Experimental studies on parametric influence on machining of Titanium with WEDM

P. Srinivasa Rao, Ch.V.S.ParameswaraRao, K. Ravindra

Abstract: **This paper presents the parametric influence on machining of Titanium with WEDM. An extensive research study has been carried out with an aim to select the optimum cutting conditions at an appropriate overcut/spark gap and to get the desired surface finish and dimensional accuracy for machining any thickness of the Titanium work piece. Mathematical correlations are developed to determine the cutting parameters, machining current, cutting speed, and spark gap/overcut. Finally the correlations are useful for evaluating the machining parameters for different machining situations arising out of customer requirements and machining time calculation, in turn cost of machining.**

***Index Terms*— WEDM, cutting speed, spark gap, surface finish, MRR, mathematical correlations.**

I. Introduction

Wirecut Electrical Discharge machining (WEDM) has been found to be an extremely potential electro-thermal process in the field of conducting, hard-to-machine materials. Owing to the high process capability it is widely used in the manufacturing of special gears, cams, intricate parts and in tool rooms for dies, moulds etc. Selection of optimum parametric combinations for obtaining higher cutting efficiency and other dimensional accuracy characteristics is a challenging task in WEDM due to presence of large number of process variables and complicated stochastic process mechanism. Hence there is a demand for research studies which should establish a systematic approach to find out the optimum parametric setting to achieve the maximum process criteria yield for different sizes and classes of engineering materials.

An effective way to solve this state problem is to focus on establishing the relationship between machining parameters and machining criteria performances. A number of research works has been carried out on different materials to study the influence of different process parameters [1-7].

In the present research study wirecut electrical discharge machining of Titanium alloy of different thicknesses has been considered. The material had good corrosion resistance and is well known for aerospace and automobile industries. It is further found that extremely difficult to machine by conventional method due excellent strength property. Different aspects of machining of many ferrous and nonferrous materials of a particular thickness have been reported by several researchers [8-14]. Siva et.al [15-17] worked to evaluate the optimal parameters for some of the tool materials. But no comprehensive research work on evaluation of machining criteria and parametric settings for any size has been reported so far in the field of wirecut electrical discharge machining of this material. No data base or technology tables are available for machining of such an important and useful material in industry. Therefore, it is imperative to develop suitable mathematical or empirical relations for determining the optimum machining parameters of this material machining. Srinivas et.al [18] worked on wire selection for machining titanium, inconel and other materials which will be useful in the present research.

Further, in majority of the past research works material removal rate (MRR) and surface finish have been considered. But in this process, cutting speed is an important factor than MRR and cutting speed is to be optimized without compromising the surface finish. Prior to machining, the knowledge of wire offset is to be programmed which will be known from spark gap value for different thicknesses at different input parameters is very much essential for effective dimensional control and accuracy in machining.

In the present work the Titanium material of different thicknesses are machined for determining the optimum values of machining parameters and criteria. For these optimum values mathematical correlations are developed and relation between different parameters/criteria and thickness are established. The developed correlations are analyzed statistically for testing the suitability using ORIGIN software.

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II. EXPERIMENTAL SETUP

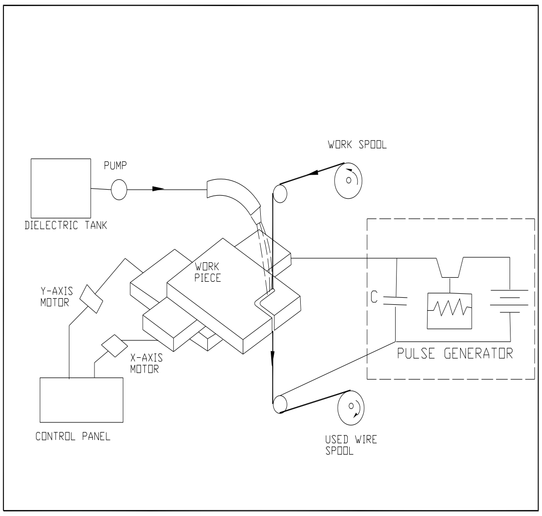

Fig.1.a Schematic view of experimental set up

Fig1.a.Shows the schematic view of the experimental set up. Fig.1b is the photo graph taken for the experimental set up and Fig.1c shows the sparking taking place during machining. The parameters set prior to machining are

Machine	: ELCUT 334,
Dielectric	: De- ionized water
Dielectric conductivity	: 38 mhos
Wire tension	: 70 N
Wire velocity	: 3.0 m/min
Wire diameter	: 0.25 mm
Wire material	: 89-11 Brass
Gap voltage	: 80 volts

