Study and Experimentation for Process Parameters on Inconel 904L by using EDM

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Abstract

EDM is an important and commercial method of machining very tough and brittle electrically conductive materials. It is broadly used in the process of making moulds and dies and sections of complex geometry and complicated shapes. The work piece material selected in this experiment is Inconel 904 taking because it's widely usage in industrial applications. The input variables are Voltage, current and pulse on time. Taguchi L9 orthogonal array is applied to optimize the processes variable. The effect of the variable parameters mentioned above upon machining characteristics such as Material Removal Rate (MRR) and Surface Roughness (SR) is studied and investigated. The obtained results showed that current was the most significant parameter followed by voltage and pulse on time for the Material removal rate (MRR) and, for Surface roughness (Ra) current was the most significant parameter followed by pulse on time and voltage. The selected electrode material is cupper and duty cycle is 90% during the whole experiment.

Keywords- EDM, Inconel, MRR and Spark Current

I. INTRODUCTION

The electrical Discharge Machining process is a most basic nontraditional machining process, where materials are removed by the thermal energy of spark occurring by means of repeated sequences of electrical ejections between small gap of a work piece and an electrode. The EDM process is commonly used for machining, electrically conductive of hard metals and alloys in automotive, aerospace and die making in the industries. The EDM is removing disagreeable material in the form of debris and produce shape of the tool surface as of a work piece via an electrical expulsion fascinated between tool and work piece i.e. (cathode and work piece) in presence of the dielectric oil. In this machining process work piece is called the anode because, it is attached to positive and tool is attached to negative so it called cathode, [4]. Dielectric fluid such as kerosene, transformer oil, distilled water, may be filled.

A. Principle of the EDM

The Electric Discharge machining process the metallic particle is removed as of the work piece allocated to controlled wearisome away action by means of repeatedly occurring spark ejection with the help of the discharge current, applied by the power supply taking place in small gap in the range of 10 – 120 µm between tool and work piece. The below figure 1.1 shows that the mechanical as well as electrical control system and electrical path for the Electric Discharge Machining process. A small crack is kept among tool and the work piece through a servo control arrangement, in which the tool in attached. Both the work piece and electrode are submerged in the dielectric medium [5]. Kerosene/ oil/deionized water is use for liquid dielectric as a catalyst for the EDM.

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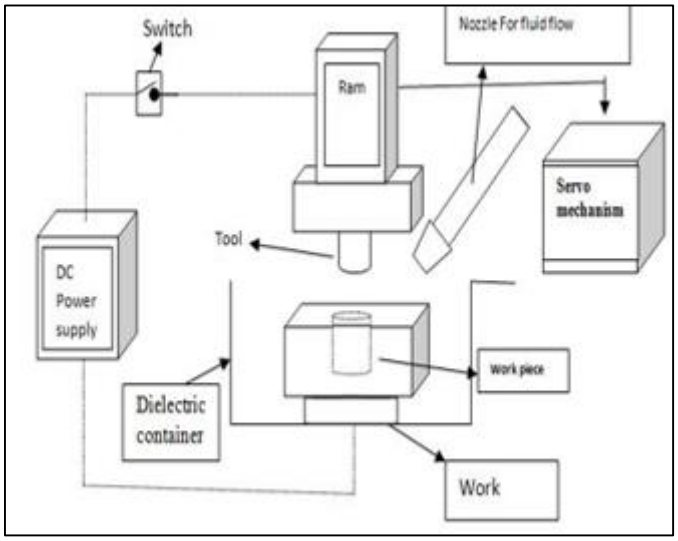

Fig. 1: Schematic setup of EDM [15]

B. Machining Parameters of the EDM

Pulse On time (T_{on}): Pulse on time is the time period express in micro seconds, when the peak current is all set to flow in each cycle. This is the time in which energy removes of the metallic subdivision from the work piece.

Pulse Off time (T_{off}): the spark off time is the time period express in micro seconds between two consecutive pulse. This time permits the melted particle to coagulate on work piece and to be wash absent by the flushing method of arc gap.

Spark gap: It is gap between electrode and work piece, in which the spark generate for eroding metallic from the work piece. It is very thin gap in the range of
20 – 125 µm.

