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Experimental Studies on parametric control for Machining Graphite with CNC WEDM

NBV Prasad [1], Dr, Ch. V. S. ParameswaraRao [2], Dr, S. Sivanaga MalleswaraRao [3]
Research Scholar [1], Professor [2] & [3],
SV University, Gajrola, U.P [1]
Department of Mechanical .Engineering [2] & [3]
PBR VITS, kavali-524201
A.P, India

ABSTRACT

The analysis of WEDM is still nowadays an important field of research due to the difficulties to measure the process characteristics: narrow gap (~10 mm), dirty environment (oil or deionised water), and high frequency (>100 kHz), etc. Nevertheless, the WEDM technology has been improved thanks to the theoretical and empirical results of different research groups that have made use of state of the art technologies to measure temperature distributions, displacements, frequencies or electrical signals for spark characterization. The accurate measurement of machined parts has also brought light to the machining process, being this aspect critical for the improvement of the EDM technology.

Thus the present work is aimed at experimental evaluation of those machining parameters for different sizes of Graphite which is a prominent electrode material. Further the effect of these parameters on cutting speed, spark gap and material removal rate is investigated and best suited values are obtained for stable and controlled machining with least wire breakage. Based on the experimental results, empirical correlations are established and validated to evaluate the above parameters analytically for different work piece sizes. The correlations are found useful for finding the best suited discharge current, cutting speed, spark gap, MRR and surface roughness under various cutting conditions. The results are represented in graphical form also.

Keywords:- WEDM, Cutting speed, MRR, Spark gap, Mathematical correlations

I. INTRODUCTION

The Wire-cut EDM is the focus of researchers and engineers especially in the field of dies, moulds, precision manufacturing, contour cutting etc. Any complex shape can be generated easily with higher accuracy and surface finish, using CNC WEDM, which is not possible to be achieved by normal EDM process. The Wire- cut EDM is precision machining process for micro machining of micro structures, such as high aspect ratio micro holes, slots and moulds. The basic characteristic of the wire cut -EDM process is similar to that of the EDM process with the main difference being in the size of the tool used, the power supply of discharge energy and the resolution of the X, Y, and Z axes movement. In order to improve the process control, it is very important to understand the effect of critical machining parameters involved in the material removal mechanism. One of the important characteristics associated with the removal mechanism of the formation of crater are diameter, spark gap, cutting speed and material removal rate. In the past many studies have clearly shown that the melting and vaporization are the causes of removal of material. The scope of development of indigenous software has further strengthened the process technology even in correcting the geometrical and technological data for improving work piece accuracy features [1].One of the main advantages of this process is that a very small internal corner radius can be achieved because the tool used is a very thin wire [2]. This machine facilitates the manufacturing engineers to cut hard to machine materials with high accuracy, surface finish, close tolerances and contours3. The WEDM is a specialized field of EDM, which requires an extensive research. An analysis of effects of various process parameters is required for achieving improved machining characteristics [4].There is an immediate need to develop Mathematical relations for successful utilization of the process with high productivity.

The parameters which demand attention for the purpose of analyzing their significant effects on the machining characteristics include discharge current gap voltage, wire material, wire tension, wire speed [5-11] etc.

II. EXPERIMENT

Figure 1 shows the experimental set up. Based on the work done by the previous researchers5,6, the best fit parameters as shown below are set on the machine before cutting:

Machine : ELCUT 334
Dielectric : De-ionized water
Dielectric conductivity: 38 mohs
Wire Tension : 70 N
Wire velocity : 3.4 m/min
Wire diameter : 0.25mm
Wire material : 66-34 Brass
Gap voltage : 80 V

Figure 1. Experimental set up on Elcut 334 machine

Using CNC part programming, rectangular slot of 4mm x 6mm and L shaped slot is cut on 5mm thick Graphite work piece by varying discharge current for 5 times. The L- slots are tested for spark gap using shadow graph technique and micro scope. The photograph of experimental setup is shown in Fig. 2. The rectangular slots are tested for surface roughness values using Tally surf. From this, the best value of discharge current is recorded for stable machining with maximum cutting speed and minimum wire breakage.

