellent surface finish. Wire EDM is a very complex process involving the different process parameters. In the present investigation and optimization of wire EDM has been carried out by using grey taguchi optimization process. The process parameters involved is pulse on time, pulse off time, wire feed rate, table feed rate and servo voltage. Surface roughness (SR) and Material removal rate (MRR) are taken as response factor. Experimental investigation carried out in ECOCUT wire EDM machine. Stainless steel 410 is subjected to machining by a tool of brass wire of 0.25mm diameter and deionized water is used as dielectric fluid. For this experiment, mixed level orthogonal array has been used. The main objective of the study is to find out the best combination of process parameters for high material removal rate and low surface roughness, by the help of analysis of variance (ANOVA) which is useful to identify the most important factor or input parameter that most affects the performance of machining. Finally Optimal setting has been verified through confirmation test and results good agreement to the predicted value***

Keywords: Wire electro discharge machining (WEDM), Material removal rate, Surface roughness, ANOVA, Grey taguchi optimization

1. Introduction

Wire EDM machining process is best option when highly accurate machining is required; it has the capable of making cuts of within a tolerance of ±0.0001. This machining is an excellent option for manufacturing delicate and intricate parts. Square edged internal cuts are difficult to produce with other machining but wire EDM makes it possible.In WEDM, the removal of material is obtained due to sparks between the tool and work pieces. The work piece and tool should have good electric conductivity. Stainless steel alloy taken as work piece which is a hardenable with highest percentage of iron-chromium alloy used for its corrosion resistance and oxidation resistance and high strength at temperature upto 1530^0 c. There is a lot of work done by WEDM in past.BrajeshLodhi [1] had done the experiment to optimize the process parameter in WEDM such as pulse on, pulse off, peak current, wire feed using RSM approach. The material was AISI D3steel. The output performance parameters were material removal rate and surface roughness. S V Subrahmanyam et al. [2] conducted the experiment to obtain grey-taughchi method of wedm of h13 hot die steel .Input parameter such as pulse on time, pulse off time, peak current, servo voltage, wire tension, wire feed, flushing pressure of die electric fluid and Zinc coated copper wire electrode were used for experimental research and determined the material removal rate and surface roughness. The performance measure was also optimized by genetic algorithm. Vikas et al. [3] conducted an experiment for optimizing various input process parameter on surface roughness in EDM. The material used was EN 41 material. Pulse on time, pulse off time, peak current, servo voltage were the input process parameters. Grey taguchi method was used to conduct the experiment. Srivastava et al.[4] investigated wire EDM process parameters on aluminium metal matrix composite Al 2024/sic. Response surface methodology technique has been used to optimize the machining parameter for minimum surface roughness and maximum material removal rate. A.kumar et al. [5] conducted an experiment to optimization of process parameter of WEDM of inconel 718 material. ANSYS software was used to conduct the experiment. Material removal rate was determined from the experiment. Numerical model provided better performance than experimental. SSivakiran et al. [6] studied the effect of machining parameter such as pulse on time, pulse off time, table feed rate, current on material removal rate in WEDM. Liner regression was developed the relationship between control parameter output parameter. The material used was EN 31 tool steel. S. Tilekar et al. [7] studied that the effect of machining parameters such as pulse on, pulse off, input current, wire feed on process performance parameter such as surface roughness and kerf width on material aluminium and mild steel. It was concluded that wire feed rate and pulse on time have significantly effect on aluminium and mild steel respectively. R.Bobbili et al. [8] optimized the machining parameter of machining. Ballistic grade aluminum alloy in wire electro discharge machining pulse on, pulse off, peak current, servo voltage were the input parameter used in this process.Taguchi method (L18) and Grey-relational analysis was used to measure the output parameter such as material removal rate, surface roughness, gap current. AmiteshGoswamiet al. [9] conducted experiments to get the best combination of process parameter on Nimonic-80A. The effect of input process parameter such as pulse on time, pulse off time, peak current, wire feed wire tension, servo voltage on output parameter material removal rate and surface roughness was investigated. ANOVA was implemented to identify significant process parameter.M. Durairaja et al. [10] investigated the effect of wire EDM process parameter on surface roughness. The material used in the experiment was stainless steel 304. Taughi grey relation analysis was used to obtain the optimal process parameter of WEDM process. The pulse on time has the major influence on the surface roughness. Dongre et al. [11] did the multi-objective optimized for silicon wafer slicing. This work demonstrated the capability of WEDM in silicon wafer slicing. RSM based experimentation was used to research work. During the experiments, wafers of various heights range from 50mm to 150mm were fabricated and capability of the process was assessed in minimizing the kerf width.

