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OPTIMIZATION OF PARAMETERS IN TRIM CUTTING OPERATION IN WEDM OF TUNGSTEN CARBIDE COMPOSITE

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Abstract

In the present work, multi trims cutting operations have been performed on WC-Co composite in wire electrical discharge machining process. The trim cutting or finish cutting is an operation where the wire electrode traces back the same path with a certain amount of offset with respect to the path of the first cut. In WEDM, the prime objective in rough cutting operation is to achieve the highest possible cutting speed, but in case of trim cutting the prime objective is to achieve the desired surface finish without sacrificing productivity. Therefore, in trim cutting, very low energy pulses are applied to obtain a good surface finish which results in very small material removal rate. Investigating the influence of parameters, namely pulse on time, peak current, wire off-set and number of trim cut on the performance characteristics (cutting speed and surface roughness) in trim cutting operation of WEDM. The optimum condition has been determined with the help of main effect plot and ANOVA table to find out which parameters have most affected the performance characteristics. The mathematical modeling has been carried out using Minitab 15 software and different models have been analyzed with the help of the Taguchi design using L18 orthogonal array.

***Keywords*:** WEDM, Surface finish, Cutting speed, Trim Cutting.

1. Introduction

Accompanying the development of mechanical industry, the demands of alloy materials having high hardness, toughness and impact resistance are increasing. Due to the favorable combination of hardness, strength and wear resistance at high temperature, tungsten carbide–cobalt (WC–Co) composite has become more desirable cutting tool material especially in the manufacturing of dies. It is a hard to machine material, produced by powder metallurgy technology and comprises of sintered WC granules held together by a cobalt binder under great tension. Processing of WC–Co composite is very difficult with conventional machining method due to its high hardness. [1]. Hence, non-traditional machining methods, including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. [2] Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface.

WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.25 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts.It is a well-established fact that a high material removal rate and a very good surface finish can never be achieved simultaneously in WEDM. This is an age-old problem and continuous efforts are being made by different researchers all over the world to fulfill such an objective [5]. A rough cut (first cut) followed by one or two trim cuts is considered as a probable solution to the above problem depending upon customer requirements. But, only a few research works are so far reported in the field of trim or finish cutting operation [6]. Though some research work has been done keeping in view of the accuracy aspects [7] but the wire offset setting for trim-cutting has never been explored in any process modeling. But the determination of wire offset setting is absolutely essential for achieving close dimensional tolerance. The purposes of trim cutting operation are to improve surface finish, job accuracies and to reduce the inaccuracies produced by minor job deformations after the first cut. It also reduces the bow effect on cut job surface produced in first cut due to unfavorable flushing conditions. Beside this, it also improves the die life by reducing the thickness of thermally affected layer formed, in the first cut, on the machined surface. The trim cutting or finish cutting is an operation where the wire electrode traces back the same path with a certain amount of offset with respect to the path of the first cut. The number of trim cutting operations followed by first cut may vary from 1 to 3 with varying amount of offset values. This total operation, i.e. trims cutting operation followed by first cut or rough cut are commonly termed as “multi-pass cutting” or sometimes simply “trim or finish cutting” operation. At the first cutting stage, it is shaped by the highest power of the wire electrode, together with high-pressure dielectric fluid and lower wire tension. In the semi-finished and finished stages, the processes are conducted with lower power, together with laminar flow of in Fig. 2. It may be noted that in multi-pass cutting operation the term “dimensional shift” (D) is defined as the perpendicular distance between actual machined job profile from the programmed path in the first cut (with zero wire offset setting) and the term “effective wire offset” (Ze) is defined as the perpendicular distance between the programmed path in first cut and dielectric fluid and higher wire tension. During experimentation wire offset in first cut was kept constant at zero. [8].

