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Parameter Optimization of Electro Discharge Machining Of AISI H11 Die Steel Material and Its Tool Wear Behavior by Using Taguchi Techniques

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Abstract--In this paper, the cutting of AISI H11 Die Steel material using electro discharge machining (EDM) with a copper electrode by using Taguchi methodology has been reported. The Taguchi method is used to formulate the experimental layout, to analyses the effect of each parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter such as peak current, gap voltage, duty cycle and pulse on time. It is found that these parameters have a significant influence on machining characteristic such as material removal rate (MRR), electrode wear rate (EWR), radial overcut (ROC). The analysis using Taguchi method reveals that, in general the peak current significantly affects the MRR, EWR and ROC.
Electric discharge machining (EDM) is one of the maximum commonly used nontraditional processes for making accurate intricate shapes on hard materials like die steels and is most preferred process to be followed for die and mold making. In this research work, Experiment plan has been designed using taguchi technique to study the effect of different parameters and their levels by conducting least number of experiments. As the most popularly used material in die and mold casting industries are the die steels hence for this work AISI H11 die steel are used as the workpiece material for slot cutting. The results are analyzed using analysis of variance (ANOVA) both analytically and graphically. Significant factors affecting the output parameters have been found using F-test and percentage contribution. From the experimental investigation copper tool followed by C18000 tool has been found to give the best MRR results and high tool wear, whereas tungsten tool has been found to give the least MRR accompanied by least tool wear.
Keywords--Aisi H11 die steel , ANOVA, Taguchi Method, Electronic Discharge Machining

I. INTRODUCTION

During the 1930s, attempts were made for the first time to machine metals and diamonds with electrical discharges. Erosion was caused by intermittent arc discharges occurring in air between the tool electrode and work piece connected to a DC power supply. These processes were not very precise due to overheating of the machining area and may be defined as 'arc machining' rather than 'spark machining.'
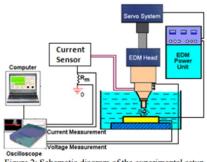

Figure 2: Schematic diagram of the experimental setup

In EDM, a potential difference is applied between the tool and workpiece. Both the tool and the work material are to be conductors of electricity. The tool and the work material are immersed in a dielectric medium. A gap is maintained between the tool and the workpiece. Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established. , the material removal in EDM mainly occurs due to formation of shock waves as the plasma channel collapse owing to

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discontinuation of applied potential difference. Generally the workpiece is made positive and the tool negative. Hence, the electrons strike the job leading to crater formation due to high temperature and melting and material removal. Similarly, the positive ions impinge on the tool leading to tool wear. In EDM, the generator is used to apply voltage pulses between the tool and the job. A constant voltage is not applied.

A. Parameters Affecting Performance of EDM

1) Discharge Voltage: Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric [Ghosh and Mallick]. Before current flows, open gap voltage increases until it creates an ionization path through the dielectric. Once the current starts flowing, voltage drops and gets stabilized at the working gap level. Higher is the voltage, more is the gap, that improves the flushing conditions and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases [Fuller, 1996].

2) Peak Current: Higher amperage is used in roughing operations and in cavities or details with large surface areas. Machined cavity is a replica of tool electrode and excessive wear will affect the accuracy of machining.

3) Pulse Duration and Pulse Interval: Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval. When the optimum pulse duration for each electrode—work material combination is exceeded, material removal rate starts to decrease.

B. Experimental Design

Designing an experiment is the principle need of any experimentation plan. In present study Taguchi Method is used for preparing experimental design. Main steps of experiment plan are listed below.

    Defining objective function
    Selecting an appropriate OA
        Selection of factors
        Pilot Experimentation
        Finalizing the factors and their levels

1) *Defining Objective Function:* The main objective of this experimentation is to study the effect of current, powder concentration, type of powder and magnetic strength on tool behavior during macro and micro EDM, PMEDM during slot cutting to analyze output parameters dimensional and profile accuracy of tool.

2) *Selecting an Appropriate OA:* The Taguchi method involves reducing the variation in a process through robust design of experiments by using a selected set of experimentation plan. Each factor is assigned column(s) depending on its DOF. Each level of a factor has an equal number of occurrences within each column; and for each level within one column, each level within any other column will occur an equal number of times as well.

3) *Selection of Factors:* Selection of factors is an important task which is to be done carefully to prepare the most effective design of experiment. Brainstorming and pilot experimentations are conducted to decide factors and their levels.

