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Optimization of Machining Parameters of Electrical Discharge Machining (EDM) on EN24 Steel

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Abstract: ***Electrical Discharge Machining (EDM) is a non-conventional machining process. EDM parameters like Pulse-on time (T_{ON}), Voltage (V) and current (I) are used to study on Material removal rate (MRR) and Surface Roughness (SR) on EN-24 steel by using copper rod as a tool. For conducting experiment, Taguchi method of L_9 orthogonal array design is used. The results were analyzed using analysis of variance (ANOVA) and response graphs. From this Study, it is found that different combinations of EDM process parameters are required to achieve higher MRR and lower SR for EN24 steel. The signal to noise ratio (S/N) and analysis of variance (ANOVA) is used to analysis the effect of the parameters of MRR and SR and also to identify the optimum cutting parameters. The effect of each parameter towards MRR and SR is to be identified. The combination results for this experiment will be useful for manufacturing engineers to select appropriate EDM process parameters to machine EN24 steel.***

Keywords: EDM, ANOVA, MRR, SR

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a non-traditional method of machining which works on the principle of thermo electrical process. The sparks are produced in between work piece and tool electrode and erodes material from the work piece according to the die design consideration in the presences of immersed dielectric medium. Generally dielectrically fluid and kerosene are used as a dielectric medium. EDM is used to machine high complex shapes and hard materials.

Nomenclature

MRR= Material removal rate SR= Surface Roughness
T_{on}= Pulse on time V= Voltage
I= Current

On Inconel 718 experiment conduct by Kuppan[1] and explains the output response measuring material removal rate (MRR) and depth averaged surface roughness (DASR) with EDM parameters. Anmada[2] was investigate the performance of copper electrode when EDM of nickel based super alloy of Inconel 718 to observe the performance of MRR, electrode wear rate (EWR) and SR. Masanori Kunieda[3] explains EDM can be achieved in gas with the help of a high-pressure gas flow supplied through a thin walled pipe electrode, the molten work piece material can be removed and flushed out of the working gap without being reattached to the electrode surface. The present manufacturing scenario, the industrial product not only requires the high precision and quality but should be produced in the minimum time in order to sustain their position in the global market compotation explained by Anbesh jamwal[4]. Shailendra pal[5] used Taguchi method works on EDM by drilling on stainless steel material using copper electrode of 3mm diameter to investigate the MRR and minimum electrode wear rate (EWR). Kanagarajan[6] invest the process of shaping hard metal and forming deep and complex shaped holes by arc erosion in all types of electrical conductive materials. By using different parameters conducting experiment on tungsten carbide and cobalt composites is evaluated in terms of material remove rate and surface roughness of the workpiece.

The study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM) with different parameters conduction kansal[7] observe MRR and SR.

Anshuman kumar sahu[8] perform work on EDM process by using nitinol as a workpiece material and Alsimg prepared by selective laser sintering (SLS) process and observe the SR by using Tauguchi L27 orthogonal array. Rajmohan [9] works on 304 stainless steel on EDM by using Taguchi L9 orthogonal array and ANVOA to observe the performance of MRR with different parameters.

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II. EXPERIMENTAL

A. Material used

EN24 steel is used as a work piece to conducting experiments by using copper rod as an electrode (tool) material. The chemical combination and mechanical properties are shown in below table.

Table 1. Chemical composition of EN24 steel material

	C	Si	Mn	P	S	Mo	Cr	Ni
Min.	0.36	0.10	0.45			0.20	1.00	1.30
Max.	0.44	0.35	0.70	0.035	0.04	0.35	1.40	1.70

Table 2. Mechanical properties of EN24 material

Mechanical properties	
Tensile strength	850-1000 (MPa)
Yield strength	680 (MPa)
Elongation	13 (%)
Impact strength	54 (J)
Hardness	248-302 (HB)
Thermal conductivity	41.9 w/m-^{0}c
Density	7840 kg/m^3
Elastic modulus	207 GPa
Melting point	1500^{0}C

B. Taguchi Method

Dr. Genichi Taguchi is developed Taguchi method to optimize the process of engineering experimentations. Taguchi method is involves to reducing the variation in a process through robust design of experiments. The idea is to implement this method in order to produce high quality of products at low cost of manufacturer. This method was developed to investigate how different parameters affect the mean and variance of a process performance characteristic, which is defined as how the process is functioning. So, he developed a method based on orthogonal arrays [OA] which is used to minimize the engineering experimentations, thus it reduce time, cost and resources.