2. Material & Method

2.1 Preparation of Specimens

The tungsten carbide cobalt (5.3%) composite has plate of 100×35×13mm size used for the experimental work. Before starting experiment, there are drill twenty holes in the specimens of equally spaced with the micro-drill EDM and the specimens of 5×4mm size are cut. The Composition of materials is WC is 94% and Co is 5.3%The experiment is carried out on the wire Cut EDM (Sprincute Electronica Ltd.). In the present study cutting rate is a measure of work-piece cutting which is digitally on the screen of the machine and is given quantatively mm/min. The reading of cutting speed is measured continually when the values of speed are becoming constant on the screen. These are measured continuously till full length of the work-piece cut. In this work the surface roughness was measured by SJ-201P.

Design of Experiment Based on Taguchi MethodThe WEDM process consists of three operations, a roughing operation, a finishing operation, and a surface finishing operation. Usually, performance of various types of cutting operations is judged by different measures. In case of finish cutting operation, the surface finish is of primary importance, whereas both metal cutting and surface finish are of primary importance for rough cutting operation. In this work, it is planned to study the behavior of five control factors viz., A, B, C, D, and E. The experimental observations are further transformed into a signal-to-noise (S/N) ratio. There are several S/N ratios available depending on the type of characteristics. The machining characteristic which has a higher value represents better machining performance, such as cutting speed, is called ‘higher is better, HB’.

Inversely, the characteristic that lower value represents better machining performance, such as surface roughness, is called ‘lower is better, LB. Therefore, ”HB” for the cutting speed ’LB’’ and for the SF were selected for obtaining optimum machining performance characteristics were selected for obtaining optimum machining performance characteristics [9].

The loss function (L) for the objective of HB and LB is defined as follows:

$$L_{HB} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2{}_{cs}}. \quad (4)$$

$$L_{LB} = \frac{1}{n}\sum_{i=1}^{n} y^2{}_{sf}\,. \quad (5)$$

Where ycs , ysf response for cutting speed and surface finishing, respectively, and n denotes the number of experiments.

The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below.

S=N ratio for cutting speed = -10 log 10(LHB) (6)

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S=N ratio for Surface Roughness = -10 log10 (LLB) (7)

The array chooses L18 (35), which have 18 rows corresponding to the number of experiments with 5 columns at mixed levels, as shown in Table 4 The plan of experiments is as follows; the first column for setting of the rough cut, the second column assigns to peak current (B), the third column to pulse on time (C), fourth column to wire off-set (D), fifth column to number of trim cut (E) and the other parameters are gap constant as shown in table 3. The experiment is conducted for each combination of factor (rows) as per selected orthogonal array shown in Table 4. ANOVA table (Table 4) has been made with the help of MINITAB 15 software to find out the predicted S/N ratios. This table is obtained by using D.O.E. approach of the software, which gives the values of S/N ratios and means for different parameters at mixed level different levels of experiments. For obtaining the best result, we have taken three trials at each level and then get the mean of that trial as our desired output.

3. Results & Discussions

From the table 5, the overall mean for the S/N ratio of cutting speed and surface roughness is found to be -25.6111db, 0.9369db. Figures 4 & 5 show graphical effects of the control factor on cutting speed and surface roughness. The analysis was made using the popular software specifically used for design of experiment applications known as MINITAB 15 before any attempt is made to use the simple model as a predictor for the measures of performance, the possible of interactions between the factors must be considered. This factorial design incorporates a simple means of testing for the presence of the interaction effects. The S/N ratio response table and response graphs are shown for S/N ratio for cutting speed in Table 6 & Fig. 3 respectively. Similarly, response table and response graphs are shown for S/N ratio for surface roughness in Table 7 & Fig. 4 respectively.