Fig.1b. Photograph of experimental set up

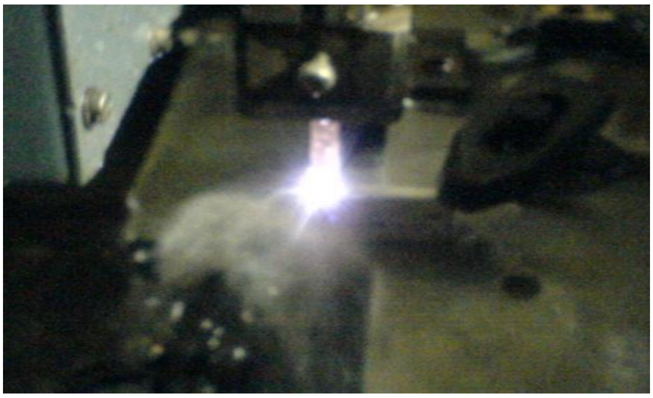

Fig. 1c.Sparking during machining

The Titanium specimens of 30mm x 50mm size on thicknesses 5, 7.5, 10, 12.5, 15, 17.5,20,25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 and 80, 90mm are prepared. The experiments are conducted on the work piece of every thickness by cutting L shape and "["shape by varying the machining current from a lower value to a value where the machining is in consistent in 5 steps. At every machining current, I value the machining criteria is measured. The machining current, I value at which the machining is consistent with continuous cutting, better finish with least wire rupture is selected as optimal. The cutting speed is noted from the machine display, surface finish is measured on "["cut using Talysurf. The cutting width is measured on L cut with shadow graph and checked with microscope. The spark gap is calculated from cutting width.

Cutting width, W= d+2 x Sg, where d is the wire diameter and Sg is the Spark gap

The MRR is calculated as, MRR = T x W x Cs where Cs is the cutting speed, mm/min and T is work piece thickness, mm.

The optimum values of machining current, cutting speed, spark gap and MRR for every thickness are used for plotting the curves and best fit curve is selected using the software. The mathematical relation is generated for this best fit curve and statistical analysis is performed to find the fitness of the curve.

III. PARAMETRIC ANALYSIS BASED ON EXPERIMENTAL DATA

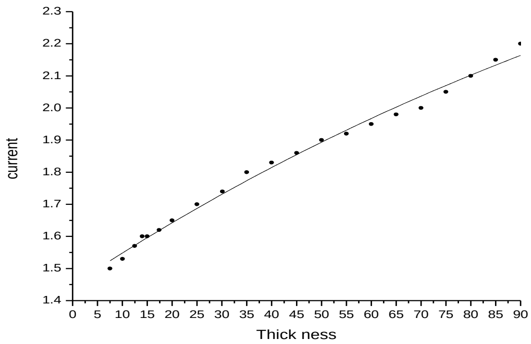

Fig.2. Influence of Thickness on machining current

The variation in the discharge current with the increase in work piece thickness is obtained and shown in Fig.2. For a specified set of machining conditions it is observed that with increase in thickness, the required machining 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. This plot is useful to extract suitable minimum discharge current required for machining of any thickness Titanium work piece with in the machine working range. By interpolation of the obtained data the equation for the best fit curve is obtained as

$$I = 3.098-\{34.628/ [1+ \exp (T + 456.92)/ 152.57]\} \quad (1)$$

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

Table. 1. Statistical data for Fig.2

Number of points	21	A1	-31.53
Degrees of freedom	17	A2	3.098
Reduced Ch-sqr	3.92E4	xo	-456.92
Residual sum of squares	0.0067	dx	152.57
R Value	0.9963		
R-square(COD)	**0.9927**		
Adj.R-square	0.9914		
Root-MS(SD)	**0.0198**		

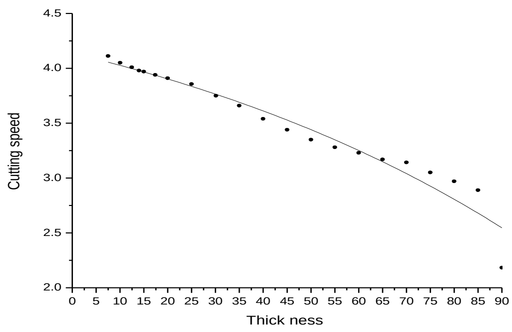

Fig 3. Influence of Thickness on cutting speed

Fig. 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. 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

Cs =-545.58+{550.714 / [1 + exp (T + 593.15) / 93.95]} (2)

Where Cs= cutting speed, mm/min.

Table.2 gives the statistical analysis, showing R2 value as 0.9472 which envisages the fitness of the curve. The standard deviation for this plot is 0.123. From this plot or from the above mathematical correlation, the cutting speed can be predicted for any size of work piece to be machined. This is also useful in evaluating the machining time and cost.

