International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 3 (2015) pp. 8387-8399

http://www.ripublication.com

Investigation of machining parameters in Electrical Discharge Machining on Inconel-625

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Abstract

The determination of machining parameters influence on material removal rate (MRR) and surface roughness with inconel – 625 is important. Due to Inconel 625 is one of the most difficult-to-machine materials which attributed to its ability to maintain hardness at elevated temperature and consequently it's very useful for hot working environment. Electrical Discharge Machining (EDM) has been an important for manufacturing process. It has proved for the machining of super-tough, electrically conductive materials such as the aerospace materials that are difficult to machine by conventional methods. The investigation of machining parameters is determined using Response Surface Methodology (RSM) and mathematical model is built by using regression analysis. Finally the developed mathematical models are validated with experimental values and the results show that the mathematical model has best agreement with experimental values.

Keyword - EDM operation, Inconel - 625, Material Removal Rate, Surface Roughness, current, pulse duration

I. INTRODUCTION

In traditional manufacturing process are replaced by advanced techniques, such as electric discharge machining (EDM), for machining of engineering materials with high strength and hardness. The main significant to the machining in EDM will be determined by electrical factors such a current, pulse on time, pulse off time and voltage. Copper is one of the metallic electrode materials of choice for EDM due to its electrical and thermal conductivity properties.

EDM is one of the material removal processes by use of thermal energy. EDM process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece with the presence of dielectric fluid [1]. Also EDM does not make contact between work piece and tool material, it eliminates the chatter, vibration and mechanical stress during machining [2]. It is controlled processes for machining metals by vaporizing the materials from work piece surface [3]. The electrode is encouraged in the direction of the work piece until the gap is small enough, so that the impressed voltage is great enough to ionize the dielectric [4]. Short duration discharges are formed in a liquid dielectric gap, which split tool and work piece. The material is removed with the erosive effect of the electrical discharges from tool and work piece [5].

However in past decades, the researchers were employed for achieving ultrasonic vibration and adding powder additives for improving the performance efficiency of EDM [6 - 8], environmental activities (analyze the machining performance with dry machining) [9], and predicting the responses with different modelling techniques [10, 11]. This work is reviews the input parameter influence on material removal mechanism, tool wear and surface quality during EDM process.

The electrode, work piece material and dielectric fluid are the main components that affect the material removal during machining at three stages of sparking, discharge and erosion [12]. And reverse polarity of sparking induce the electrode material deposition on work piece material during material removal [13]. Similarly electrostatic forces and stress distribution acting on the cathode electrode are to be the major causes of material removal [14]. Various researchers were employed for improving the material removal with frame electrode [15], wire frame electrode [16], and axial motion of electrode with CNC controlled machine. The wire frame and frame electrodes take lesser machining time for rough cutting operation. Similarly 3D electrodes with CNC controlled machines presented better machining time [17]. Subsequently the supply of oxygen in between the gap improves the MRR in EDM process [18].

However, Inconel 625 is one of the most difficult-to-machine material which attributed to its ability to maintain hardness at elevated temperature and consequently it's very useful for hot working environment. Formation of complex shapes by this material along with reasonable speed and surface finish is not possible in traditional machining. This alloy is characteristically difficult to machine due to its poor thermal properties, high toughness, high hardness, and high work hardening rate. Usually, a nonconventional machining method like electrical discharge machining (EDM) is chosen for machining Inconel 625 in order to overcome such limitations. However, due to the great physical properties of Inconel 625, the cutting process for this material is become an issue in order to improve the speed of machining process. This alloy has attracted many researchers because of its increasing applicability and the machinability of aerospace alloys will continually decline as service demands increase in order to satisfy the demand for higher temperature capability for structural engine alloys.

II. EXPERIMENTAL SETUP

The main objective of this work is to investigate the machining parameters such as current, voltage, pulse on time and pulse off time on MRR and surface roughness on inconel 625.

A. *Tool and Work piece material*

The copper electrode was used for experimental runs. Inconel 625 square block 100 X 100 X 5mm thickness materials were used for EDM experiments. The chemical composition of the work piece material tested and the same is tabulated in table 1.

