International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 21 (2018) pp. 15270-15277
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Study on Machining Response in Wire EDM OF Inconel 625

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Abstract

Inconel is mainely a super alloy which is mixture of nickel and chromium .Inconel is a conductive material. Super alloys are suitable for WEDM. Wire EDM is a non-convectional machining process .WEDM is mainly used for machining very hard and tough material like super alloys. Inconel 625 is a corrosion oxidation resistant nickel alloy that is used both for its high strength and outstanding aqueous corrosion resistance. The inconel625 alloys are often employed in aerospace industry components due to their outstanding mechanical properties. The properties of inconel, alloy 625 that make it an excellent choice for sea-water applications are freedom from local attack, high corrosion-fatigue strength, and resistance to chloride-ion stress-corrosion cracking. WEDM is used making industries, automobiles, aerospace, nuclear, computer and electronics industries.

In these experiment, the brass wire is used for cutting the material .the brass wire diameter is 0.25micron.For seeing the brass wire like human hair .experiment is done on inconel 625 alloy for checking the dimension deviation, surface roughness and material removal rate .This paper deals with finding optimal control parameters viz.. Input parameter are pulse on time, pulse off time, input current, sensitivity, wire feed, wire tension, and water pressure but here considering parameter are pulse on time, pulse off time, input current and water pressure.in the rectangular sheet of inconel 625 material removal in square shape .In the present research . Tauguchi's L-18 orthogonal array 's has been used to design for experimental run. Taguchi L-18 orthogonal array along with ANOVA is used for optimize the different parameters like sensitivity, Ton, Toff and water pressure. These parameters are used to minimize dimension deviation, surface roughness and maximum material removal rate is obtained.

Keywords: Wire EDM, Taguchi DOE, ANOVA,S/N ratio, Grey Relational Analysis.

INTRODUCTION

Wire Electrical Discharge Machining is a non-traditional machining process which is based on thermos electrical energy between the work piece and an electrode with deionized water as the dielectric medium and erodes the work piece to produce complex two and three dimensional shapes according to a numerically controlled (NC) path. The wire cut EDM is a discharge machine that uses CNC movement to produce the desired contour or shape ,It does not require a special shaped electrode as in the case of EDM, Where as it uses a continuous traveling vertical wire under tension as electrode. The electrode in wire EDM has a very small diameter whose path is controlled by the machine computer to produce the required shape to produce required shape. During this process the wire travels vertically downwards and table movement is horizontal which is controlled by the CNC controller work piece is held on table with the help of fixtures which does not cause any obstruction in the wire path. In here work piece as anode and wire acts as cathode: and material is removed from the anode by spark erosion mechanism. In WEDM the brass wire was used as cutting tool material. The wire diameter was 0.25mm.

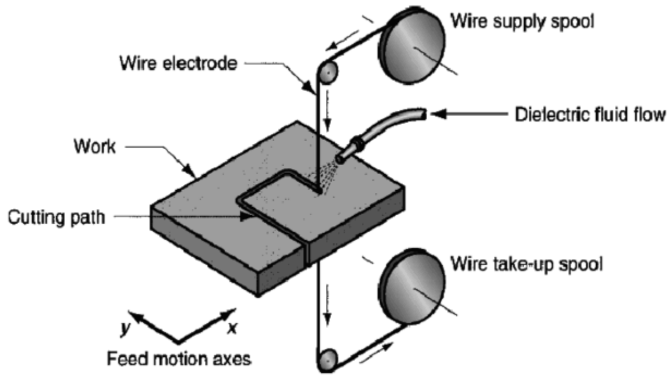


Figure 1. Wire EDM process

In this study ,the machining variable investigated were sensivity , pulse on time ,pulse off time, and water pressure .Analysis of variance (ANOVA)technique was used to find out the dimension deviation, surface roughness and material removal rate. The application of Inconel 625 is one such alloy which is widely used in aerospace industry ,jet engine components such as turbine blades ,aircrafts ducting system ,engine exhaust systems, because of its unique combination of mechanical, physical and chemical properties. In here machining of 18 holes which is in square shape.

