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PREDICTION AND ANALYSIS OF ELECTRIC DISCHARGE MACHINING (EDM) DIE SINKING MACHINING OF PH 15-5 STAINLESS STEEL BY USING TAGUCHI APPROACH

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EDM is effectively used in many application like aerospace, turbine, medical and etc., due to its non-contact process between work piece and tool. In this study, the important machining process parameters such as peak current, pulse on time, pulse off time and fluid pressure are inspected that incitement to distress the performance of the operation Material removal rate (MRR) and Tool wear rate (TWR). Subsequently tool geometry and materials that are predominantly affect the work piece response factor as Surface roughness (SR). Hence copper electrode with coating of brass material and different tool geometry are also considered. PH15-5 stainless steel precipitated hardening steel was machined up to 5 mm depth with EDM die sinking machine using 27 number of experiments designed

Keywords: EDM, PH15-5, mathematical model, microstructure, Taguchi method,

INTRODUCTION

Electric discharge machining (EDM) of non-traditional techniques capable of producing high strength and electric conductivity material. It uses thermal energy to melt and wear away the surface of the work piece by creating plasma channel through a serious of spark in-between two electrodes submerged in dielectric fluids.

In a study conducted by Abbas et al. [1] reviewed that EDM machines were the thermal energy process which yields higher surface finish aircraft components, surgical tools and medical implants, automobile component and gas turbine parts. This process pertinent to implement for new advanced material that cannot be achieved through the conventional machining processes. To augment the proficiency of machine, it requires a higher level of technique in obtaining the optimum working parameter for every new material. Asfana Banu & Mohammad Yeakub Ali [3], reviewed different types of EDM process and mathematical modelling that relate input and output factor.

MRR is the most important factor in order to achieve higher maximum Metal removal rate (MRR). Biradar et al. [4] examined optimal process parameter of EDM machine for machining High carbon high chromium die steel (HCHCr) with titanium nitride coated copper electrode and found that it statistically improved the Tool wear rate (TWR) and Metal removal rate (MRR). EDM was used to machine some stainless steel of high strength stainless steel alloys to get highest MRR and lowest TWR [2]. Machining of stainless steel with conventional machines nonexistence in obtaining surface roughness and process performance [2]. Therefore, non-conventional machining process such as EDM is required to improve performance and obtaining surface finish and dimensional accuracy [11]. Among the different grades of stainless steel, PH15-5 was not explored in EDM machining process.

Precipitated hardened stainless steel has wide variety of application such as aerospace, nuclear and chemical industries [11]. PH 15-5 stainless steel more difficult to machine after precipitation hardening process due to its strength [6]. Therefore, this work revealed the importance of EDM machining parameter of PH 15-5 and most predominant factors that affect the performance and accuracy of the job.

EXPERIMENTAL METHOD

PH15-5 stainless steel material of diameter 30 x 50 mm rod was selected for die sinking EDM machining process shown in Figure1. The different shape of tool electrode with 12 mm size and 55 mm height were cut from rectangular block by electro wire cutting machine and brass coating for about 5 micron thickness done through electroplating process. Weight of the work piece and tool were measured using weighing machine and Surface roughness (SR) was measured through mitutoyo profilometer with $\lambda = 8$. MRR and TWR calculated by the following equation (1) and (2)

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Figure 1 Operation with rectangle tool shape

$$\text{Metal removal rate} = W_b - W_a / M_t \quad (1)$$

w– machining timehere,

W_b – weight of the work piece before machining

W_a – weight of the work piece after machining

M_t – machining time

$$\text{Tool wear rate} = W_{TB} - W_{TA} / M_T \quad (2)$$

where

W_{TB} - weight of the work piece before machining

W_{TA} - weight of the work piece after machining

M_T - machining time

TAGUCHI METHOD AND DESIGN OF EXPERIMENT

Taguchi is a statistical method for conducting experiments at minimum cost by using different orthogonal arrays [8, 9]. It can also be utilized to forecast and optimize the effect of input parameters based on the output responses. Optimum parameters that regulate the process performance of many manufacturing processes are found via effective and systematic approach of Taguchi techniques. The application of Taguchi widely used in many sector [10]. It determines deviation between the experiment and preferred value by means of loss function through signal to noise ratio (S/N) [10]. Generally, S/N ration always uses three kind of quality characteristic such as lower-the-better, higher-the-better, and nominal-the-better [9]. The main aim of this study is to maximize the MRR and minimize the TWR &SR. [10] Here lower-the-better and higher-the-better was predicted by using the following equation 3 and 4.