B. *Machines used*

The experiments were conducted on EMS5030 make EDM machine and the specification of machine tool is as follows, Mechanism of process Controlled erosion (evaporation and melting)through a series of electric sparks, Maximum work height 175 mm, Main table traverse (X, Y) 280, 200 mm, Electrode diameter range 0.25 mm to 15 mm, Interpolation Linear and circular.

TABLE 1 Chemical composition of Inconel 625

Elements	Ni	Cr	Fe	Mo	Nb	Co	Mn	Al	Ti	Si	C	S	P
Percentage	58	22-23	5	10.09	3.15-4.15	1	0.5	0.4	0.4	0.5	0.1	0.015	0.015

C. *EDM tests.*

The experimental setup is shown in fig. 1. The experiments were conducted based on 4 factors with 3 levels. So that, totally 9 experiments with two replicates were carried out as shown in table 2. The average of two replicates was taken for experimental investigation.

D. ***Measurement of responses.***

The material Removal Rate is calculated based on the work piece material weight difference as shown in eq. 1.

$$MRR = \frac{\text{Initial weight of work piece- Final weight of work piece}}{\text{Machining time}} \quad (1)$$

The surface roughness of the job was measured by using the surface roughness tester of Mitutoyo make and SJP 210P.

TABLE 2Experimental run details

SL NO	CURRENT (A)	VOLTAGE (V)	PULSE ON (μSec)	PULSE OFF TIME (μSec)	MRR (g/min)	SURFACE ROUGHNESS (μm)
1	2	5	5	7	0.044	5.89
2	3	5	6	7	0.0906	7.338
3	4	5	7	7	0.1703	9.323
4	2	5	8	7	0.0913	7.266
5	3	5	9	7	0.1392	8.344
6	4	5	10	7	0.1569	9.24
7	3	5	4	7	0.1059	7.531
8	4	5	5	7	0.1262	8.271
9	5	5	6	7	0.1986	9.005

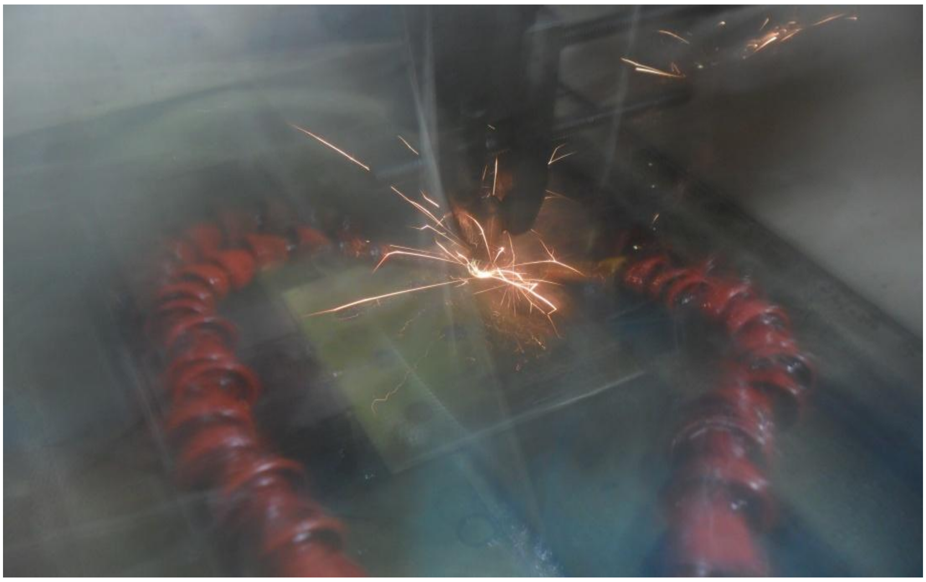


Fig 1. Experimental setup

III. RESULTS AND DISCUSSION

The experimentally measured MRR and surface roughness is analysed with response surface methodology. The evaluated results are established for identifying the effects of current, voltage, pulse on time and pulse off time on different responses are discussed in sections A - D. Response surface methodology is the combination of mathematical and statistical techniques is used to find out the relationship between independent and dependent variables. The following analysis were conducted using design expert software. Based on the results obtained the following conclusions were made.

