Mathematical Modelling and Analysis of Machining Parameters in WEDM for WC-10%Co Sintered Composite

Y.S.Sable [1], R.B.Patil [2], Dr.M.S.Kadam [3]

Abstract - In this paper, effect of wire electrical discharge machining parameters on WC-10%Co sintered composite is studied. Influence of pulse-on time, pulse-off time, peak current, servo voltage and wire tension are investigated for surface roughness (R_a) during machining of Tungsten carbide Cobalt sintered composite. In order to analyse the effect of process parameter on response characteristics Response surface methodology is used. Based on face-centred central composite design for five experiments and five levels 32 experiments were conducted. A mathematical equation is derived to predict performance. The validity of derived model was verified. Since error obtained was 4.19 %, higher coefficient of determination is 99.26 %, the model is valid. Surface, response contour plots were utilized to analyze performance. ANOVA was used to find out the most significant parameters which affect the response characteristics.

Key words: ANOVA, Response surface methodology, Surface roughness, WC-10%Co

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1 INTRODUCTION

WEDM is a versatile thermo-electric process. In WEDM the material is removed by a series of electrical circuit controlled discrete discharges between the wire electrode and the work material in the presence of a dielectric fluid. Which creates a path for each discharge as the fluid becomes ionized in the gap. The region in which discharge occurs is heated to extremely high temperatures, so that the work surface is melted and removed [1]. The control parameters are spark exposure time (On-time), capacitor charging time (Off-time), current intensity (Ignition- current), servo voltage , electrode wire tension, dielectric supply pressure, work material melting temperature, wire feed speed, machine rigidity-capability, which can classify as machine parameter, material parameter, electrical parameter, and mechanical parameter. Five important parameters of significance were selected in the present work- pulse-on time, pulse-off time, peak current, servo voltage and wire tension for Surface roughness response characteristics. Response-surface methodology (RSM) is one of the important techniques in statistics used to determine the relationship between the effects of process parameters and responses [2]. A lot of works being done with other materials but there have not been significant research publications till today on processing of these hard WC-Co composite materials by WEDM. Kanagarajan and Palanikumar [3] have studied influence of pulse on time, current, and flushing pressure on Material removal rate and Surface roughness while machining WC-30%Co composites and using RSM developed a model that relates the effect of process parameter on response parameter. Lee and Li [4] elucidated the effect of discharge energy on integrity of EDMed surface of tungsten carbide. It was found that the surface roughness is a function of two main parameters: peak current and pulse duration. At high peak current and or long pulse duration, rough surface and abundance of micro-cracks were observed. P. Saha, and S. K. Pal [5] have done optimization of WEDM parameters using NSGA II. Experiments were carried out based on Taguchi design of experiments involving six control factors such as pulse on-time, pulse off-time, peak current, capacitance, gap voltage, and wire feed rate. Cutting speed, surface roughness and kerf width were considered as the measures of performance of the process.

Literature review states RSM is a combination of mathematical and statistical techniques and is used for developing improved and optimizing the parameter for the output responses. S. S. Baraskar, S. S. Banwait, and S. C. Laroiya [6] have been developed model for SR, MRR and TWR for most significant process parameters namely dis-charge current, pulse-on time and pulse-off time using response surface methodology in EDM process of EN-8 steel with copper electrode and statistical analysis were done for response characteristics. Mohan Kumar Pradhan and Chandan Kumar Biswas [7] Response surface methodology was used to investigate the relationships and parametric interactions between the three controllable variables namely discharge

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current, pulse duration, and pulse off time on the material removal rate (MRR). Experimentation has done with pulse on time, wire tension, delay time, wire feed speed and ignition current intensity as input parameters for three responses namely material removal rate, surface roughness, and wire wear ratio. The machining parameters are optimized with the multi response characteristics of the material removal rate, surface roughness, and wire wear ratio. K. Jangra and S. Grover [8] Developed mathematical model and investigated the multimachining characteristics in WEDM of WC-5.3%Co composite using a Response surface methodology. four input parameters –pulse-on time, pulse-off time, servo voltage and wire feed – were investigated for four output machining characteristics: CS, SR, and RoC. Anish Kumar, Vinod Kumar and Jatinder Kumar [9] Investigated the effect of WEDM parameters namely pulse on time, pulse off time, peak current, spark gap voltage, wire feed and wire tension on surface roughness. The surface roughness has been optimized using multi-response optimization through desirability. The ANOVA has been applied to identify the significance of developed model. The test results confirm the validity and adequacy of the developed RSM model.