Analysis of the result leads to the conclusion that factors at level A1, B3, C1, D1, E3 gives maximum cutting speed. Although factors A, B, C and D do not show significant effect, but significant interaction between factors A and E and A and D is observed for material removal rate as shown in Fig. 5 factor C is having the least significance effect of improving the cutting speed. Similarly it is recommended to use the factors at level A1, B2, C1, D1, E3 for maximization of surface roughness and the interaction graphs in Fig. 7. Factor B, E and D have least contribution for maximization of the surface roughness. However the interaction between factors C and D and C and A cannot be neglected. Table 8 and 9 shows the results of the ANOVA for cutting speed and surface roughness Table 8, the rough setting is the most significant process parameter for affecting cutting speed (83.65%). The number of trim cuts affects the cutting speed by 13.74%. The wire offset, peak current, pulse on has an insignificant effect on cutting speed 1.24%, 0.31%, 0.02% respectively. According to Table 9, the pulse on was found to be the major factor affecting the surface roughness (77.63%), whereas the rough setting (7.76%), wire offset (6.04%), the number of trim cut (3.26%) and peak current (1.54%) factors affect the surface roughness. It is interesting to note that the optimal setting of the parameters for cutting speed and surface roughness are quite different and poses difficulty to achieve the goals of all objectives.

4. Confirmation Experiment

The optimal combination of machining parameters has been determined in the previous analysis. However, the final step is to predict and verify the improvement of the observed values through the use of the optimal combination level of machining parameters. The estimated S/N ratio for cutting speed can be calculated with the help of the following prediction equation. For each performance measure, an experiment conducted for the different factor combination and compared with the result obtained from the predictive equation as shown in table 6. The resulting model seems to be capable of predicting cutting speed and surface roughness to a reasonable accuracy. An error of 1.08% and 2.47% for an S/N ratio of cutting speed and surface roughness is predicted. However, these errors can be further reduced if the number of measurements is increased. This validated the development of the parameters.

A mathematical model for predicting the measures of performance based on knowledge of the input is given as:

$$\bar{\eta}_1 = \eta_m + \left(\bar{A}_1 - \eta_m\right) + \left(\bar{B}_3 - \eta_m\right) + \left(\bar{C}_1 - \eta_m\right) + \left(\bar{D}_1 - \eta_m\right) - \left(\bar{E}_3 - \eta_m\right) \quad (8)$$

Where,

$\bar{\eta}_1$ = Predicted Average

η_m = Overall experimental average

$\bar{A}_1, \bar{B}_3, \bar{C}_1, \bar{D}_1, \bar{E}_3$ = Mean response for factors and interactions at designated levels.

By combining like terms, the equation reduces to

$$\bar{\eta}_1 = \eta_m + \sum_{i=1}^{n}(\eta_1 - \bar{\eta}_m) \quad (9)$$

The new combination of factor level $\bar{A}_1, \bar{B}_3, \bar{C}_1, \bar{D}_1, \bar{E}_3$ is used to predict cutting speed through prediction equation it is found to be $\bar{\eta}_1$ = -27.2974. Similarly, a prediction equation is developed for the estimation S/N ratio of surface roughness as given in eq. (10).

$$\eta_2 = \eta_m + \left(\bar{A}_1 - \eta_m\right) + \left(\bar{B}_2 - \eta_m\right) + \left(\bar{C}_2 - \eta_m\right) + \left(\bar{D}_1 - \eta_m\right) - \left(\bar{E}_3 - \eta_m\right). \quad (10)$$

By combining like terms, the equation reduces to

$$\bar{\eta}_2 = \eta_m + \sum_{i=1}^{n}(\eta_2 - \eta_m) \quad (11)$$

A new experimental set up with factor levels as $\bar{A}_1, \bar{B}_3, \bar{C}_1, \bar{D}_1, \bar{E}_3$ is considered to predict the S/N ratio for SF and is found to be $\bar{\eta}_2$ = 0.4345. From Fig. 1 it is seen that a layer of material is removed from the job surface during trim cutting or finish cutting operation. It is obvious that the surface produced by the rough cutting operation is totally removed by finish cutting operation. Thus it is expected that parameter setting used in rough cutting operation has no impact on the final surface finish. In view of the above facts, it was decided to select the particular parametric combination which results in maximum cutting speed in rough cut, irrespective of the surface finish.

