Parametric Evaluation for Machining Die-Steel with WEDM

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Abstract- Wire electro discharge machining (WEDM) has become one of the most popular processes for producing precise geometries in hard materials, such as those used in the tooling industry. With the demands on the minimization of surface roughness, decrease of the producible geometric dimensions and improvement of the machining accuracy, Micro-Wire-EDM with a wire diameter of 80µm-250 µm has been a key technology for micro-machining. This work deals with the effect of the input parameter i.e thickness of the job on output parameters such as discharge current, cutting speed, spark gap/over cut, metal removal rate and surface roughness value of high carbon high chromium steel (HC-HCr), a die steel cut by wire-electrical discharge machining (WEDM). To obtain a precise workpiece with good quality, the parameters to be set on the machine are optimized experimentally. The output criteria can be estimated for a given thickness of the workpiece using the mathematical correlations developed.

***Index Terms*-** wire electrical discharge machining, discharge current, cutting speed, spark gap, MRR

I. Introduction

During the last decade, WEDM has become an important nontraditional machining widely used in the aerospace, automotive and tool & die industries. WEDM has nearly obtained a monopoly position in some important areas, due to its capability of machining any material with electrical conductivity more than 0.01S/cm with high cutting speed, high precision and satisfying surface finish. 5-axis CNC WEDM machine has been routinely employed in the machining of complex 3-dimensional shape and the surface roughness has improved to better than 0.2mRa. The range of materials that are machined by WEDM has increased considerably, including now sintered carbides, PCD, PCBN and specific ceramics. In WEDM, the erosion mechanism has been described as melting and/or evaporation of the surface material by the heat generated in the plasma channel. A spark is produced between the wire electrode (usually smaller than 0.3mm) and workpiece through deionized water,(used as dielectric medium surrounding the workpiece) and erodes the workpiece to produce complex two and three-dimensional shapes. Usually some extra repetitive finish cuttings along the contour of a previous cut are necessary, by offsetting the wire by a value, so that the specified accuracy and good surface quality can be obtained.

II. Major Areas of WEDM Research

The available information in the existing literature is divided into 6 categories and reviewed in the same order.

- Influence of machining parameters
- Pulse classification
- Effect of wire electrode parameters on machining criteria
- Thermal load on wire electrode
- Adaptive systems
- Parametric optimization

Parametric Optimization

In this section the authors work on machining of few ferrous materials DC53 tool steel of 27mm thick, SKD 11 tool steel, X210 Cr 12 steel of 17.3, 25, 34mm thick, stainless steel of 10, 15mm thick, En8, En31, AISI 420 steel of 31.5mm thick, non-conductive materials, ceramics like sintered carbide, polycrystalline diamond, sailon, boron nitride, silicon nitride and 5mm thick nonferrous materials, copper, brass, aluminum, graphite, tungsten carbide were discussed. The authors evaluated the optimal parameters of machining to maximize the MRR and surface finish. Hadda and Tehrani [1] designed their experiments using Taguchi L18 array and conducted wire electrical discharge turning operations on AISI D3 steel. They performed regression analysis and determined the optimum values of spark on time and electrode rotational speed for achieving higher material removal rate and better surface roughness values.

Kanlayasiri and Boonmung [2&3] optimized the parameters effecting surface finish, for machining DC53 tool steel of 27mm thick with using 0.25mm diameter wire by designing the experiments with Taguchi method. The authors developed mathematical model for optimization to predict surface roughness values and errors. The developed model has shown a maximum error of 30%. Mohammadi et al. [4] performed 54 precision turning experiments. ANOVA is used for analyzing the effect of input parameters on response. The authors considered the power, spark-on time, spark-off time, wire velocity, wire tension, wire speed and rotational speed as parameters and material removal rate as response. The authors developed mathematical relations for determining the material removal rate. Haddad and Tehrani [5] performed turning operations using L18 orthogonal array on DIN X210 Cr 12 steel. The authors derived mathematical model for material removal rate determination and its effect on surface roughness and roundness of machined surface. The die rotational speed, power and pulse off time exhibit significant effect on material removal rate. Tarng et al. [6] optimized the cutting parameters for better cutting performance using feed forward neural net work through simulated annealing algorithm. The process parameters considered for optimization are thickness of work piece, material, spark-on time, spark-off time, machining current, voltage and capacitance on cutting speed and surface roughness as response. The authors machined SUS 304 stainless steel of 10 and 15mm thicknesses. The predicted optimized values are: For 10mm thick job: Ra value 16.1μm, cutting speed 1.63mm/min and for 15mm thick job: Ra value 1.65μm, cutting speed 1.65mm/min

