International Journal of Advanced Mechanical Engineering.
ISSN 2250-3234 Volume 4, Number 5 (2014), pp. 573-581

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Modeling and Experimental Investigation of Process Parameters in WEDM of WC-6%Co Composite using Response Surface Methodology

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Abstract

In this paper, wire electrical discharge machining of WC-Co composite is studied. Wire electrical discharge machining (WEDM) is a best alternative for machining of WC-Co composite into intricate and complex shapes. The present work is undertaken on 94% WC and 6% Cobalt. The present work is aimed to optimize the parameters of WEDM process by considering the effect of input parameters like pulse-on-time, pulse-off-time, voltage and current. Experiments have been conducted with these parameters in two different levels data related to process responses like cutting speed and dimension deviation. These data have been utilized to fit a quadratic mathematical model (RSM) for each of the response, which can be represented as a function of the process parameter. Predicated data have been utilized for identification of the parametric influence in the form of graphical representation for showing influence of the parameters on selected response.

Keywords: WEDM, WC-6%Co composite, Cutting Speed, Dimensional Deviation, Response Surface Methodology, Desirability Function.

INTRODUCTION
Tungsten carbide (WC-Co) composite is a powder metallurgy product which possesses high hardness even at elevated temperatures which makes it suitable for dies and tool industries. Machining of WC-Co composite is very difficult with conventional machining processes like turning, milling and grinding because of its high hardness and high melting temperature. Wire electrical discharge machining (WEDM) is a specialized form of electrical discharge machining (EDM) process which is potentially used to generate intricate and complex geometries in hard

conductive materials without making any mechanical contact. In WEDM, material is eroded due to the melting/evaporation of work surface which is mainly due to the localized high temperature generation in plasma channel between the work material and downward moving wire electrode (as shown in Fig. 1). In WEDM, achieving higher machining cutting speed or material removal rate is prime objective during rough cutting operation.

Mahapatra and Patnaik (2006) reported that discharge current, pulse duration, dielectric flow rate are highly significant for both MRR and SR while machining of D2 tool steel with WEDM. Influence of composition and grain size of WC-based cermets on machinability by WEDM has been studied by Lauwers et al. (2006).