Material selection : INCONEL 625 sheet of 200×135×6mm was selected as work piece material. materials have been selected based on their properties.

Table 1: chemical composition of Inconel 625

Elements	Nickel	Chromium	Molybdenum	Iron	Niobium
% value	58%	20-23%	8-10%	5%	3.15-4.15%

LITTERATURE REVIEW:

M.S.Hewidy et al. in 2005 did modelling for machining parameters of wire electrical discharge machining of Inconel 601 using response surface methodology [RSM] .They used peak current, duty factor , wire tension and water pressure as input parameters and metal removal rate, wear ratio and surface roughness as output parameters . They found that an increase of the volumetric metal removal rate . They increase is, however ,diminished after 7 A [4].

Hari Sing and Rohit Garg in 2009 have investigated the effect of number of WEDM process parameters on material removal rate by applying one -factor- at –a- time approach and reported that pulse on time ,peak current and servo voltage have considerable influence [3].

Thomas R. Newton et al. in 2009 tried to final the parameters which affect the formation of re-cast layer in Inconel 718. They found that average thickness re-cast layer increased when energy per spark, current pulse duration and peak discharge current were increased. They found they average thickness of re-cast layer varying from 5 to 9 Wire diameter and spark cycle time do not play major role in the formation of recast layer[5].

Muthu Kumar V et al in 2010 used. Grey Relational Analysis. Taguchi Method and ANOVA to find out the optimal cutting Incoloy 800 super alloy in wire EDM process. They selected Gap Voltage, pulse On-time, Pulse Off-time and Wire Feed as input variables and MRR, surface roughness and Kerf as output variables. They found that optimum conditions for cutting is 50 v Gap voltage, 10 µs pulse on-time , 6 µs pulse off-time and 8mm/minute Wire Feed rate When applying the Grey-Taguchi method ,they found that MRR increased from 0.05351 g/min to 0.05765 g/min, surface roughness reduced from 3.31 µm to 3.10 µm and the kerf width reduced from 0.324 to 0.256mm respectively [6].

Vinod Kumar et al. in 2012 tried to optimize the process parameters of wire EDM for cutting Nimonic-90. They found that cutting speed increased slowly with increasing peak current.

But at high pulse duration [Ton=120µs] there was sharp increase of cutting speed with increase of peak current from 40A to 80 A . With increasing pulse on time, the cutting speed increased continuously but machining became unstable at higher pulse on time. Maximum cutting speed is obtained at pulse on time 118 µs and pulse off time 40 µs [7].

C.D. Shah et al. in 2013 used RSM to optimize the process parameters in Inconel 600.Taguchi Mixed L 18 orthogonal array is used to find the best MRR. From the experiment they found that pulse on time and pulse off time are more significant factors [8].

G. Rajyalakshmi et al .in 2013 used Taguchi-grey analysis to find the optimum cutting condition for Inconel 825 in wire EDM. They combined the orthogonal array design of experiment with grey relational analysis. Taguchi L36 orthogonal array is used. From the grey relational analysis optimum condition includes Pon105µs,Poff 50µs,servo voltage 70 V, flushing pressure 15Kg/cm^2,wire feed rate 2m/min. wire tension 9 Kg-f, by applying the taguchi-grey relation analysis they found that MRR increases from 119.625 to 126.85mm/min^3,surface roughness decrease from 1.68 to 1.44 µm[9].

Priyaranjan sharma et al.in 2015 found the MRR ,SR ,recast layer, topography, micro hardness of Inconel 706 for turbine disk application. The proposed experimental plan was based on OFAT approach. the micro hardness and RLT have been examined using the low and high settings of servo voltage and pulse on time .EDAX analysis has been carried out to study metallurgical changes in the machined surface. They found that pulse on time, pulse off time and servo voltage are most important factors, whereas servo feed is not important. They also found that wire feed of 6m/min and flushing pressure of 1.96 bar give higher MRR and SR[12].