Table 1

At this value of current, the best value of cutting speed, spark gap is recorded and material removal rate (MRR) is computed. The experiment is repeated for 19 different work piece thicknesses varying from 5mm to 80mm. The best value of discharge current obtained for each thickness and the corresponding cutting speed, spark gap and material removal rate (MRR) are represented in graphical form.

The experimental data thus obtained is subjected to statistical analysis (ANOVA) and the mathematical correlations for this best fit curve are taken in to consideration.

III. RESULTS AND DISCUSSIONS

3.1 The results obtained during the experimentation are tabulated in Table 1.

S.No.	Thickness, T mm	Current,I amp	P, Watts	Cutting speed mm/min	Spark gap µm	MRR mm^3/min	Ra, µm
1	5	0.75	63.75	1.60	33.00	2.53	2.2
2	7.5	1.17	99.45	1.18	48.95	3.07	2.15
3	10	1.50	127.5	1.00	61.30	3.72	2.13
4	12.5	1.85	157.5	0.79	71.50	3.88	2.11
5	15	2.10	178.5	0.69	80.00	4.24	2.09
6	17.5	2.30	195.5	0.62	86.97	4.59	2.05
7	20	2.50	212.5	0.56	93.00	4.88	2.02
8	25	2.70	229.5	0.47	101.72	5.32	2.01
9	30	2.83	240.5	0.41	107.57	5.72	2.00
10	35	2.93	249.0	0.36	111.46	5.95	1.99
11	40	3.00	255.0	0.33	113.73	6.30	1.96
12	45	3.09	262.6	0.30	115.49	6.49	1.96
13	50	3.20	272.0	0.28	117.00	6.77	1.92
14	55	3.33	283.0	0.26	118.64	6.96	1.85
15	60	3.50	297.5	0.25	120.00	7.35	1.76
16	65	3.66	311.1	0.22	122.46	7.07	1.62
17	70	3.82	324.7	0.21	124.37	7.33	1.54
18	75	3.95	335.7	0.20	125.69	7.52	1.54
19	80	4.00	340.0	0.20	126.00	8.03	1.52

3.2. Analysis of Variance. In order to statistically analyze the results, ANOVA was performed. Pooled version of ANOVA for cutting speed, spark gap, MRR and surface roughness are given in Tables 1-4. T=Thickness, mm, I= Current, amp, P=Power, watts

3.3 Regression Coefficient for Second Order Equations.

The regression coefficient of the second order equations are obtained by using the experimental data (Table 1). The regression equations for the response characteristics as a function of three input process parameters considered in this experiment are given below:

The Optimal parameters for machining Graphite are listed in table.

The variation in the discharge current with the increase in work piece thickness is obtained and is shown in Fig. 2.