4) *Calculation of DOF:* DOF denotes the number of the independent comparisons that can be made in any experiment. The number of factors considered for experimentation, their respective levels determine the total degree of freedom required for designing OA. Mathematically, DOF for each factor is calculated as, DOF= n-1, where n is the level of each factor

5) *Selection of OA for PMEDM:* Different factors considered for PEDM experiments and their levels are listed in Table 3.2.

Factors (unit)	Levels		
	Level 1	Level 2	Level 3
Current (A)	2	4	6
Magnetic field (T)	0.1	No	-
Tool material	Copper	C18000	Tungsten
Powder type	Tungsten	Copper	Titanium
Concentration (g/L)	2	4	6
Pulse-on time (µs)	50	100	200

Factors and their levels for magnetic assisted PMEDM

C. Experimental Set Up

1) Machine Set Up: The experimentation work is performed on T-3822 M Electric Discharge Machine of Victory Electromech placed in non-traditional machining lab at Thapar University, Patiala. A separate arrangement is added for performing powder mixed EDM, a mild steel tank with inside dimensions as length 330 mm, breadth 180 mm, height 187 mm and plate thickness 3 mm. Capacity of the used tank is 9 L. A stirrer with the maximum speed of 1400 rpm is used to properly mix the powder in the dielectric medium.

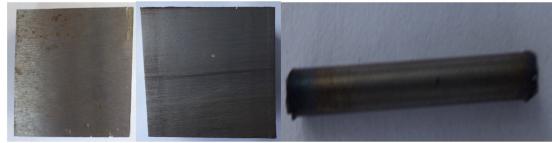| S. No	Parameter	Value
1	Voltage	$135\pm5\%$ V
2	Polarity	Positive
3	Machining time	8min
4	Pulse-off time	57µs
5	Dielectric medium	EDM oil

EDM machine with stirrer arrangement

Various input parameters varied on the EDM machine for present study are current and pulse on time. Levels of the input parameters are decided on the basis of pilot experimentation.

Some parameters that are kept constant during the study are listed in

B. Work piece and Tool Electrode Details

For experimentation, die steel material is used as workpiece. Before machining, workpiece is properly grinded from both the sides for maintain perfect alignment of workpiece with the tool electrode during machining. Three electrode materials used for machining purpose, namely copper, tungsten and C18000 (alloy (Copper, Chromium, Nickel, Silicon (beryllium free)), all with diameter 2.4mm and 30mm length. Workpiece materials before machining and tool electrodes are shown in

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II.   RESULTS

The effect of powder mixed in dielectric, concentration of powder, current, tool material and pulse-on duration is analyzed on MRR and TWR with and without using external magnetic field. Using Taguchi experimental design, L18 orthogonal array is used for the experiments using bar magnets of 0.1 T. Schematic representation of the tool and the workpiece is shown in Fig. 4.1. Tool is made in contact with the workpiece up to 10 mm in length and machining duration is kept 10 minutes.

A.   MRR for H11 Workpiece

The results for MRR calculated by the Eq. are given in Table

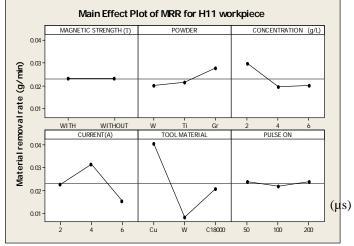| Exp. No	Magnetic strength	Powder	Concentration (g/L)	Current (A)	Tool material	Pulse-on (µs)	MRR (g/min)
1	With	W	2	2	Cu	50	0.05200
2	With	W	4	4	W	100	0.00533
3	With	W	6	6	C18000	200	0.01333
4	With	Ti	2	2	W	100	0.01200
5	With	Ti	4	4	C18000	200	0.02733
6	With	Ti	6	6	Cu	50	0.02000
7	With	Gr	2	4	Cu	200	0.06000
8	With	Gr	4	6	W	50	0.00800
9	With	Gr	6	2	C18000	100	0.01000
10	Without	W	2	6	C18000	100	0.01733
11	Without	W	4	2	Cu	200	0.02533
12	Without	W	6	4	W	50	0.00666
13	Without	Ti	2	4	C18000	50	0.03133
14	Without	Ti	4	6	Cu	100	0.02733
15	Without	Ti	6	2	W	200	0.01200
16	Without	Gr	2	6	W	200	0.00533
17	Without	Gr	4	2	C18000	50	0.02466

Results of MRR for H11 workpiece

The results are analyzed using ANOVA. It helps in identifying the important process parameters affecting the response. Results for mean of MRR calculated at 90% confidence level ANOVA table for MRR of H11workpiece.