5. Conclusions

In this study, an investigation on the surface roughness and cutting speed based on the parameter design of the Taguchi method in the optimization of WEDM operations has been investigated and presented in trim cutting process. Summarizing the mean experimental results of this study, the following generalized conclusions can be drawn:

1. Based on the analysis of variance (ANOVA) results, the highly effective parameters on both the surface roughness and cutting speed were determined.

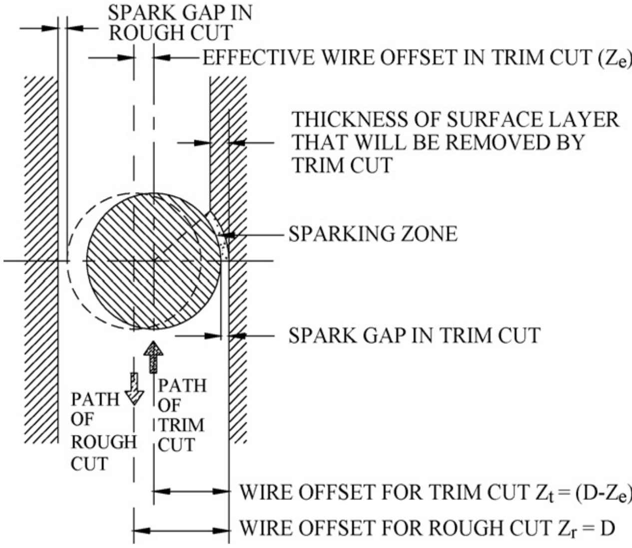
2. The cutting speed is affected strongly by the rough setting (91.7%), whereas the number of trim cut (7.46%) and wire off set (0.6%) have a significant statistical influence.

3. The surface roughness is the effected strongly by the pulse on (77.63%) whereas the rough setting is (7.76%) and wire off set (6.04%) has a significant statistical influence.

4. Based on the signal-to noise ratio results in Tables 5.1, we can conclude that the A1B3 C1D1E3 (rough setting=A1, peak current=70Amp., pulse on time=105 µs, wire off set=120 µm, number of trim cut=3) and A1B2 C1D1E3 (rough setting = A1, peak current = 70 Amp, pulse on time=105 µs, wire off set=120 µm, number of trim cut = 3) settings are the optimal WED machining parameters for surface roughness and cutting speed, respectively.

5. The comparison of the predicted Surface Roughness and Cutting Speed with the experimental Surface Roughness and Cutting Speed using the optimum process parameters in WEDM has shown a good agreement between the predicted and experimental results but there are error in 1.08% error in cutting speed and 2.47% error in surface roughness respectively.

6. The estimated S/N ratio and mean S/N ratio at optimum level are found to be almost same indicating the validation of the experimental and predicted result.