A. Analysis of Variance

ANOVA is the statistical technique used to calculate the size of the difference between data set. The elements of ANOVA table are source of variance, sum of squares, degrees of freedom, mean square, f ratio, and the probability associated with the F ratio. Table 3 shows the ANOVA table for experimental data of MRR and surface roughness as dependent variables, and current, voltage, pulse on time and pulse off time as independent variables.

Material removal rate data analysis: from the model F value of Table 3, 10.62 imply that the model is significant for MRR. There is only a 2.09% chance that a "model F value" could be large due to noise. The values of "prob>F" less than 0.0500 indicate that model terms are significant. Values greater than 0.1000 indicate that model terms are not significant. "adeq precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. This analysis ratio of 9.343 indicates an adequate signal. Therefore the model can be used to navigate the design space.

Surface roughness data analysis: from the model F value of Table 3, 8.43 imply that the model is significant for surface roughness. There is only a 3.13% chance that a "model F value" could be large due to noise. The values of "prob>F" less than 0.0500 indicate that model terms are significant. Values greater than 0.1000 indicate that model terms are not significant. "adeq precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. This analysis ratio of 7.925 indicates an adequate signal. Therefore the model can be used to navigate the design space.

TABLE 3 Analysis of variable for all responses

Material removal rate					
Source	Sum of squares	DF	Mean Square	F-Value	P – Value prob > F
Model	0.016	4	4.098E-003	10.62	0.0209
Current	4.747E-007	1	4.747E-007	1.230E-003	0.9737
Voltage	2.712E-003	1	2.712E-003	7.03	0.0569
Pulse on	3.526E-004	1	3.526E-004	0.91	0.3932
Pulse off	1.681E-004	1	1.681E-004	0.44	0.5454
Residual	1.544E-003	4	3.859E-004		
Total	0.018	8			
Surface roughness					
Model	9.05	4	2.26	8.43	0.0313
Current	0.038	1	0.038	0.14	0.7269
Voltage	1.06	1	1.06	3.94	0.1182
Pulse on	0.51	1	0.51	1.91	0.2391
Pulse off	7.200E-003	1	7.200E-003	0.027	0.8778
Residual	1.07	4	0.27		
Total	10.13	8			

B. ***Effect of current, voltage pulse on time and pulse off time on MRR***

The fig. 2 shows the effect of current and voltage on MRR on inconel 625 work piece material with copper electrode. Based on the graph, if the voltage is increases the MRR also increases. The maximum voltage 5v produces higher MRR 0.16 gm/min. But the current has less influence on MRR as compared with voltage. There is no significant change in MRR if current changes. Similarly the fig. 3 shows the effect of pulse on time and pulse off time on MRR. The pulse off time has more significant on MRR than pulse on time. There is no changes occurs on MRR if the pulse on time increases. So the voltage and pulse off time decides the higher material removal rate than pulse on time and current.