1) *Taguchi design experiments in STATISTICA 9.0:* STATISTICA 9.0 offers many possible ways in which an experiment can be carried out. The experiment design can be reduce by creating number of ordinary orthogonal arrays. For each of these arrays can be used to design experiments to suit numerous experiment situations. A number of orthogonal arrays, such as L_4, L_8, L_9, L_{12}, L_{16}, L_{18} and $L_{27}$and so on, created for two or three level factors. STATISTICA 9.0 estimates response tables and creates main effects and S/N ratios plans intended for:

a) S/N ratios [Signal-to-noise ratios] vs. control factors.

b) Mean vs. control factors.

Normally, the full factorial design would require 3^3=27 experiments should be run, but by using Taguchi quality design concept method there can be reduce in to 9 rows (number of experiments). Hence it is called L_9 orthogonal array, which optimize the design for performance, quality and cost.

The experiment values can be arranged in a table by using L_9 orthogonal is as follows:

Table 3: L_9 orthogonal array arrangement

Experiments Run order	Levels		
	L1	L2	L3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

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To conduct the experiment, pulse-on-Time (T_{ON}), voltage (V) and current (I) should be taken as parameters with some constant values. These can be shown in below table 4 and design matrix is represented in the Table 3

Table 4: Machining parameters and levels

Machining Parameters	Symbols	Units	Levels		
			L1	L2	L3
Pulse-on-time	T_{ON}	µsec	45	55	65
Voltage	V	Volts	60	120	180
Current	I	Amps	25	40	55

III. CONDUCT OF EXPERIMENTS

EDM machine is used to conducting experiments on EN-24 steel, by machining a hole of 10 mm depth on EN-24 steel material by a copper rod as tool of 10 mm diameter. Nine experiments were conducted according to the parameters shown in table 4. For every experiment, the parameters like Pulse on Time, Voltage and Current are varies on arrangement as Table 3. The working process and parameter adjustments and programming the machine by control panel on the EDM machine. When tool reached work piece in EDM machine then electrical current produces is called plasma. This plasma can convert electrical energy into thermal energy at a certain distance between tool and work piece in the dielectric fluids. The work piece gets melted or vaporized at a certain contact point. The process is repeated for all experiment as the parameters arrangement by the operator. Weight of the work piece is measured before and after machining to calculate the MRR. Stylus type Surface roughness tester is used to measure the SR of the work piece for each machining parameter. MRR can be calculated by the equation on below.

$$MRR = \frac{\text{intial weight of workpiece} - \text{final weight of workpiece}}{\text{machining time}} \quad (1)$$

Table 5: parameter analysis and there results.

Experiment Run order	Pulse-ON-Time (T_{on}) (µsec)	Voltage (V) (Volt)	Current (I) (Amp)	Material removal Rate (MRR) (gms/min)	Surface Roughness (SR)
1	45	60	25	18.38	2.7
2	45	120	40	28.79	4.37
3	45	180	55	17.32	2.38
4	55	60	40	12.75	3.2
5	55	120	55	15.68	3.1
6	55	180	25	30.59	2.36
7	65	60	55	20.93	4.2
8	65	120	25	23.78	2.8
9	65	180	40	19.83	2.95

IV. RESULTS AND DISCUSSIONS

The operations done on selected parameter on table 4 obtaining different machining performance. Analysis of variance (ANOVA) is used to find the significant parameter among the all parameters and evaluating minimum variance. The equations are shown below are used to calculate S/N ratio of MRR and SR.

$$S/N_{(MRR)} = -10log[\frac{1}{(MRR)^2}] \quad (2)$$

$$S/N_{(SR)} = -10log[(SR)^2] \quad (3)$$

By applying above equations, the S/N ratio can be calculated for each experiment value of L_9 orthogonal for both MRR and SR. The following table shows the calculated values of S/N ratio of MRR and SR.