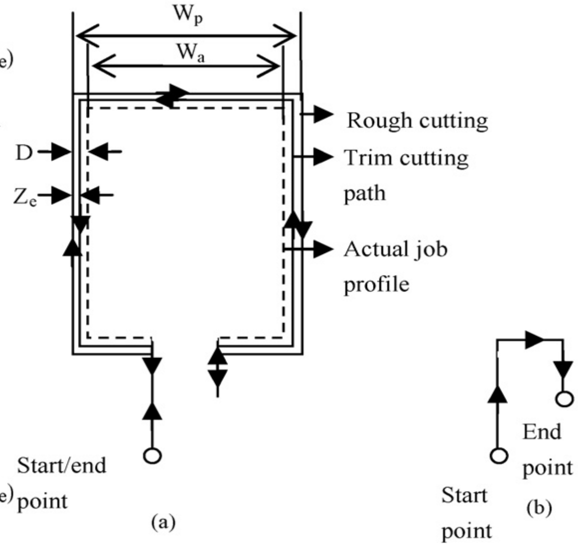
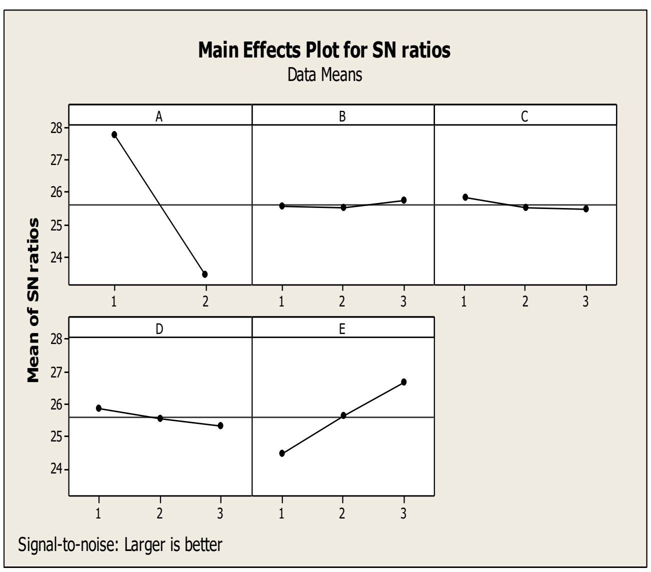


Figure 1 Details of trim cutting operation. Figure 2 Wire paths planning for machining of test specimen in trim cutting followed by rough cutting operation [8]



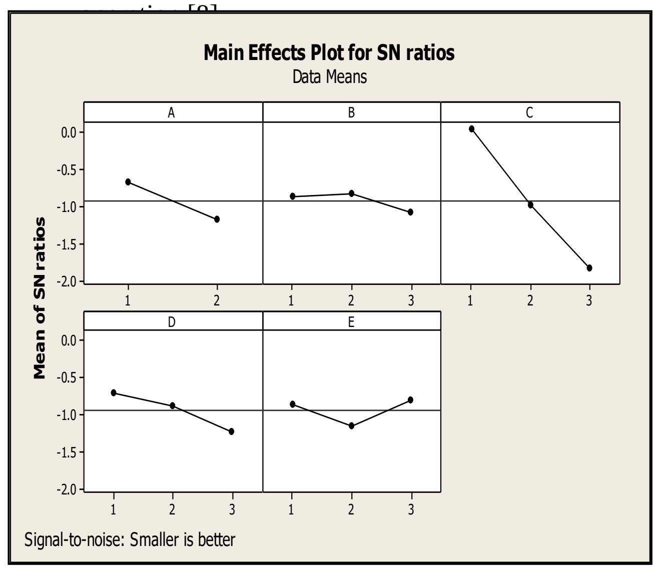


Figure 3 Effect of control factors on Cutting Speed Figure 4 Effect of control factor on Surface Finis

Table 1 Input variable parameters

Sr. No	Variables Input	Level 1	Level 2	Level 3
1	Rough setting	A1	A2	-
2	IP (Amp.)	90	80	70
3	TON (µs)	105	109	113
4	WOFF (µm)	120	125	130
5	TNo. of	1	2	3

Table 2 Setting of rough cut

A1	IP=90	TON=112
A2	IP=150	TON=122

	SF=2080	SV=30
	WP=1	WT=12

Table 3 Constant Parameters

Sr. No.	Parameters	Value
1	Wire Tension	12
2	Wire feed	5
3	Flushing Pressure	1
4	Spark Gap Set Voltage	30
5	Servo Feed	2080
6	TOFF	42