2. Experimental Procedure

2.1 Materials and methods

The material used in the study was stainless steel. The chemical composition of the material is shown in Table 1. The work material in the form of sheet plate with dimension of 500x200x8 mm has been taken for the experimental work. The experiment was performed on Eco-cut model CNC WEDM machine at Central Tool Room & Training Centre (CTTC), Bhubaneswar, India. Experimental set up shown in fig 1. Based on the literature review, five process parameter such as pulse on time, pulse off time, table feed rate, wire fed rate and servo voltage were taken and see their effect on performance parameter such as MRR and surface roughness. The factor and levels are represented in the Table 2. There are five input factor with mixed level design where pulse on time, pulse off time, table feed rate was four level, Wire feed rate and servo voltage were two level factor. So taguchi L_{16} orthogonal array with five input factor was selected for the experiment. The deionized water was used as the dielectric fluid. The material removal rate was calculated by using equation (1) and surface roughness is calculated by using measurement device SJ-410.

$$\mathbf{MRR} = \frac{\mathbf{l \times h \times k}}{\mathbf{t_m}} \text{ .... } \mathbf{(1)}$$

Where l=Cutting length, h=cutting thickness, k=kerf cutting, t_m= Machining time.

Table 1: Chemical composition of stainless steel of grade 410

Chromium	Manganese	Sulphur	Phosphorus	Silicon	Nickel	Carbon	Ferric(iron)
14.5%	1.00%	0.03%	0.04%	1.00%	0.60%	0.08%	82.75%

2.2 Design of Experiment by Taguchi method

The experimental results employed by L_{16} orthogonal array based on the taguchi method by using Minitab software version18.

TABLE 2: **Input factor and their level**

Machining parameter	**LEVELS**			
	1	**2**	**3**	**4**
Pulseontime(μs)	3	5	6	9
Pulseofftime(μs)	2	4	6	8
Tablefeedrate (mm/min)	6	7	8	9
Wirefeedrate (m/min)	1	5	-	-
Servovoltage (volt)	4	6	-	-

Figure1: Experimental Set up

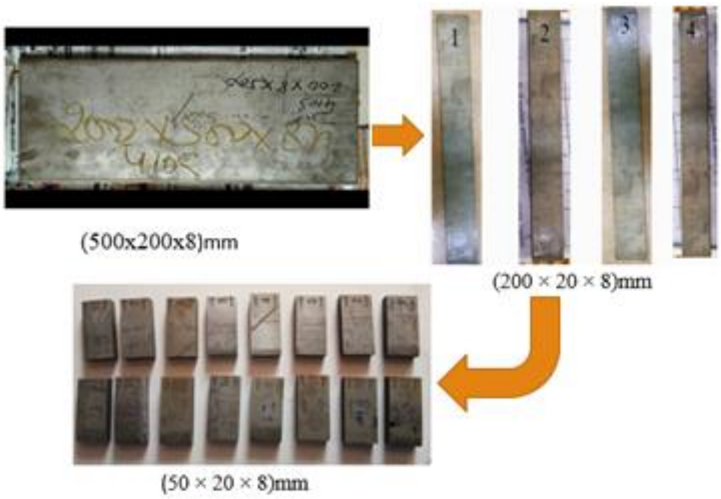

Figure 2: work piece after machining

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3. Optimization Techniques

3.1 Grey Based Taguchi Method

To improve the manufacturing process adopted the Taguchi method, which is solving only single objective optimize problem. But in Taguchi method, it could not solve the multi-object optimize problem. To overcome this Taguchi method coupled with grey relation analysis, which is used to solve multi response optimization problem.

Step1: Calculate S/N ratio value for response by using below formula.

- Larger is better:

$$\text{S/N ratio}(\eta) = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{1}{y_i^2}$$

This is termed as larger is better type problem where maximization of the characteristic is intended.

- Smaller is better:

$$\text{S/N ratio}(\eta) = -10\log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n} y_i^2$$

Step2: Grey-Relational Generation

In grey relational analysis experimental data are first normalized because of reduce the variability and avoiding different units. It's a method which is converting original data to a comparable data. The response of transformed sequence can be grouped in to two quality characteristics. For smaller is better characteristic

$$x_i^*(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

For larger is better characteristic, equation is used for normalization:

$$x_i^*(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Step3: Grey-Relational Coefficient and Grade

Once the responses value is normalized then next step is to calculate the deviation of sequence by using the equation

$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)|$

Then Grey-Relational Coefficient is determined by using equation

$$\varepsilon_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}}$$

As shown in equation Grey-Relational Grade is computing by averaging the GRC of each response value.

