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PREDICTION MODELS FOR WEDM THROUGH RESPONSE SURFACE METHODOLOGY (RSM)

***Srinivas K[1] and Gopala Krishna G[2]**

[1&2]Department of Mechanical Engineering, J.B. Institute of Engineering & Technology (Autonomous), Hyderabad.

ABSTRACT

The hot working applications like pressure die casting tools require many characteristics such as high hardenability, toughness and wear resistance. All these requirements are perfectly fulfilled by H-13 hot die tool steel material. Generally H-13 hot die tool steel cannot be machined using traditional machining process due to its high hardness and strength. It can be machined only by advanced machining processes. In this paper Wire-cut Electric Discharge Machining (WEDM) of H-13 hot die tool steel is considered for the study. Pulse duration, pulse frequency and wire speed are considered as parameters and their effect on performance measures i.e. metal removal rate (MRR), kerf (K), and surface roughness studied through experimental investigation. Using Response Surface Methodology, considered parameters are optimized for maximum MRR and minimum for kerf and Surface roughness. These parameters are adjusted to improve the performance of WEDM. Analysis o Variance (ANOVA) and F-Test are carried out for the error evaluation. It is found that errors are within limits. Finally Response Surface Methodology is applied to generate a mathematical model for MRR, Surface Roughness, Kerf.

Keywords: Wire cut EDM, Response Surface Methodology, ANOVA.

1.Introduction

The hot work applications like pressure die casting tools, extrusion tools, forging dies, stamping dies and plastic moulds requires high hardenability, excellent wear resistance, high toughness and thermal shock resistance and very high polish. H-13 hot die tool steel is commonly used to satisfy all these requirements. H-13 hot die tool steel material cannot be machined through traditional machining processes due to its high hardness and strength. It can be machined through advanced machining processes. The chemical composition of H-13 hot die tool steel is given by Carbon-0.40%, Silicon-1.00%, Chromium-5.30%, Molybdenum--1.40%, Vanadium-1.00% and remaining percentage is Iron [1]

Advanced machining processes are used only when there is no suitable traditional machining process to meet necessary requirements efficiently and economically. Among all the advanced machining processes, wire cut EDM is employed because of its tight tolerances and high surface finish. Based on intense literature survey, it is noticed that very few works were reported on WEDM of H-13 hot die tool.

Wire electric discharge machining (WEDM) process is also known as wire-cut EDM. It is a non-traditional machining process. In this process a thin single brass or copper coated electrode is fed through the work piece which is immersed in the dielectric fluid, mainly deionized water is used as a dielectric fluid. The wire-cut types of machines were used in the sixtieth century for the resolution of making tools and dies by hardened steel [2].

In WEDM metal is cut with a special metal wire electrode that is programmed to travel along a preprogrammed path. A WEDM process generates spark discharges between a small wire electrode (usually less than 0.5 mm diameter) and a work piece with deionized water as the dielectric medium and erodes the work piece to produce complex two and three dimensional shapes according to a numerically controlled (NC) path. The mechanism involved in this WEDM is melting and evaporation. The cutting mechanism of WEDM as shown in the Fig 1.1

