EXPERIMENTAL INVESTIGATION ON H11 STEEL IN ABRASIVE MIXED EDM PROCESS USING ALUMINIUMELECTRODE FOR SURFACE ROUGHNESS

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Abstract

In this experimentation, various effects of input parameters in Electric Discharge Machining (EDM) process like polarity, peak current, pulse on time, duty cycle, gap voltage and concentration of abrasives powder in dielectric fluid are calculated experimentally for surface roughness investigation. A standard orthogonal array of L18 by Taguchi is used for experimental process. Al is used as tool electrode for the machining of H11 steel on Electronica Smart ZNC EDM. Main effects of factors are taken into account in this study. This study show result show the input process parameters are affecting the response variable i.e. (Surface roughness).

Keywords: Powder mixed EDM (PMEDM), Surface roughness (SR), Taguchi method

1. INTRODUCTION

Among several non-conventional manufacturing techniques, EDM, which is a thermoelectric process that erodes workpiece material by controlled high frequency electrical discharges between the tool piece and workpiece surface under the presence of dielectric medium has drawn a great interest of researchers' as it has broad applications in industry. Approximately 12,000^{o}C temperature is generated by the spark in the discharging gap between electrode and workpiece surface. Due to this high temperature material is eroded by evaporation and melting from both the tool electrode and the workpiece surface. Rather the suitability of EDM process for machining very tough and hard metals and alloys, its use is restricted by low machining efficiency and poor surface finish due to its time consumption. To overcome these limitations, combination of some suitable foreign materials like powderedmetal particles is added in dielectric fluid of EDM to get one of the alternatives suggested by various researchers [3, 10]. Conductive powders has helped the dielectric fluid to enlarge the gap distance and hence improving the surface finish while reducing the spark energy and dispersing the discharges more uniformly throughout the surface of workpiece under investigation[2]. M. L.Jeswani[7]found 60% of improvement in MRR and15% reduction in TWR when 4 g/lof graphite powder was suspended in dielectric fluid. B. H. Yan et al.[1] noted that peak currents of EDM-drilling and volume fraction ofAl2O3 were confirmed to have significant effects on the material removal rate and surface roughness. H. K. Kansal et al. [2]noted that adding silicon powder in dielectric of EDM improves rate of material removal and surface finish. Furthermore peak current and concentration of abrasives in dielectric fluid have the influential effects on material removal rate and SR. H. K.Kansal, et al. [3] presented a tutorial introduction, comprehensive history and review of research workcarried out in the area of PMEDM. The machiningmechanism, current issues, applications andobservations were also discussed. P. Pecas et al.[9]found positive influence of the adding silicon powderin the dielectric fluid of EDM for reduction ofcrater dimensions and surface roughness of themachined surfaces. M. S. Popa et al. [8] presentscomparatively the values of the roughness by EDM process on different types of materials andby different process parameters. P. Singh et al. [10] indicated that both theconcentrations of aluminium powder and grain sizeof powder mixed in dielectric fluid strongly affect themachining performance of hastalloy steel.The addition of aluminium powder in dielectric fluidimproves surface finish of hastalloy steel.

This studyis carried out on H 11steelmaterialon powder mixed EDM. For this, an experimental study is conductedto investigate the surface roughness in die-sinkingEDM process.

2. EXPERIMENTATION

2.1 Equipment's used in the experiment

Electronica made "Smart ZNC die-sinking ElectricDischarge machine tool" with MOSFET S50 ZNCpulse generator have 400 lt dielectric capacitywith DC servo feed control system is used in the experimental setup. Figure 1 shows a photograph ofthis equipment.

Fig. 1 Electronica-Smart ZNC-EDM machine tool

Standard EDM oil of 125CC having SAE 40 is used asdielectric fluid medium with side injection of dielectricfluid for jet flushing system was employed toassure adequate supply of the EDM process debrisfrom the gap zone during investigation.Cylindrical solid rod of aluminium with 8 mm diameter isused as tool electrode. Various properties of aluminium are given in table 1.

Table 1: Properties of Copper

Properties	Values
Melting point	660.323°C, 1220.581°F, 933.473 K
Boiling point	2519°C, 4566°F, 2792 K
Density (g cm^{-3})	2.70

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Further, aluminium powder is used to mix in the dielectric fluid of EDM. Typical properties of aluminium powder are given in table 2.

Table 2: Properties of aluminium abrasive powder

Color	Grey
Density	2.70 g/cm^3
Specific heat capacity (25 °C)	24.200 J.mol^{-1}. K^{-1}
Melting point	933.47 K
Thermal conductivity (300 K)	237 W·m^{-1}·K^{-1}
Electrical resistivity (20°C)	28.2 nΩ·m

2.2 Material used in the experiments

H11 is a special alloy steel, categorized as chromiumtool steel. Its high toughness and hardness makes well suited for hot work applications. Typicalapplications of H11 steel are dies, punches, piercingtools, mandrels, extrusion tooling, hot-work forgingand helicopter rotor blades, etc. Typical compositionof H11 steel is given in table 3.