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

Once the optimum level of factor is determined using GRG, then the final step is to predict and verified quality characteristic using equation (8)

$$\gamma_{predicted} = \gamma_m + \sum_{i=1}^{q}\gamma_o - \gamma_m$$

Table 3: S/N ratio value of experimental results

RUN	Ton	Toff	TFR	WF	SV	MRR (mm^3/min)	Ra (μm)	S/N ratio, MRR	S/N ratio, Ra
1	3	2	6	1	4	7.544	1.661	17.552	-4.407
2	3	4	7	1	4	7.817	2.218	17.861	-6.919
3	3	6	8	5	6	5.311	2.505	14.504	-7.976
4	3	8	9	5	6	4.298	2	12.665	-6.021
5	5	2	7	5	6	6.777	1.464	16.621	-3.311
6	5	4	6	5	6	5.317	1.748.	14.513	-4.851
7	5	6	9	1	4	7.375	2.108	17.355	-6.477
8	5	8	8	1	4	7.427	2.011	17.416	-6.068
9	6	2	8	1	6	7.513	1.776	17.516	-4.989
10	6	4	9	1	6	7.519	1.631	17.523	-4.249
11	6	6	6	5	4	6.239	2.046	15.902	-6.218
12	6	8	7	5	4	6.814	1.704	16.668	-4.629
13	9	2	9	5	4	8.496	2.075	18.584	-6.34
14	9	4	8	5	4	7.41	1.987	17.396	-5.964
15	9	6	7	1	6	6.72	1.799	16.547	-5.101
16	9	8	6	1	6	6.630.	1.995	16.43	-5.999

Table 4: Grey relational coefficients and grey grade

Run Order	GRC MRR	GRC Ra	GRG	RANK
1	0.7414	0.3953	0.5683	8
2	0.8036	0.6882	0.7459	2
3	0.4204	1.0000	0.7102	3
4	0.3333	0.5440	0.4387	15
5	0.6012	0.3333	0.4672	14
6	0.4210	0.4274	0.4242	16
7	0.7066	0.6088	0.6577	4
8	0.7170	0.5501	0.6335	5
9	0.7348	0.4385	0.5866	7
10	0.7361	0.3849	0.5605	9
11	0.5246	0.5702	0.5474	11
12	0.6070	0.4107	0.5089	13
13	1.0000	0.5878	0.7939	1
14	0.7136	0.5369	0.6252	6
15	0.5923	0.4479	0.5201	12
16	0.5788	0.5412	0.5600	10

4. Results & Discussion

4.1 Effect of Control Factor on MRR

An ANOVA (shown in table 5) was performed to obtain the percentage contribution of each factor effect on MRR. It was observed that servo voltage ,with contribution of 28.44% ,has the highest influence on MRR followed by pulse off time with 23.06% , wire feed rate 22.73% , pulse on time 15.29% and then table feed rate , with 4.46% . From the response table (4.8), the main effect plot for S/N ratios was plotted in fig (2). In this experiment S/N ratio of MRR is calculated based on mixed level orthogonal array and here MRR is taken as large-is –better because when MRR value is large the function is better function and it affected the experiment and experiment time. From above table and graph its indicate that, in the first input factor when pulse on time increase then the value of S/N ratio is also increase from 15.65 to 17.24. In second factor the value of pulse off time is increased from 2µs to 8µs and it affected the S/N ratio from 17.57 to 15.79 and value is gradually decrease, then in third input factor table feed rate value is gradually increased from 6mm/min to 9mm/min then S/N ratio value is also influenced, as result is gradually increased then gradually decreased certain a point. But in wire feed rate and servo voltage here taken two level and value is increased from (1 to 5) mm/min and (4 to 6) v and influenced both S/N ratio result is decreased from 17.28 to15.80 and 17.34 to 15.79 respectively