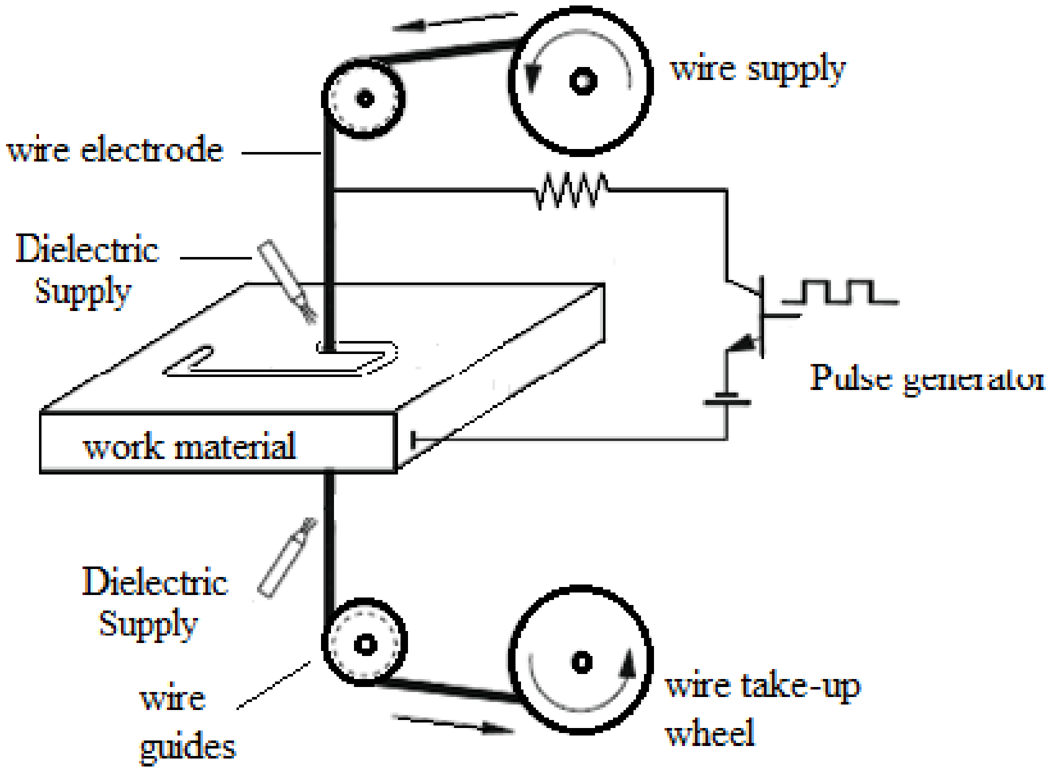

Figure 1 Schematic Representation of WEDM

Muthuraman and Ramakrishnan studied Micro structural Characterization of Wire Electro Discharge Machined Tungsten Carbide Cobalt Metal Matrix Composite and concluded On-time and Ignition-current are significant parameters for material removal rate and Off-time is critical to control surface roughness. Hewidy et. al. (2005) investigated the effect of input parameters on the metal removal rate, wear ratio and surface roughness while machining of Inconel 601 with WEDM using RSM. They concluded that the volumetric metal removal rate generally increase with increase of peak current value and water pressure. Jangra and Grover (2012) described the modeling and experimental investigation of process parameters in

WEDM of WC-5.3%Co using response surface methodology. They reported that the T_{on}, T_{off}, SV and WF produce significant influence on each performance characteristic. Muthuraman et al (2012) investigated the Modeling and Analysis of MRR in WEDMed WC-CO Composite by Response Surface Methodology. Kumar and Ravikumar(2013) investigated the effect of input parameters while machining of Al-SiC (20%) with WEDM using RSM technique, concluded that the factors like speed, feed, time on and time off have been found to play a significant role for MRR and surface roughness.

2 Experimental Procedure

2.1 Work material and machining parameters

Tungsten carbide composite with cobalt concentration (6%) has been taken as a work material in the form of a rectangular block of thickness of 20 mm. Brass wire of 0.25 mm diameter was used as an electrode. De-ionized water was used as dielectric fluid. An electrode gap up to 0.5 mm has been kept between wire and work. Dielectric after flushing and filtering was recycled. The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. In present machine tool, range of the important parameters is as follows: discharge current, 10–230 amp; pulse-on time, 101– 131 MU; pulse-off time, 0–63 MU; servo voltage 0–99V; dielectric flow rate, 0–12 litre per minute ($lmin^{-1}$), wire feed, 1–9 m/min; wire tension, 1–9 gms.

In present investigation, four important WEDM parameters, namely pulse-on time (T_{on}), pulse-off Time (T_{off}), servo voltage (SV) and current have been considered with two levels (Table 1) to study their effect on cutting speed as response parameter. Wire tension and wire feed parameters were kept constant at 8m/min and 8 unit resp. High flow rate results in quick and complete flushing of melted debris out of the spark gap.

Table 1.Input parameter levels selected and their ranges

Symbol	Parameters	Levels	
		(-1)	(+1)
A	Pulse-on-time (MU)	106	116
B	Pulse-off-time (MU)	30	60
C	Current(amp)	80	180
D	Voltage (volt)	40	80

Therefore, dielectric flow rate is kept at maximum value of 12 $l\ min^{-1}$. Vertical cutting was performed at zero wire offset.

2.2 Experimental design using RSM

Based upon the input factors and their levels as listed in Table 1, the experimental plan was designed on the basis of standard RSM design called face centered Central Composite Design (CCD).