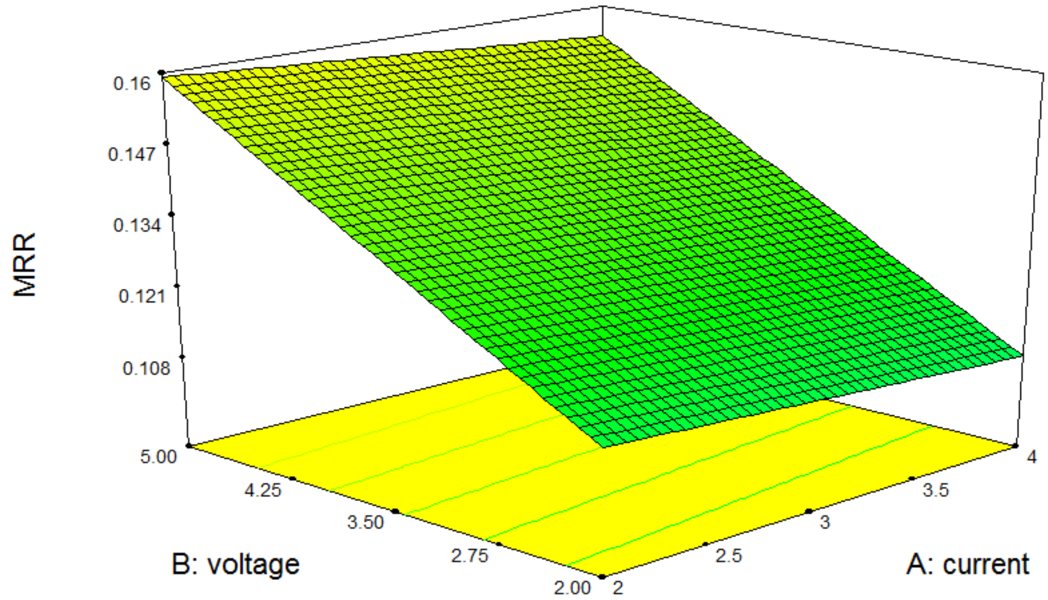


Fig 2. Effect of current and voltage on MRR

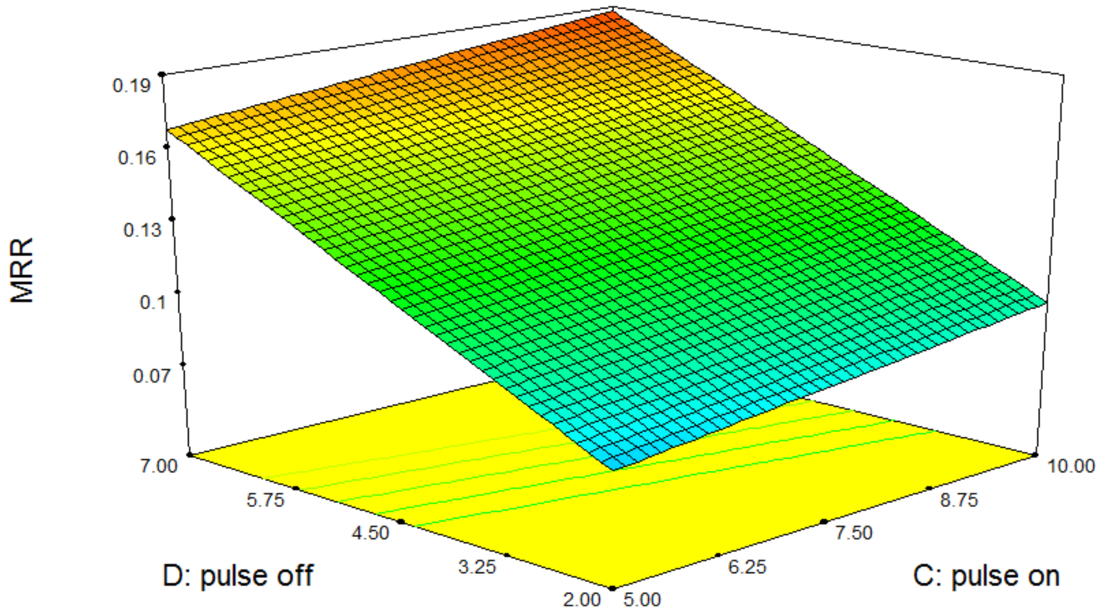


Fig 3. Effect of pulse on time and pulse off time on MRR

C. ***Effect of current, voltage pulse on time and pulse off time on surface roughness***

The fig 4 shows effect of current and voltage on surface roughness with Inconel 625 work piece material. According to the plot the current and voltage increases the surface roughness value also increases. The high level of current 4A and high level of voltage 5V produces the higher surface roughness value of 9.4µm. so the better surface finish occurs at lower levels of current and voltage. Subsequently the fig. 5 shows the effect of pulse off time and pulse on time on surface roughness. The lower level of pulse on time and lower level of pulse on time produces better surface finish than higher levels of pulse off and pulse on time. Finally the lower level of current, voltage, pulse on time and pulse off time produces better surface finish.