Table. 2 Statistical data for Fig.3

Number of points	21	A1	5.134
Degrees of freedom	17	A2	-545.58
Reduced Ch-sqr	0.015	xo	593.15
Residual sum of squares	0.26	dx	93.95
R Value	0.973		
R-square(COD)	**0.947**		
Adj.R-square	0.937		
Root-MS(SD)	**0.123**		

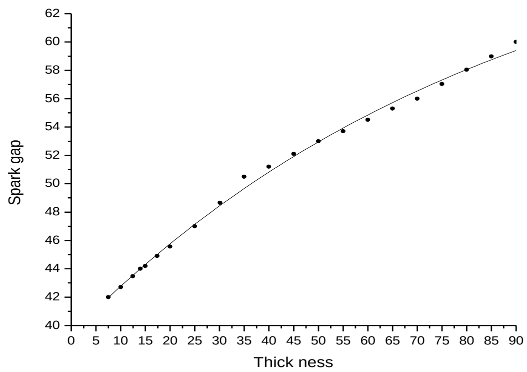

Fig 4. Influence of Thickness on Spark gap

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 proportionate to the thickness. The best suitable curve is drawn and error analysis is carried out. The mathematical correlation obtained is

Sg = 70.34- {1733.54/ [1 + exp (T +343.18)/ 85.62]} (3)

Where Sg is the spark gap in micro meters.

The statistical analysis presented in Table 3 shows the values of R2 = 0.9968 and standard deviation as 0.3557 are obtained and are tabulated in Table.3. The correlation is useful in finding the spark gap in turn cutting width, to compute the MRR and program the wire off set during CNC part programming, and hence higher accuracy can be achieved.

Table.3 Statistical data for Fig 4

Number of points	21	A1	-1663.2
Degrees of freedom	17	A2	70.34
Reduced Ch-sqr	0.126	xo	-343.18
Residual sum of squares	2.151	dx	85.62
R Value	0.998		
R-square(COD)	0.9968		
Adj.R-square	0.9963		
Root-MS(SD)	0.3557		

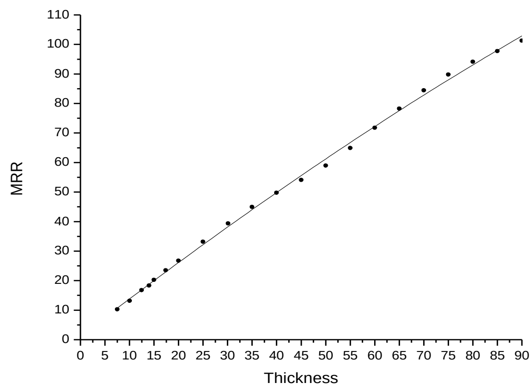

Fig 5. Influence of Thickness on MRR

MRR is a calculated value obtained as a product of cutting speed, cutting width and thickness of the work piece. The change in MRR with increase in thickness is shown in the Fig.5. The plot shows a constant rise with a positive slope up. This is due to the increase in thickness, decrease in cutting speed and increase in cutting width.

However in this process, cutting speed is an important factor as the machining is a through and through operation.

Mathematical correlations:

The mathematical correlations developed for the best fit curves are listed.

$$y = A_2 + \left\{ \frac{A_1 - A_2}{\left[1 + \exp\left(x - x_0\right)/dx\right]} \right\}$$

I = 3.098-{34.628/ [1+ exp (T + 456.92)/ 152.57]} (1)
Where I = discharge current, amp, T = thickness, mm

Cs = -545.58+{550.714/[1+exp(T + 593.15) / 93.95]} (2)
Where Cs= cutting speed, mm/min.

Sg = 70.34- {1733.54/ [1 + exp (T +343.18)/ 85.62]}(3)
Where Sg is the spark gap in micro meters.

IV. CONCLUSIONS

The influence of parameters, like discharge current, job thickness, on the machining criteria such as cutting speed, spark gap, surface finish, material removal rate are determined. The results are useful in setting the parameters required for quality cuts on Titanium. Suitable parameters can be selected for machining with the wire available. The mathematical relations developed are much more beneficial to estimate the cutting time, cost of machining and accuracy of cutting for any size of the job within machine range. The maximum error obtained in the calculated values and experimental values are less than 2%. These results will be useful to make the Wire EDM system to be efficiently utilized in the modern industrial applications like die and tool-manufacturing units for parametric setting, machining time and cost calculations and also for process planning. The minimum possible corner radius that can be achieved in this process of machining can also note from the experimental data.

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