The principle followed by *F*-test is that, greater is the *F* value for an input parameter the larger is its effect on output parameter. ANOVA shows the results of MRR of PMEDM with and without the use of magnetic strength. Under such experimental conditions the two factors i.e. tool material (*F* value 15.56) and current (*F* value 4.27) are found to be significant. The highest MRR is achieved using copper tool followed by C18000 alloy and, the tungsten tool is found to give the least MRR among the three tool materials used. The following pattern is observed due to difference in their electrical conductivities as the electrical conductivity of copper is found to be the highest. Thus MRR achieved by the tungsten is very low due to its poor electrical conductivity.

The second significant factor is the current having *F* value as 4.27. Initially the MRR is found to increase with increase in current till the current reaches value of 4 A after that the MRR begins to decrease when current approaches the value of 6 A. The reason behind this may be due to the situation of arcing rather than spark and also due to the fact that as the current increases the downward movement of tool becomes fast as a result there is not enough time for the removal of debris and the suspended powder which of arcing.

The next highest value of *F* is for the concentration 1.58 g/L. MRR is found to decrease with concentration because as the amount of powder suspended in the dielectric increases, the circulation of the powder particles is not enough also with increase in concentration above a certain level arcing occurs as the effective gap between the tool and the workpiece decreases with increase in concentration. The performance of factors at various levels is clearly abscissa represents levels of various factors and ordinate represents MRR (g/min). The center line represents mean value of the levels.

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Parameter	Symbol	DOF	SS	Variance	*F*- value	*p*-value	PC
Magnetic strength (T)	A	1	0.00000	0.00000	0.0	0.989	0
Powder	B	2	0.000201	0.000101	0.91	0.452	3.822
Concentration (g/L)	C	2	0.000383	0.000192	1.73	0.255	7.284
Current (A)	D	2	0.000802	0.000401	3.63	0.093	15.252
Tool material	E	2	0.003192	0.001596	14.44	0.005	60.707
Pulse-on time (µs)	F	2	0.000017	0.000008	0.08	0.927	0.323
Residual error		6	0.000663	0.000111			12.60
Total		17	0.005258				

Main effects plot of MRR for H11 work **piece**

The highest MRR is achieved on suspension of graphite powder as its density and electrical resistivity is least among the all three. The MRR obtained by titanium is slightly higher as compared to tungsten but less than graphite as the electrical resistivity and density of titanium is less than tungsten but higher than graphite. Thus less is the density and electrical resistivity of a powder more is the MRR achieved by it till the concentration reaches an optimum level. The effect of pulse on duration and magnetic strength have not been found to be very significant and have been ranked as 5th and 6th respectively based on their *F* values. The MRR is found to increase on increasing the pulse on duration as more melting and vaporization of workpiece will take place when time for which the energy supplied increases. Magnetic strength has least effect on the MRR. The MRR obtained under the influence of magnetic field is slightly less than that obtained without the use of magnets but overall the effect of this factor is negligible. Based on the ANOVA the factors are assigned ranks and are listed in Table 4.3.

Level	Magnetic strength (T)	Powder	Concentration (g/L)	Current (A)	Tool material	Pulse-on time (µs)
1	0.023110	0.01997	0.029665	0.022665	0.040553	0.023775
2	0.023181	0.021665	0.019663	0.031552	0.008220	0.021775
3		0.027775	0.020108	0.015220	0.020663	0.023887
Delta	0.000071	0.007778	0.010002	0.016332	0.032333	0.002112
Rank	6	4	3	2	1	5

Response table for MRR of H11workpiece

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B. Optimal design

In the experimental study, the mean effect plots (Fig. 4.1.) is used to evaluate the mean MRR at optimal trial conditions considering higher F-value and corresponding percentage contribution two parameters are found to be significant tool material and current. The level of these factors which gives the maximum MRR are noted from main effect plot (Fig. 4.1) and the corresponding MRR for D_2, E_1 is directly obtained from Maximum value of these parameters is selected because MRR is the higher the better type of response variable. Desired mean in this case is estimated as:

$$\mu_{D_2,E_1} = \overline{D_2} + \overline{E_1} - \overline{T} = 0.031552 + 0.040553 - 0.0231456 = 0.0489594 \text{ g/min}$$