2 EXPERIMENTAL WORK

In the present research work, a 5-axis CNC WEDM, Electronica Machine Tools Ltd., India, SPRINT CUT-734 was used for the study. Brass wire electrode of 0.25 mm diameter employed as tool electrode, distilled water used as cooling media. This study took WC-10% Co sintered composite as the workpiece material. The composition and the physical properties of the work-piece are given in TABLE 1

In present investigation, five important WEDM parameters, namely pulse-on time, pulse-off time, peak current, servo voltage and wire tension has been considered with five levels each as shown in TABLE 2. The parameter range was selected on the basis of pilot experiments and literature survey and other parameters are kept constant at their default settings.

TABLE 1 COMPOSITION AND PHYSICAL PROPERTIES OF WC-10% Co

Composition	WC-90 wt%, Co 10 wt%
Hardness (Hv 30)	>1550
Transverse Rupture Strength (N/mm2)	>3600
Grain Size	0.7 microfine

The response variables Surface roughness (R_a) is measured by Hommel Tester T500 in test lab of Indo German Tool room, Aurangabad. Surface roughness tester traces the surface of various machine parts and calculates the R_a based on roughness standards and displays the results in µm.

model, the combination of factors that gives the best response, can then be established. The WEDM process was studied with a standard RSM design, CCD. The MINITAB 16 software was

3 EXPERIMENTAL DESIGN

The experiments were performed using face-centred central composite design. The pilot experimentation was done for the selection of process parameters levels during machining. Table 2 shows the process parameters and their levels.

TABLE 2 PROCESS PARAMETERS AND THEIR LEVELS

Parameters	**Levels**				
	-2	-1	0	+1	+2
T_{on}	106	112	118	124	130
T_{off}	30	34	38	42	46
IP	190	200	210	220	230
SV	15	20	25	30	35
WT	4	6	8	10	12

4 RESPONSE SURFACE METHODOLOGY

Response surface methodology is a collection of statistical and mathematical methods that is useful for modeling and analysis of engineering problems. In this technique, the main objective is to optimize the response surface that is influenced by various process parameters. The RSM has been applied for modeling and analysis of machining parameters in the WEDM process in order to obtain the relationship to the surface roughness. In the RSM, the quantitative form of relationship between desired response and independent input variables is represented as follows:

$$Y = f\,(T_{on}, T_{off}, IP, SV, WT) \pm \varepsilon \qquad (1)$$

Where y is the response (yield), f is the response function, ε is the experimental error, and T_{on}, T_{off}, IP, SV, and WT are independent parameters. By plotting the expected response of Y, a surface, known as the response surface, is obtained. The form of f is unknown and may be very complicated. Thus, RSM aims to approximate f by a suitable lower ordered polynomial in some region of the independent process variables. If the response can be well modelled by a linear function of the independent variables, the function (equation (2)) can be written as

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots.. + \beta_k x_k + \epsilon \qquad (2)$$

However, if a curvature appears in the system, then a higher order polynomial such as the quadratic model (equation (3)) may be used

$$Y = \beta_0 + \sum_{i=1}^{K} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X^2_{ii} + \sum_{i=1}^{k} \beta_{ij} X_i X_j \qquad (3)$$

The objective of using RSM is not only to investigate the response over the entire factor space, but also to locate the region of interest where the response reaches its optimum or near optimal value. By studying carefully the response surface used for regression and graphical analysis of the data obtained. The optimum values of the selected variables were obtained by solving the regression equation and by analyzing the response surface contour plot.

5 MATHEMATICAL MODELLING

The 32 experiments according to CCD design were conducted and R_a values were obtained for each experimental run as listed in TABLE 3.