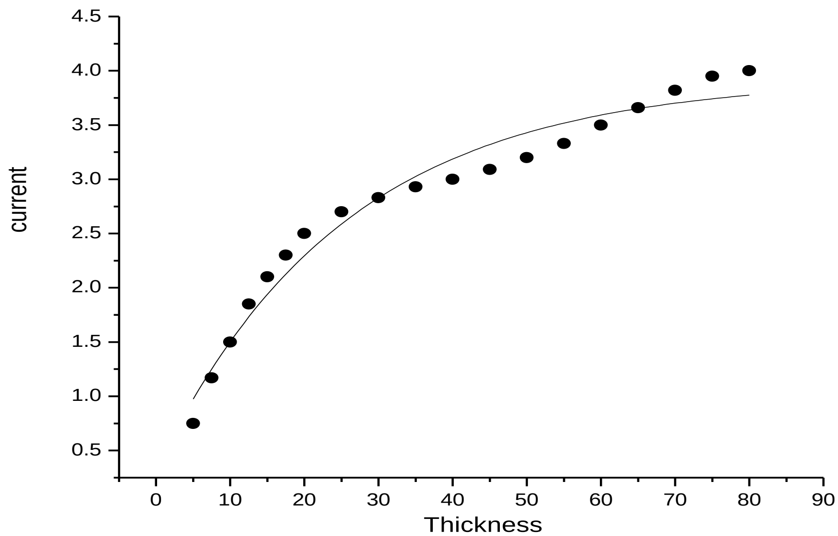

Figure 2. Effect of discharge current on thickness

For a specified set of machining conditions it is observed that with increase in thickness, the required current also increases. This is attributed to the high amount of energy required for high thickness job in which machining is possible only by increasing the current. However the rate of current rise is found decreasing with increasing thickness. Thus this plot is useful to extract suitable minimum discharge current required for machining of any thickness Graphite work piece with in the machine working range. By interpolation of the obtained data the equation for the best fit curve is obtained as

I = 3.92-{7456.62/ [1+ exp (T + 193.05)/ 25.28]} **(2)**

Where I = discharge current, amp, T = thickness, mm

Figure 3 shows the effect of thickness on cutting speed for various sizes of the work pieces. The plot indicates that as thickness of the work piece increases the cutting speed decreases rapidly. For thickness beyond 70mm the cutting speed almost remains constant. If the thickness increases, the volume of metal to be removed increases which demands more energy and it may become a machine constraint. At the same time the spark is jumping to the sides of the wire causing more width of cut, reducing the cutting speed. The data thus obtained is subjected to interpolation and the best fit curve correlation is obtained in the form

C_S = 2.4562 + 0.01796 T + 147 I - 1.75 P + 0.000309 T*T - 51.4 I*I + 0.00716 P*P + 3.44 T*I - 0.0407 T*P **(3)**

where C_s = cutting speed, mm/min

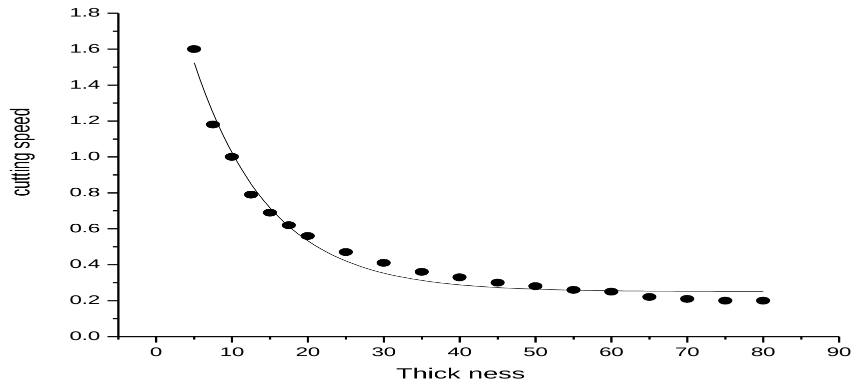

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Figure 3. Effect of cutting speed on thickness

Table 2: ANOVA for cutting speed

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F
Model	2.65	6	0.44	1009.11	< 0.0001
A-T	5.238E-003	1	5.238E-003	11.95	0.0047
B-C	3.267E-004	1	3.267E-004	0.75	0.4049
C-P	3.133E-004	1	3.133E-004	0.71	0.4144
AB	3.742E-004	1	3.742E-004	0.85	0.3737
AC	3.724E-004	1	3.724E-004	0.85	0.3748
BC	0.019	1	0.019	43.55	< 0.0001
Residual	5.260E-003	12	4.384E-004		
Cor Total	2.66	18			

Table 2 presents pooled ANOVA for cutting speed. The ANOVA was carried out at confidence level of 95%. F- value of the model shows 1009.11 that implies the model is significant. The model terms which are having p-values less than 0.05 are significant The Model is significant. Thickness and interaction of current and power are significant model terms.

The variation of spark gap with the increase in thickness of work piece is depicted in the Fig. 4. The curve shows an increasing trend in spark gap with increase in thickness of work piece. This may be due to the property of spark, which jumps longer at higher current values an essential requirement at higher thickness. However the rate of variation is low for thickness beyond 60mm.