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Table 6: S/N ratio of MRR and SR.

Experiment Run order	Pulse-ON-Time (T_{on}) (µsec)	Voltage (V) (Volt)	Current (I) (Amp)	Material removal Rate (MRR) (gms/min)	S/N ratio of MRR	Surface Roughness (SR) (µm)	S/N ratio of SR
1	45	60	25	18.38	25.2869	2.7	8.6593
2	45	120	40	28.79	29.1848	4.37	12.8096
3	45	180	55	17.32	24.7709	2.38	7.5315
4	55	60	40	12.75	22.1102	3.2	10.1029
5	55	120	55	15.68	23.9069	3.1	9.8272
6	55	180	25	30.59	29.7115	2.36	7.4582
7	65	60	55	20.93	26.4153	4.2	12.4649
8	65	120	25	23.78	27.5242	2.8	8.9432
9	65	180	40	19.83	25.9464	2.95	9.3964

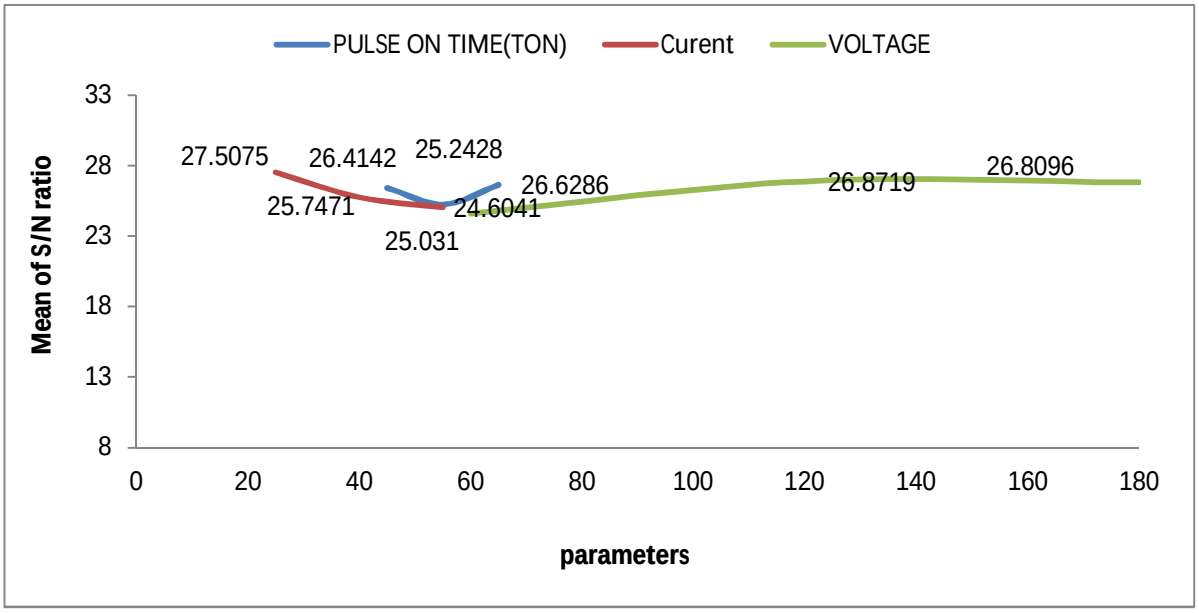
A. Mean Signal To Noise Ratio For Material Removal Rate

In table 6, we calculate S/N ratio for the parameters of MRR. Now we can calculate the mean S/N ratio from S/N ratio of MRR according to the parameter arrangement. The below table shows mean S/N ratios. Delta means variations of highest value and lowest value of mean S/N ratio of the parameters. Rank should be given from highest value to lowest value.