TABLE 3 EXPERIMENTAL RESULTS

Trial No.	T_{on} (µs)		T_{off} (µs)		IP (A)		SV (V)		WT (gram)		R_a (µm)
	actual	coded	actual	coded	actual	coded	actual	coded	actual	coded	
1	112	-1	34	-1	200	-1	20	-1	10	1	2.01
2	124	1	34	-1	200	-1	20	-1	6	-1	2.72
3	112	-1	42	1	200	-1	20	-1	6	-1	1.75
4	124	1	42	1	200	-1	20	-1	10	1	2.59
5	112	-1	34	-1	220	1	20	-1	6	-1	2.19
6	124	1	34	-1	220	1	20	-1	10	1	2.98
7	112	-1	42	1	220	1	20	-1	10	1	1.95
8	124	1	42	1	220	1	20	-1	6	-1	2.8
9	112	-1	34	-1	200	-1	30	1	6	-1	1.23
10	124	1	34	-1	200	-1	30	1	10	1	1.95
11	112	-1	42	1	200	-1	30	1	10	1	1.06
12	124	1	42	1	200	-1	30	1	6	-1	1.88
13	112	-1	34	-1	220	1	30	1	10	1	1.52
14	124	1	34	-1	220	1	30	1	6	-1	2.28
15	112	-1	42	1	220	1	30	1	6	-1	1.25
16	124	1	42	1	220	1	30	1	10	1	1.99
17	106	-2	38	0	210	0	25	0	8	0	1.18
18	130	2	38	0	210	0	25	0	8	0	2.8
19	118	0	30	-2	210	0	25	0	8	0	2.14
20	118	0	46	2	210	0	25	0	8	0	1.72
21	118	0	38	0	190	-2	25	0	8	0	1.71
22	118	0	38	0	230	2	25	0	8	0	2.18
23	118	0	38	0	210	0	15	-2	8	0	2.68
24	118	0	38	0	210	0	35	2	8	0	1.26
25	118	0	38	0	210	0	25	0	4	-2	1.94
26	118	0	38	0	210	0	25	0	12	2	2.06
27	118	0	38	0	210	0	25	0	8	0	1.96
28	118	0	38	0	210	0	25	0	8	0	1.98
29	118	0	38	0	210	0	25	0	8	0	2.04
30	118	0	38	0	210	0	25	0	8	0	2.02
31	118	0	38	0	210	0	25	0	8	0	1.98
32	118	0	38	0	210	0	25	0	8	0	2.03

For analysis of the data, to check the good fit of the model Analysis of Variance is very much required. Model adequacy checking includes testing for significance of the regression model, for significance on model coefficients, and for lack of fit. For this purpose, ANOVA is performed.

The ANOVA of the model for R_a is shown in TABLE 4. The lack-of-fit term is insignificant, which is desired. The result of the model for R_a is given in TABLE 4. The value of R^2 = 99.26 %, R^2 (adj) = 99.12 %, R^2 (pred.) = 98.82 % which means that the regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response R_a .The associated P-value for the model is lower than 0.05 (i.e. α = 0.05, or 95 per cent confidence), indicating that the model is considered to be statistically significant [7].

Regression equation is in terms of uncoded parameters:

Surface Roughness (R_a) = - 5.39233 + 0.06576*T_{on} - 0.02552 * T_{off} + 0.01129 * IP -0.07225 * SV + 0.00396 * WT
(4)

TABLE 4 ANOVA OF MODEL

Source	DF	Seq SS	MS	F	P	
Regression	5	7.42635	1.48527	701.58	0.000	Significant
Residual Error	26	0.05504	0.00212			
Lack-of-Fit	21	0.04976	0.04976	2.24	0.189	Not Significant
Pure Error	5	0.00528	0.00106			
Total	31	7.48140				
S = 0.0460112 PRESS= 0.0879994 R-Sq = 99.26% R-Sq(pred) = 98.82% R-Sq(adj) = 99.12%						

Fig. 1 displays the normal probability plot of the residuals for MRR. Notice that the residuals are falling on a straight line, which means that the errors are normally distributed and the regression model agree fairly well with the observed values.