Jesudas et al. [7] developed a mathematical model using Taguchi analysis for optimizing the parameters of machining bronze-alumina alloy metal matrix composite. L9 orthogonal array is followed for design. ANOVA is applied to find the velocity of the optimal parameters derived. Rajurkar and Wang [8] performed experiments on work pieces of different thickness and developed an adaptive control system which monitors and controls the spark frequency according to on line identification of work piece thickness. Lok and Lee [9] machined 10 samples of Sailon material, 40mm thick under preset conditions, evaluated MRR as 4.5-6.0 mm^3/min. The authors compared the machining rate of Sailon with that of SKD11 steel and found that Sailon material machinability is poor. It was also revealed that the material removal rate increased with increase in machining current to some extent and then decreased. Kuriakose and Shunmugam [10] designed the experiments using Taguchi L18 array and conducted on Ti6A14V material with 0.25mm diameter brass coated wire under preset conditions, 80V, 8-12A machining current, 4-8μs pulse time. Formation of oxides was observed due to high temperature generation, macro and micro level stresses induced during the process. The authors observed that when the time between two pulses is larger, non-uniform cooling and heating occurs and suggested coated wire as electrode from metallurgical point of view.

Calýk and Çayda [11] presented an experimental investigation of the machining characteristics of AISI D5 tool steel in wire electrical discharge machining process. During experiments, parameters such as open circuit voltage, pulse duration, wire speed and dielectric fluid pressure were changed to explore their effect on the surface roughness and metallurgical structure. Optical and scanning electron microscopy, surface roughness and micro hardness tests were used to study the characteristics of the machined specimens and it was found that the intensity of the process energy does affect the amount of recast and surface roughness as well as micro cracking, the wire speed and dielectric fluid pressure do not seem to have much of an influence. Kadam and Basu [12] performed experiments on 17.3mm thick HC-HCr steel with 0.25mm diameter wire by varying duty factor, machining current and wire speed. The authors optimized the cutting speed and surface roughness and developed mathematical equations using regression analysis. Rao et al. [13-16] studied the effect of process parameters on the yield criteria for machining different nonferrous materials and developed mathematical correlations to evaluate the parameters. Kuriakose et al. [17] machined titanium alloy of 40mm thickness with zinc coated brass wire, 0.25mm diameter at preset machining conditions 80V voltage, 8-16A machining current, 8-10m/min wire speed,1-1.2kN wire tension while optimizing the machining parameters, cutting speed and surface roughness using data mining technique.

Kuriakose and Shunmugam [18] explained that the influence of cutting parameters on cutting velocity and surface finish are quite opposite. The authors developed a relationship between input and output variables using multiple regression model and non-dominated sorting genetic algorithm is used to optimize the multiple objectives. The authors considered voltage, machining current, spark ON, OFF times, wire speed, wire tension, injection pressure and work piece height as parameters and determined their effect on cutting speed and surface finish. The experiments on 60mm thick Ti6A14V Titanium alloy yielded a cutting speed of 0.9735mm/min and surface roughness of 3.2μm as optimum. Hewidy et al. [19] observed that right selection of the machining conditions is the most important aspect in processes related to the WEDM of Inconel 601 material. The work highlights the development of mathematical models for correlating the inter-relationships of various WEDM machining parameters of Inconel 601 material such as: peak current, duty factor, wire tension and water pressure on the metal removal rate, wear ratio and surface roughness.

Prakash and Ranganath [20] have machined En8, En31 and HC-HCr materials and analyzed the data for optimizing the parameters to evaluate MRR and surface roughness values. Kannan et al. [21] have carried out experiments on OHNS die steel of 30mm thick. The authors designed the experiments with Taguchi's design of experiment, L8 orthogonal array, 7 parameters and 2 levels. The experimental results were analyzed by ANOVA for optimum conditions such as minimum surface roughness and maximum cutting speed. Mohammadi et al. [22] used WEDM for machining of precise cylindrical forms on hard and difficult-to-machine materials An L18 (21×37) Taguchi standard orthogonal array was chosen for the design of experiments. The signal-to-noise (*S/N*) ratio analysis is employed to find the optimal conditions.

Based on the literature review, it is understood that authors have considered the values of machine settings like wire tension, wire speed, wire diameter, wire material and dielectric conductivity as follows.

Gap voltage: 90V
Wire diameter: 0.25mm
Wire tension: 80N
Wire speed: 4.7 m/min
Dielectric conductivity: 48 mhos
Flushing pressure: 1.5kN/mm^2
Spark on time: 5μs

III. EXPERIMENTAL SET UP

Fig1.Shows the schematic view of the experimental set up.

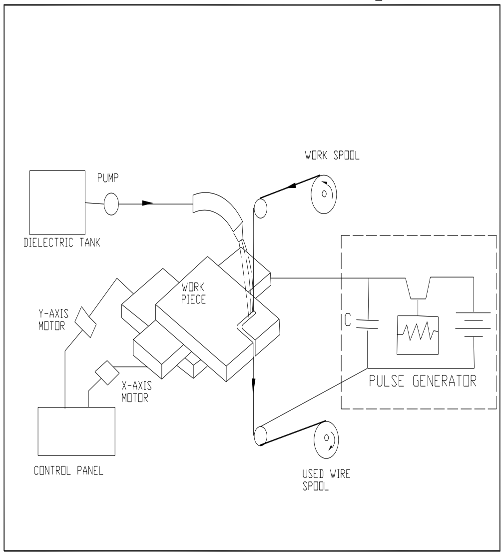

Figure 1: Schematic view of experimental set up

The HC-HCr steel specimens of 20mm x 40mm 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 80mm 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 (wire off set) is calculated from cutting width.