Table 3: Composition of H11 steel

Element	C	Mn	Si	Cr	Ni	Mo	V	Cu	P	S
%	0.37	0.35	1	5.13	0.3	1.36	0.45	0.25	0.03	0.03

The selection of this material was made taking intoaccount its wide range of applications as stated above.

Parameters like polarity, peak currentand pulse on time, duty cycle, gap voltage andconcentration of metal powder in the dielectricfluid are taken as input parameters in the process. Inthis experimentation, one input process parameter i.e. polarityvaries at two levels and all other parameters i.e. peakcurrent, pulse on time, duty cycle, gap voltage andpowder concentration varies at three levels. Table 4shows design scheme of input process parameters andtheir actual values with levels. Output characteristicsof EDM i.e. surface roughness is proportional to theproduct of the energy transferred per pulse and pulsefrequency during sparking. So, the experimentsare performed at different levels of input parameters to the process.

Table 4: Design scheme of input process parametersand their levels.

Parameter Symbol	Parameter	Units	Level 1	Level 2	Level 3
A	Polarity		Positive	Negative	----
B	Peak Current	A	0.5	3	6
C	Pulse on Time	µs	50	100	150
D	Duty Cycle		9 (0.69)	10 (0.82)	11 (0.88)
E	Gap Voltage	V	40	60	80
F	Powder concentration	g/l	0	6	12

3.2 Response variables selected

In this investigation, our output parameter i.e. SR is takenas response variable. In mechanical measurementscience the roughness of the workpiece surface is expressed in many ways like arithmetic average(Ra), average peak to valley height (Rz) and peakroughness (Rp), etc. The arithmetic mean surfaceroughness value (Ra) of machined surface isused in this study. Ra is the arithmetic averageroughness of the deviations of the roughness profilefrom the central line along the measurement. It canbe represented as:

$$R_a = 1/L \int_0^L |h(x)dx|$$

Where,

h(x): Value of roughness profile

L: Evaluation length

Measurements are carried out of 6 mm measurementlength at the bottom of the blind holes usingaMitutoyo-Surftest SJ-400 surface roughness tester.

Fig 2: Mitutoyo - Surftest SJ-400 surface roughnesstester

To get higherproductivity of EDM process, valueof SR should be as small as possible. Therefore, theSR is regarded as “the smaller-the-bettercharacteristic” in this study.

3.3 Experimental Design (Orthogonal array)

The Taguchi method isa special design of orthogonalarray to study the entire parameters with only asmall number of experimental runs. This method is apowerful tool in the design of experiment methods& can optimize the performance of characteristics withthe settings of process parameters and lower thesensitivity of the system performance to variation. In this test, methodology of Taguchiisapplied to plan and analyze the number of experiments. Anorthogonal array L18 is used to plan the experimentalruns. This table has 6 columns and 18 rows with onetwo-level input parameter and five three-level inputparameters. Each input parameter is assigned to acolumn and 18 machining parameter combinationsare required as per L18 orthogonal array. Theexperimental layout using an L18 orthogonal array(coded levels) is shown in table 5.

Exp. No.	A: Polarity	B: Peak Current (A)	C: Pulse on Time (µs)	D: Duty Cycle	E: Gap Voltage (V)	F: Concentration of powder (g/l)
1	1	1	1	1	1	1
2	1	1	2	2	2	2
3	1	1	3	3	3	3
4	1	2	1	1	2	2
5	1	2	2	2	3	3
6	1	2	3	3	1	1
7	1	3	1	2	1	3
8	1	3	2	3	2	1
9	1	3	3	1	3	2
10	2	1	1	3	3	2
11	2	1	2	1	1	3
12	2	1	3	2	2	1
13	2	2	1	2	3	1
14	2	2	2	3	1	2
15	2	2	3	1	2	3
16	2	3	1	3	2	3
17	2	3	2	1	3	1
18	2	3	3	2	1	2

Table 5: Design layout using an L18 orthogonal array(coded levels)

3.4 Experimental Procedure

The working tank of EDM machine is of 800 x 500 x 350 mmdimension. As per theexperimental plan, concentration of powder is to be varied as 0 g/l, 6 g/l and 12 g/l. But insuch a large working tank`s the processwill be costly in making the desired powderconcentration in dielectric. To avoid problem and to obtainthe desired powder concentration, a small tank of 7liter capacity was made in the workshop& isplaced in the working tank. An external dielectric pump with twonozzles was placed in this tank to maintain thecirculation of powder suspended dielectric fluid inthe discharge gap between tool electrode andworkpiece surface.

Fig. 3 Small working tank and jet flushing system usedin the EDM process

Two nozzles of dielectric pump were placed in such away so that these do not come beneath the tool tipmoved downward by the servo system of machinetool. The downward movement of tool electrodetowards workpiece surface has been controlled byservo feed control system of EDM machine tool,which maintained uniform sparking gap between theadjacent surfaces of work piece and tool electrode.Guide wheels on the EDM machine tool tank helpedto position the workpiece with respect to the axis ofapproaching tool electrode. All the experiments inwhich 6g/l and 12 g/l powder concentration used areperformed in this small tank. Experiments in whichpure EDM oil (0 g/l concentration of aluminumpowder) used are performed in machine tool workingtank.