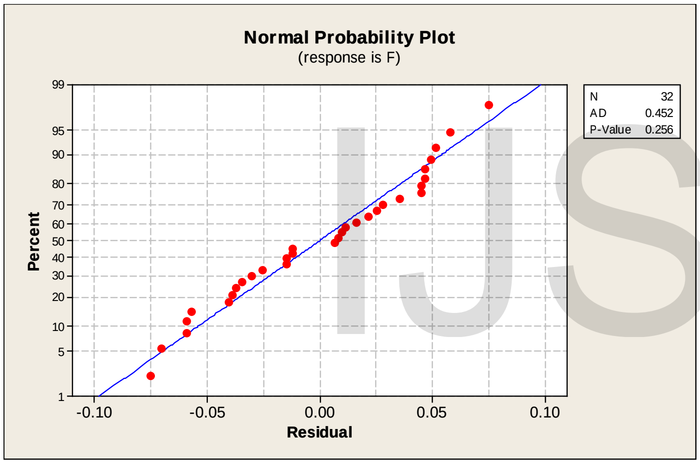

Fig. 1 Normal probability plot

6 RESULT AND DISCUSSION

From ANOVA TABLE 5 Pulse on time, Pulse off time, Peak, current, Servo voltage, are significant parameters for R_a, because their P value<0.05. In TABLE 5 from the percentage of contribution column it is clear that contribution or effect of Pulse on time higher 49.94% and below to that Servo voltage 41.86 % hence most significant. Peak current and Pulse off time having contribution 4.09%, 3.34%, respectively hence significant. Wire tension having percentage of contribution is 0.00% hence it is not significant.

6.1 Response analysis

From fig. 3 a it is clear that the surface roughness has an increasing trend with the increase of pulse on time and at the same time it decreases with the increase of pulse off time. The surface roughness is most affected by the amount of discharge energy which increases with increase in pulse on-time. The surface roughness depends on the size of spark crater which mainly depends on the discharge energy and re-deposition of melted material on work surface. Increasing pulse-on time

TABLE 5 PARAMETER ANOVA FOR R_a

Source	DF	Seq SS	MS	F	P	% p of Contribution	Remark
TON	1	3.73670	3.73670	1765.07	0.000	49.94%	Most Significant
TOFF	1	0.25010	0.25010	118.14	0.000	3.34%	significant
IP	1	0.30600	0.30600	144.54	0.000	4.09%	significant
SV	1	3.13204	3.13204	1479.45	0.000	41.86%	Most Significant
WT	1	0.00150	0.00150	0.71	0.407	0.00%	Not Significant
Total	31	7.48140					

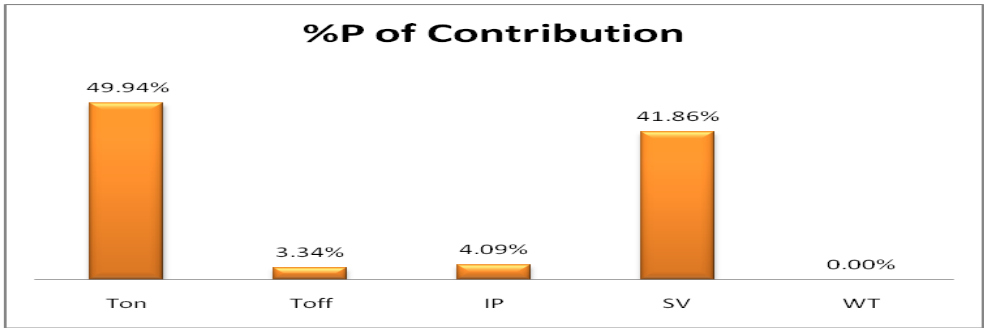

Fig. 2 Percentage contribution of parameters

increases the discharge energy across the electrodes which results in deeper erosion crater on the work surface and hence increases the surface roughness. Increasing Pulse off time-value increases the time between two consecutive sparks which results in complete flushing of the carbide debris out of the spark gap, and hence low re-deposition of eroded material results in low surface roughness. It is seen from Fig. 3 b that surface roughness increases slightly with increase in the peak current values. The higher is the peak current setting, the larger is the discharge energy. This leads to increase in surface roughness. It is observed from Fig. 3 c that surface roughness decreases with increase in servo voltage. Decreasing servo voltage Increases the discharge energy across the electrodes which results in deeper erosion crater on the work surface and hence increases the surface roughness. It is seen from Fig.3 d that surface roughness shows mild tendency to increase with increase in the wire tension. This can be attributed to minimize the wire bending due to increase wire tension which leads to a dynamic condition of wire.