Table 4 The L18 (3)5 Orthogonal Array

EXP.NO.	A	B	C	D	E	S/N RATIO
1	1	1	1	1	1	S/N1
2	1	1	2	2	2	S/N2

__________and likewise__________

Table 5 Experimental results

Ex. No.	A1&A2	Ip (Amp.)	Ton (µs)	Woff(µm)	Tnumber	Ra(µm)	S/N-R (expt.)	Csp(mm/ min)	S/N-R (expt.)
1	1	90	105	120	1	0.92	0.7242	23.1	-27.2722
2	1	90	109	125	2	1.13	-1.0616	24.84	-27.9030
3	1	90	113	130	3	1.21	-1.1656	25.3	-28.0624
4	1	80	105	120	2	0.95	0.4455	24.86	-27.9101
5	1	80	109	125	3	1.03	-0.2567	26.4	-28.4321
6	1	80	113	130	1	1.25	-1.9382	21.3	-26.5676
7	1	70	105	125	1	0.95	0.4455	22.4	-27.0050
8	1	70	109	130	2	1.16	-1.2891	24.03	-27.6151
9	1	70	113	120	3	1.2	-1.5836	29.68	-29.4493
10	2	90	105	130	3	1.01	-0.0864	16.8	-24.5062
11	2	90	109	120	1	1.13	-1.0616	12.87	-22.1916
12	2	90	113	125	2	1.28	-1.1442	14.918	-23.4742
13	2	80	105	125	3	1.03	-0.2567	17.367	-24.7945
14	2	80	109	130	1	1.16	-1.2892	12.439	-21.8957
15	2	80	113	120	2	1.22	-1.7272	14.986	-23.5137
16	2	70	105	130	2	1.14	-1.1381	14.891	-23.4585
17	2	70	109	120	3	1.12	-0.9844	17.89	-25.0522
18	2	70	113	125	1	1.26	-2.0074	12.439	-21.8957

Table 6 Response table for S/N Ratio (Larger is better)

Level	A	B	C	D	E
1	27.80	25.57	25.82	25.90	24.47
2	23.42	25.52	25.51	25.58	25.65
3		25.75	25.49	25.35	26.72

Delta	4.38	0.23	0.33	0.55	2.24
Rank	1	5	4	3	2

Table 7 Response table for S/N Ratio (Smaller is better)

Level	A	B	C	D	E
1	-0.6855	-0.8808	0.0223	-0.698	0.8544
2	-1.1884	-0.8371	-0.991	-0.881	-1.153
3	-1.0929	-1.8427	-1.233	-0.804	
Delta	0.5029	0.2558	1.8651	0.535	0.3485
Rank	3	5	1	2	4

Table 8 Result of analysis of variance (ANOVA) for cutting speed

SOURE	DF	VARIANCE	ADJ.SS	ADS.MS	F	P	Contri. %
A	1	423.502	423.502	423.502	639.30	0.000	83.65
B	2	1.573	1.573	0.787	1.19	0.354	0.31
C	2	0.086	0.086	0.043	0.07	0.937	0.02
D	2	6.257	6.257	3.128	4.72	0.044	1.24
E	2	69.572	69.572	34.786	52.51	0.000	13.74
ERROR	8	5.300	5.300	0.682			1.05
TOTAL	17	506.290					

Table 9 Results of analysis of variance (ANOVA) for surface roughness

SOURCE	DF	VARIANCE	ADJ.SS	ADS.MS	F	P	Contri. %
A	1	0.016806	0.016806	0.016806	16.44	0.004	7.76
B	2	0.003344	0.003344	0.001672	1.64	0.254	1.54
C	2	0.168078	0.168078	0.084039	82.21	0.000	77.63
D	2	0.013011	0.013011	0.006506	6.36	0.022	6.04
E	2	0.007078	0.0078078	0.003539	3.46	0.083	3.26
ERROR	8	0.008178	0.008178	0.001022			3.77
TOTAL	17	0.216494					

Table 10 Result of the confirmation experiment for cutting speed

	Optimal machining parameter	
	Prediction	Experiment
Level	A1B3C1D1E3	A1B3C1D1E3
S/N ratio of cutting speed (db)	-27.2974	-27.005

Table 11 Result of the confirmation experiment for Surface Roughness

Optimal machining parameter

	Prediction	Experiment
Level	A1B3C1D1E3	A1B3C1D1E3
S/N ratio of surface roughness (db)	0.4345	0.4455

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