Table 2. Test conditions in face centered central composite design for four parameters

Std	Run	Factor 1 A:Ton (MU)	Factor 2 B:Toff (MU)	Factor 3 C:current (Amp)	Factor 4 D:Voltage (volt)	Response 1 Mean Cutting Speed (mm/min)	Response 2 dimensional Deviation (mm)
1	19	108	37	100	50	0.5405	0.059
2	17	113	37	100	50	0.8	0.065
3	30	108	52	100	50	0.2702	0.0575
4	15	113	52	100	50	0.3636	0.0485
5	21	108	37	150	50	0.5714	0.07
6	20	113	37	150	50	0.8695	0.059
7	29	108	52	150	50	0.289	0.0545
8	9	113	52	150	50	0.4255	0.053
9	26	108	37	100	70	0.4347	0.0615
10	22	113	37	100	70	0.606	0.0615
11	10	108	52	100	70	0.2439	0.028
12	11	113	52	100	70	0.2857	0.044
13	25	108	37	150	70	0.4445	0.068
14	2	113	37	150	70	0.625	0.051
15	12	108	52	150	70	0.2667	0.036
16	1	113	52	150	70	0.3125	0.041
17	18	106	45	130	60	0.2985	0.0685
18	5	116	45	130	60	0.6415	0.0635
19	8	111	30	130	60	0.783	0.0775
20	23	111	60	130	60	0.1651	0.0475
21	3	111	45	80	60	0.4255	0.0645
22	6	111	45	180	60	0.5128	0.055
23	14	111	45	130	40	0.5882	0.0725
24	24	111	45	130	80	0.3435	0.0215
25	4	111	45	130	60	0.4651	0.0565
26	27	111	45	130	60	0.4651	0.061
27	7	111	45	130	60	0.4761	0.0615
28	13	111	45	130	60	0.4651	0.0565
29	16	111	45	130	60	0.4651	0.061
30	28	111	45	130	60	0.4761	0.0565

3. Modelling of WEDM Parameters

Using the experimental data, regression equations has been developed for correlating the Cutting speed (CS) and Dimensional Deviation with input WEDM parameters. Design expert (DX9), a statistical tool, has been utilised to analyse the experimental data. Using Analysis of Variance (ANOVA), quadratic Vs two factors interaction

(2FI) model has been suggested for machining speed. Table 3 shows the summary of fitted model. Adequacy of the results can be analysed by residual plots (Kanlayasiria and Boonmung, 2007) as shown in fig 2

Table 3a ANOVA table for fitted model for mean cutting speed

ANOVA for Response Surface 2FI model						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.85	10	0.085	956.71	< 0.0001	significant
Residual	1.681E-003	19	8.846E-005			
Lack of Fit	1.519E-003	14	1.085E-004	3.36	0.0936	not significant
Pure Error	1.613E-004	5	3.227E-005			
Cor. Total	0.85	29				

Regression equation in terms of coded factors:

Cutting speed= +0.47+ 0.079*A-0.16*B+ 0.019*C-0.061*D-0.036* AB+6.890E-003*AC-0022*AD + 4.883E-004* BC + 0027*BD + 6.446E-003*CD (1)

Regression equation in terms of actual factors

Cutting speed=-14.96381+0.15703*T_{on} + 0.17280*T_{off} – 0.010044*current + 0.077797*voltage-1.94360E-003* T_{on}* T_{off}+ 1.10243E-004*T_{on}*current – 8.71339E-004*T_{on}*voltage+ 2.60428E-006* T_{off}* current + 3.59629E-004*T_{off} voltage-2.57839E-005* current*voltage (2)

Table 3b. ANOVA analysis values for cutting speed

Std. Dev.	9.405E-003	R-Squared	0.9980
Mean	0.46	Adj R-Squared	0.9970
C.V. %	2.03	Pred R-Squared	0.9926
PRESS	6.270E-003	Adeq Precision	124.574

The final regression equation for performance measures are obtained as follows: The significant factors A, B, C, D, AB, AC, AD, BD, CD. Values of ‘‘p-value>F’’ less than 0.0500 shows model terms are statistically significant at 95% confidence level. Perturbation curve shows the effect of each process input parameter on mean cutting speed with a common point where all four input parameters meats to achieve max. mean cutting speed.