4. RESULTS & DISCUSSIONS

By testing the workpiece at right angles under thetip of stylus of surface roughness tester, three valuesof Ra were taken into consideration at the bottom for each machinedhole. Then theaverage of values was takenas Ra value. Table 6 showsvariation of actual values of each input parameter andexperimental results obtained in all eighteenexperiments.

Exp No.	A : Polarity	B : Peak Current (A)	C : Pulse on time: (µs)	D : Duty Cycle	E : Gap Voltage (V)	F : Concentration of powder (g/l)	R_a : Surface roughness (µm)
1	Positive	0.5	50	9	40	0	3.45
2	Positive	0.5	100	10	60	6	2.22
3	Positive	0.5	150	11	80	12	1.53
4	Positive	3	50	9	60	6	4.55
5	Positive	3	100	10	80	12	4.34
6	Positive	3	150	11	40	0	5.56
7	Positive	6	50	10	40	12	5.26
8	Positive	6	100	11	60	0	7.11
9	Positive	6	150	9	80	6	7.22
10	Negative	0.5	50	11	80	6	3.22
11	Negative	0.5	100	9	40	12	2.25
12	Negative	0.5	150	10	60	0	3.74
13	Negative	3	50	10	80	0	2.54
14	Negative	3	100	11	40	6	2.17
15	Negative	3	150	9	60	12	1.90
16	Negative	6	50	11	60	12	3.13
17	Negative	6	100	9	80	0	2.72
18	Negative	6	150	10	40	6	2.87

Table 6: Design layout using an L18 orthogonal array
(actual values) and experimental results

The results as per table 6 were then put toMinitab 16.1 software for further analysis. ANOVAtables are used to summarize the results to see thesignificance of input machining parameters on theoutput measure i.e. SR. This table concludesinformation of analysis of variance and case statisticsfor further interpretation. After the ANOVAprocedure, further analysis was performed withgraphic plots. The main effects plots of the means forthe output response parameter are obtained usingMinitab 16.1 software.

A. Analysis of Surface Roughness (SR)

The main effect plots for means for SR at differentlevels of particular machining parameters are plotted infigure 4 keeping the objective as “Smaller is better”.ANOVA was performed to study the significance ofeach input machining parameters in effecting theSR. The ANOVA for SR isgiven in table 7.

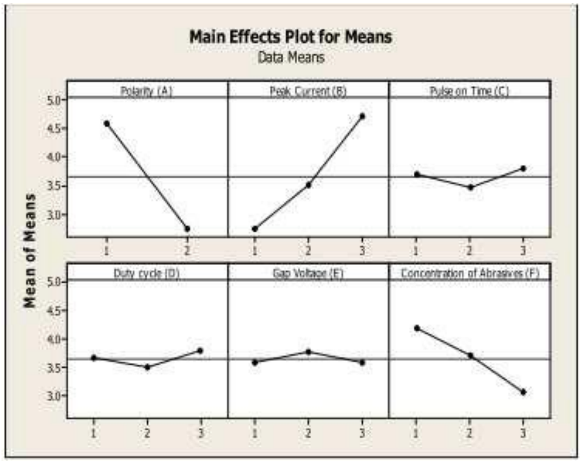

Fig. 4 Main effect plot for means for SR

Based on this plot the effect of each factor can begraphically assessed. It is clear from figure 4 that SRis minimum at the 2nd level of polarity, 1st level ofpeak current, 2nd level of pulse on time, 2nd level ofduty cycle, 1st level of gap voltage and 3rd level ofabrasive powder concentration. This main effect plotfor means for SR suggests the same levels of theparameters (A2, B1, C2, D2, E1 and F3) as the bestlevels for minimum SR.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Polarity (A)	1	15.4939	15.4939	15.4939	5.40	0.059
Peak Current (B)	2	11.9886	11.9886	5.9943	2.09	0.205
Pulse on Time (C)	2	0.3491	0.3491	0.1746	0.06	0.941
Duty Cycle (D)	2	0.2619	0.2619	0.1309	0.05	0.956
Gap Voltage (E)	2	0.1308	0.1308	0.0654	0.02	0.978
Powder Concentration (F)	2	3.7781	3.7781	1.8891	0.66	0.551
Residual Error	6	17.2010	17.2010	2.8668		
Total	17	49.2034				

Table 7: ANOVA for SR

The results of ANOVA indicate that all the inputmachining parameters affect the output responsecharacteristics i.e. SR.

5. CONCLUSIONS

Following are the conclusions which can be takenout by varying each input parameters during machining of H11 specimen withaluminium electrode.

- Negative polarity of tool electrode is desirablelowering of surface roughness.
- Suspension of powder particles in dielectric fluidimproves surface roughness.
- Higher peak currents produce more roughsurfaces in EDM process.

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