Discharge current (Ip): Current is measured in the ampere (A). Discharge current is accountable directly for material removal. It have energy for melting and evaporation.

Duty cycle (τ): It is the ratio of pulse on time with respect to entire cycle time express in the percentage. This parameter is calculated as the ratio of the pulse on time and full cycle time.

Voltage (V): It is the potential difference that can be applied by the power supply in controlled manner. Voltage is also another most important factor which affects the material removal.

Diameter of electrode (D): It is the diameter of electrode or the tool material. Diameter of the tool is most important factor considered on the machining. This experiment 15 mm tool diameter is utilized.

C. Characteristics/Specification of EDM

The EDM description by machinery practice parameter, the material removal rate and additional purpose that show in below table no. 1

Table 1: Specification on EDM

S.N.	*Characteristics*	*Range*
1	*Mechanism of process*	*Controlled erosion i.e. melting and evaporation aided by cavitations*
2	*Spark gap*	*10 - 125 µm*
3	*Spark frequency*	*200 – 500 kHz*
4	*Peak voltage across the gap*	*30 - 250 V*
5	*Maximum material removal rate*	*5000 mm^3/min*
6	*Specific power consumption*	*2-10 W/mm^3/min*
7	*Dielectric fluid uses*	*EDM oil, Kerosene and water with Glycol, silicon-based oil, deionized water, hydrocarbon fluids etc.*
8	*Electrode material*	*Copper, Brass, Graphite, Cu-Graphite alloys, Cu-W alloys, Zinc alloys, Tungsten.*
9	*Materials application*	*All electrically conductive metals and alloys can be machined.*
10	*Shape application*	*Micro-holes for nozzles, thin slots, visionless complex craters.*

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D. Dielectric Fluid

Dielectric is a fluid which is used as a coolant, flushing medium and also a catalyst conductor.
The requirements are [9].
The dielectric should have necessary and constant dielectric strength to serve as insulation between tools and work, cultivate the breakdown voltage is reached.
It must be de-ionizing quickly afterwards the spark ejection has taken place.
It must need small viscosity and a gracious moistening ability to provide effective cooling mechanism and remove the turn sharply particles from the machining gap.
It should flush out of the element create during the spark out of the gap. This is the most significant purpose of the dielectric fluid. Unsatisfactory flushing can result in arcing decreasing the life of the electrode and increasing of the machining time.
It should be chemically in the neutral, so as not to attack to the tool, job and the changeable table or the tank.

II. EXPERIMENTAL SETUP

A. EDM Machine Tool

The experiments were performed by using the EDM process; model ECOLINE-FCO200 (die sinking type) with positive polarity of the electrode while the work piece is kept negative. The dielectric oil is used in EDM. (Specific gravity 0.762).

Fig. 2: EDM SETUP [Source: Medha Enterprises Kanpur]

Table 2: Physical Properties & Mechanical Properties of Inconel 904L

Density	*7.96 g/cm*
Specific Heat	*450 J/kg-°K*
Electrical Resistivity	*95.2 Microhm-cm at 20°C*
Modulus of Elasticity	*190 GPa*
Melting Range	*1300–1390°C*
Thermal Conductivity 212°F (100°C)	*12.9 W/m-°K*
Yield Strength	*220*
Ultimate Tensile Strength	*490*
Hardness	*70–90 Rockwell B*

B. Mechanism and Evaluation of the MRR

The MRR is the ratio of variation in work piece weight before and multiplication of after machining to the density of the material and machining time.

$$MRR = \frac{W_i - W_f}{\rho t} \qquad (3.1)$$

Where,
W_i = initial weight before machining of the work piece
W_f = final weight after machining of the work piece
t = machining time(s)
ρ is the density of Inconel 902 = 0.00795 g/mm^3

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C. Evaluation of the Surface Roughness

The Surface Roughness is measured of texture of the surface. It is measured in µm. If the Surface Roughness is high then the surface is rough and if low then surface is the smooth. It is denoted by the (Ra). The values are measured by using the Portable style type profilometer, the arithmetic mean of three readings is take places as the final results.

