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Optimizing Process Parameters of Spark and Wire-Cut Edm through Anova using Stainless Steel Aisi 316 Material

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***Abstract:** In the present research work, Stainless Steel AISI 316 as per ASTM A 276 has been employed as the base material to perform Spark and Wire-Cut EDM. The main agenda behind performing Spark and Wire-Cut EDM on Stainless Steel AISI 316 is to find out the effect of machining parameters like surface roughness (SR) and MRR (Material Removal Rate). In-case of wire-cut EDM, brass wire) of 0.25 mm diameter is used as a tool and distilled water is used as dielectric fluid and experimental process parameters like Current (A) (2, 3 and 4 Amps), Pulse ON time (B) (25, 30 and 35 µs) and Wire feed rate (C) (40, 60 and 80 mm/sec). Similarly for spark cut EDM copper rod of 12 mm diameter and 65 mm length. Process parameters like Current (A) (6, 12 and 16 Amps), Voltage (B) (30, 35 and 40 Volts) and Pulse ON time (C) (50, 100 and 200µs) were maintained during the experimentation. Statistical tools ANOVA & L-9 Orthogonal Array (OA) have been employed to optimize the machining parameters like Surface Roughness (SR) and MRR (Material Removal Rate).*

***Keywords:** SR, MRR, Spark EDM, Wire-cut EDM, L-9 orthogonal array.*

I. INTRODUCTION

Wire-EDM works on electrical discharge produced during the machining process, also known as electro- erosion process. Due to the large gap voltage, high spark is produced thereby temperature raises to 10,000^{0}C thereby leading to removal of metal from the work piece. Stainless Steel AISI 316 as per ASTM A276 is used as a base material. Tool used for WEDM is brass which is a copper and Zinc based alloy, which founds its wide applications in the construction of exhaust manifolds, furnace parts, photographic equipment and evaporators due to high corrosion resistance and melting point up to 1400^0 C.

Fig.1. Spark EDM machine

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Fig.2. Wire-cut EDM machine

II. CHEMICAL COMPOSITION OF STAINLESS STEEL (SS) AISI 316 AND TOOLS USED FOR SPARK EDM (BRASS) AND WIRE-CUT EDM (COPPER)

Brass wire of 0.25 mm diameter as per (IS:65/35) 65% Copper and 35% Zinc has been employed in WEDM due to high tensile strength and good thermal conductivity compared to copper wires. In this process, brass wire is selected as a tool due to its availability, properties and low cost. The gap between the wire and base material usually varies between 0.02-0.75 mm and is maintained constant throughout the entire process. In case of spark EDM 99% pure copper rod as per (EN 12164) comprising of 12 mm diameter and 65 mm length has been employed. Choosing optimal machining process parameters in WEDM is a crucial step. Taguchi based optimization technique is single parameter optimization based on the (S-N) signal to noise ratio. Besides, statistical tool Analysis of Variance (ANOVA) was used to test the process significance. The chemical composition of SS AISI 316 is presented in Table - I.

Table- I: Chemical composition of SS AISI 316(wt %) [9]

C	Si	Mn	P	S	Cr	Ni	Mo	N	Fe
0.08	1.0	2.0	0.04	0.03	18	14	3	0.1	61.7

III. EXPERIMENTAL SETUP

In this experimentation Taguchi design L 9(OA) technique has been employed for both Spark EDM and Wire EDM to find out the optimum parameters. Spark EDM tool employed for performing the operation is shown in fig. 3. Spark and wire EDM work piece are shown in fig. 4, fig. 5 respectively.

Profilometer for measuring surface roughness is shown in fig. 6,work piece SS AISI 316 produced in Wire-EDM before machining on wire EDM is shown in fig. 7(a) and Work piece after machining is shown if fig. 7(b). Similarly work piece SS AISI 316 produced in Spark-EDM before machining on wire EDM is shown in fig. 8(a) and work piece after machining is shown in fig. 8(b) respectively. M achining parameters and their factor levels for wire EDM and s park EDM process are shown in Tables II and III respectively. MRR is calculated as the ratio of the work piece's weight change before and after machining to the machining time and density of work piece.

$$\text{MRR} = \frac{Wbm - Wam}{t \times \rho}$$

Whereas:

