

# Analysis of Wire Wear in WEDM

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## Abstract

**Objective:** This paper emphasizes the effect of cutting parameter on the size of crater and wire wear ratio because wire breakage is most common problem in WEDM and wire crater is very much responsible for wire breakage. **Methods/statistical Analysis:** Many researchers had adopted various methods for the evaluation of the dominating parameters on wire EDM process. In this study Response Surface Methodology (RSM) was used as a statistical analytical tool for the evaluation of the parametric effect on wire creator of wire EDM process. OLYAMPUS BX51M optical microscope was used for the observation of wire creator. For experiment MAXICUT WEDM machine was used and experiment were conducted on INCONEL 625 work piece and zinc coated brass wire of 0.25mm diameter was used. **Finding:** The experiments were conducted under different cutting parameters, which are open circuit voltage, pulse duration, wire speed and flushing pressure. As a result it was found that crater size increases with increase in pulse duration because increased pulse duration contributes to large energy content of spark discharge further it was also found that the creator size also increases with open circuit voltage and feed wire speed whereas decrease with increase in flushing pressure. **Applications/Improvements:** This analysis can become the basis for industries where the manufacturing is done by the wire EDM process and wire breakage is the common problem.

**Keywords:** ANOVA, Crater size, WEDM, RSM, Wire Crater

## 1. Introduction

Wire Electric Discharge Machining (WEDM) is non-traditional machining process, it is mainly a spark erosion process used to produce 2D and 3D structure by using wire as an electrode. Fine surface finish and high degree of accuracy makes it valuable for a manufacturing operation like die forming (stamping dies, extraction dies etc). The advantage of WEDM is work piece is not coming in contact with wire electrode. The insulating property of dielectric fluid is disappear for friction of time when pulse of electricity delivered from power supply, due to this small spark jump the distance between work piece and wire electrode, due that small amount of metal melted out and flush out by dielectric fluid. The appropriate set of machining parameters is very much required for optimum result from WEDM process. The main set of parameters is pulse duration, open circuit voltage, wire speed, and dielectric pressure. During WEDM process wire breakage

is a dominant and time consuming problem. For wire breakage wire crater is very much responsible, and wire crater is affected by these parameters like pulse duration, wire speed, open circuit voltage and flushing pressure. Many publisher work shows that the importance of the surface roughness the material and kerf width on wire breakage. wire breakage also effect the machining rate and product tolerance and for wire breakage wire crater is very much responsible so The investigation of wire creator is very much important for wire rapture, surface roughness, kerf size and for machining accuracy. In<sup>1</sup> has worked towards the prevention of wire rapture by developing the wire edm frequency monitoring system, which detects the thermal load on wire. In<sup>2</sup> had established a finite difference thermal model to understand and predict the thermal distribution along the wire in the zone of discharge channel to predict the wire rapture. In<sup>3</sup> analyze the effect of machining parameters like pulse duration, open

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circuit voltage, wire speed, dielectric voltage, dielectric flush on wire wear ratio. In<sup>4</sup> had analyzed the effect of machining parameters on wire wear ratio and MMR and he also find out that  $T_{on}$  and  $T_{off}$  are the most influencing parameters in MRR. In<sup>5</sup> investigated the nozzle influence on wire breakage and experimentally shown that at short kerf with wire breakage often occurs. In<sup>6</sup> has worked on the fluid flow and debris motion in kerf of wedm by using CFD simulation and analyzed the nozzle shape, flushing position flow rate, and flushing direction for effective debris exclusion and for better performance for In<sup>7</sup> Analyzed the effect of machining parameters like open circuit voltage, pulse duration, wire speed, and dielectric flushing pressure on size wire crater experimentally. In<sup>8</sup> described the effect of six machining parameters that is ( $T_{on}$ ,  $T_{off}$ , pulse duration, open circuit voltage, flushing pressure and wire feed) on wire breakage and surface integrity of material. J.R. In<sup>9</sup> experimentally investigated the effect machining parameters on wire wear rate and has Experimentally find out that peak current increases the wire wear slowly but pulse on time increase wire wear rapidly. In<sup>10</sup> determined the effect of various parameters on the wire strength and evaluate some practical equation for wire strength. Fracture and material yielding are the cause of wire failure. In<sup>11</sup> investigate that for the same material removal rate zinc coated brass wire performed better than bare brass wire and wire wear rate is also lower in zinc coated brass wire. S. In<sup>12</sup> Attempt to predict the erosion of wire EDM electrode from the temperature calculation during the single discharge. A Heat affected zone in the wire is described as the portion which temperature is greater than recrystallization value. In<sup>13</sup> After number of tasting by using EDM pulse analyzer system, proven that thermal loading is the major factor for wire rapture. In<sup>14</sup> A energy driven model is proposed by author to determine the wire crater and also determine that erosion energy is required to form a crater by using physiothermal properties of the material. I. In<sup>15</sup> develop a acquisition system, which can store extensive experimental data of stable and unstable tests on WEDM, to predict the wire breakage.