III. METHODOLOGY

A. Taguchi's Robust Design Method

By using Taguchi's robust design methodology job can be manufactured rapidly and at the minimum cost. Robust design planning is to improve the quality of the job without eliminating the causes, minimizing outcomes of the variation. Robust design is designing with least sensitivity to variations in the uncontrollable parameters. Taguchi's method to quality control applies to the complete process of developing and manufacturing a product from initial conception through design and engineering to manufacturing and production.

B. Selection of Control Factors and Levels

The three control factors are selected such as the Voltage, current (B) and spark on time (C). Inconel 902 work-pieces are used in this experimentation. The control levels and their alternative levels are show in the table No. 3.

Table 3: Control Factors and Levels

Factors /Levels	*Voltage V(v)*	*Current I (A)*	*Pulse on Time T_{on} (µsec)*
1	*60*	*4*	*200*
2	*70*	*6*	*300*
3	*80*	*8*	*400*

C. Orthogonal Arrays

The taguchi method has been used to create a scheme of tabulated designs (arrays) which permit the maximum number of most important outcomes to be predictable in an impartial way, with minimum number of the iterations in experiment.. Generally used orthogonal arrays contain the L4, L9, L12, L18, and L27. The columns in the orthogonal arrays indicate factor and its consequent the levels, and each row in orthogonal arrays constitutes an experimental run in which is achieved at the given factor settings. Typically either 2 or 3 levels are selecting for each the factor. To Selection the number of levels and quantities properly of constitutes the bulk of the effort in planning the robust design experiments.

D. Selection of Orthogonal Array

To the selection of particular orthogonal array from the normal orthogonal arrays depends on the number of factors, levels of each control factor and total degrees of freedom.

1) Total number of control factors = 3
2) Total number of levels for each control factors = 3
3) Total degrees of freedom of factors = 3 x (3-1) = 6 and
4) Total Number of experiments to be conducted = 9

Selection on the base of these values and required the total minimum number of experiments to be conducted 9, nearest the orthogonal Array fulfilling this condition is L9 (3^3).

The standard L9 (3^3) Orthogonal Array is listing in Table No. 2. The Factor assignment for L9 (3^3) has been done which is show in Table No.4.

Table 4: Standard L9 (3^3) O.A

S.NO	*LEVEL*		
	1	*2*	*3*
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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E. Signal to Noise Ratio

The parameters are settings and then calculated through analysis of the "signal-to-noise" (S/N) ratio, where the factor levels that maximize appropriate the S/N ratio are optimal. There are three standard types of the S/N ratios, depending upon the preferred performance response [31].

1) Smaller the better (for making the system reply such as small as possible):

$$\text{SNs}=-10\ log\left(\frac{1}{n}\sum_{i=1}^{n} {y_i}^2\right) \qquad (4.1)$$

2) Nominal the best (for reducing variability approximately the target)

$$SN_T=10\log\left(\frac{y^2}{S^2}\right) \qquad (4.2)$$

3) Larger the better (for making the system reply such as large as possible)

$$SN_L=-10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right) \qquad (4.3)$$

F. ANOVA (Analysis of Variance)

So the ANOVA helps to compare variability's within the experimental data. In this experimentation ANOVA (analysis of variance) table is made with help of the MINITAB 17 software. When performance varies one calculates the average loss by the statistically averaging quadratic loss and average loss is proportional to the mean square error of Y about it's the target T.

G. Various formulas for ANOVA

Degrees of Freedom (DOF); the Degree of freedom indicates the number of independent elements in the sum of squares. The degrees of freedom for each element of the modeling show:

DOF (Factor) = r-1
DOF (Error) = n_t-r
Total = n_t-1
Where,
n_t = total number of observations and
r = number of factor levels

H. Sum of squares (SS)

The sum of squares (SS TOTAL) is total number of the variation in the data. SS (Factor) is the deviation of the expected factor level mean around the overall mean and also known as the sum of squares between treatments. The sum of squares (SS) Error is the deviation of an observation from its corresponding mean factor level. It is as also known as error within treatments. To calculates:

SS (Factor) = $SN_i\ (Y_i - Y_m)^2$
SS (Error) = $S_iS_j\ (Y_{ij} - Y_i)^2$
SS (Total) = $S_iS_j\ (Y_{ij} - Y_{mi})^2$
Where,
Y_i = the mean of observations at i^{th} factor level,
Y_m = Mean of all observations
Y_{ij} = the value of jth observation at the ith factor level.