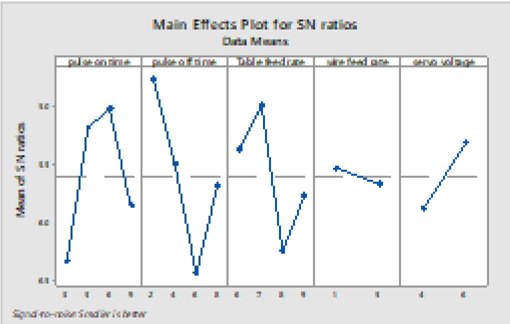

Figure 2: SN ratio graph for surface roughness

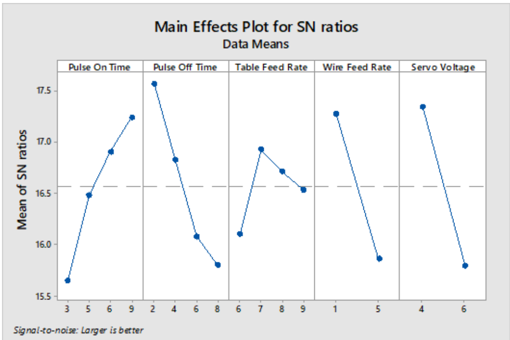

Figure3:S/Nratio graph material removal rate

4.2 Effect of Control Factor on Ra

An ANOVA (shown in table 5) was performed to obtain the percentage contribution of each factor effect on Ra. It was observed that pulse off time with contribution of 27.90%, has the highest influence on Ra followed by pulse on time with 22.42%, table feed rate 16.99%, servo voltage 5.64% and then wire feed rate, with 0.52%

From the response table (6), the main effect plot for S/N ratios was plotted in fig (3) in this experiment S/N ratio of Ra is calculated and here Ra is taken as smaller-is-better. From above table and graph its indicate that, in the first input factor pulse on time increase the value of S/N ratio is also increase from -6.331 up to certain point value -5.020 then gradually decrease from -5.020 to 5.851. When pulse off time increase then S/N ratio value decrease from -4.762 to -6.443 then it's gradually increased up to -5.679. In third input factor table feed rate value is gradually increased from 6mm/min to 9mm/min then S/N ratio value is also influenced, as result first gradually increased then after decreased up to certain a point then suddenly increased to -5.771. But in wire feed rate and servo voltage here taken two level and value is increased from (1to 5)mm/min and (4 to 6)v and influenced both S/N ratio, as result its decreased from -5.526 to -5.664 and increased from -5.878 to-5.311respectively.

4.3 Analysis of Variance

ANOVA is commonly used to investigate whether the experimental design parameter have a significant effect on the responses. Analysis of Variance (ANOVA) was performed on balanced data for wide variety of experimental design. ANOVA calculates the F-ratio, which is the ratio between the regression mean square and the mean square error. If the calculated value of F-ratio is higher than the tabulated value of F-ratio for MRR and Surface roughness, then the model is adequate at desired α (error term) level to represent the relationship between machining responses and machining parameters. These analyzes were done by using MINITAB software version-18.

Table 5:ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
Pulse On Time	3	0.10786	0.10786	0.03595	3.39	0.135	15.29%
Pulse Off Time	3	0.16264	0.16264	0.05421	5.11	0.075	23.06%
table Feed Rate	3	0.03148	0.03148	0.01049	0.99	0.483	4.46%
Wire Feed Rate	1	0.16036	0.16036	0.16036	15.11	0.018	22.73%
Servo Voltage	1	0.20058	0.20058	0.20058	18.90	0.012	28.44%
Error	4	0.04245	0.04245	0.01061			6.02%
Total	15	0.70536					100.00%

Table 6: ANOVA for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
pulse on time	3	0.008480	0.008480	0.002827	0.51	0.695	11.91%
pulse off time	3	0.005753	0.005753	0.001918	0.35	0.794	8.08%
table feed rate	3	0.013549	0.013549	0.004516	0.82	0.547	19.04%
wire feed rate	1	0.003412	0.003412	0.003412	0.62	0.476	4.79%
servo voltage	1	0.017915	0.017915	0.017915	3.25	0.146	25.17%
Error	4	0.022066	0.022066	0.005516			31.00%
Total	15	0.071175					100.00%

Table 7: Confirmation tests

Initial Design Parameters	Optimal Design Parameters	
	Prediction	Experiment
Setting level - A4B1C4D2E1	A4B3C3D1E1	A2B4C3D1E1
Grey relational grade - 0.7939	0.7750	0.6335
Improvement in GRG	18%	22%

5. Conclusions

- The analysis of variance resulted that when pulse on time increase MRR also increase but in case of table feed rate MRR increased up to a point then it was decreased. But MRR decrease when pulse off time, servo voltage, wire feed rate were increased
- In the case of SR when pulse on time increase then SR increase then its decrease, SR gradually decrease when wire feed rate increased and SR increased when servo voltage increased. In pulse on time increase then SR decrease and then it's increased. When wire feed rate increased then SR increase initially then decreased and again its increased
- While applying the grey–Taguchi method, confirmation tests were performed to verify the improvement of 0.1604 in GRG, from 0.7939 for the initial design parameters (A4B1C4D2E1), to 0.6335 for the optimal parameters (A2B4C3D1E1).
- Finally the optimal process parameter based on grey relational analysis for the wire EDM of stainless steel 410S include 5µs pulse on time, 8µs pulse off time, 8mm/min table feed rate, 1m/min wire feed rate and 4v servo voltage.

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