Confidence interval

$$CI = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}}$$

Where $F_{\alpha,V_1,V_2} = F$ ratio

$\alpha = 0.1$ (risk)

Confidence $= 1 - \alpha$

$v_1 =$ DOF for mean (always 1)

$v_2 =$ Total DOF (=17)

$\overline{T}$ = Average of all experimental trials

n_{eff} = Number of tests under that condition using the participating factors

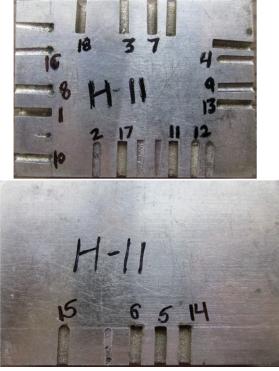$$n_{eff} = \frac{N}{1+DOF_{D,E}} = \frac{18}{1+4} = 3.6$$

N is the number of trial in the experiment

V_e = Variance of error

$$CI = \sqrt{\frac{3.03 \times 0.000111}{3.6}} = \pm 0.00966$$

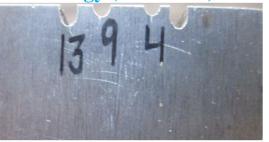Thus the optimum value of MRR is given by (0.0489594 ± 0.00966) g/min.

The workpiece samples from different views of H11 after each cut is shown in Figures shows top view which indicates the length of cut shows the side views where depth till which machining has been completed can be seen.
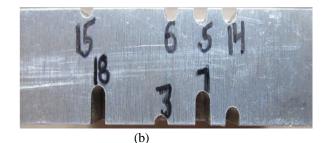

(a)

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(b)

(a) Top view of H11 workpiece (b) Side views of H11 workpiece

C. Results and Analysis of TWR

The effect of powder mixed in dielectric, concentration of powder, current, tool material and pulse on duration on tool wear rate is analyzed with and without using external magnetic field on tool wear rate, using Taguchi experimental design. L18 orthogonal array is used for the experiments using bar magnets of 0.1 T. It is smaller the better type of response variable. TWR is calculated by measuring the initial and final weight of the tool using a weighing machine with least count of 0.001 g
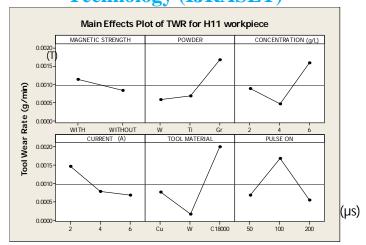
$$\text{TWR} = \frac{W_i - W_f}{t} \text{ g/min}$$

Where W_i = Initial weight of the workpiece (g)

W_f = Final weight of the workpiece after the experimentation (g)

(Note: For 90% CI, $F_{critical(2,6)}$ = 3.46, $F_{critical(1,6)}$ = 3.78, PC= percentage contribution)

Based on this analysis conducted, most significant factor is tool material. The highest tool wear is observed with C18000 alloy followed by copper tool. Tungsten tool has been found to give the least tool wear. This is because of difference in the melting points of the tool materials. Thoriated tungsten having 2% thorium has the highest melting point 3695 K hence it gives the lowest tool wear whereas there is not much difference in the melting points of opper and C18000 alloy the melting point of pure copper is approximately 1357 K and C18000 is 1311 K approx. Thus the tool wear of C18000 is slightly higher than that of copper. Tool wear of a particular material also depends on the density of that material; the density of copper is 8.75 g/cm^3 of alloy C18000 is 8.81 g/cm^3 whereas the density of the thoriated tungsten is almost double of them hence tool wear observed in the tungsten used is almost negligible. Thermal conductivity of copper at 100 °C is about 400 W/m-K and of alloy C18000 is 208 W/m K and that of   tungsten is 173 W/m-K although tool wear is found to decrease with increase in thermal conductivity but in this case it is not a dominating factor. Pulse on duration is the second factor affecting the tool wear rate after the tool material. Tool wear rate increases with pulse on duration till 100 µs after that tool wear rate begins to decrease as the level reaches tool 200 µs, the reason behind this may be that as the pulse on durations increase the layer of carbon deposited on the tool due to decomposition of dielectric and from melting if workpiece also increases as a result it protects the tool from wear. Concentration is the third factor affecting the tool wear rate. The tool wear rate decreases with increase in concentration. This may be because as the amount of powder is increased in the dielectric the spark is diffused homogenously and also it widens the plasma channel. The fourth factor affecting the tool wear rate is the type of powder suspended in the dielectric, maximum tool wear is observed when the graphite is suspended in the dielectric as it has maximum conductivity whereas titanium and tungsten powder suspension gives almost the same tool wear rate.