**Corresponding Author - E- mail: srinivask005@gmail.com*

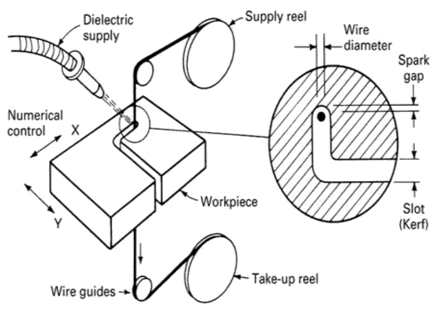

Fig. 1.1 Cutting mechanism of WEDM

Amit Joshi et al. [3] conducted experiments for modeling of Surface Finish on WEDM using RSM on pure titanium with brass wire. In which they considered pulse on time (TON), pulse off time (TOFF), gap voltage (SV) as input process parameters and surface finish as output performance measure. Neeraj Sharma et al. [4] investigated for Modeling and multi response optimization on WEDM for HSLA by RSM. They conducted the experiments on D2 tool steel with brass wire and optimized the values of Pulse-on time, Pulse-off time, Servo gap voltage, Peak current, Wire tension by considering the cutting speed and dimensional deviation as output performance measures. Yu Huang et al. [5] conducted the experiments for the optimization of cutting conditions of YG15 on rough and finish cutting in WEDM based on statistical analysis. In which they optimized the values of pulse-on time, pulse-off time, power, cutting feed rate, wire tension, wire speed, and water pressure by considering surface roughness (Ra) and material removal rate (MRR) as output performance measures. Parveen Kumar et al. [6] conducted experiments for optimization of input parameters of WEDM (titanium alloy) by using Taguchi method. In which they considered pulse-on time, pulse-off time, power, cutting feed rate, wire tension, wire speed, water pressure and material removal rate, wire wear ratio, surface flatness as output performance measures. Danial Ghodsiyeh et al. [7] studied on current research trends in WEDM on Ti6Al4V with copper wire. In which they considered pulse on time, pulse off time, servo voltage, peak current, dielectric flow rate, wire speed, wire tension as input process parameters and material removal rate (MRR), surface roughness (Ra), sparking gap (Kerf), wire lag (LAG) and wire wear ration (WWR) and surface integrity factors as output performance measures by using Response Surface Methodology, Taguchi method and nontraditional optimization techniques. Pandu R. Vundavilli et al. [8] investigated for the parameter optimization of WEDM Process using Genetic Algorithm and Particle Sworm Optimization on Titanium alloy (Ti6A14 V)) by considering applied voltage, ignition pulse current, pulse-off time, pulse duration, serve controlled reference mean voltage, servo-speed variation, wire speed, wire tension injection pressure as input process parameters and cutting velocity and surface finish as output performance measures.

2. Methodology

In this, Response Surface Methodology (RSM) technique is applied to generate mathematical models for output process parameters in terms of input process variables. In this Methodology Design-Expert software is used. In Design expert software, first choose the order of equations to be generated. After that the design of experiments table is selected to conduct the experiments based on coded values of order of the equation. The responses to be entered in the table and go to ANOVA option for analysis. It will evaluate the performance measures. If errors are within the limit then those values are significant. Then the mathematical models are generated for output performance measures in terms of input process parameters.

2. 1 Response Surface Methodology [RSM]

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques. It is useful for developing, improving, and optimizing the processes. The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process. Thus performance measure or quality characteristic is called the response. The input variables are sometimes called independent variables and they are subject to the control of the scientist or engineer. The field of response surface methodology consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistical modeling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the values of the process variables that produce desirable values of the response. In this report we will concentrate on the second strategy: statistical modeling to develop an appropriate approximating model between the response y and independent variables $X_1, X_2, X_3, ...X_k$

In general, the relationship is

$$Y = f(X_1, X_2, X_3, ...X_k) + \varepsilon ; \qquad (1)$$

For the case of two independent variables, the first-order model in terms of the coded variables is

$$Y = \beta_0+\beta_1X_1+\beta_2X_2 \qquad (2)$$

The form of the first-order model in Equation is sometimes called a main effects model, because it includes only the main effects of the two variables 1x and2x. If there is an interaction between these variables, it can be added to the model easily as follows:

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_{12}X_1X_2 \qquad (3)$$

This is the first-order model with interaction. Adding the interaction term introduces curvature into the response function.

Often the curvature in the true response surface is strong enough that the first-order model (even with the interaction term included) is inadequate. A second-order model will likely be required in these situations. For the case of two variables, the second-order model is

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_{11}X_{12}+\beta_{22}X_{22}+\beta_{12}X_1X_2 \qquad (4)$$

This model would likely be useful as an approximation to the true response surface in a relatively small region. The second-order model is widely used because the second-order model is very flexible. It can take on a wide variety of functional Forms, so it will often work well as an approximation to the true response surface.

The second-order model is

$$Y = \beta_0+\sum\beta_jX_j+\sum\beta_{jj}X^2_j+\sum\sum\beta_{ij}X_iX_j \qquad (5)$$

Data for fitting second order model is given in the table mentioned in experimentation and data collection. The regression coefficients are obtained by using the Design-Expert software by giving the units of the input and output parameters. So the regression equation is obtained.

2.2 Analysis of Variance (ANOVA)

ANOVA shows the effect of input process parameters on output performance measures. It give the information about the effect of process parameters in the order of their significance it means which parameter is more effecting and which is less effecting in the order of their effect. This software is selected because it is simple and reliable to measure significance of process parameters. To check the significance of the mode, analysis of variance (ANOVA) conducted for the quadratic regression model. On the basis of the experimental values, statistical testing is carried out by using ANOVA. The statistical significance of the second-order equation is statistically significant if $P<0.0001$. However, the lack of fit is not statistically significant at 99% confidence level. Here P represents the P- functional value. The p-value is the level of marginal significance within a statistical hypothesis test representing the probability of the occurrence of a given event. The p-value is used as an alternative to rejection points to provide the smallest level of significance at which the null hypothesis would be rejected.