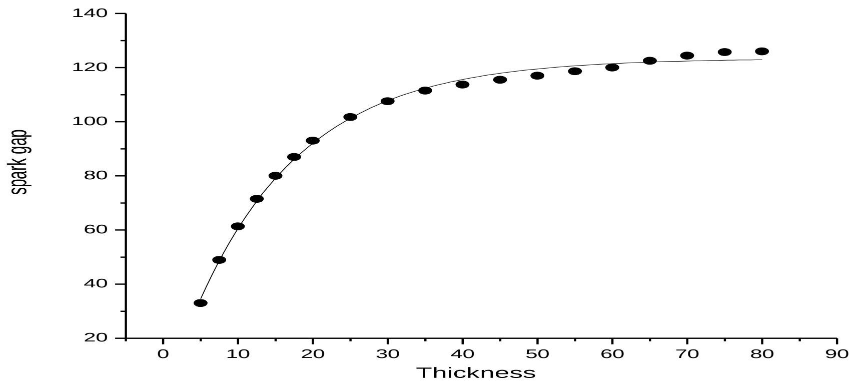

Figure 4. Effect of spark gap on thickness

The data thus obtained is subjected to interpolation and the best fit curve correlation is obtained in the form

S_G=3.13+ 1.204 T- 15385 I+181.4 P- 0.00128 T*T+ 5509 I*I- 0.762 P*P- 374 T*I+4.39T*P (4) where S_G is the Spark gap

Table 3. ANOVA for spark gap

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F
Model	14068.73	6	2344.79	1257.60	< 0.0001
A-T	22.29	1	22.29	11.96	0.0047
B-C	1.71	1	1.71	0.92	0.3572
C-P	1.65	1	1.65	0.88	0.3660
AB	0.50	1	0.50	0.27	0.6141
AC	0.52	1	0.52	0.28	0.6065
BC	0.49	1	0.49	0.26	0.6182
Residual	22.37	12	1.86		
Cor Total	14091.10	18			

Table 3 presents pooled ANOVA for spark gap. The ANOVA was carried out at confidence level of 95%. F- value of the model shows 1257.60 that implies the model is significant. The model terms which are having p-values less than 0.05 are significant The Model is significant. Thickness is found to be significant model terms among the model terms.

The change in **MRR with increase in thickness** is shown in the Fig. 5. The plot shows a constant rise with a positive slope. This may due to the increase in cutting speed and spark gap.

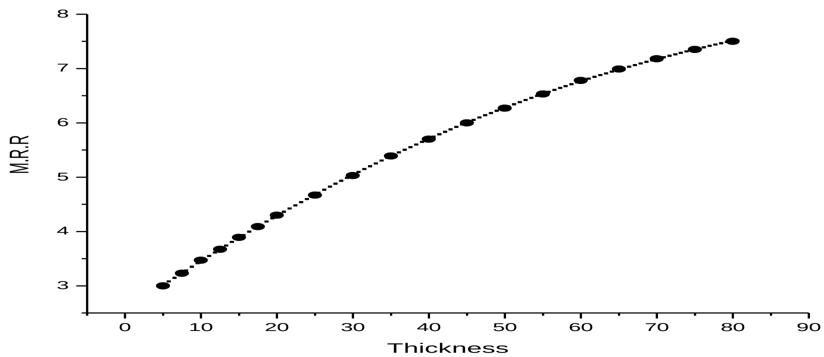

Figure 5. Effect of MRR on thickness

MRR=1.401+ 0.2233 T- 909 I+ 10.69 P+0.001797 T*T+ 345 I*I- 0.0476 P*P- 25.8 T*I + 0.302 T*P

(5)

where MRR is material removal rate, mm^3/min.