EXPERIMENTAL DETAILS

TAUGHI METHOD

Taguchi methods are statically methods, or sometimes called robust design, developed by GENICHI taguchi.to improve the quality of manufactured goods. taguchi method is used to reduce variation and trails. these method is used to improve high quality at low total cost. taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process is functioning. To evaluate the effects of machining parameters on performance characteristic .In here the input parameters are sensitivity, pulse on time, pulse off time and water pressure and output performance are dimension deviation, surface roughness and material removal rate .In this study the taguchi method ,a powerful tool for optimizing the process parameters is applied .taguchi method systematically reveals the complex cause effect relationship between parameters and performance.

SELECTION of ORTHOGONAL ARRAY:

In MINITAB software ,DESIGN OF EXPERIMENT is done by using taguchi to create taguchi analysis .the process are selection of orthogonal array, assignment of parameters and interactions to orthogonal array ,data analysis ,determination of confidence intervals and confirmation experiment.

In here taguchi's L18,a mixed type of orthogonal array is used to conduct the experiments. In L18 orthogonal array sensitivity parameter having two levels and other parameters having three levels

Table 2. Process parameters and their levels

Symbol	Parameters	Unit	Level 1	Level 2	Level 3
A	Sensitivity	V	5	10	
B	Pulse on time	µs	105	110	115
C	Pulse off time	µs	45	50	55
D	water pressure	N/m^2	85	90	95

Taguchi's suggests two different routes to carry out complete analysis. First is the standard approach. Where the results of a single run is to use the S/N ratio .The second approach ,which taguchi's strongly endorse for multiple runs, is to use the Grey relation analysis .After completing these two approach ANOVA is carried out to study the relative effect of machining parameters on the performance parameters.

Single Response Optimization

The "smaller-the –better" quality characteristics has been used for calculating the signal to noise (S/N) ratio for dimension deviation and surface roughness . The higher-the-better is consider for material removal rate. The formula for" Smaller-the-better " in S/N ratio

$$\text{S/N ratio}_{rs,dd} = -10 log \frac{1}{n}(\sum_{i=1}^{n} y_i^2)$$

The formula for "Higher-the-better" in S/N ratio ,it can be calculated by

$$\text{S/N ratio}_{mrr} = -10 log \frac{1}{n}(\sum_{i=1}^{n} \frac{1}{y_i^2})$$

Grey Relational analysis : In order to minimize these machining problem, scientific method based on taguchi design of experiments issued .however ,taguchi method has been designed to optimize single performance characteristics and is not appropriate for multiple-performance optimization . the GRG was used to solve the complicated interrelationships among the multiple performance characteristics effectively.as a result, optimization of the complicated multiple performance characteristics can be converted into optimization of single grey relational grade.

Steps in Grey relational analysis are

1. 1.Normalizing the experimental results of each performance characteristics.
2. Calculating the grey relational coefficient.
3. Calculating the grey relational grade by the mean value of grey relational coefficient.
4. Performing the response table and response graph for each level of the parameters.
5. Selecting the optimal levels of machining parameters.
6. Confirmation test and verifies the optimal levels of machining parameters

RESULT AND DISCUSSION

Table 3 shows the observed data of the surface roughness ,dimension deviation and material removal rate.