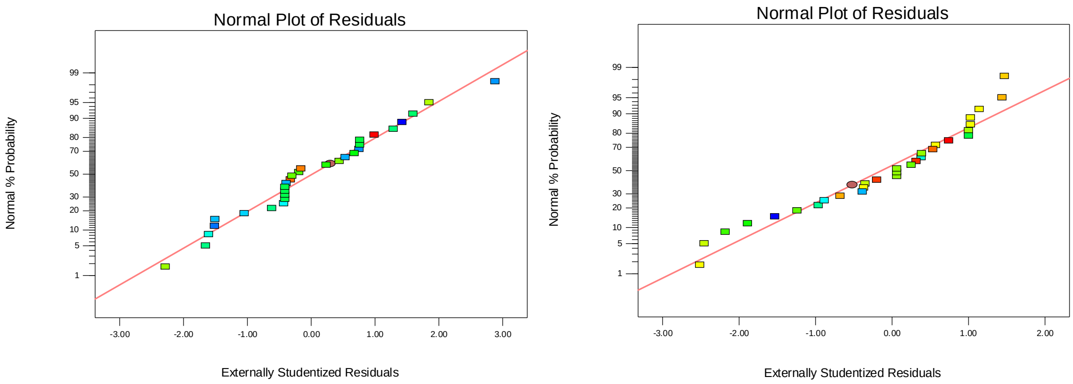

Figure 2 Normal probability plot of residuals for CS and DD

Table 3a ANOVA table for fitted model for Dimensional Deviation

ANOVA for Response Surface 2FI model						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2.727E-003	10	2.727E-004	12.00	< 0.0001	significant
Residual	4.317E-004	19	2.272E-005			
Lack of Fit	3.989E-004	14	2.849E-005	4.34	0.0571	not significant
Pure Error	3.283E-005	5	6.567E-006			
Cor Total	3.158E-003	29				

Table 3d. ANOVA analysis values for dimensional deviation

Std. Dev.	4.767E-003	R-Squared	0.8633
Mean	0.056	Adj R-Squared	0.7914
C.V. %	8.45	Pred R-Squared	0.5040
PRESS	1.566E-003	Adeq Precision	13.267

Final Equation in Terms of Coded Factors:

Dimensional Deviation = +0.056 +6.498E-004*A-6.462E-003* B-1.141E-003* C-6.562E-003* D+2.968E003* AB-3.070E-003* AC+2.450E-004* AD-3.964E-004 * BC-4.202E-003* BD+2.825E-004* CD

Final Equation in Terms of Actual Factors:

Dimensional Deviation =+0.10372-1.06549E-003* Ton-0.014797* Toff+5.43430E-003* current+6.30205E-004* Voltage+1.58298E-004* Ton * Toff-4.91228E-005* Ton * current+9.79899E-006* Ton * Voltage-2.11399E-006* Toff * current-5.60223E-005* Toff * Voltage+1.12990E-006* current* Voltage

From ANOVA table, B, D, AB, AC, AD are found to be significant factors in terms of dimensional deviation

4. Optimization Using Desirability Function

Derringer and Suich (1980) described a multiple response method called desirability. It is an attractive and user friendly method for industry for optimization of multiple response characteristics problems. The method makes use of an objective function, D(X), called the desirability function and transforms an estimated response into a scale free value (di) called desirability. The desirable ranges are from zero to one (least to most desirable respectively). The factor settings with maximum total desirability are considered to be the optimal parameter conditions. The simultaneous objective function is a geometric mean of all transformed responses.