I. Pure Sum of Square

SS' (Factor) = SS (Factor) – DF (Factor) * MS (Error)

J. Mean Square (MS)

To the determination for the mean square for the factor and error are:
MS (Factor) = SS (Factor)/ DF (Factor)
MS (Error) = SS (Error)/ DF (Error)

K. F Value

The F- test is used to calculate whether the factor means are equal or not.
F = MS (Factor)/ MS (Error)
For numerator, the degrees of freedom are r -1 and for the denominators are N_t – r. Larger values of the F support rejecting the null hypothesis that the means are in equal.

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IV. ANALYSIS AND DISCUSSION OF RESULT

Table 5: Control Factors and Levels

Factors /Levels	*Voltage V(v)*	*Current I (A)*	*Pulse on Time T_{on} (µsec)*
1	*60*	*4*	*200*
2	*70*	*6*	*300*
3	*80*	*8*	*400*

Die-shiking opertaion have been performed total 11 times including 2 pilot experiments on workpiece. The dimension for shinking operation performed was 30 mm diameter and 0.5 mm depth which was common for all the experiments.

Fig. 3: Machined work piece

A. MINITAB 17 Software Discuss and Analyze the MRR

1) S/N Ratio calculation For Material removal rate (MRR)

By using Taguchi methodology obtained the signal to noise (S/N) ratio. at this point signal represents the desired values as the mean and the noise represents the undesired values as the standard

Table 6: Taguchi orthogonal arrays design for S/N ratio: MRR

Exp. Run	*Voltage V(v)*	*Current I (A)*	*Pulse on Time*	*MRR (mm^3/min)*	*S/N Ratio*
1	*60*	*4*	*200*	*5.2310*	*14.3717*
2	*60*	*6*	*300*	*8.4101*	*18.4960*
3	*60*	*8*	*400*	*13.2012*	*22.4123*
4	*70*	*4*	*300*	*7.1202*	*17.0499*
5	*70*	*6*	*400*	*10.2602*	*20.2231*
6	*70*	*8*	*200*	*12.4210*	*21.8831*
7	*80*	*4*	*400*	*8.2015*	*18.2779*
8	*80*	*6*	*200*	*10.5602*	*20.4734*
9	*80*	*8*	*300*	*12.4089*	*21.8747*

2) Effect of Control Factor on MRR

Table 7: Response table for S/N ratio- larger-the-better (MRR)

Level	*Voltage V(v)*	*Current I (A)*	*Pulse on Time T_{on} (µsec)*
1	*18.43*	*16.57*	*18.91*

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2	*19.72*	*19.73*	*19.14*
3	*20.21*	*22.06*	*20.30*
Delta	*1.78*	*5.49*	*1.39*
Rank	*2*	*1*	*3*