Table 7: Response table for mean S/N ratio of MRR

Level	Pulse on Time (A) T_{on}	Voltage (B) V	Current (C) I
1	26.4142 (A1)	24.6041 (B1)	27.5075 (C1)
2	25.2428 (A2)	26.8719 (B2)	25.7471 (C2)
3	26.6286 (A3)	26.8096 (B3)	25.0310 (C3)
Delta	1.3858	2.2678	2.4765
Rank	3	2	1

According to the above table 7 mean S/N values we can plot Graphs and find out the effective parameters of MRR.



Graph 1: Response Graphs for S/N Ratios of MRR

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Table 8: Analysis of variance (ANOVA) for MRR

Factors	D.O.F	SS	MSS	F-value	% contribution	Rank
Pulse on time(T_{ON})	2	3.3382	1.6691	1	14.45	3
Voltage(V)	2	10.11	5.0055	2	43.34	1
Current(I)	2	9.7447	4.8724	2	42.19	2
Error	5					
Pooled Error	4	13.0829	3.2707			
Total	8					

Note: - D.O.F= Degrees of freedom, SS= sum of squares, MSS= mean sum of squares.

1) Formulas

$(SS)T_{ON} = \frac{1}{3}(\text{total of A1})^2 + \frac{1}{3}(\text{total of A2})^2 + \frac{1}{3}(\text{total of A3})^2 - \frac{1}{9}(\text{total of A})^2$

$(SS)V = \frac{1}{3}(\text{total of B1})^2 + \frac{1}{3}(\text{total of B2})^2 + (\text{total of B3})^2 - \frac{1}{9}(\text{total of B})^2$

$(SS)I = \frac{1}{3}(\text{total of C1})^2 + \frac{1}{3}(\text{total of C2})^2 + \frac{1}{3}(\text{total of C3})^2 - \frac{1}{9}(\text{total of C})^2$

D.O.F = no. of. Levels - 1

$\text{MSS} = \frac{Sum\ of\ squares}{D.O.F}$

$\text{F-Value} = \frac{\text{mean square value}}{\text{mean square pooled error}}$

$\text{Percentage contribution} = \frac{\text{Sum of squares of individual}}{\text{Total Sum of squares}} \times 100$

The relative importance of the parameters with respect to the MRR is investigated by analysis of variance (ANOVA). Table 8 explains the ANOVA results for MRR. From the Table 8, it is observed that Voltage (V) is 43%, Current (I) is 42% and Pulse on time (T_{ON}) is 14% is a statistical significance on the MRR.

Thus, by the parameters the experiment process should be done and calculate the S/N ratio. And also calculate the average S/N ratio of MRR and presented in Table 7. The S/N ratio response graphs for MRR are shown in Graph 1. In MRR, the greater S/N ratio value corresponds to better performance. Based on analysis of S/N ratios, the optimal parameters of machining for the MRR is obtained at a Pulse on time of 65 µs, Voltage of 120 V and Current of 25 amps.

a) Calculation for Surface Roughness (SR)

b) Mean signal to noise (S/N) ratio of SR

In the Table 6 for every parameter the Surface Roughness and S/N ratio should be calculated.

