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Experimental investigation and modelling of PMEDM process with aluminium powder suspended dielectric on AISI-H11

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ABSTRACT

H11 is widely used in die and mould making industries. However these materials are difficult to process owing to the large cutting forces and high cost incurred on tool consumption. H11 is a hard material and is difficult to machine by traditional machining methods because of its high abrasion resistance, high compressive strength and excellent wear resistance. In the present work a study has been made to analyze the process parameters of powder mixed electric discharge machining of AISI H11 with copper electrode. Response surface methodology is used to plan and analyze the experiment. Pulse on time, current and powder concentration are chosen as input variables and are used to study the process performance in terms of MRR. Experiments were performed on ZNC EDM with dielectric circulation system developed in-house. Analysis of variance test has been carried out to check the adequacy of the developed regression model. The results identify the most important parameters to maximize MRR.

Keywords: PM, EDM, AISI-H11, Aluminium powder, RSM

1. INTRODUCTION

The basic principle of metal removal in the conventional methods of machining involves the use of a tool, generally harder than the work-piece and is subjected to wear. The removal of metal is by compression shear chip formation. Alternatively, non-conventional machining methods do not rely on direct contact between the tool and the work-piece; hence the tool need not be harder than the job. Powder mixed electrical discharge machining (PMEDM) is a relatively new material removal process applied to improve the machining efficiency and surface finish in presence of powder mixed dielectric fluid [1-2]

PMEDM has more complex mechanism than conventional EDM. Under the application of suitable voltage, an electric potential is developed between two electrodes of the process facing each other with a spark gap. The powder fills up the spark gap under the influence of high electric potential; these powder particles get energized and act as conductors and form chains in the sparking gap. Due to bridging of the spark gap, the insulating strength of dielectric fluid reduces. This leads to increase in gap size between tool electrode and work piece. Easy short circuiting, hence more discharging frequency, the material removal rate increases. The added powder also changes the shape of channel carrying the discharge energy. This widening and enlarging of channel carries more uniform discharge energy among powder particles. This produces shallow craters and hence improves surface finish [3].

H11 alloy steel is categorized as chromium tool steel. Because of its high toughness and hardness, it is well suited for manufacturing dies. Applications of AISI H11 are found in hot-work forging, extrusion dies and aerospace precision components. For better machining rate and machining accuracy, powder mixed electrical discharge machining of H11tool steel has been carried out.

2. LITERATURE REVIEW

Researchers all over world have carried out work to analyze/improve MRR, surface finish and other machining output parameters for various hard and tough materials by adding powders of different materials in the dielectric during electric discharge machining of various materials. Wu [1] discussed the improvement of the machined surface by adding aluminium powder and surfactant into dielectric fluid. Wong Y.S., et al. [2] investigated that graphite powder particles enhance machining rate of SKH-54 tool steel Q.Y., et al. [4] reported the reduction in surface roughness, reduction in tool wear rate and improvement in machining rate by the addition of additives (conductive & inorganic oxide particles). They further noticed that these changes are quite appreciable in mid finish machining and finish machining phases. Erden et al. [5] investigated the effect of abrasive powder mixed into the dielectric fluid and proposed that the machining rate increased with an increase of the powder concentration due to decreasing the time lag. Jeswani [6] investigated the effect of addition of graphite powder to kerosene and proposed that the material removal rate was improved by around 60% and electrode wear ratio was reduced about 15% by using the kerosene oil mixed with 4 g/l graphite powder. Tzeng et al. [7] studied the effects of various powder characteristics (aluminium, chromium, copper, and silicon carbide) on the efficiency in electro-discharge machining of SKD-11 alloy. It is reported that the particle size, the particle concentration, the particle density, the electrical resistivity and the thermal conductivity are significant factors affecting the EDM performance. Guu et al. [8] studied the surface morphology, surface roughness and micro-cracking in the electrical discharge machining of AISI D2 tool steel. The investigating parameters were pulsed current 0.5, 1.0, 1.5 Amp, Pulse-on duration 3.2, 6.4 µs pulse-off duration 20 µs, and reported that the higher pulsed current and higher pulse-on duration cause a poorer surface finish. Shabgard, et al. [9] presented an experimental investigation to consider the machining characteristics in EDM process of FW4 welded steel and reported that the regression technique is an important tool for representing the relation between machining characteristic and EDM process input parameters.