B. Main Effcet Plot for S/N Ratio: MRR

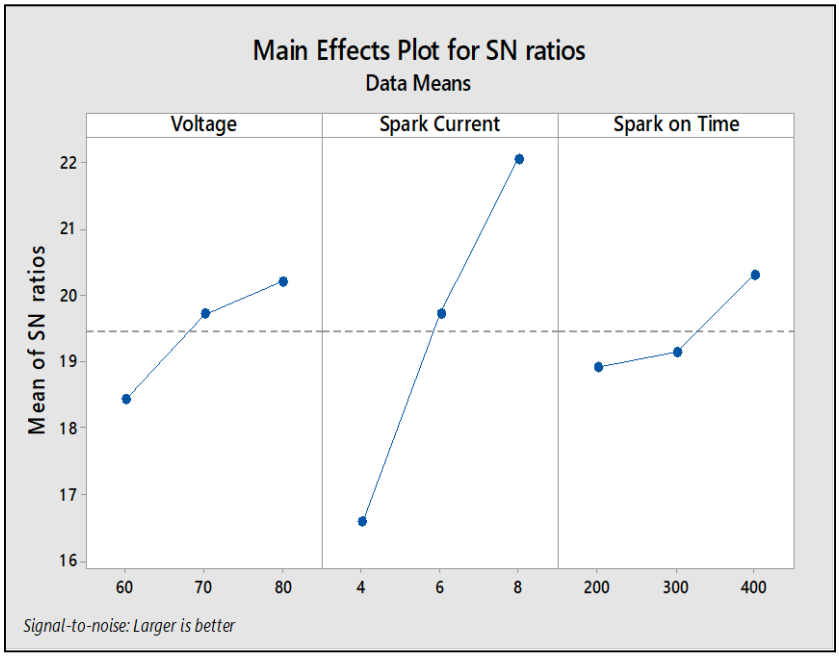

Fig. 4: Main Effect Plot for the S/N Ratio (Material Removal Rate)

Table 8: Response Table for Means: MRR

Level	*Voltage V(v)*	*Current I (A)*	*Pulse on Time T_{on} (µsec)*
1	*8.947*	*6.851*	*9.40*
2	*9.934*	*9.743*	*9.313*
3	*10.390*	*12.677*	*10.554*
Delta	*1.443*	*5.826*	*1.241*
Rank	*2*	*1*	*3*

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C. Main Effect Plot for Means: MRR

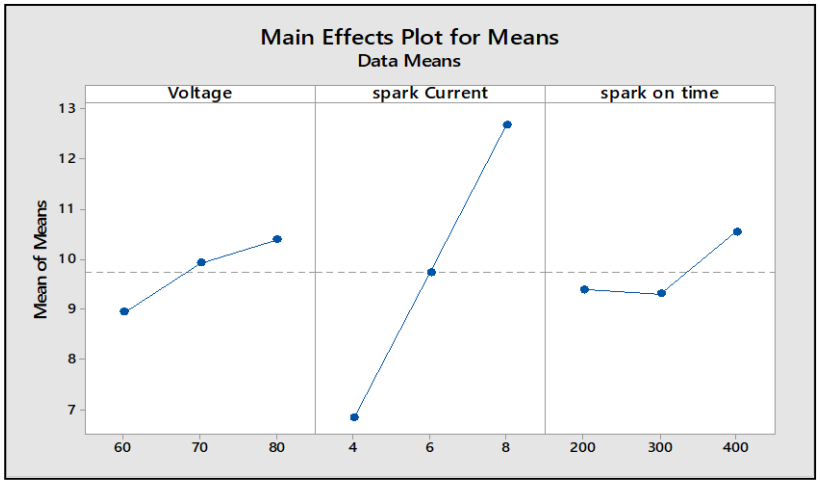

Fig. 5: Main Effect Plot for the Means (Material Removal Rate)

D. ANOVA Table for S/N Ratio: MRR

Table 9: Analysis of Variance for SN Ratio (MRR), using Adjusted SS for Tests

Source	*DOF*	*Adj SS*	*Adj MS*	*F*	*P*
Voltage (V)	*2*	*5.085*	*2.542*	*2.48*	*0.287*
Current(I)	*2*	*45.565*	*22.783*	*22.25*	*0.043*
Pulse on time(T_{on})	*2*	*3.355*	*1.677*	*1.64*	*0.379*
Error	*2*	*2.048*	*1.024*		
Total	*8*	*56.053*			

E. ANOVA Table for Means: MRR

Table 10: Analysis of Variance for Means (MRR), using Adjusted SS for Tests

Source	*DOF*	*Adj SS*	*Adj MS*	*F*	*P*
Voltage V(v)	*2*	*3.263*	*1.6314*	*2.16*	*0.316*
Current I (A)	*2*	*50.917*	*25.4583*	*33.72*	*0.029*
Voltage V(v)	*2*	*2.872*	*1.4360*	*1.90*	*0.345*
Error	*2*	*1.510*	*0.7550*		
Total	*8*	*58.561*			

1) Confirmation Test for the MRR

Previously the optimal level of the cutting parameters are selected, the final step is to predict and verify the improvement of the performance characteristics by using the optimal level of the cutting parameters.