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.

IV. RESULTS AND DISCUSSIONS

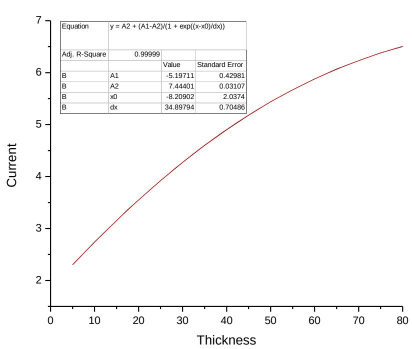

Figure 2: Effect of thickness on current

The variation in the discharge current with the increase in work piece thickness is shown in Fig.2. For a specified set of machining conditions it is observed that with increase in thickness, the required discharge 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 HC-HCr steel work piece with in the machine working range. By regression analysis of the data the equation for the best fit curve is obtained as

I=7.444 - [12.641/ {1+exp [(T+8.209)/34.898]}]

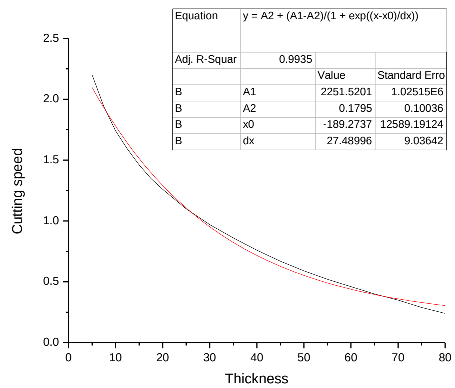

Figure 3: Effect of thickness on cutting speed

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. 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 regression analysis and mathematical correlation for the best fit curve is obtained as

C_s = 0.1795+ [2251.34/ {1+exp [(T+189.27)/27.49]}]

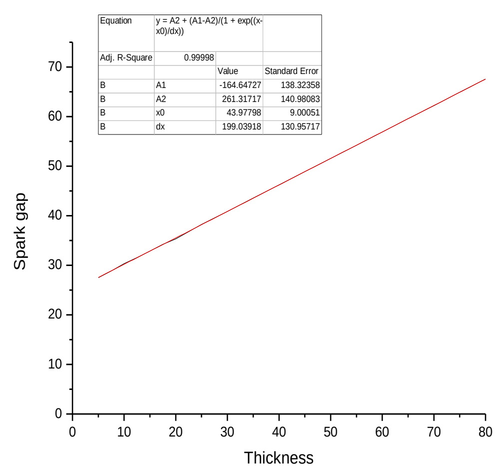

Figure 4: Effect of thickness on spark gap

The variation of spark gap occurred with change in workpiece thickness is shown in fig.4. The plot shows a steep increment in spark gap with increase in current. This may be due to higher energy in sparks at higher current. High energy spark jumps longer causing more material to melt and evaporate, creating wider cut. Spark gap should be as low as possible, as it causes unnecessary machining in width direction, reducing the cutting in length direction. The length of cut decreases with increase in spark gap, even though MRR is increasing. The spark gap value must be known in before hand for programming the cutter path other wise accuracy of machining will be lost. The best suitable curve is drawn and statistical analysis (ANOVA) is carried out. The mathematical correlation obtained is
S_g = 261.31- [425.95/ {1+exp [(T-43.98)/199.03]}]

The statistical analysis shows the values of R^2 = 0.9998 and standard deviation as 0.0034. 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.

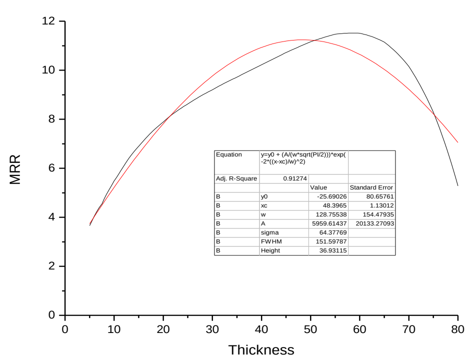

Figure 5: Effect of thickness on MRR

Fig.5 depicts the change in MRR with increase in workpiece thickness The experimental observations reveal that beyond 60mm thickness, the machining is not stable and wire rupture occur frequently. MRR is a calculated value obtained as a product of cutting speed, cutting width and thickness of the work piece. The plot shows a constant rise with a positive slope up to 50mm thickness and then falls. This is due to the increase in thickness, decrease in cutting speed and increase in cutting width. Beyond 40mm thickness the cutting speed is decreasing drastically contributing to lower the MRR. However in this process, cutting speed is an important factor as the machining is a through and through cutting operation.

V. 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 HC-HCr die steel. Suitable parameters can be selected for machining with the 0.25mm diameter wire. The mathematical relations developed are much more beneficial for machine settings, 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 & tool manufacturing units for parametric setting, machining time, cost calculations and also for process planning.

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