3. DESCRIPTION OF EXPERIMENTS

The experimentation was done on ZNC Electrical Discharge Machining set-up (Sparkonix S25/50 ZNC EDM), to determine find out the effects of machining parameters on MRR.The efficiency of erosion depends upon the absence of any foreign material in the dielectric system. It is also necessary that the carbon particles produced during the erosion should be cleared from the sparking zone; hence various flushing techniques like injecting the dielectric between the sparking zones, suction of carbon particles from the sparking zone are used. The system consists of filters, pump, valves and drain. A well–designed dielectric system to give trouble free circulation of the dielectric to the tank is mandatory requirement of good EDM machine. It was energized by a 50 ampere Pulse generator and a controller to produce rectangular shaped current pulses. The existing dielectric circulation system of the EDM machines needed 125 litres of kerosene in circulation. The mixing of powder with the whole of the dielectric fluid was avoided. This is because different levels of concentration of powders were to be mixed into dielectric for experimentation. Moreover, it was also not possible to circulate the powder mixed dielectric through the existing circulation system because the filters might clog due to presence of powder particles and debris. Therefore, there was a need to develop a new powder mixed circulation system for the experimentation. To fulfil this requirement, a new experimental set up for PMEDM was designed and developed in the workshop.

The new PMEDM system was designed for 35 litres of dielectric fluid for experimentation. The system consisted of a mild steel tank called machining tank. It was placed in the work tank or the main tank of the EDM machine. The machining was performed on the wok piece, held rigidly by a work piece fixture assembly placed in the machining tank. The machining tank was filled up with the dielectric fluid. The dielectric fluid was circulated by the means of a ¼ hp circulation pump .Two gate valves were provide one on the delivery side and another on the drain side of the tank. Gate valves were used there to control the flow of the dielectric. A hydraulic pressure gauge was installed in the set up to check the pressure of the dielectric fluid. A nozzle was used in the delivery pipe to increase the pressure for flushing. Magnetic forces were used to separate the debris from the dielectric fluid.

3.1 Materials used in Experiments

As observed from literature survey that considerable work has been done on various aspects of electrical discharge machining of low carbon steels, carbides, few die steels but sufficient data was not available on powder mixed EDM of high chromium steel (H11) even though it is widely used in die and mould making industries. There is a need to investigate the machining of this material with copper electrode and using powder mixed kerosene as dielectric fluid by varying different machining parameters like discharge current, pulse time on and powder concentration. Table 1 shows the chemical composition of AISI-H11.

Table 1 Chemical composition of H11 steel (wt. %)

Element	C	Mg	Si	Cr	Ni	Mb	Vn	Cu	Ph	S	Fe
Weight	0.33-0.43	0.20-0.50	0.80-1.20	4.75-5.50	0.3	1.10-1.60	0.30-0.60	0.25	0.03	0.03	90-92

3.2 Polarity

The polarity used in this experimentation is straight polarity that is work piece is connected to the positive terminal and the tool to the negative terminal of the dc supply.

3.3 Powder

The powder selected for present study is Aluminium powder. The powder size of 300 meshes equal to 46 microns.

3.4 Experimental Settings

The experimental settings that have been applied in the study are shown in table 2.

Table 2 Machining conditions

Tool electrode	Copper
Work piece	AISI H-11
Polarity	Straight
Time of experiment	25 minutes
Voltage	60 V
Dielectric	Kerosene
Flushing pressure	0.5 kg/cm^2
Method of flushing	Side flushing

4. EXPERIMENTAL DESIGN

The central composite design (CCD) is one of the most popular classes of designs used for a second-order model. CCD designs comprise a set of two-level factorial points, axial points and centre runs. The factorial points contribute to the estimation of linear terms and two-factor interactions, and are the only points which contribute to estimation of the interaction terms. The axial points contribute to the estimation of quadratic terms. In the absence of axial points, only the sum of the quadratic terms can be estimated. The centre runs provide an internal estimate of pure error and contribute towards the estimation of quadratic terms. The process is studied with a standard RSM design called face centred central composite design. In this investigation a total 20 experiments were conducted at the stipulated conditions.