3. Experimentation & data collection

To investigate the influence of the process parameters on MRR, surface roughness and Kerf, initially developed a mathematical model from the experimental values. The experiments were conducted by varying the process parameters. The most significant process parameters are those parameters which can affect the output performance measures in higher order. The other parameters are not affecting within a considered amount. So omited these variables and are kept constant during the experimentation. These parameter values are not used directly in this analysis. These are converted from the natural values with coded value. Those coded values as shown in Table 3.1

In RSM, experimental set up is designed based on the number of process parameters and their levels. Pulse duration, pulse frequency and wire speed are considered as three process parameters with three levels. This experimental array has chosen from design of expert software. For the experimentation, full factorial array is considered with 20 experiments. The experimental set up and experimental values are shown in respective columns in MRR, Ra, and Kerf in the same table 3.2.

Table 3.1. Experimental setup with coded values for the parameters

Parameter /coded value	-1.682	-1	0	1	1.682
Pulse duration (µsec)	4	7	10	13	16
Wire speed (m/min)	7	7.4	8	8.4	9
Pulse frequency (KHz)	30	34	40	44	50

Table 3.2. Reponses for the performance measures

Exp. No.	Pulse duration	Wire speed	Pulse frequency	MRR	Ra	Kerf
1	-1	-1	-1	0.3670	3.42989	0.3053
2	1	-1	-1	0.4299	3.53593	0.3228
3	-1	1	-1	0.3635	1.88296	0.2827
4	1	1	-1	0.4260	2.5193	0.2642
5	-1	-1	1	0.3757	3.6579	0.3340
6	1	-1	1	0.4621	3.8099	3.8099
7	-1	1	1	0.3958	3.9242	3.9242
8	1	1	1	0.4666	2.2216	2.2216
9	0	0	0	0.3972	2.7724	2.7724
10	0	0	0	0.4476	3.3071	3.3071
11	0	0	0	0.4026	3.4774	3.4774
12	0	0	0	0.3885	2.5277	2.5277
13	-1.682	0	0	0.3829	2.7517	2.7517
14	-1.682	0	0	0.4013	3.0081	3.0081
15	0	-1.682	0	0.4106	3.194	3.194
16	0	-1.682	0	0.4011	2.9147	2.9147
17	0	0	-1.682	0.3977	3.1038	3.1038
18	0	0	-1.682	0.4065	3.0158	3.0158
19	0	0	0	0.3973	3.1671	3.1671
20	0	0	0	0.4072	2.9767	2.9767

4. Results and analysis

The experimental values are entered in Design Expert software to analyze the results. After analyzing the results, click on fitting summery. It shows a linear, two-factor interaction (2FI), quadratic and cubic polynomials to the response. After the computations are completed, the program displays the results. Next it shows several extremely useful summary tables for model selection. The program automatically underlines at least one “Suggested” model. Always confirm this suggestion by looking at these tables. The F value is the ratio of the mean regression sum of squares divided by the mean error sum of squares. Its value will range from zero to an arbitrarily large number. This arbitrary number can also be called as critical F value. This value depends upon desired confidence level and degrees of freedom. In our experimental analysis its value chosen as 9.55 If F value is more than this, it should be rejected.

4.1 Model Fitting For MRR, Surface Roughness & Kerf

The Design Expert software is used to generate the second order mathematical models for MRR, Surface roughness and Kerf. ANOVA is applied and is discussed in the following sections.

4.1.1 Analysis of Variance for MRR

ANOVA is applied for maximization of MRR and it is found that errors are within the limit. It is represented in the Table 4.1.1

Table 4.1.1. ANOVA table for MRR

Source	Sum of squares	DF	Mean square	F value	Prob > F
Block	4.532E-004	1	4.532E-004	-	-
Model	8.003E-003	6	1.334E-003	2.43	0.0895 significant
A	1.661E-003	1	1.661E-003	3.03	0.1073
B	1.185E-004	1	1.185E-004	0.22	0.6503
C	2.564E-004	1	2.564E-004	0.47	0.5070
AB	3.105E-003	1	3.105E-003	5.66	0.0348
AC	1.431E-003	1	1.431E-003	2.61	0.1321
BC	2.432E-003	1	1.431E-003	2.61	0.1321
Residual	6.578E-003	12	5.481E-004	-	-
Lack of Fit	3.049E-003	8	3.812E-004	0.43	0.8547 significant
Pure Error	3.528E-003	4	8.821E-004	-	-
Cor Total	0.015	19	-	-	-

The Model F-value of 2.43 implies the model is significant. There is only a 0.08% chance that a "Model F-Value" this large could occur due to noise values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, A^2 and AB are significant model terms. The values greater than 0.1000 indicate the model terms are not significant.