Table 4: ANOVA for MRR

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F
Model	47.90	6	7.98	397.49	< 0.0001
A-T	0.68	1	0.68	33.93	< 0.0001
B-C	8.429E-004	1	8.429E-004	0.042	0.8411
C-P	8.405E-004	1	8.405E-004	0.042	0.8413
AB	0.013	1	0.013	0.67	0.4301
AC	0.013	1	0.013	0.66	0.4322
BC	0.014	1	0.014	0.70	0.4181
Residual	0.24	12	0.020		
Cor Total	48.14	18			

Table 4 presents pooled ANOVA for MRR. The ANOVA was carried out at confidence level of 95%. F- value of the model shows 397.49 that implies the model is significant. The model terms which are having p-values less than 0.05 are significant The Model is significant. Thickness is found to be significant model terms among the model terms.

Table 5. ANOVA for surface roughness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F
Model	0.85	6	0.14	140.82	< 0.0001
A-T	3.863E-003	1	3.863E-003	3.85	0.0432
B-C	2.021E-003	1	2.021E-003	2.02	0.1811
C-P	2.064E-003	1	2.064E-003	2.06	0.1769
AB	1.757E-003	1	1.757E-003	1.75	0.2102
AC	1.774E-003	1	1.774E-003	1.77	0.2081
BC	8.679E-005	1	8.679E-005	0.087	0.7736
Residual	0.012	12	1.002E-003		
Cor Total	0.86	18			

Table 5 presents pooled ANOVA for surface roughness. The ANOVA was carried out at confidence level of 95%. F- value of the model shows 397.49 that implies the model is significant. The model terms which are having p-values less than 0.05 are significant The Model is significant. Thickness is found to be significant model terms among the model terms.

$$\mathbf{Ra = 2.078 + 0.2587\,T + 248\,I - 1.62\,P + 0.001704\,T{*}T - 36.7\,I{*}I + 0.008246\,P{*}P + 1.82\,T{*}I - 0.03754\,T{*}P} \quad (6)$$

Multi-objective optimization

Multi-objective optimization analysis was performed to achieve the target value of all four responses, i.e. surface roughness, MRR, spark gap and cutting speed The MINITAB software was also utilized for multi-objective optimization. Desirability function is an important factor in optimization that uses a gradient algorithm to calculate desirability for surface roughness, MRR, spark gap and cutting speed separately. The desirability value should lie between 0 and 1. As shown in the Figure 6, thickness of 5mm, 1.4625 amp of current and 123.9877 W of power found to be significant.

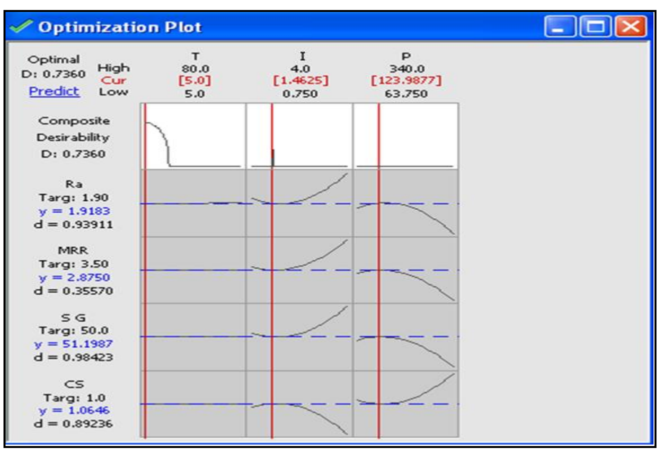

Figure 6. Multi response optimization of process parameters

IV. CONCLUSIONS

The influence of parameters, like discharge current, job thickness, on the machining criteria such as cutting speed, spark gap, material removal rate are determined. The results are useful in setting the parameters required for quality cuts on Graphite. Suitable parameters can be selected for machining with the available wire. The mathematical correlations developed are much more beneficial to estimate the cutting time, cost of machining and accuracy of cutting for any size of the Graphite work piece within the machine operating range. These results will be useful to make the Wire EDM system to be efficiently utilized in the present day die and tool manufacturing units and to make electrodes for EDM and ECM processes.

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