Coded and real level value of various input parameters were obtained using face centred composite design (FCCD) in RSM along with their designation and are shown in Table 3.

Table 3 the coded and real levels of independent parameters

Parameters	Symbol	Levels		
Coded valves		-1	0	+1
Current(Amperes)	A	3	6	9

Pulse on time(µS)	B	60	105	150
Powder concentration(grams/litre)	C	0	1	2

4.1. Response Surface Modeling

As stated earlier Response surface methodology has been applied for modeling and analysis of parameters. The quantitative relationship between desired responses and independent process variables can be represented as

Y= f (X1, X2, X3... Xn) Where Y is the desired response, f is the response function and X1, X2... are independent Parameters. By plotting the expected responses, a surface known as Response surface is Obtained. RSM aims at approximating f by using the fitted second order polynomial regression model which is called the quadratic model. The model can be represented as follows.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$

5. RESULTS AND DISCUSSION

In this section the effect of controlling parameters such as current, pulse on time and powder concentration on MRR are presented. The plots showing the effect of parameters on response have drawn accounting the effect of all factors.

Table 4 Input machining parameters and output response parameters

S. No.	Ww_i (gms)	Ww_f (gms)	Time (Minutes)	MRR
1	276.29	275.78	25	0.0204
2	243.7	242.09	25	0.0644
3	250.35	249.59	25	0.0304
4	262.75	260.51	25	0.07866
5	256.12	255.54	25	0.0232
6	272.22	270.48	25	0.0696
7	245.57	244.77	25	0.03217
8	263.32	261.18	25	0.0856
9	264.91	264.2	25	0.0284
10	266.52	264.72	25	0.072
11	266.41	265.44	25	0.0388
12	243.05	241.85	25	0.048
13	254.69	253.6	25	0.0436
14	267.69	266.45	25	0.049
15	266.6	265.7	25	0.0413
16	277.37	276.14	25	0.0452
17	241.65	240.66	25	0.04304
18	264.68	263.51	25	0.0468
19	262.64	261.48	25	0.0464
20	273.56	272.59	25	0.04217

5.1. Analysis of MRR

The fit summary recommended that the quadratic model is statistically significant for analysis of MRR. The results of the quadratic model for MRR in the form of ANOVA are given in table 5.

Table 5 ANOVA table for MRR

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	5.948E-003	9	6.609E-004	350.91	<0.0001significant
A-current	5.315E-003	1	5.315E-003	2822.23	<0.0001
B-pulse time on	3.188E-004	1	3.188E-004	169.27	<0.0001

C-concentration	6.580E-005	1	6.580E-005	34.94	0.0001
AB	4.973E-006	1	4.973E-006	2.64	0.1352
AC	1.673E-005	1	1.673E-005	8.89	0.0138
BC	2.782E-006	1	2.782E-006	1.48	0.2522
A^2	6.846E-005	1	6.846E-005	36.35	0.0001
B^2	8.170E-013	1	8.170E-013	4.338E-007	0.9995
C^2	3.288E-006	1	3.288E-006	1.75	0.2158
Residual	1.883E-005	10	1.883E-006	3.66	0.1148 insignificant
Lack of Fit	1.593E-005	6	2.655E-006		
Pure Error	2.900E-006	4	7.251E-007		
Cor Total	5.967E-003	19			

Std. Dev = 0.0177209	RSquared=0.9968	PRESS=2.014E-004
Mean=0.047	AdjRSquared=0.9940	Adeq Precision=64.113
C.V.%=2.90	PreR-Squared=0.9663	

From table 5 the Model F-value of 350.91 implies the model is significant. There is only a 0.01% 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, AC, and A2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 3.66 implies the Lack of Fit is not significant relative to the pure error. There is a 11.48% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good - we want the model to fit. The "Pred R-Squared" of 0.9663 is in reasonable agreement with the "Adj R-Squared" of 0.9940."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 64.113 indicates an adequate signal. Therefore, this model can be used to navigate the design space.