## 2. Experiments

The experimental work and studies were performed on a 5-axes ELECTRONICA MAXICUT MACHINE TOOL figure(1). Different setting of parameters are used for experiments like pulse duration ( $T_{on}$ ), open circuit voltage ( $S_v$ ), wire speed ( $V$ ), dielectric flushing ( $Q$ ).

Throughout the experiment pulse interval time, table feed, wire tension kept constant. In this experiment There are 31 different combination of machining parameters are used,. Zink coated brass wire with 0.25mm diameter and deionized water as the dielectric fluid have been used during experimentation is used in this experiment. INCONEL ALLOY 625 used as a work piece material in this experiment (table 1). Small thickness material is used in this experiment due to prevent overlapping of crater to make size measurement easy. A photograph of wire crater is shown in figure(2a, b) .The wire crater size is measured by diameter( $d$ ) and area ( $A$ ). The size measured in this study are average of 10 crater on each sample of the wire for crater measurement OLYAMPUS BX51M Optical microscope with 0.002 mm accuracy is used (figure 3). The levels of the input parameters have been determined by conducting pilot experiments on the material. Five levels for each of the four factors (Table 2) have been used for a full factorial design with single replication.

The Experiment is designed by MINITAB 17 software and data of wire crater dimensions are collected by using optical microscope ,which is shown in (Table 3), collected data has been analyzed by using RSM software and Mathematical relationships between the process parameters and performance measures have been developed.



Figure 1. Experimental setup.

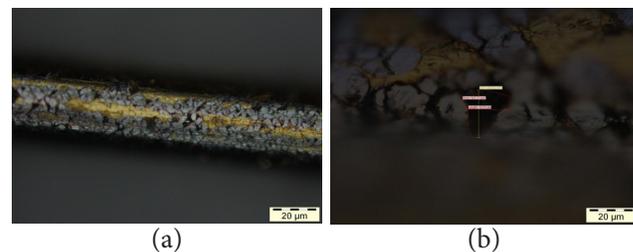


Figure 2. (a). Wire Crater. Image (b). used wire image.



**Figure 3.** Optical microscope (OLYMPUS BX51M).

**Table 1.** composition of INCONEL 625

Materials	%
Ni	58 min
Cr	20-30
Mo	8-10
Nb+Ta	3.15-4.15
Fe	5

**Table 2.** Levels of Process Parameters

Control factor→ level↓	Pulse duration(μs)	Open circuit voltage(v)	Dielectric flushing pressure (kg cm <sup>-2</sup> )	Wire speed (m min <sup>-1</sup> )
+2	1.35	75	8	9
+1	1.25	65	7	7
0	1.17	55	6	5
-1	1.05	45	5	3
-2	0.95	35	4	1

## 3. Result and Discussion

### 3.1 Response Surface Methodology

In<sup>16</sup> observed that RSM is the most powerful tool and widely used technique to analyze accurate values with limited number of process parameters. In<sup>17</sup> analyzed that It is a collection of mathematical and statistical techniques that are useful for modeling and analysis of responses which are influenced by several variables. In<sup>18</sup> analyze that the response can be represented graphically, either in a three-dimensional space or as contour plots that helps to visualize the shape of the response surface. In this work, RSM is chosen to develop the mathematical models. In<sup>19</sup> conclude that The most