S.no	Process Parameters				Surface roughness			SR(µm)	S/N(SR)	DD	S/N (db)	MRR	S/N (db)
	Sensivity	Ton	Toff	WP	1	2	3						
1	1	1	1	1	1	0.29	0.23	0.506	5.917	0.6	4.437	1.2013	1.593
2	1	1	2	2	0.72	0.37	0.34	0.476	6.448	0.8	1.938	1.083	0.693
3	1	1	3	3	0.55	0.84	0.29	0.56	5.036	0.86	1.31	1.075	0.628
4	1	2	1	1	0.81	0.33	0.38	0.506	5.917	0.93	0.63	1.1079	0.89
5	1	2	2	2	0.95	0.58	0.42	0.65	3.742	1.33	-2.477	1.231	1.805
6	1	2	3	3	0.76	1	0.29	0.683	3.312	1.4	-2.923	1.2931	2.233
7	1	3	1	2	0.83	0.84	0.43	0.7	3.098	1.53	-3.694	1.176	1.408
8	1	3	2	3	0.81	0.6	0.23	0.546	5.256	0.13	17.721	1.1396	1.135
9	1	3	3	1	0.34	0.42	0.34	0.366	8.73	0.4	7.959	1.456	3.263
10	2	1	1	3	0.34	0.25	0.41	0.33	9.63	0.86	1.31	1.151	1.222
11	2	1	2	1	0.38	0.48	0.28	0.38	8.404	0.53	5.514	1.1837	1.465
12	2	1	3	2	0.21	0.81	0.3	0.44	7.131	0.933	0.602	1.097	0.804
13	2	2	1	2	0.69	0.32	0.36	0.456	6.821	0.6	4.437	1.27	2.076
14	2	2	2	3	0.82	0.45	0.59	0.62	4.152	0.8	1.938	1.366	2.709
15	2	2	3	1	0.41	0.37	0.42	0.4	7.959	1.33	-2.477	1.56	3.862
16	2	3	1	3	0.75	0.38	0.39	0.506	5.917	0.66	3.609	1.293	2.232
17	2	3	2	1	0.92	0.89	0.8	0.87	1.21	0.46	6.745	1.031	0.265
18	2	3	3	2	0.76	0.98	0.35	0.696	3.148	0.6	4.437	1.431	3.113

Where

DD=Dimension Deviation, SR=Surface Roughness, MRR=Material Removal Rate,

WP=water pressure, Ton-pulse on time, Toff=pulse off time.

The S/N ratio plot are drawn below the figure2 ,figure3 and figure4

Table 4. Response Table for Signal to Noise Ratios for surface roughness Smaller is better

Level	A	B	C	D
1	5.273	7.094	6.217	6.356
2	6.041	5.317	4.869	5.065
3		4.560	5.886	5.550
Delta	0.768	2.535	1.348	1.292
Rank	4	1	2	3

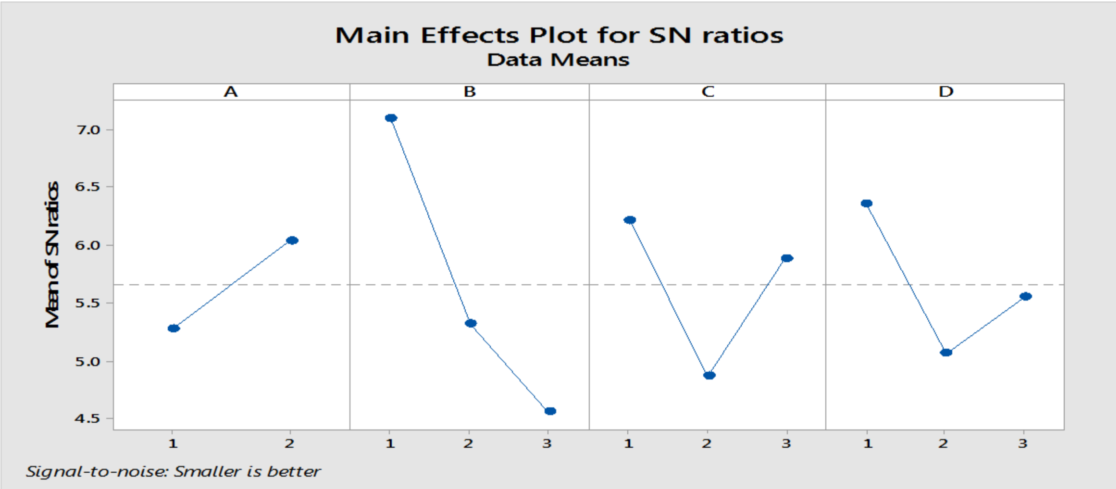


Figure 2. Main Effect plot for Surface Roughness

Table 5: Response Table for Signal to Noise Ratios for dimension deviation Smaller is better

Level	A	B	C	D
1	2.7669	2.5187	1.7883	3.8014
2	2.9018	0.1452	5.2300	0.8739
3		6.1295	1.4848	3.8277
Delta	0.1349	6.2747	3.7452	2.9537
Rank	4	1	2	3