D. ***Regression analysis***

The relationship between dependent and independent variable requires a statement of statistical model. This work contains more than one independent variable, so that it needed a regression model. Equations 2 and 3 are the empirical relationship between independent and dependent variables. Here, C, V, Pon and Poff are known as current, voltage, pulse on time and pulse off time, respectively.

$$mrr = -0.025441 - 2.45667E-003*C + 0.015330*V + 4.05567E-003*Pon + 0.018333*Poff \quad (2)$$

$$sr = 3.38733 + 0.69200*C + 0.30267*V + 0.15467*Pon + 0.12000*Poff \quad (3)$$

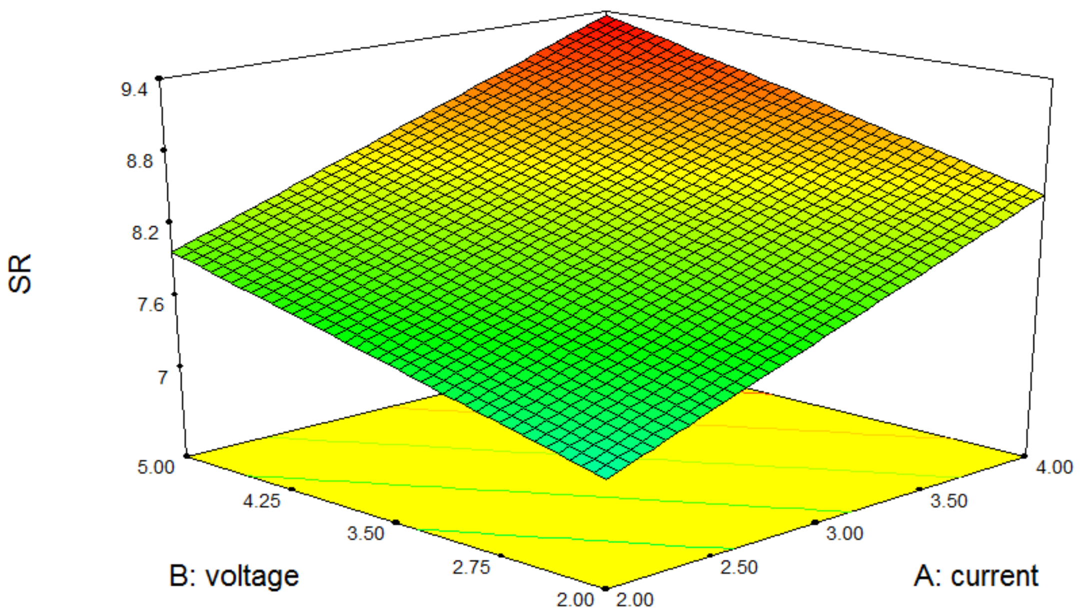


Fig 4. Effect of current and voltage on surface roughness

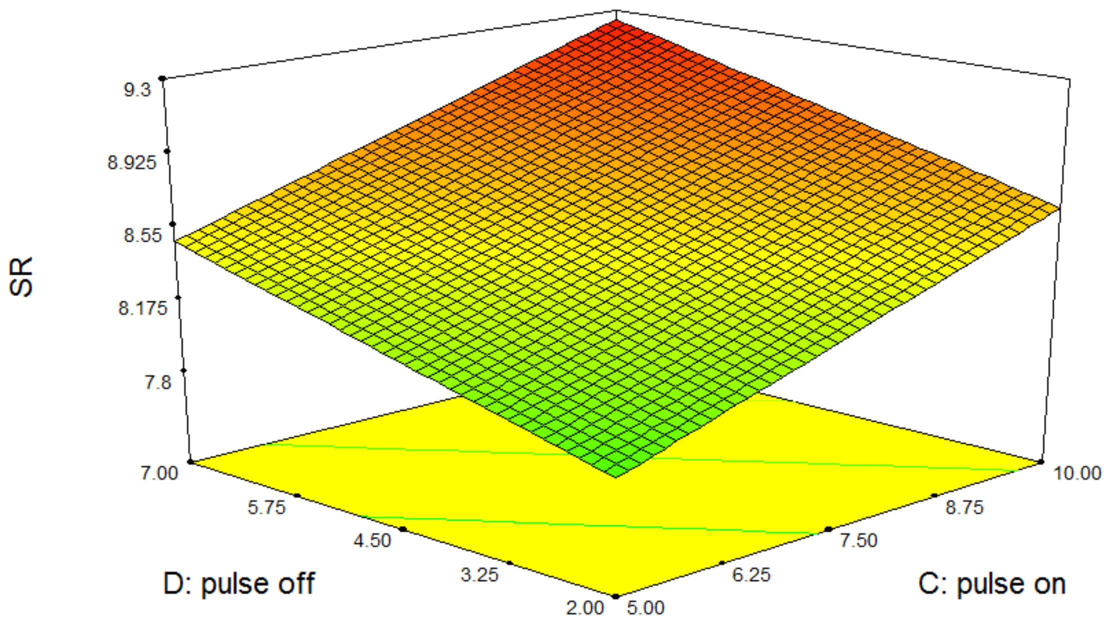


Fig 5. Effect of pulse on time and pulse off time on surface roughness

TABLE 4 Comparison between experimental and RSM value for MRR