**Table 3.** Experimental design and finding

SN	TON	SPEED	SV	Q	Dia	Area
1	-1	-1	-1	-1	77.87	4762.54
2	1	-1	-1	-1	181.99	15707
3	-1	1	-1	-1	88.32	6127
4	1	1	-1	-1	130.9	11300.86
5	-1	-1	1	-1	46.394	3846.193
6	1	-1	1	-1	12.89	130.5
7	-1	1	1	-1	108.61	12654
8	1	1	1	-1	113.47	10114.8
9	-1	-1	-1	1	120	11309.8
10	1	-1	-1	1	153.16	13100
11	-1	1	-1	1	120.65	11433
12	1	1	-1	1	134.52	14213.6
13	-1	-1	1	1	11.35	101.27
14	1	-1	1	1	22.11	384.19
15	-1	1	1	1	168.58	15820.25
16	1	1	1	1	129.43	13158.8
17	-2	0	0	0	14.03	154.8
18	2	0	0	0	121.51	11597.2
19	0	-2	0	0	136.56	14647.2
20	0	2	0	0	183.39	26417.38
21	0	0	-2	0	134.78	14269.8
22	0	0	2	0	16.2	206.144
23	0	0	0	-2	135.49	6249.504
24	0	0	0	2	94.82	7045.25
25	0	0	0	0	91.78	162.96
26	0	0	0	0	121.52	11599.4
27	0	0	0	0	100.012	202.24
28	0	0	0	0	91.82	6622.1
29	0	0	0	0	161.87	8828.227
30	0	0	0	0	156.62	7578.123
31	0	0	0	0	100.012	679.89

common forms of RSM are low-order polynomials (first or second-order). First order model of RSM shows very low predictability, so second order model is preferred. Also if there is curvature in the system, then a second order polynomial must be used. The second order model is expressed as

$$y = b_0 + \sum_{i=1}^n b_i x_i + \sum_{i=1}^n b_{ii} x_i^2 + \sum_{i < j} b_{ij} x_i x_j + \epsilon$$

Where,  $y$  is the response variable,  $x_i$  are the independent variables,  $b_i$  &  $b_{ij}$  are the coefficients,  $\epsilon$  is the experimental error.

Empirical relations between the process parameters and performance measures have been developed using MINITAB 17 statistical software as given below:

DIA-

$$116.455 + 14.652\text{TON} + 19.266\text{V} - 26.322\text{SV} - 12.903\text{TON} \times \text{TON} + 10.149\text{SPEED} \times \text{SPEED} - 10.973\text{SV} \times \text{SV} - 5.773\text{TON} \times \text{SPEED} - 15.673\text{TON} \times \text{SV} + 30.374\text{SPEED} \times \text{SV}$$

AREA-

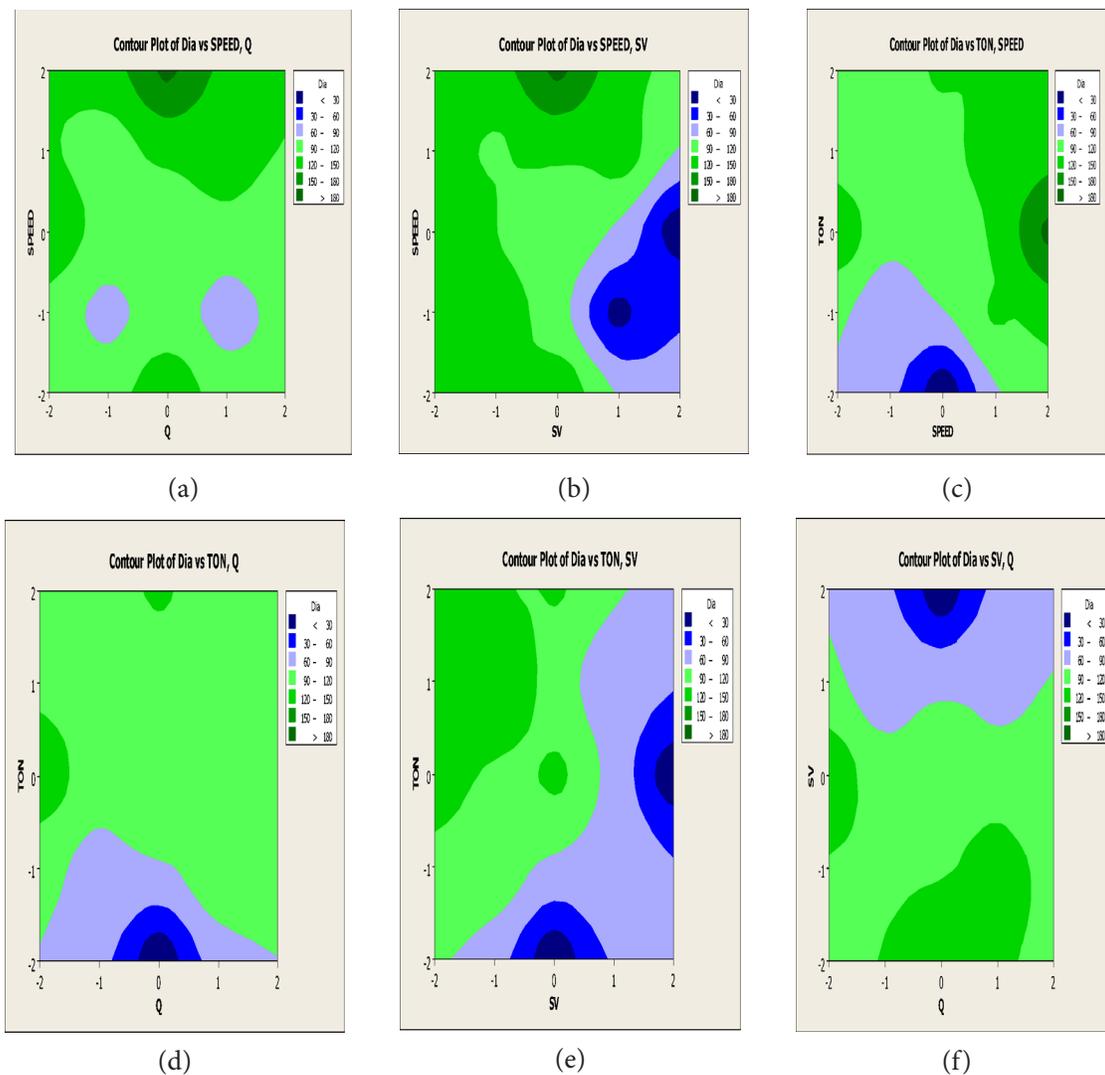
$$5311.23 + 1455.85\text{TON} + 2875.88\text{SPEED}$$