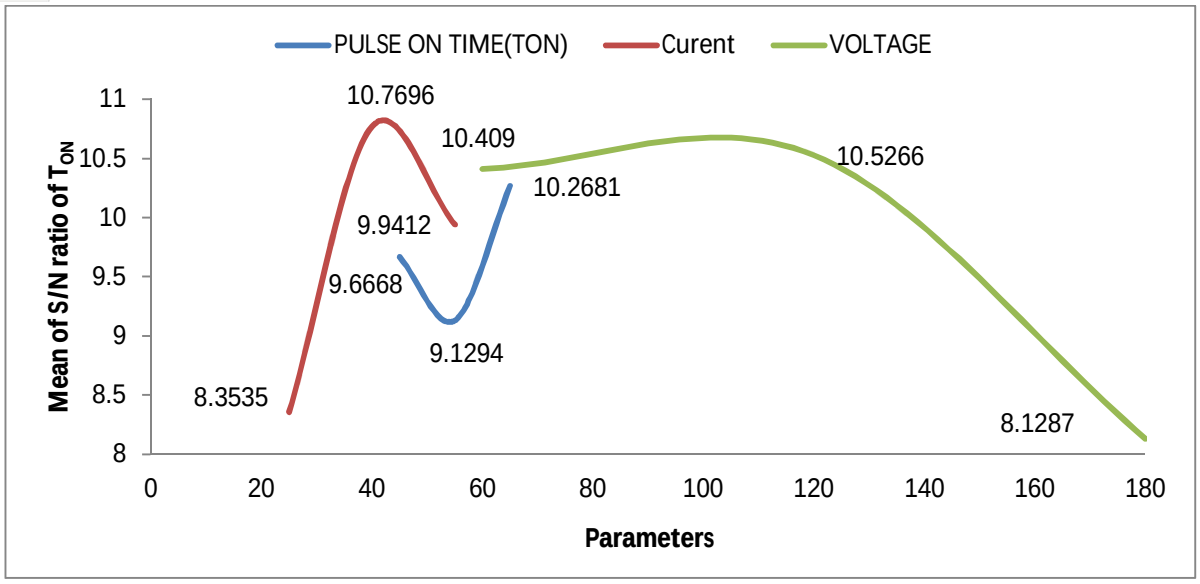
Table 9: Calculations for mean signal noise ratio for Surface Roughness

Level	A (Pulse on time) T_{ON}	B (Voltage) V	C (Current) I
1	9.6668 (A1)	10.4090 (B1)	8.3535 (C1)
2	9.1294 (A2)	10.5266 (B2)	10.7696 (C2)
3	10.2681 (A3)	8.1287 (B3)	9.9412 (C3)
Delta	1.1387	2.3979	2.4161
Rank	3	2	1

From the S/N ratio the mean S/N ratio values should be calculated to specific parameters, and those values are placed in below Table. Delta value should be calculated by variation of highest value and lowest value and Rank should be given from highest value to lowest value.

According to the above Table 9, the mean S/N ratio for every parameter should be plot on graph to observe the efficiency of SR.

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Graph 2: response Graphs for S/N ratio for SR.

Table 10: Analysis of variance (ANOVA) of SR

Factors	D.O.F	SS	MSS	F-value	% contribution	Rank
Pulse on time(T_{ON})	2	1.947	0.9735	1	8.87	3
Voltage(V)	2	10.9364	5.4682	2	49.87	1
Current(I)	2	9.0442	4.5221	2	41.24	2
Error	5					
Pooled error	4	10.9905	2.7478			
Total	8					

Note: - D.O.F= Degrees of freedom, SS= sum of squares, MSS= mean sum of squares.

The relative importance of the parameters with respect to the SR is too investigated by analysis of variance (ANOVA). Table 10 explains the ANOVA results for SR. From the Table 10, it is observed that Voltage (V) is 49%, Current (I) is 41% and Pulse on time (T_{ON}) is 9% is a statistical significance on the SR.

Thus, by the parameters the experiment process should be done and calculate the S/N ratio. And also calculate the average S/N ratio of SR and presented in Table 9. The S/N ratio response graphs for SR are shown in Graph 2. In SR, the lower S/N ratio value corresponds to better performance. Based on analysis of S/N ratios, the optimal parameters of machining for the MRR is obtained at a Pulse on time of 55µs, Voltage of 180V and Current of 25amps.

V. CONCLUSION

On the basis of experimental results, calculation of S/N ratio and analysis of variance (ANOVA) of MRR and SR, the following conclusions are obtained for EDM of EN24 steel.

A. The voltage and current are the most significant machining parameters for MRR in EDM of EN24 steel. The highest material removal rate (MRR) can be obtained on parameter combination is Pulse on time 65µs, Voltage 120V and Current 25 amps.

B. The voltage and current are the most significant machining parameters for SR in EDM of EN24 steel. The lowest surface roughness (SR) can be obtained on Parameter combination is Pulse on time of 55µs, Voltage of 180V and Current of 25amps.