The "Lack of Fit F-value" of 0.43 implies the Lack of Fit is significant. There is only a 1.87% chance that a "Lack of Fit F-value" this large could occur due to noise. Significant lack of fit is bad then that is the right model to fit.

The final equation obtained in terms of coded factors is

MRR= + 0.41 - 0.011 X A + 2.945E-003 X B + 4.333E-003 X C - 0.020 X A X B + 0.013 X A X C - 0.013 X B X C (6)

Where,

A = pulse duration (µsec)

B = wire speed (KHz)

C = Pulse frequency (KHz)

4.1.2 Analysis of variance for surface roughness:

ANOVA is applied for minimization of Surface Roughness and it is found that errors are within the limit. It is represented in the Table 4.1.2

Table 4.1.2. ANOVA table for Surface Roughness

Source	Sum of squares	DF	Mean square	F value	Prob > F
Block	0.021	1	0.021	-	-
Model	3.04	1	0.34	1.39	0.3145 significant
A	0.57	1	0.57	2.37	0.1582
B	0.024	1	0.024	0.099	0.7601
C	0.34	1	0.34	1.39	0.2693
A^2	0.33	1	0.33	1.37	0.2713
B^2	0.39	1	0.39	1.59	0.2384
C^2	0.41	1	0.41	1.69	0.2256
AB	0.66	1	0.66	2.72	0.1337
AC	0.25	1	0.25	1.02	0.3391
BC	0.26	1	0.26	1.07	0.3284
Residual	2.18	9	0.24	-	-
Lack of Fit	1.90	5	0.38	5.54	0.0630 significant
Pure Error	0.28	4	0.070	0.070	-
Cor Total	5.24	19	-	-	-

The "Lack of Fit F-value" of 5.54 implies the Lack of Fit is significant and the fnal equation obtained in terms of coded factors is

SR= + 3.38 + 0.21 X A + 0.042 X B + 0.16 X C - 0.15 X A^2- 0.16 X B^2 + 0.17 X C^2 + 0.29 X A X B + 0.18 X A X C - 0.18 X B X C (7)

Where,

A = pulse duration (µsec)

B = wire speed (KHz)

C = Pulse frequency (KHz)

4.1.3 Analysis of Variance for Kerf:

ANOVA is applied for minimization of Kerf and it is found that errors are within the limit It is represented in the table 4.1.3

Table 4.1.3. Analysis of variance table for Kerf

Source	Sum of squares	DF	Mean square	F value	Prob > F
Block	9.508E-004	1	9.508E-004	-	-
Model	0.022	9	2.475E-003	1.65	0.2341 significant
A	4.305E-004	1	4.305E-004	0.29	*0.6053*
B	3.678E-003	1	3.678E-003	2.45	0.1520
C	4.214E-003	1	4.214E-003	2.81	0.1282
A^2	2.487E-003	1	2.487E-003	1.66	0.2302
B^2	3.971E-003	1	3.971E-003	2.64	0.1383
C^2	1.690E-003	1	1.690E-003	1.24	0.2935
AB	4.865E-003	1	4.865E-003	0.27	0.6185
AC	0.014	1	1.501E-003	1.13	0.3163
BC	9.828E-003	1	1.966E-003	3.24	0.9084
Residual	3.685E-003	9	9.212E-004	-	-
Lack of Fit	0.011	5	2.167E-003	2.53	0.2413 significant
Pure Error	4.978E-004	4	1.244E-004	-	-
Cor Total	0.037	19	-	-	-

The final equation obtained in terms of coded factors is

Kerf=+0.31 + 5.614E-003 A + 0.016 X B + 0.018 X C - 013 X A^2-0.017 X B^2-0.011 X C^2 + 7.064E-003 X A X B + 0.015 X A X C- 0.025 X B X C (8)

Where,

A = pulse duration (μsec)
B = wire speed (KHz)
C = Pulse frequency (KHz)

5. Conclusions

The Wire-cut EDM is a complex process having many numbers of factors affecting the process. The main factors considered are: pulse duration, pulse frequency, wire speed. The following conclusions are arrived from these factors.

- The most significant process parameter is pulse duration, and followed by pulse frequency and wire speed respectively in the order of their significance.
- The effects of these factors on MRR, surface roughness and Kerf evaluated for the machining of H-13 hot die tool steel on WEDM. Based on ANOVA and F-test the errors are evaluated and it is found that errors are within the limits.
- Using Response Surface Methodology prediction models are developed to estimate MRR, Surface roughness, Kerf.

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