$$\eta = S/N = -10log\frac{1}{n}\sum_{i=1}^{n} y_i^2 \quad (3)$$

$$\eta = S/N = -10log\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2} \quad (4)$$

Where $y_{i=}$ measured data at the i[th] experiment

n = number of observation in a experiments

s^2 = variance of observed data(y)

Table 1 shows different level of process parameter of voltage (A), current (B), pulse on (C), pulse off (D), shape (E) and pressure (F) were selected as control parameter and their level were tabulated. Based on Taguchi experimental design, L27 (3^6) orthogonal array was selected for conducting an experiments in EDM sinking machine and to predict the effect of process parameters on responses

Table 1 Machining parameters and their level

Input Parameters	Unit /	L1	L2	L3
A	V	30	35	40
B	A	5,5	9	12,5
C	μs	6	8	10
D	μs	4	5	6
E	-	S	R	T
F	kg/cm^2	60	75	90

Analysis of variance for input parameters

The main aim of this analysis is to find the significant factor that affect responses during operation and percentage of contribution of control factor tabulated in Table 2 determined through ANOVA, which was carried out using Minitab17. Significant factors achieved by sum of squared deviation of each machining parameters. The F-ratio is used to check the critical parameter of machining process, which affect the performance of the machine. The F-values in the ANOVA table identify the important input parameter are statistically compared. It also shows the percentage of contribution of each parameter, higher the percentage infers greater significant on responses. In Table 2, reveals the percentage of contribution of each process parameter. Current is most significant factor in both coated and non-coated copper tool. Ton, T-off, voltage and pressure substantially affect the response factors. Shape of the tool doesn't has influence on none of the output parameter.

ANALYSIS AND EVALUATION OF EXPERIMENT RESULT

MRR, TWR and SR were measured through the experimental design for the different blend of the input parameter by using L_{27} orthogonal array. Signal to noise ratio (S/N) gives optimized process parameters among twenty seven number of experiments. The highest MRR and lowest TWR are most important for improvement of the production and lowering the tool cost. SR ensure quality of the machined features. Therefore the "higher-the-better" equation for MRR, "lower-the-better" equation for TWR and for SR were used for the calculation of the S/N ratio.

Table 2 **Percentage of contribution for different control factor**

	UNCOATED COPPER TOOL						COATED COPPER TOOL					
	A	B	C	D	E	F	A	B	C	D	E	F
MRR / % of contribution	1,54	89,36	5,13	3,77	0,00	0,13	3,96	82,70	10,16	2,9	0,017	0,14
TWR / % of contribution	1,91	88,58	5,50	3,65	0,01	0,21	4,01	82,00	10,52	3,10	0,02	0,18
SR / % of contribution	18,8	58,7	13,6	8,8	0,0	0,1	39	41	19	0	0	0

Analysis of the consequence of each input factor on the MRR and TWR were performed. This table shows the optimal levels of input parameter by using Taguchi techniques. Optimal machining parameters of the input factor was found according to the highest S/N ratio for the response factor in the levels of input parameter [1]. Therefore, the optimum condition of input parameters were identified as tabulated in Tables 3,4

From the S/N ratio value, the MRR increases as current, pulse on time and pressure increased and decreases with increase of voltage. It was first decreased and then increased to some extent by pulse off time. The current and pulse on time increases energy required to remove the material from work piece. The pressure increases removal rate considerably due to high fluid flow. TWR and SR minimized as current and pulse on time decreased due its energy level. They were increased as melted material form a layer thickness on work piece as well as on electrode as decrease in fluid pressure. Rectangle shape of tool gives highest removal rate in both tool. Current is most influence parameter that affect all response parameter as per signal to noise ratio response table.

Table 3 **Optimum value while machining with copper tool**

	voltage / V	current / A	t_{on} / μs	t_{off} / μs	shape	pressure / kg/cm^2
MRR	A1	B3	C3	D1	E2	F3
TWR	A2	B1	C1	D2	E1	F1
SR	A3	B1	C1	D3	E2	F3

Table 4 **Optimum value while machining with Brass coated copper tool**

MRR	A1	B3	C3	D1	E3	F3
TWR	A3	B1	C1	D2	E2	F1
SR	A3	B1	C1	D3	E2	F3

MATHEMATICAL MODEL AND PREDICTION PERFORMANCE

Regression analysis was mostly used for making relationship between dependent variable and independent variables [2]. The developed regression equations shown in equations 5 to 10.