$$2494.63\text{SV} - 4.63\text{TON} \times \text{TON} + 3659.44\text{SPEED} \times \text{SPEED} + 335.86\text{SV} \times \text{SV} - 409.25\text{TON} \times \text{SPEED} - 1832.66\text{TON} \times \text{SV} + 3068.16\text{SPEED} \times \text{SV}$$

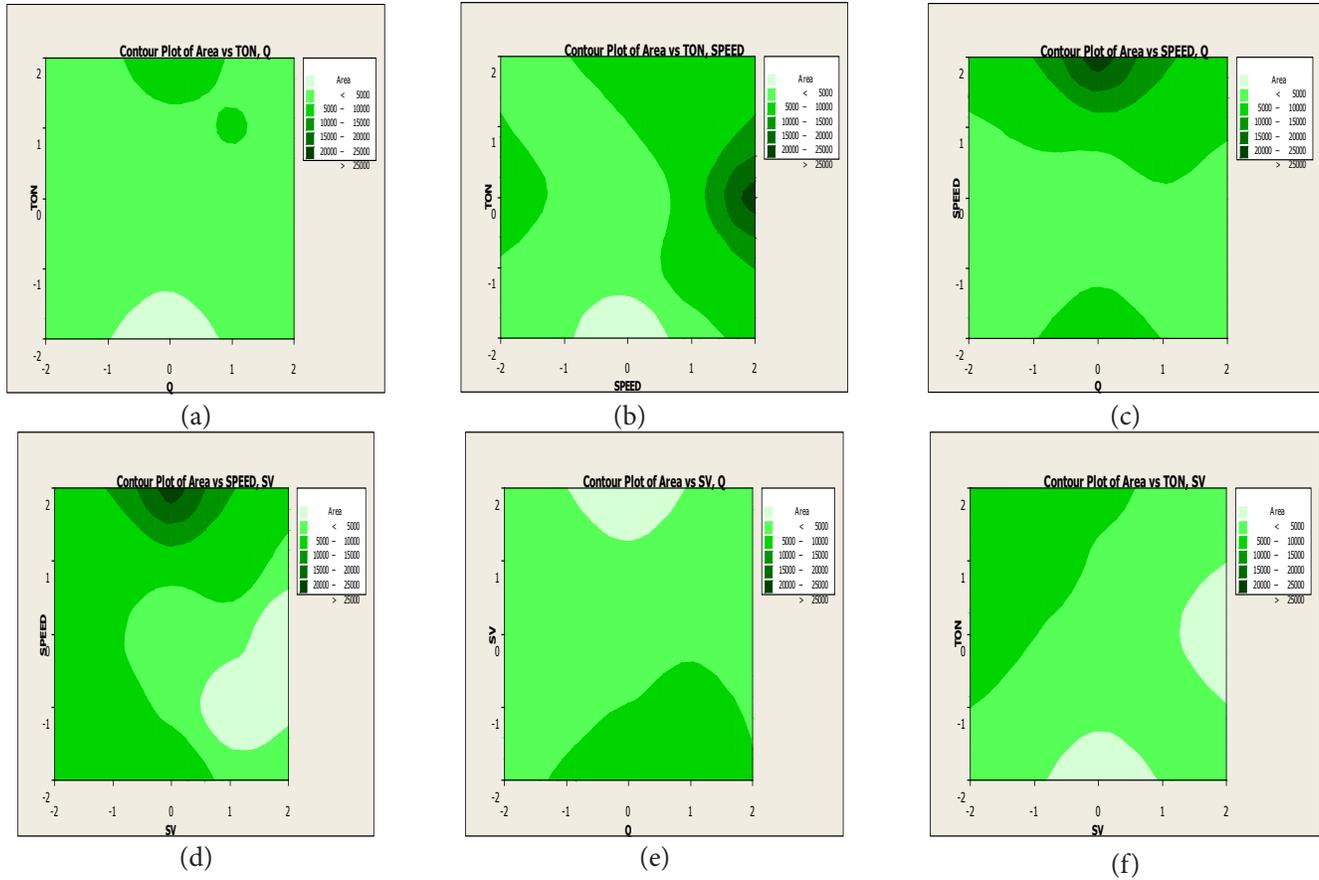
These mathematical relations shows the most affect- ing parameters which affects most the crater dimensions like diameter and area.