Wbm- Weight of work piece before machining

Wam- Weight of work piece after machining

t- Machining time- 20min

ρ- Density of stainless steel work piece (i.e.8000kg/m^3)

Table- II: Experimental setup of process parameters for Wire EDM process

Machining Parameters	Units	Levels		
		Level 1	Level 2	Level 3
Current (A)	Amps	2	3	4
Pulse ON time (B)	µs	25	30	35
Wire feed rate (C)	mm/sec	40	60	80

Table-III: Experimental setup of process parameter for Spark EDM process

Machining Parameters	Units	Levels		
		Level 1	Level 2	Level 3
Current (A)	Amps	6	12	16
Voltage (B)	Volts	30	35	40
Pulse ON time (C)	µs	50	100	200

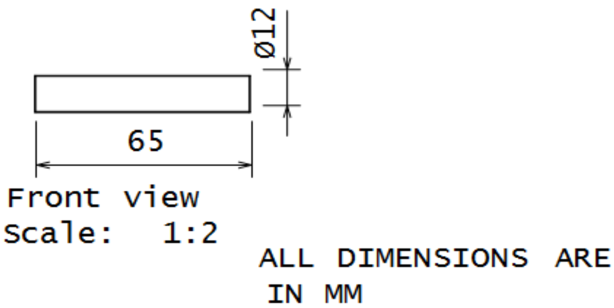

Fig. 3 Spark EDM tool

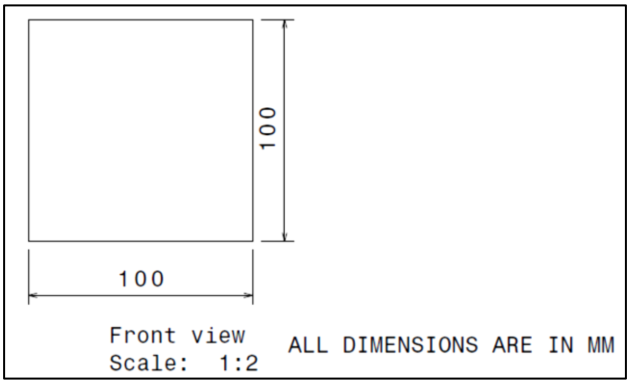

Fig. 4 Spark EDM work piece

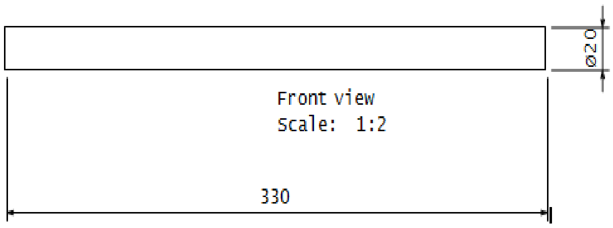

Fig. 5 Wire-EDM work piece

Fig. 6 Profilometer for measuring surface roughness

A. Design of Experiments (DOE):

For spark EDM and wire-cut EDM process total nine experimental trials had been conducted for each machining process with three factors at three levels. Work pieces before and after machining for both the process is shown in the Fig.3 and Fig.4. For spark EDM process the MRR is obtained from the measured weight before and after machining of each operation and in wire EDM process the MRR is obtained directly from the machine. In spark EDM operation machining time for each operation is 20minutes. Design of experiment and output data for wire EDM and spark EDM are presented in Tables IV and V respectively.

Table- IV: L-9 orthogonal array for wire EDM Process

S No	Current (amps)	T_{on} (μs)	Wire Feed Rate (mm/sec)	SR (μm)	MRR (m^3/min)
1	2	25	40	6.56	1.08
2	2	30	60	4.44	1.52
3	2	35	80	4.14	2.54
4	3	25	60	7.00	1.79
5	**3**	**30**	**80**	**3.55**	**2.03**
6	3	35	40	4.03	0.84
7	**4**	**25**	**80**	**7.25**	**3.81**
8	4	30	40	4.99	0.95
9	4	35	60	8.16	2.03