CURRENT (A)	VOLTAGE (V)	PULSE ON (μSec)	PULSE OFF TIME (μSec)	EXPERIMENTAL MRR (g/min)	PREDICTED MRR (g/min)	% OF DEVIATION
2	2	5	2	0.044	0.057	-30.100
3	2	6	4	0.0906	0.096	-5.412
4	2	7	7	0.1703	0.152	10.692
2	3	8	2	0.0913	0.085	7.184
3	3	9	4	0.1392	0.123	11.638
4	3	10	7	0.1569	0.180	-14.461
2	5	4	2	0.1059	0.099	6.347
3	5	5	4	0.1262	0.137	-8.904
4	5	6	7	0.1986	0.194	2.303

TABLE 5 Comparison between experimental and RSM value for surface roughness

CURRENT (A)	VOLTAGE (V)	PULSE ON (μSec)	PULSE OFF TIME (μSec)	EXPERIMENTAL SURFACE ROUGHNESS (μm)	PREDICTED SURFACE ROUGHNESS (μm)	% OF DEVIATION
2	2	5	2	5.89	9.44	8.61
3	2	6	4	7.338	6.39	-60.22
4	2	7	7	9.323	7.48	12.92
2	3	8	2	7.266	8.68	19.80
3	3	9	4	8.344	7.16	-19.51
4	3	10	7	9.24	8.24	14.23
2	5	4	2	7.531	9.45	10.79
3	5	5	4	8.271	7.14	-25.48
4	5	6	7	9.005	8.23	13.63
2	2	5	2	5.89	9.44	8.61