In this research, there are three dependent variables such as MRR, TWR and SR defined with respect to the independent input factors and the estimated by equation are given in (6)-(11). Estimated equation for MRR, TWR and SR were established for linear regression model. The coefficient of determination (R^2) of the equation with linear regression model for MRR,TWR and SR were found as 96,32 %, 95,97 % and 98,25 % respectively, by Brass coated Copper tool and 94,59 %, 94,69 % and 93,78 % respectively by copper. R^2 is a statistical measurement of regression line approximate the real experiment data points and its value should be between 0.8 and 1 [11]. Therefore, it could be possible to apply for calculating MRR, TWR and SR while selecting process parameters in the EDM die sinking machine for PH 15-5 stainless steel.

Regression equation with brass coated copper tool

$$MRR = -0{,}1264 - 0{,}00455\,A + 0{,}03188\,B + 0{,}01957\,C - 0{,}00190\,D + 0{,}0118\,E + 0{,}000280\,F \quad (5)$$

$$TWR = -0{,}0473 - 0{,}001498\,A + 0{,}010609\,B + 0{,}006651\,C - 0{,}00028\,D + 0{,}00043\,E + 0{,}000116\,F \quad (6)$$

$$SR = 3{,}444 - 0{,}03800\,A + 0{,}05476\,B + 0{,}08540\,C - 0{,}01778\,D - 0{,}00056\,E - 0{,}0963\,F \quad (7)$$

Regression equation with copper tool

$$MRR = -0{,}1007 - 0{,}000475\,A + 0{,}01908\,B + 0{,}00783\,C - 0{,}00242\,D + 0{,}00012\,E + 0{,}000172\,F \quad (8)$$

$$TWR = -0{,}0394 - 0{,}000346\,A + 0{,}007025\,B + 0{,}003054\,C - 0{,}00010\,D + 0{,}00020\,E + 0{,}000080\,F \quad (9)$$

$$SR = 3{,}448 - 0{,}03656\,A + 0{,}09857\,B + 0{,}1052\,C - 0{,}1256\,D + 0{,}0033\,E - 0{,}107\,F \quad (10)$$

RESULT AND DISCUSSION

As described, highest MRR and lowest tool wear rate among 27 experiments were obtained as 0,374101 gram/minute in brass coated copper tool and 0,016425 gram/minute in copper tool respectively. Average value of MRR and TWR are 0,171658 and 0,057147 in brass coated copper tool but in copper tool 0,118088 and 0,042041 respectively. The brass coated copper tool give better performance on MRR and TWR because it improve strength when added with zinc but copper oxidized in nature. MRR value always better in brass coated tool whereas TWR and SR fluctuated in both tool. Machined surface was captured by using optical microscope with 200 X as shown in Figures 2 and 3. Some melted content present on the surface machined with

Figure 2 Optical microscope image of machined surface

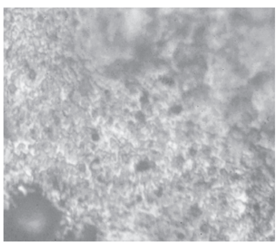

Figure 3 Optical microscope image of surface with Brass coated copper tool

copper tool but it was less in surface machined by brass coated copper tool.

CONCLUSION

In this study, an exploration on the MRR, TWR and SR were analyzed and predicted based on experimental design of Taguchi method. The following generalized conclusions were drawn from the experimental result of PH 15-5 Stainless Steel:

- The highest MRR and lowest TWR are generated during machining of PH 15-5 with Brass coated copper electrode tool which indicates removal rate increased compare to copper tool.
- The highest effective factor were recognized as current followed by pulse on time , pulse off time, voltage, pressure and shape for MRR and TWR whereas machining by copper tool. Furthermost current followed by pulse on time, voltage, pulse off time, pressure and shape have significant while machining with copper tool.
- The ANOVA analysis discovered that the current was the most significant factor for all output response in EDM die sinking machining process.
- The regression analysis revealed that all data values are accurately predict the responses value.
- In conclusion, the Taguchi method was successfully applied for an experimental design and improved performance of EDM Die sinking machine.

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Note: The responsible translator for English language is G. Kumar, Ambo University, Ethiopia.