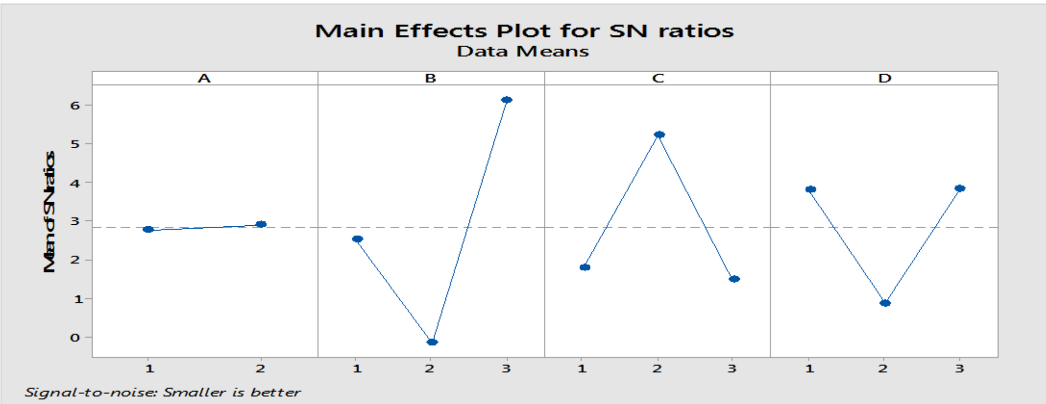


Figure 3. Main Effect Plot for Dimension Deviation

Table 6: Response Table for Signal to Noise Ratios

Larger is better

Level	A	B	C	D
1	1.516	1.067	1.570	1.890
2	1.972	2.263	1.345	1.650
3		1.903	2.317	1.693
Delta	0.456	1.195	0.972	0.240
Rank	3	1	2	4

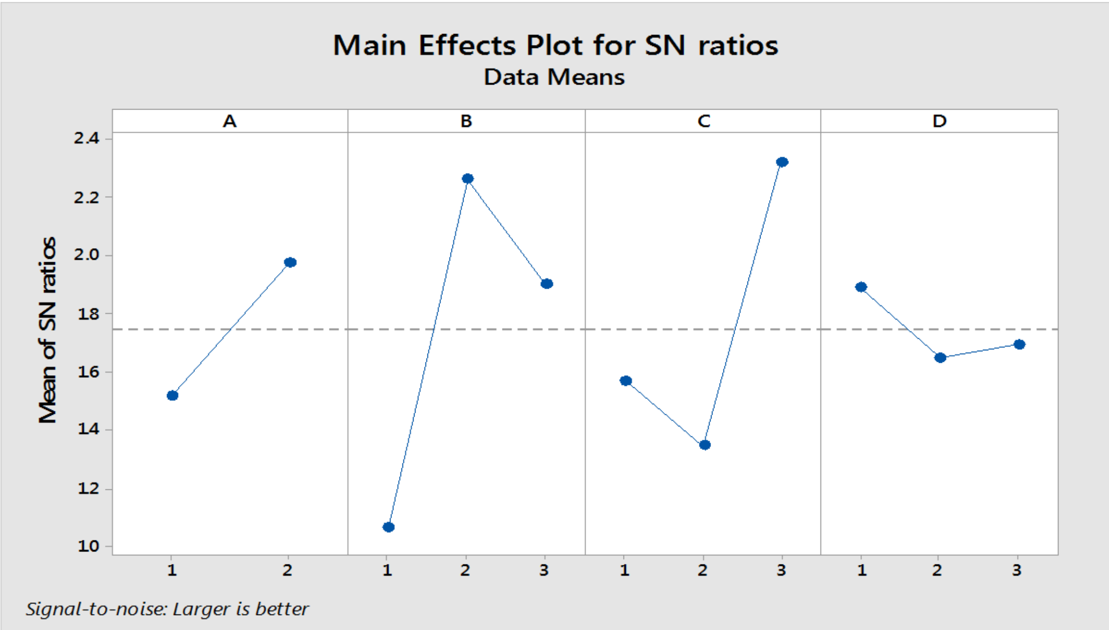


Figure 4. Main Effect Plot for Material Removal Rate

In here the plots of dimension deviation,surface roughness and material removal rate ,the input parameters of sensivity and water pressure are increased.the input parameters of pulse on time and pulse off time were fluctuated.