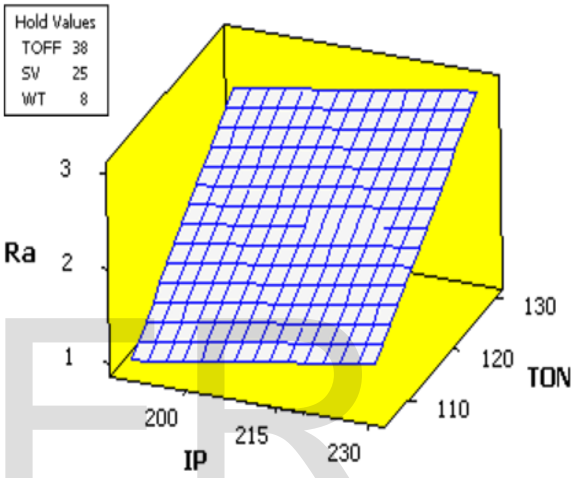

Fig. 3 b Surface Plot of R_a vs T_{on}, IP

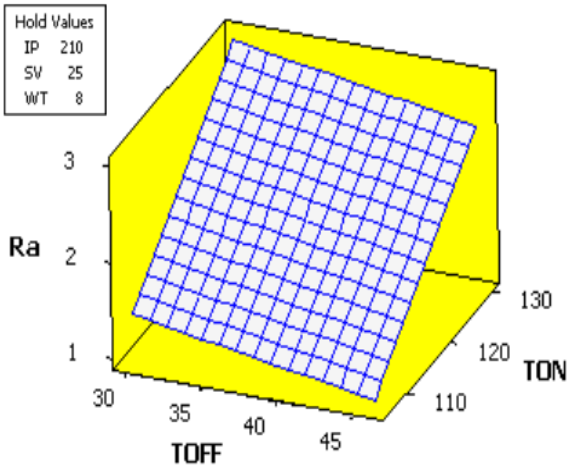

Fig. 3 a Surface Plot of R_a vs T_{on}, T_{off}

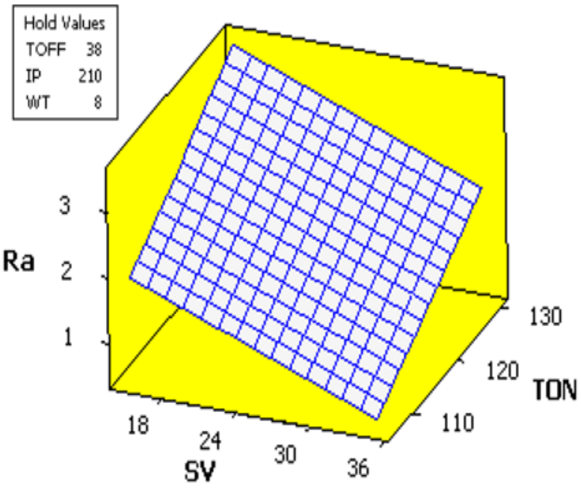

Fig. 3 c Surface Plot of R_a vs T_{on}, SV

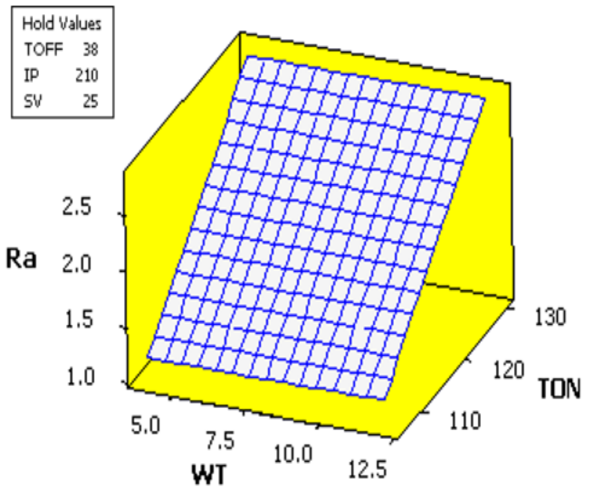

Fig. 3 d Surface Plot of R_a vs T_{on}, WT

7 CONCLUSION

In this study, the effects of the Pulse on time, Pulse off time, Peak current, Servo voltage, and Wire tension on the Surface roughness were experimentally investigated in WEDM for WC-10%Co sintered composite. It is found that increasing the Pulse on time, Peak current and Wire Tension the Surface roughness value increases. Whereas increasing the Pulse off time, Servo voltage the Surface roughness value decreases.

The mathematical relationships between the process parameter and response parameter are established by Response surface methodology. Analysis of variance (ANOVA) on experimental data shows that model is statically significant.

The most significant parameter for R_a is Pulse on time and Servo Voltage. Whereas, Peak current, Pulse off time are the significant parameters. Wire tension is not significant parameter for R_a base on ANOVA method.

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