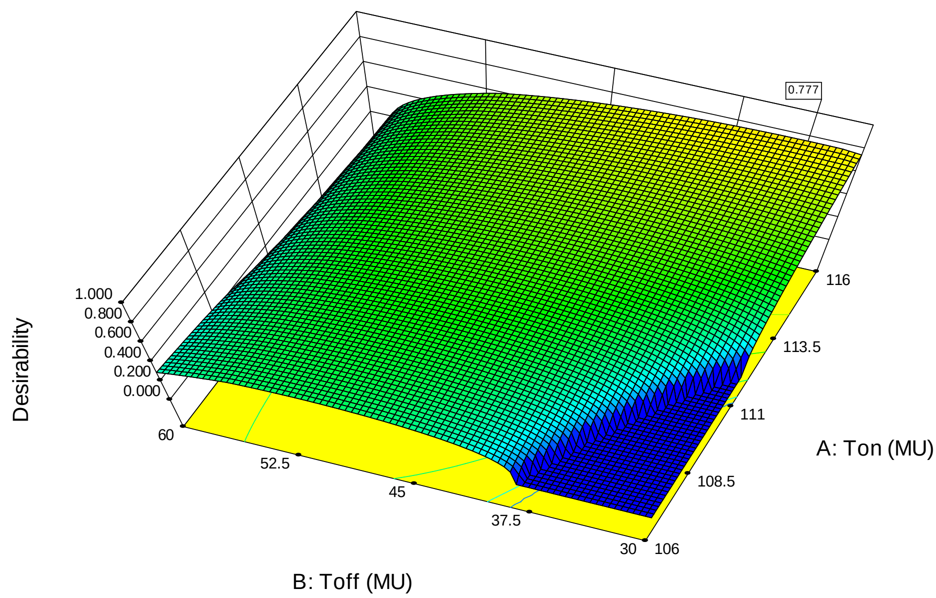

Fig. 3a. Desirability plot for maximum cutting speed and minimum dimensional deviation

4.1 Optimal Solution

The goal of optimization is to find a good set of conditions that will meet the desired goal. It is not necessary that the value of desirability is always 1.0 as the value is completely dependent on how closely the lower and upper limits are set relative to the actual optimum value. The set of conditions possessing highest desirability value have been selected as optimum conditions for maximum cutting speed and minimum dimensional deviation.

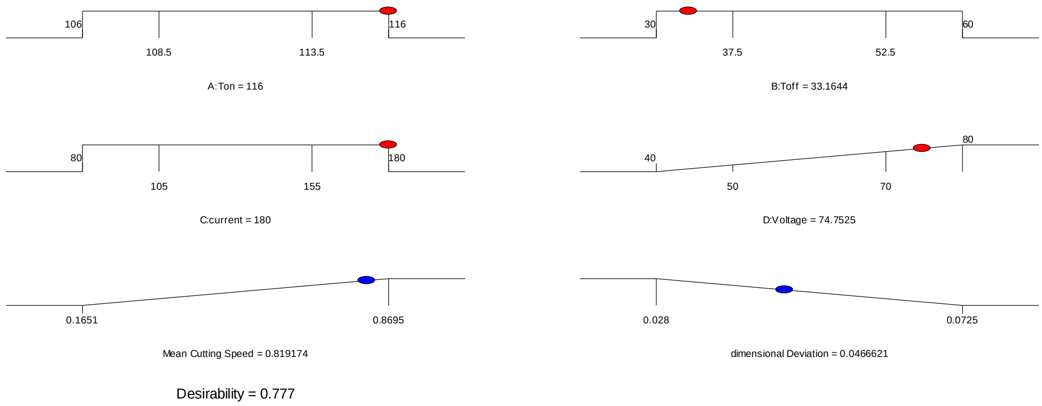

Fig. 3b. Ramp graph for Max. Desirability (0.777)

The constraints for the max. desirability has been shown in fig 4b by the help of ramp chart. Table 4 shows the set of conditions correspond to maximum desirability value for CS. Figure 4a shows the 3D surface plot for desirability. Fig 2 and 3 shows the Normal probability plot of residuals for CS and perturbation curve.

5. Conclusion

Quadratic Vs two factors interaction (2FI) has been found the best fit model for cutting speed. Cutting speed increases with increase in value of T_{on} and current, while current and T_{on} do not have much effect on dimensional deviation. Minimum value of voltage and pulse off current is desirable for high cutting speed and vice versa for dimensional deviation. Figure 2 shows that the residuals are normally distributed about a straight line and there is no problem with the observed results. Predicted value of max. CS was 0.8695 while confirmatory value comes to be 0.819174. For dimensional dev., predicted value was 0.028 while confirmatory value is 0.0466.

Table 4. Optimal conditions for maximizing cutting speed

S.No.	T_{on}	T_{off}	current	voltage	Dimensional deviation	Desirability value
1	116	33.1644	180	74.7525	0.0466525	0.777

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