ANOVA

ANOVA of Surface Roughness S/N ratio

source	DF	Seq SS	Contribution	Adj SS	Adj Ms	F-value	P-value
sensitivity	1	11.3568	13.05%	11.3568	11.3568	0.5	0.495
Ton	2	37.7170	43.34%	37.7170	18.8585	1.92	0.198
Toff	2	14.6290	16.81%	14.6290	7.3145	0.56	0.589
W.p	2	13.8110	15.87%	13.8110	6.9055	0.48	0.631
Error	10	9.51194	10.93%				
Total	17	87.026	100.00%				

AVONA for S/N ratio dimension deviation

Source	DF	Seq SS	Contribution	Adj SS	Adj Ms	F-value	P-value
sensitivity	1	1.05435	8.43%	1.05435	0.05383	0.09	0.765
Ton	2	6.53376	52.24%	6.53376	2.51647	4.4	0.043
Toff	2	2.52020	20.15%	2.52020	0.6345	1.11	0.367
W.p	2	1.68346	13.46%	1.68346	0.21629	0.38	0.694
Error	10	0.7154	5.72%				
Total	17	12.5072	100.00%				

ANOVA of S/N Material Removal Rate

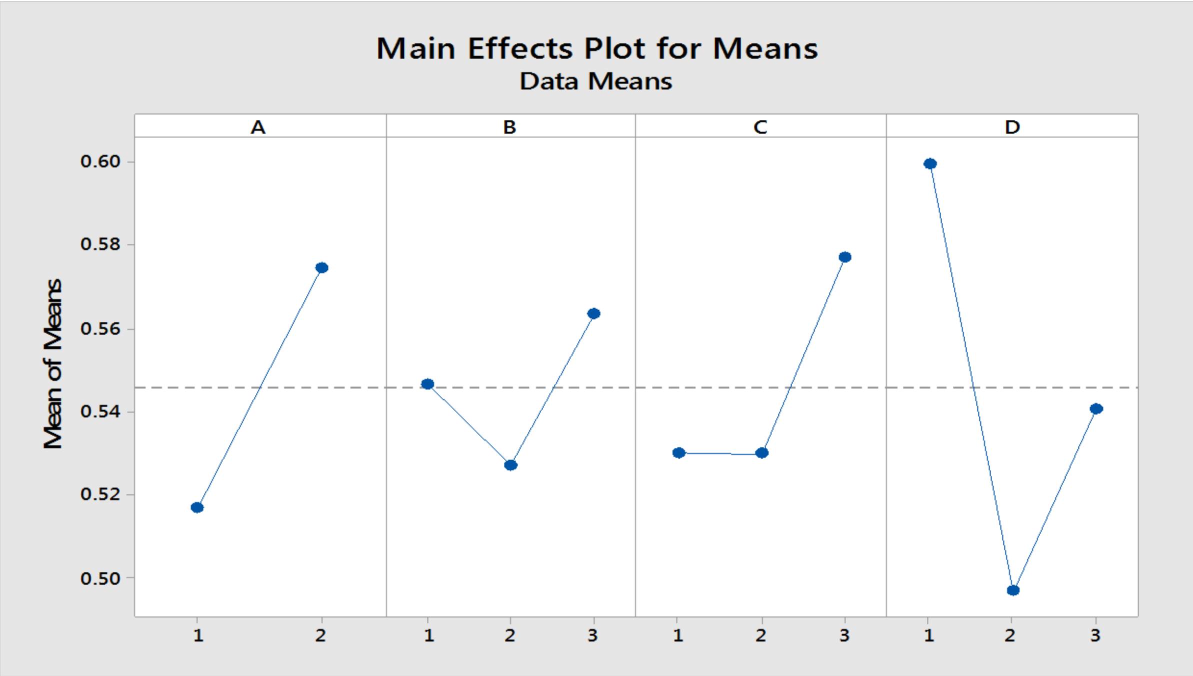
source	DF	Seq SS	Contribution	Adj SS	Adj Ms	F-value	P-value
sensitivity	1	2.3095	13.43%	0.9339	0.93389	1.11	0.318
Ton	2	7.0904	41.23%	4.51	2.25501	2.67	0.118
Toff	2	5.1694	30.06%	3.106	1.55302	1.84	0.209
W.p	2	1.0559	6.14%	0.196	0.09801	0.12	0.892
Error	10	1.5718	9.14%				
Total	17	17.1972	100.00%				