Fig. 7 (a) SS AISI 316 work piece before machining on wire EDM

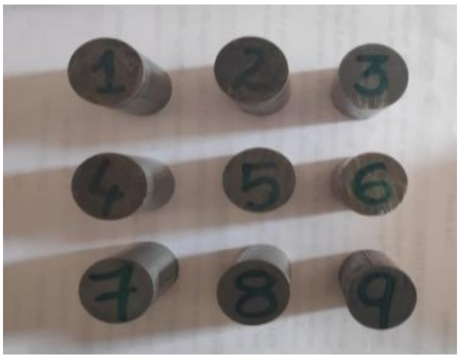

Fig. 7 (b) SS AISI 316 work piece after machining on wire-EDM

Table-V: L-9 orthogonal array for spark EDM process

S No	Current (amps)	Voltage (volts)	T_{on} (μs)	SR (μm)	MRR (mm^3/min)
1	**6**	**30**	**50**	**6.56**	**0.000625**
2	6	35	100	7.07	0.001875
3	6	40	200	7.82	0.0012
4	12	30	100	8.32	0.0025
5	**12**	**35**	**200**	**9.27**	**0.0037**
6	12	40	50	8.15	0.00225
7	16	30	200	8.45	0.00312
8	16	35	50	8.01	0.00187
9	16	40	100	8.09	0.00125

Fig. 8 (a)SS AISI 316 work piece of spark EDM before machining

b) Work piece after machining

Fig. 8 (b) SS AISI 316 work piece of spark EDM after machining operation.

IV. RESULTS AND DISCUSSION

A. Input parameters of wire EDM effecting Surface Roughness (SR):

Taguchi method is used to analyze the results of machining parameters and identify the optimum parameter for "smaller the better" (as the required response is surface roughness) criteria. Response table and Analysis of Variance (ANOVA) are carried out using MINITAB software for wire EDM and the results are shown in Tables -VI and VII respectively. From both the Table-VI and VII, it clearly indicates that the **pulse ON time at level 2(i.e. 30μs)** is the optimum parameter in order to obtain better surface finish and having 45.74% of contribution and after that current and wires feed rate are the significant factors effecting surface roughness respectively. Fig.9 represents the main effect of Means versus SR.

Table-VI: Response table of Wire EDM on SR

Level	A	B	C
1	5.077	6.967	5.223
2	4.860	4.327	6.533
3	6.800	5.443	4.980
Delta	1.940	2.640	1.553
Rank	2	1	3

Table-VII: ANALYSIS OF VARIANCE on SR for Wire EDM

Source	df	Seq SS	Contr -ibution	Adj SS	Adj MS	F-Value	P-Value
Current	2	9.9183	32.21%	9.9183	4.9592	42.99	0.023
T_{on}	2	14.0841	45.74%	14.0841	7.0420	61.05	0.016
Wire feed Rate	2	6.5617	21.31%	6.5617	3.2809	28.44	0.034
Error	2	0.2307	0.75%	0.2307	0.1154		
Total	8	0.7949	100.00%				

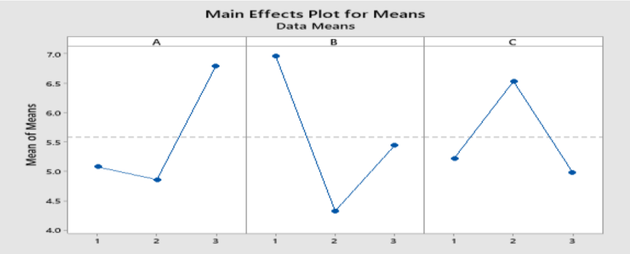

Fig. 9 Process parameters influencing mean data of SR

B. Input parameters of wire EDM effecting MRR:

Taguchi method is used to analyze the machining parameters for "larger the better" (because response here is MRR) criteria. Response table and ANOVA are obtained using MINITAB as shown in Tables -VIII and IX respectively to find out the optimum parameter and the percentage contribution among the other factors. From Tables -VIII and IX it is observed that **wire feed rate** is the optimum parameter **at level 3(i.e. 40mm/sec)** having more effect on obtaining high MRR and the percentage contribution for the wire feed rate at level 2 is 87.48%. Other parameters like current and pulse ON time has very less impact on material removal on the work piece. Fig. 10 represents the main effects plot for means versus MRR.