The valve of R^2 and adjusted R^2 is over 99%, this means the regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response (MRR). The associated P-valve for the model is lower than .05 (i.e. α = .05, or 95% confidence) indicates the model is considered to be statistically significant [2,6]. The lack of fit term is non-significant as it is desired. Further, A(current), B(pulse on time), C(concentration of aluminium powder), AC(interaction effect of current with factor concentration), A^2(second order of term current) have significant effect and significant model terms. The results prove that the powder added into the dielectric fluid enhances the MRR .The other model terms are said to be non significant and are eliminated.

The response is ranges from 0.0204g/min to 0.0856g/min and the ratio of maximum to minimum is 4.19. After eliminating the non significant terms, the final response equation for MRR is given as follows

Final Equation in Terms of Coded Factors:

*MRR = +0.044 + 0.023 * A +5.418E-003 * B + 2.572E-003 * C + 1.446E-003 *A*C+4.995E-003*A2 ....(1)*

Final Equation in Terms of Actual Factors:

*MRR = +0.011372 - 4.28243E-005 * current +7.27125E-005 * pulse time on-3.87041E-003 * concentration+4.82083E-004 * current *concentration + 5.54960E-004 * current...(2)*

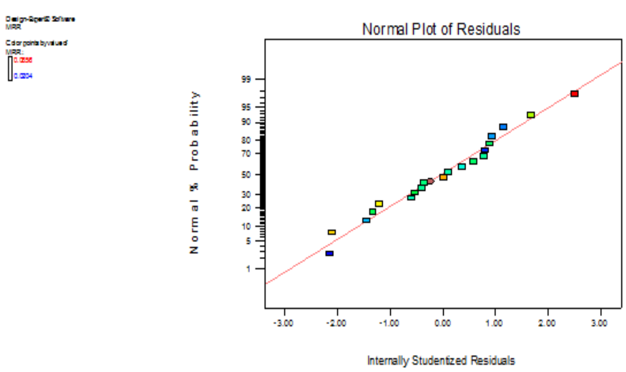

Figure 1 Normally probability plot residuals for MRR

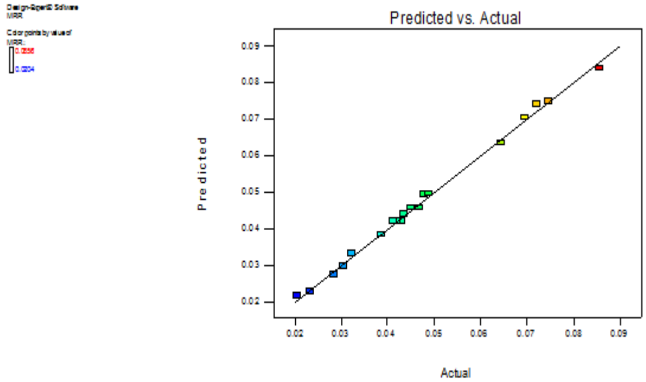

Figure 2 Plot of actual vs predicted response of MRR

Figure 1 displays the normal probability plot of residuals are falling on a straight line, which means that the errors are normally distributed. Further, each observed value is compared with the predicted value calculated from the model in figure 2. It can be seen that the regression model is fairly well fitted with the observed values. Figure 3 shows the estimated response surface for MRR in relation to design parameters of peak current and pulse on time. As observed from the figure, the MRR tends to increase, considerably with increase in peak current for any value of pulse on time. Maximum MRR is obtained at high peak current (9A) and high pulse on time (150 µsec). This is due to their dominant control over input energy.