Table 7. Grey Relation Analysis:

S.NO	D.D	S.R	MRR	GRG	RANK
1	0.598	0.605	0.424	0.543	9
2	0.511	0.649	0.357	0.506	12
3	0.490	0.540	0.353	0.461	14
4	0.467	0.605	0.369	0.480	13
5	0.368	0.458	0.446	0.424	17
6	0.355	0.433	0.498	0.429	16
7	0.333	0.422	0.408	0.388	18
8	1.000	0.556	0.386	0.647	3
9	0.722	0.882	0.718	0.774	1
10	0.490	1.000	0.393	0.627	5
11	0.636	0.844	0.413	0.631	4
12	0.466	0.711	0.364	0.513	11
13	0.598	0.682	0.477	0.586	6
14	0.511	0.482	0.577	0.523	10
15	0.368	0.794	1.000	0.721	2
16	0.569	0.605	0.498	0.557	8
17	0.680	0.333	0.333	0.449	15
18	0.598	0.425	0.672	0.565	7

Table 8. Response data for GRA

Level	sensitivity	pulse on time	pulse of time	water pressure
1	0.517	0.547	0.53	0.6
2	0.575	0.527	0.53	0.497
3		0.563	0.577	0.541
Delta	0.058	0.036	0.047	0.103
Rank	2	4	3	1



ANOVA results for GRG:

source	DF	Seq SS	Contribution	Adj SS	Adj Ms	F-value	P-value
sensivity	1	0.061	22.17%	0.061	0.061	1.8	0.209
ton	2	0.0333	11.95%	0.0333	0.01665	0.14	0.867
toff	2	0.0363	13.04%	0.0363	0.01665	0.22	0.803
W.p	2	0.0983	35.25%	0.0983	0.01815	1.13	0.362
error	10	0.049	17.59%	0.0983	0.04915		
total	17	0.279121	100.00%				

CONFIRMATION TEST

The confirmation experiment is very important in parameter design. In these this study ,a confirmation experiment was conducted for dimension deviation by utilizing the level of optimal process parameters(A2B3C2D1).The same process is repeated for surface roughness(A2B1C1D1) and material removal rate(A2B2C3D1).

Table 6.18 Optimal condition of Taguchi

Response Characteristics	Optimal Parameters Condition	Optimal combination (Predicted value)	Optimal combination (experimental value)
SR	A2B1C1D1	0.3609	0.3812
DD	A2B3C2D1	0.3070	0.3104
MRR	A2B2C3D1	1.4550	1.4473

CONCLUSION

- In this experimental work, an attempt was made to determine the important machining parameter for performance measure like surface roughness, dimension deviation, and material removal rate in wire EDM process. The optimization techniques of Taguchi and grey relation analysis is used to minimize the surface roughness, dimension deviation, and maximize the material removal rate.
- The surface roughness optimal condition are sensitivity-10, Ton-105, Toff-45 and water pressure- 85. In this case optimal predicted value is 0.3609.
- The dimension deviation optimal condition are sensitivity-10, Ton-115, Toff-50 and water pressure-85. In this case optimal predicted value is 0.3070.
- The material removal rate optimal condition are sensitivity-10, Ton-110, Toff-55and water pressure-85. In this case optimal predicted value is 1.4550.

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