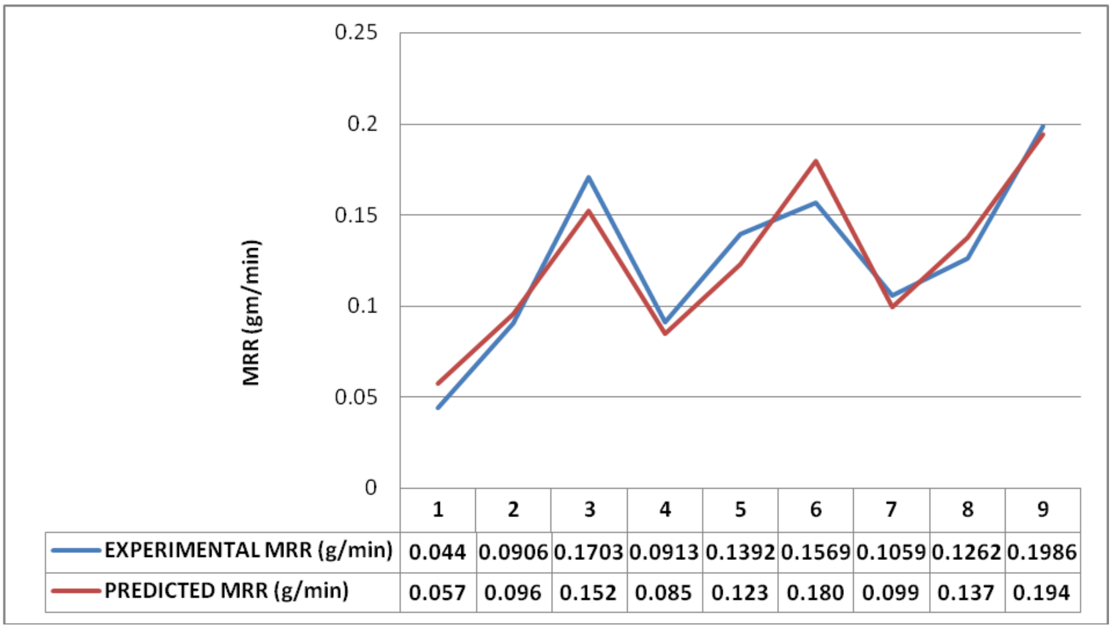
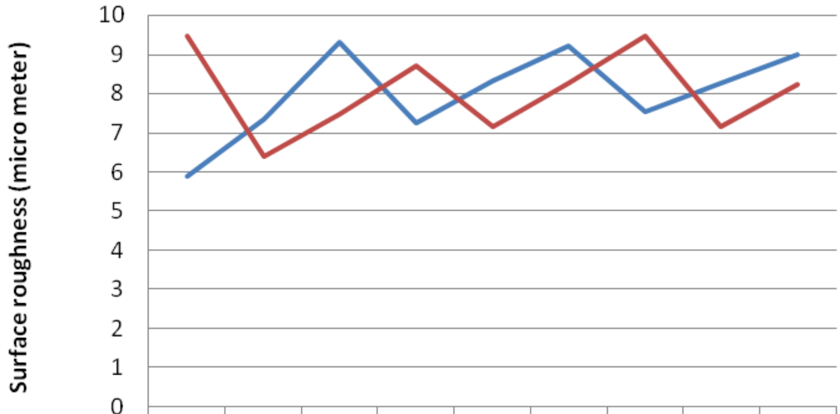


Fig 6. Comparison plot for experimental and RSM value of MRR



	1	2	3	4	5	6	7	8	9
EXPERIMENTAL SURFACE ROUGHNESS (µm)	5.89	7.338	9.323	7.266	8.344	9.24	7.531	8.271	9.005
PREDICTED SURFACE ROUGHNESS (µm)	9.44	6.39	7.48	8.68	7.16	8.24	9.45	7.14	8.23

Fig 7. Comparison plot for experimental and RSM value of surface roughness

The developed models were validated with 9 data sets of experimental design used for the model development. The predicted values of MRR and surface roughness were compared with the corresponding experimental values and the percentage of deviation is tabulated in table 4. Based on experimental and theoretical investigation, the following discussions are made. The average deviation between experimental results and RSM model results are -16.62 for MRR and -20.71 for surface roughness. Thus the equations can be used to predict the MRR and surface roughness value for EDM of Inconel 625 for any combinations of EDM parameters within the range of experiments. The fig 6 and 7 shows the validation results of experimental and RSM value. The validation results show that the experimental and RSM value has smaller deviation.

IV. CONCLUSIONS

This experimental work reveals the following conclusions on EDM operation on Inconel 625 work piece material. Main objective of this work is to develop the empirical model using RSM .

- The response surface methodology is one of the best techniques to identify the effects of machining parameters on EDM process.
- The voltage and pulse off time are have the significant effect on material removal rate. The higher level of voltage and pulse off time produce higher material removal rate. The current and pulse on time are both does not have any impact on aterial removal rate.

- The voltage, current, pulse on time and pulse off time are have significant effect on surface roughness. The higher level of current, voltage, pulse on time and pulse off time are produced the poor surface finish.
- The RSM models were developed based on design of experiment with current, voltage, pulse on time and pulse off time as an input and MRR and surface roughness were responses.
- The RSM model has smaller deviation from experimental data. This confirms that the developed model can be used to predict the MRR and surface roughness value in effective manner.

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