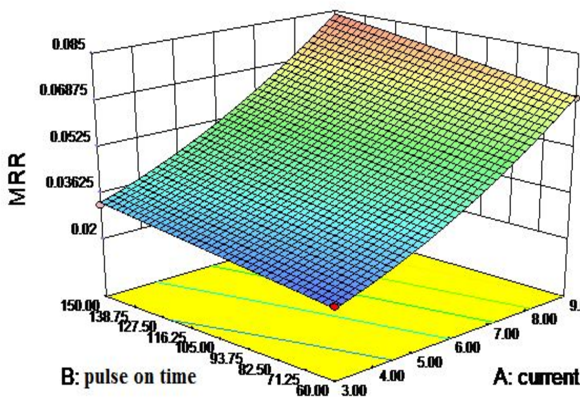

Figure 3 Effect of T_{on} and current on MRR at concentration of 2 g/ltr.

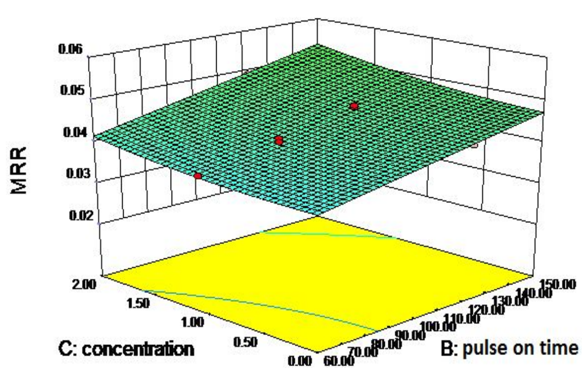

Figure 4 Effect of Concentration and Pulse on Time on MRR (current 6 amperes)

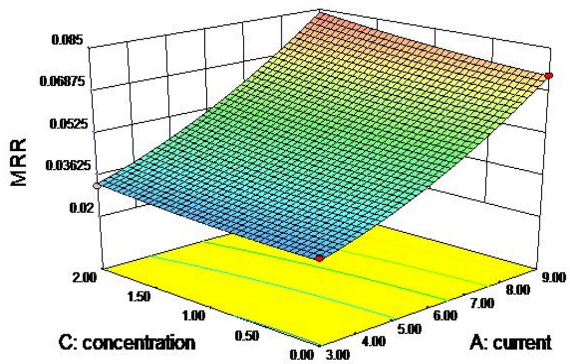

Figure 5 Effect of Current and Concentration on MRR at pulse on time 150µs

The effect of pulse on time and concentration on MRR is shown in figure 4. The figure displays that the MRR increases with increase in concentration and pulse on time. The reason is dominant control over the internal energy. The MRR tends to increase with increase in gap concentration but at lower rate compared to pulse on time. Hence maximum MRR is obtained at concentration of 2g/L and pulse on time of 150 µsec.

The effect of concentration and peak current on MRR is shown in figure 5. Figure shows that MRR increases with increase in peak current. This is due to dominant control over the input energy. The effect of concentration on MRR can be also seen from this figure. The powder added into dielectric fluid enhances the MRR and with increase in concentration of the powder, the MRR tends to increase. This is because the additive causes bridging effect between both the electrodes, facilitates the dispersion of discharge into several increments and hence increases the MRR. The maximum MRR is obtained at highest level of concentration of added Al powder (2g/l) and peak current (9A).

6. CONFIRMATION EXPERIMENTS

Once the optimal level of the process parameters is selected, the final step is to predict and verify the improvement of the performance characteristics using the optimal level of the machining parameters. Experiments were performed on the machine and were compared with optimal response valves.

Table 6 Experimental validations of developed models with optimal parameter setting.

Responses	Predicted	Experimental	Error (%)
MRR g/min	.0679397	.071	4.32

7. CONCLUSION

The following conclusions are drawn from the experimental study:

The EDM process has been successfully modelled in terms of MRR using Response Surface Methodology. Results showed that central composite design is a powerful tool for providing experimental diagrams and statistical-mathematical models, to perform the experiments efficiently and economically.

- There is improvement in MRR of the work surface after using the Aluminium powder into the dielectric fluid of EDM.
- The slope of the curve indicate that the MRR increase with the increase in the current and concentration of the aluminium powder.
- The analysis of variance revealed that peak current and concentration are most the influential parameters on MRR.
- The error between experimental and predicted values at the optimal combination of parameters setting for MRR is 4.32%. This confirms excellent reproducibility of the experimental conclusion

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