By selecting the optimal level of the design parameters, the final step is to verify and validate the predict (obtained) parameter to those found throughout the experimental work to access the quality exclusivity of the machining process Predicted values: Optimized values find by using the MINITAB 17 software

V. EXPERIMENTAL VALUES

To estimate the S/N ratio using the optimal machining parameters for the MRR can be obtained and the corresponding the MRR can also be calculated by using above formula.

Table 11: Confirmation table for MRR

Optimal Machining Parameters		
	Predicted values	*Experimental Values*

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Level	$A_3B_3C_3$	$A_1B_3C_3$
MRR (gm/min)	14.1072	13.2012
S/N Ratio	31.5725	31.7526

A. By MINITAB 17 Software Discuss and Analyze the SR

1) S/N Ratio calculation for Surface Roughness (SR)

By using Taguchi methodology to find the Signal to noise(S/N) ratio. Here signal represents the desired values as of the mean and the noise shows that the undesired values of (sigma) standard deviation. Thus the signal to noise(S/N) ratio represents the amount of the difference which are present in the performance characteristics. Currently the desirable objective is to be optimize the response value of the Surface roughnes (SR). So here Smaller-the-better type signal to noise (S/N) ratio is gives the optimum in the result.

Table 12: Taguchi Orthogonal Arrays design for S/N ratio: SR

Exp. Run	*Voltage*	*Spark Current*	*Spark on Time*	*Surface Roughness*	*S/N Ratio*
1	60	4	200	6.8615	-16.7284
2	60	6	300	8.2561	-18.3355
3	60	8	400	9.7584	-19.7876
4	70	4	300	7.2564	-17.2144
5	70	6	400	8.9856	-19.0709
6	70	8	200	9.1547	-19.2329
7	80	4	400	7.1562	-17.0936
8	80	6	200	7.259	-17.2175
9	80	8	300	9.1058	-19.1864

2) Effect of Control Factor on SR

Table 13: Response table for S/N ratio- Smaller-the-better (SR)

Level	*Voltage*	*Spark Current*	*Pulse on time*
1	-18.28	-17.01	-17.73
2	-18.51	-18.21	-18.25
3	-17.83	-19.40	-18.65
Delta	0.67	2.39	0.92
Rank	3	1	2

B. Main Effect Plot for S/N Ratio: SR

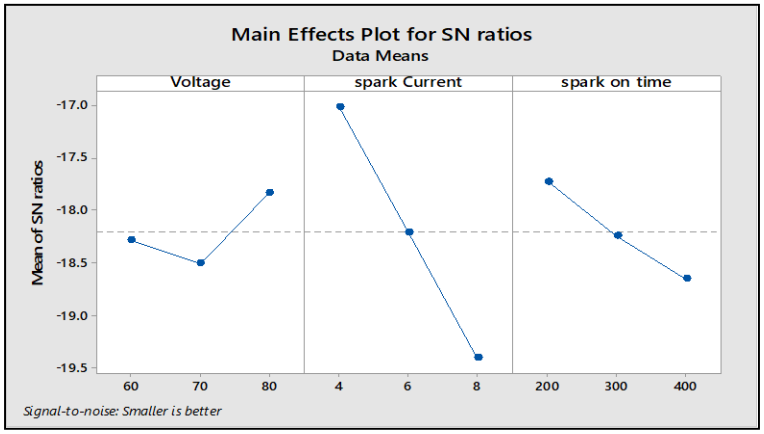

Fig. 6: Main Effect Plot for the S/N Ratio (Surface roughness)

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Table 14: Response table for Means- Smaller-the-better (SR)

Level	Voltage	Spark Current	Pulse on time
1	8.292	7.091	7.758
2	8.466	8.167	8.206
3	7.840	9.340	8.633
Delta	0.625	2.248	0.875
Rank	3	1	2