Table-VIII: Response table of wire EDM on MRR

Level	A	B	C
1	1.7133	2.2267	0.9567
2	1.5533	1.5000	1.7800
3	2.2633	1.8033	2.7933
Delta	0.7100	0.7267	1.8367
Rank	3	2	1

Table-IX: ANOVA table on MRR for Wire EDM

Source	df	Seq SS	Contr-ibution	Adj SS	Adj MS	F-Value	P-Value
Current	2	0.0506	5.93%	0.05056	0.025	188.9	0.0327
T_{on}	2	0.0560	6.57%	0.05604	0.028	209.4	0.0295
Wire feed rate	2	0.0746	87.48%	0.07464	0.732	789.9	0.0053
Error	2	0.0027	0.03%	0.00027	0.001		
Total	8	0.0853	100.00%				

Fig. 10 Process parameters influencing mean data of MRR

C. Input parameters of spark EDM effecting surface roughness:

Taguchi method is used to analyze the machining parameters for "smaller the better" (because response here is SR) criteria. Response table and ANOVA are obtained using MINITAB as shown in Tables -X and XI respectively. From Tables-X and XI, it is observed that **current at level 1(i.e. 6amps)** is the most optimum factor in order to obtain less surface roughness and having 66.57% of contribution. After that pulse ON time is the second machining factor having higher effect on SR with 28.89% of contribution, whereas voltage is not an optimumpa rameter during machining to obtain good surface finish.Fig. 11 represent the main effect plot for means versus SR.

Table-X: Response table of spark EDM on SR

Level	A	B	C
1	7.150	7.777	7.573
2	8.580	8.117	7.827
3	8.183	8.020	8.513
Delta	1.430	0.340	0.940
Rank	1	3	2

Table-XI: ANOVA table for SR

Source	df	Seq SS	Contri bution	Adj SS	Adj MS	F-Value	P-Value
Current	2	3.27002	66.57%	3.2700	1.63501	85.11	0.012
Voltage	2	0.18416	3.75%	0.1841	0.0920	4.79	0.173
T_{on}	2	1.41929	28.89%	1.4192	0.7096	36.94	0.026
Error	2	0.03842	0.78%	0.0384	0.0192		
Total	8	4.91189	100.00%				

Fig.11 Process parameters influencing mean data of SR

D. Input parameters of spark EDM effecting MRR:

Taguchi method is used to analyze the machining parameters of spark EDM process for "larger the better" (because response here is MRR) criteria. Similarly response and ANOVA tables are obtained from MINIITAB s oftware as shown in table XII and table XIII respectively, fro m these table XII and table XIII it represents that input

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current at level 1(i.e. 6amps) is the most effective and significant parameter which influence the MRR during machining operation. From ANOVA table it is observed that current is having percentage of contribution of 49.78, whereas T_{on} is having 25.31% which is second parameter effecting MRR and voltage is having very less percentage contribution and thus it is having very less influence on MRR for spark EDM. Fig.12 represents the main effects plot means versus MRR.

Table-XII: Response table of spark EDM on MRR

Level	A	B	C
1	0.001250	0.002082	0.001582
2	0.002817	0.002482	0.001875
3	0.002080	0.001583	0.002690
Delta	0.001567	0.000898	0.001108
Rank	1	3	2

Table-XIII: ANOVA table for MRR

Source	df	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	2	0.0004	49.78%	0.00004	0.00002	6.06	0.0142
Voltage	2	0.0001	16.69%	0.00001	0.00001	2.03	0.330
T_{on}	2	0.0002	25.31%	0.00002	0.00001	3.08	0.0245
Error	2	0.0001	8.22%	0.00001	0.0000		
Total	8	0.0008	100.00%				

Fig.12 Spark EDM process parameters influencing MRR

V. CONCLUSION

Upon successful experimentation and statistical analysis performed using ANOVA the below are the observation made:

- Minimum surface roughness (R_z) obtained on Wire-EDM is at 3A, 30µs and 80 mm/sec is 3.35µm.
- Minimum surface roughness (R_z) obtained on Spark-EDM is at 6A, 30V, 50µs is 6.56µm.
- Maximum MRR obtained on Wire-EDM is at 4A, 25µs and 80 mm/sec is 3.81mm^3/min.
- Maximum MRR obtained on Spark-EDM is at 12A, 200µs and 35V is at 0.0037mm^3/min.
- From the above observation it is concluded that Wire EDM shows minimum surface roughness and maximum material removal rate when compared to spark EDM while performing cutting operation.

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AUTHOR'S PROFILE

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