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Main effect plots of TWR for H11 workpiece

Based on the analysis the factors are ranked according to their significance of affecting tool wear rate, shown in table

Level	Magnetic strength (T)	Powder	Concentration (g/L)	Current (A)	Tool material	Pulse-on (µs)
1	0.001128	0.000575	0.000888	0.001472	0.000768	0.000688
2	0.000829	0.000688	0.000467	0.000787	0.000162	0.001692
3		0.001672	0.001580	0.000677	0.002005	0.000555
Delta	0.000299	0.001097	0.001113	0.000795	0.001843	0.001137
Rank	6	4	3	5	1	2

Response table of TWR for H11 workpiece

Optimal design

In the experimental study, the mean effect plots. are used to evaluate the mean TWR at optimal trial conditions. From Table considering higher F-value and corresponding percentage contribution three parameters are found to be significant tool material followed by current and type of powder. The level of these factors which gives the minimum TWR are noted from main effect and the corresponding TWR for E_2 and F_3 is directly obtained. Minimum value of these parameters is selected because TWR is the lower the better type of response variable. Desired mean in this case is estimated as:

$$\mu_{E_2} = \overline{E_2} + \overline{F_3} - \overline{T} = 0.000162 + 0.000555 - 0.0010122$$
$$= -0.0002952 \equiv 0$$

The optimal calculation for population mean (µ) gives negative value. This situation may appear for responses which are lower the better type and where the optimum/target value is zero. For such case negative value of µ may not have any physical significance and is to be considered as zero.

Confidence interval

$$CI = \sqrt{\frac{F_{\alpha,v_1,v_2}V_e}{n_{eff}}}$$

Where F_{α,v_1,v_2} = F ratio

       $\alpha = 0.1$ (risk)

       Confidence = $1 - \alpha$

       v_1 = DF for mean (always 1)

       v_2 = Total DOF (=17)

       $\overline{T}$ = Average of all experimental trials

n_{eff} = Number of tests under that condition using the participating factors

$$n_{eff} = \frac{N}{1+DOF_{E,F}} = \frac{18}{1+4} = 3.6$$

     N is the number of trial in the experiment

V_e = Variance of error

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$$CI = \sqrt{\frac{3.03 \times 0.000002}{3.6}} = \pm\, 0.001297$$

Thus the optimum value of TWR is given by (0 ± 0.001297) g/min.

This experimental investigation was mainly aimed at comparing the tool wear behavior of the three tool material copper, C18000 and tungsten with and without using the external magnetic field. Different process parameters like current, pulse-on time, powder suspended in dielectric (tungsten, titanium and graphite) was varied at three levels with and without using magnetic field. Different output parameters measured are MRR, TWR, geometrical tool wear characteristics (corner wear, side wear), overcut. Some significant conclusions drawn on the basis of analysis of results

1) Tool material is found to be the most significant factor in case of all the response variables measured with copper giving the highest MRR and TWR followed by C18000 alloy and tungsten.
2) Besides tool material current is found to be the significant factor in affecting MRR for H11 and D3 workpiece materials, type of powder suspended in dielectric is found to affect the MRR for H13 and D3 workpiece materials.
3) Including the tool material factor TWR is affected by pulse-on duration for H11 and D3 workpiece, by magnetic strength for H13 workpiece.
4) AISI H13 workpiece material is found to have maximum MRR and D3 workpiece has shown minimum TWR.
5) Graphite powder has reported better MRR compared to the two other powders used.
6) Trials conducted in the presence of external magnetic field have reported to show better MRR and less TWR.
7) Maximum MRR is achieved at the powder concentration of 2g/L.
8) Maximum corner wear is reported in tool material C18000 alloy while maximum side wear is shown in tungsten tool.
9) Overcut is found to decrease with increase in pulse-on duration, presence of magnetic strength is also found to decrease the overcut.
10) Maximum depth of cuts is achieved using copper as a tool material and using 4 A of current setting.

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