### 3.2 Analysis of Plots

Analysis of experimental data were done by the response surface methodology (RSM) and contour graphs are plotted with different response parameters (Area and Diameter) with machining parameters (Ton, speed, Sv, Q) Shown in Figure 4 and 5.



**Figure 4.** (a). Dia vs speed and Q. (b). Dia vs speed and sv. (c). Dia vs Ton and speed. (d). Dia vs Ton and Q. (e). Dia vs Ton and sv. (f). Dia vs sv and Q.



**Figure 5.** (a). Area vs Ton and Q. (b). Area vs Ton and Q. (c). Area vs Ton and speed. (d). Area vs speed and sv. (e). Area vs sv and Q. (f). Area vs Ton and sv.

### 3.3 Contour Plots between Diameter and Various Machining Parameters

Figure 4(a,b,c,d,e,f) shows that the effect of machining parameters like Ton, wire speed, flushing pressure, open circuit voltage on crater diameter. These graphs show the interaction between crater diameter and all the variable parameters. Graphs show that increase with pulse duration, open circuit voltage, and wire speed crater diameter increases and increase with flush pressure wire crater diameter is decreases.

### 3.4 Contour plots between Area and Various Machining Parameters

Figure 5(a,b,c,d,e,f) shows that the effect of machining parameters like Ton, wire speed, flushing pressure, open circuit voltage on crater area. These graphs show the interaction between crater area and all the variable parameters. Graphs show that increase with pulse duration, open circuit voltage, and wire speed crater area increases and increase with flush pressure wire crater area is decreases.

### 3.5 Analysis of Variance for Diameter

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	61903	61903	6878.1	10.55	0.000
Linear	3	30689	30689	10229.8	15.68	0.000
Square	3	11990	11990	3996.5	6.13	0.004
Interaction	3	19224	19224	6408.1	9.82	0.000
Residual Error	21	13697	13697	652.3		
Lack-of-Fit	5	2999	2999	599.7	0.90	0.507
Pure Error	16	10699	10699	668.7		
Total	30	75601				

### 3.6 Analysis of Variance for Area

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	996797146	996797146	110755238	9.82	0.000
Linear	3	398721282	398721282	132907094	11.79	0.000
Square	3	391040054	391040054	130346685	11.56	0.000
Interaction	3	207035810	207035810	69011937	6.12	0.004
Residual Error	21	236769736	236769736	11274749		
Lack-of-Fit	5	40370162	40370162	8074032	0.66	0.660
Pure Error	16	196399574	196399574	12274973		
Total	30	1233566883				

These are ANOVA tables, which obtained by the RSM method. ANOVA table also called variance table. Usually it is used to check the accuracy of the table. Degree of freedom or DF shows that these are free to vary. Sequential sum of square shows the variation due to specific factor. Basically sequential sum of square or SEQSS varies due to the specific factor, it totally depends upon the order of factor entered into the model. seqss is equal to the Adjss also called adjusted sum of square due to the orthogonal design of the present work. Adjss does not depend upon the factor entered in to the model, ADJMS is called adjusted mean square and mathematically and it is also equal to the ratio of the seqss to DF, F – value is used as the for the F-test and is taking all factor at a time or to find out the regression co-efficient. F-values are used to calculate the P-value and  $\alpha$  value used to check the significant of model. Anova table for WWR, AREA, and for DIA shows that model is quite significant.