C. Main Effect Plot for Means: SR

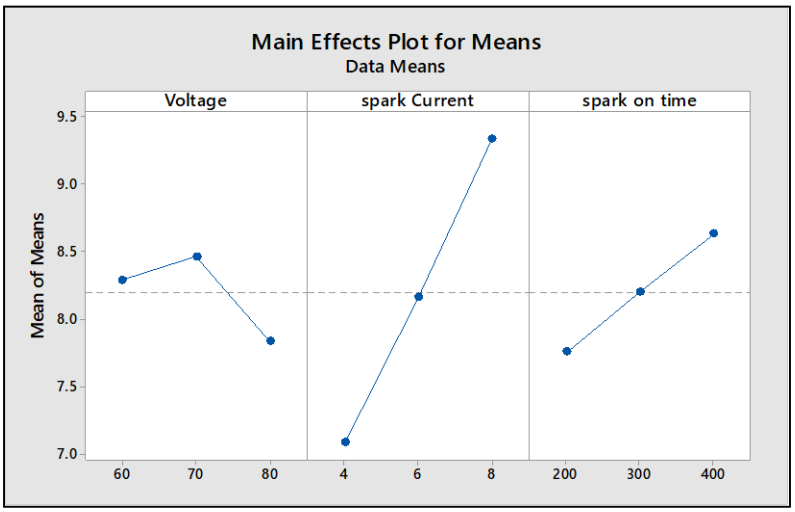

Fig. 7: Main Effect Plot for the Means (Surface roughness)

D. ANOVA Table for S/N Ratio: SR

Table 15: Analysis of Variance for SN Ratio (SR), using Adjusted SS for Tests

Source	DOF	Adj SS	AdJ Ms	F	P
Voltage	2	0.62504	0.31252	8.08	0.110
Spark Current	2	7.58678	3.79339	98.10	0.010
Pulse on Time	2	1.14865	0.57432	14.85	0.063
Error	2	0.07734	0.03867		
Total	8	9.43781			

E. ANOVA Table for Means: SR

Table 16: Analysis of Variance for Means (SR), using Adjusted SS for Tests

Source	DOF	Adj SS	AdJ Ms	F	P
Voltage	2	0.7068	0.35338	7.17	0.122
Spark Current	2	8.5690	4.28451	86.89	0.011
Pulse on Time	2	1.2884	0.64420	13.06	0.071
Error	2	0.0986	0.04931		
Total	8	10.6628			

F. Confirmation Test for SR

1) Predicted Values

Optimized values find by using the MINITAB 17 software.

2) Experimental Values

To estimate the signal to noise(S/N) ratio using the optimal machining process parameters for the surface roughness can be obtained and the matching the surface roughness can also be measured by surface roughness tester.

Table 17: Confirmation table for SR

Optimal Machining parameter		
	Predicted value	Experimental
Level	$A_3B_1C_1$	$A_1B_1C_1$
Ra	6.2915	6.8615
S/N Ratio	-16.1560	-16.7284

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VI. CONCLUSION

In this study were to decide ideal state of the machining parameters and the criticalness of each parameter to the execution attributes. The aggregate no. of investigation run performed in this analysis were 9 trials operate randomized parameters which is finished by using MINITAB 17 programming. The following conclusions are drawn based on the performance of the machining characteristics studies:

A. For Metal Removal Rate (MRR)

For Material removal rate from all selected parameters, spark current (I) is the mainly significant input factor affecting the machining of inconel902.
(i). the optimum machining parameter is 80V Voltage, 8 A Current and 400 Pulse on time.

B. For Surface Roughness (Ra)

in Surface Roughness from the all selected parameters, spark current (I) is the most significant input factor affecting the machining of Inconel902 followed by spark time and voltage.
(i). the optimum machining parameter is 80 V Voltage, 4 A Current and 200 Pulse on time.

C. Scope for Future Work

In the present study an attempt has been made to optimization the EDM process parameter for Inconel 902. The experimentation is consist of three input factors such as Voltage, spark current and spark on time each of them consist of three levels. In this work the main importance on machine for maximum material removal rate (mrr) and minimum SR. The experimentation used L9 Orthogonal Array and obtain optimal parameters by Design of experiment (DOE) MINITAB 17 software and also done a confirmation test by using ANOVA.

1) There is option of minimizing the carbon deposit on electrode tool by means of any surface finishing process during the machining process and optimize the result. Carbon deposition on the tool reduce the spark energy and due to this material removal rate is reduced.
2) These work can be further extended with increase in the number of levels, using L27 or other type of the Orthogonal Array and using deferent kinds of Optimization and confirmation Tests.

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