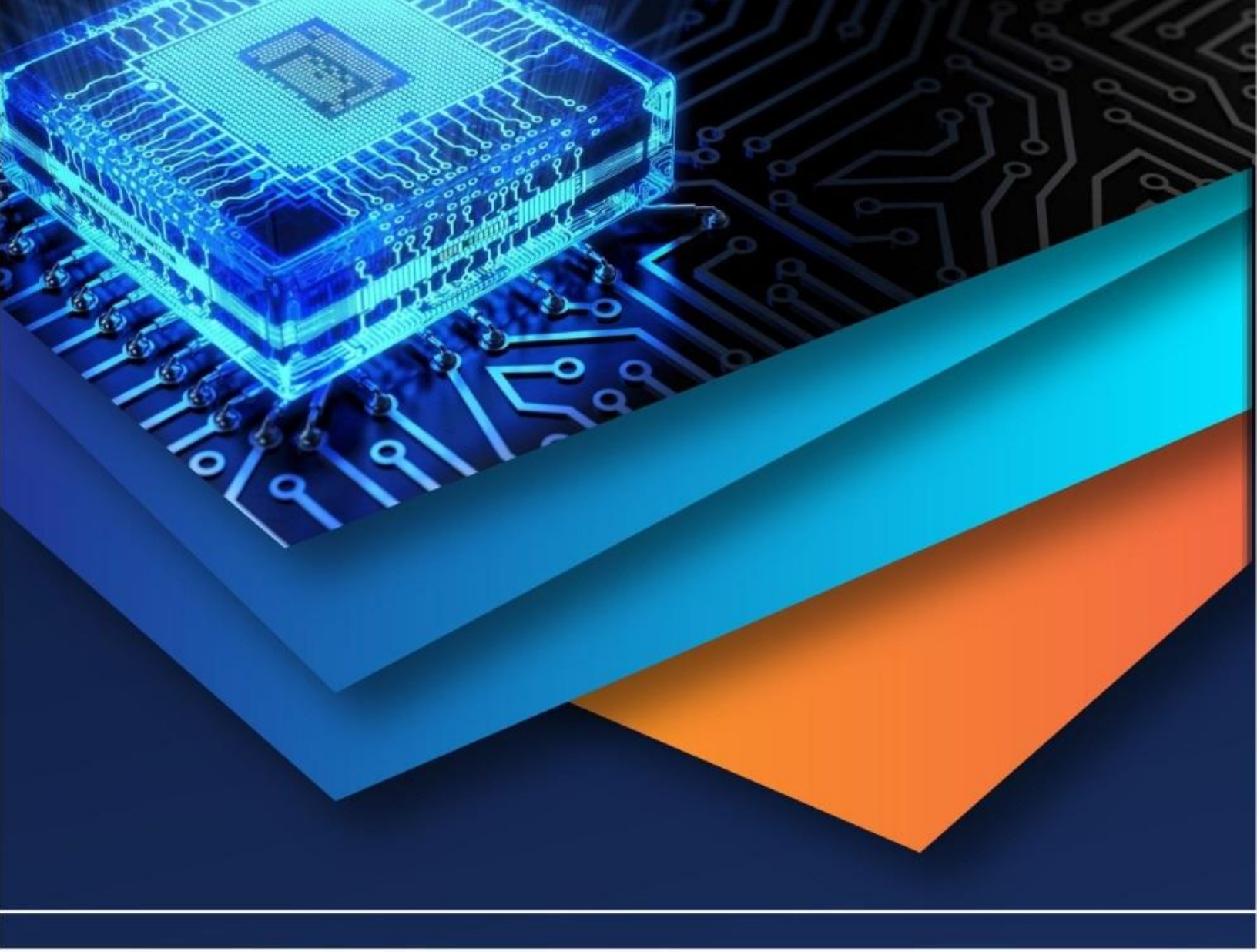
C. Based on the experiment results with minimum number of trails on cutting parameters, Taguchi method is efficient methodology to find the optimum cutting parameters.

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