## 4. Conclusion

In this analysis, the effect of machining parameters like open circuit voltage, pulse duration, wire speed and dielectric pressure and the dimension of wire crater is experimentally analyzed in WEDM. Mathematical relationships between the process parameters and performance measures have been developed. The most effective machining parameter are open circuit voltage and pulse duration which are verified by ANOVA method and F-test analysis. Dielectric flushing pressure and wire speed are the less influencing machining parameters.

## 5. References

1. Wang WM, Rajurkar KP. Monitoring sparking frequency and predicting wire breakage in WEDM. ASME Production Engineering Division. 1992; 55:49–64
2. Banerjee S, Prasad BVSSS, Mishra PK. A simple model to estimate the thermal loads on an EDM wire electrode. Journal of Materials Processing Technology. 1993; 39:305–17.
3. Tosun N, Cogun C. (An investigation on wire wear in WEDM), Received 20 feb 2002. received in revised form 19 july 2002, accepted 29 october 2002.
4. Goswami A, Kumar J. Investigation of surface integrity, material removal rate and wire wear ratio for WEDM of Nimonic 80A alloy using GRA and Taguchi method, Received 20 March 2014 Received in revised form 7 May 2014 Accepted 14 May 2014.
5. Okada A, Konishi T, Okamoto Y, Kurihara H. ( Wire breakage and deflection caused by nozzle jet flushing in wire EDM)
6. Okada A, Uno Y, Onoda S, Habib S. (Computational fluid dynamics analysis of working fluid flow and debris movement in wire EDMed kerf)
7. Tosun N, Cogun C, Pihtili H. The Effect of cutting parameters on wire crater size in wire EDM) 2003 Springer-Verlag London Limited
8. Kumar A, Kumar V, Kumar J. Parametric Effect on Wire Breakage Frequency and Surface Topography in WEDM of Pure Titanium. 2013 Sep; 1.
9. Mevada JR, Shah CD, Khatri BC. A Wear Investigation of Repeatedly used Wire in Wire Cut Electrical Discharge Machine. 2012 Dec; 2(12).
10. Luov YF. Rupture failure and mechanical strength of the electrode wire used in wire EDM. 1998 Mar 12.
11. Ranganath BJ, Sudhakarand KG, Srikantappa AS. Wire failure analysis in wire EDM process. 2003 Dec.
12. Banerjee SI, Prasad BVSSS, Mishra PK. Analysis of three-dimensional transient heat conduction for predicting wire erosion in the wire electrical discharge machining process. 1995 Jun 6.
13. Dekeyser W, Snoeys R, Jennes M. A thermal model to investigate the wire rupture phenomenon for improving performance in EDM wire cutting. 1985; 4(2).
14. Giridharan A, Samuel GL. Modeling and analysis of crater formation during wire electrical discharge turning (WEDT) process. Received: 4 July 2014 /Accepted: 20 October 2014 /Published online: 6 November 2014 Springer-Verlag London 2014
15. cabanes I, Portillo E, M. arcos JA. Sa'nchez (An industrial application for on-line detection of instability and wire breakage in wire EDM) Received 30 August 2006 Received in revised form 15 December 2006 Accepted 19 April 2007
16. Hewidy MS, El-Taweel TA, El-Safty MF. Modelling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM. Journal of Materials Processing Technology. 2005; 169(2):328–36
17. Dubey AKr, Dubey V. Experimental study of Nd: YAG laser beam machining-An overview. Journal of Materials and Processing Technology. 2008; 195:15–26.
18. Montgomery DC. Design and analysis of Experiments. 2011, 5th Edition, John Wiley & sons, Inc
19. Kumar A, Kumar V, Kumar J. Prediction of Surface Roughness in Wire Electric Discharge Machining (WEDM) Process based on Response Surface Methodology. International Journal of Engineering and Technology. 2012 Apr; 2(4):708–19.