

Experimental Investigation on H11 Steel in Abrasive Mixed EDM Process Using Silicon Powder with Al Electrode 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 shows 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°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 powdered metal 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 through out the surface of workpiece under investigation[2.. 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 work carried out in the area of PMEDM. The machining mechanism, current issues, applications and observations were also discussed. M. L.Jeswani[7] found 60% of improvement in MRR and 15% reduction in TWR when 4 g/l of graphite powder was suspended in dielectric fluid. P. Pecos et al.[9]found positive influence of the adding silicon powder in the dielectric fluid of EDM for reduction of crater dimensions and surface roughness of the machined surfaces'. H. Yan et al.[1] noted that peak currents of EDM-drilling and volume fraction of Al₂O₃ were confirmed to have significant effects on the material removal rate and surface roughness. M. S. Popa et al. [8] presents comparatively the values of the roughness by EDM process on different types of materials and by different

process parameters. P. Singh et al. [10] indicated that both the concentrations of aluminium powder and grain size of powder mixed in dielectric fluid strongly affect the machining performance of hastalloy steel. The addition of aluminium powder in dielectric fluid improves surface finish of hastalloy steel.

This study is carried out on H 11 steel material on powder mixed EDM. For this, an experimental study is conducted to investigate the surface roughness in die-sinking EDM process.

2. EXPERIMENTATION

2.1 Equipment's used in the experiment

Electronica made "Smart ZNC die-sinking Electric Discharge machine tool" with MOSFET S50 ZNC pulse generator have 400 lt dielectric capacity with DC servo feed control system is used in the experimental setup. Figure 1 shows a photograph of this equipment.



Fig- 1 Electronica-Smart ZNC-EDM machine tool

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

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

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

Table 2: Properties of silicon abrasive powder

Physical/Mechanical	SI Units	Values
Density	g/m ³	3.1
Porosity	%	0
Color	-	Black
Flexural strength	MPa	550
Elastic Modulus	GPa	410
Shear Modulus	GPa	-
Bulk Modulus	GPa	-
Poisson's ratio	-	0.14
Compressive strength	MPa	3900
Hardness	Kg/mm ²	2800
Fracture toughness K _{Ic}	MPa m ^{1/2}	4.6
Max use temperature	°C	1650
Thermal properties		
Thermal Conductivity	W/m °K	120
Coefficient of Thermal Expansion	10 ⁻⁶ / °C	4.0
Specific heat	J/Kg °K	750
Electrical		
Volume Resistivity	Ohm cm	10 ² -10 ⁶

2.2 Material used in the experiments

H11 is a special alloy steel, categorized as chromium tool steel. Its high toughness and hardness makes well suited for hot work applications. Typical applications of H11 steel are dies, punches, piercing tools, mandrels, extrusion tooling, hot-work forging and helicopter rotor blades, etc. Typical composition of 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 into account its wide range of applications as stated above.

3. DESIGN OF THE EXPERIMENTS

3.1 Design factors selected with range

Parameters like polarity, peak current and pulse on time, duty cycle, gap voltage and concentration of metal powder in the dielectric fluid are taken as input parameters in the process. In this experimentation, one input process parameter i.e. polarity varies at two levels and all other parameters i.e. peak current, pulse on time, duty cycle, gap voltage and powder concentration varies at three levels. Table 4 shows design scheme of input process parameters and their actual values with levels. Output characteristics of EDM i.e. surface roughness is proportional to the product of the energy transferred per pulse and pulse frequency during sparking. So, the experiments are performed at different levels of input parameters to the process.

Table 4: Design scheme of input process parameters and their levels

Symbol	Parameter	Units	Level 1	Level 2	Level 3
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A	Polarity		Positive	Negative
B	Peak Current	A	0.5	2	4
C	Pulse on Time	μs	50	75	100
D	Duty Cycle		9 (0.69)	10 (0.82)	11 (0.88)
E	Gap Voltage	V	40	70	100
F	Powder Concentration	g/l	0	4	8

3.2 Response variables selected

In this investigation, our output parameter i.e. SR is taken as response variable. In mechanical measurement science the roughness of the workpiece surface is expressed in many ways like arithmetic average (Ra), average peak to valley height (Rz) and peak roughness (Rp), etc. The arithmetic mean surface roughness value (Ra) of machined surface is used in this study. Ra is the arithmetic average roughness of the deviations of the roughness profile from the central line along the measurement. It can be represented as:

$$R_a = \frac{1}{L} \int_0^L |h(x)| dx$$

Where,

h(x): Value of roughness profile

L: Evaluation length

Measurements are carried out of 6 mm measurement length at the bottom of the blind holes using a Mitutoyo-SurfTest SJ-400 surface roughness tester.



Fig- 2: Mitutoyo - SurfTest SJ-400 surface roughness tester

To get higher productivity of EDM process, value of SR should be as small as possible. Therefore, the SR is regarded as “the smaller-the-better characteristic” in this study.

3.3 Experimental Design (Orthogonal array)

The Taguchi method is a special design of orthogonal array to study the entire parameters with only a small number of experimental runs. This method is a powerful tool in the design of experiment methods & can optimize the performance of characteristics with the settings of process parameters and lower the sensitivity of the system performance to variation. In this test, methodology of Taguchi is applied to plan and analyze the number of experiments. An orthogonal array L18 is used to plan the experimental runs. This table has 6 columns and 18 rows with one two-level input parameter and five three-level input parameters. Each input parameter is assigned to column and 18 machining parameter combinations are required as per L18 orthogonal array. The experimental layout using an L18 orthogonal array (coded levels) is shown in table 5.

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

Exp No.	A: Polarity	B: Peak Current (A)	C: Pulse on time (μ s)	D: Duty Cycle	E: Gap Voltage (V)	F: Concentration of Powder (g/l)
1	1	0.5	0.5	0.5	0.5	0.5
2	1	0.5	2	2	2	2
3	1	0.5	4	4	4	4
4	1	2	0.5	0.5	2	2
5	1	2	2	2	4	4
6	1	2	4	4	0.5	0.5
7	1	4	0.5	2	4	4
8	1	4	2	4	0.5	0.5
9	1	4	4	0.5	2	2
10	2	0.5	0.5	4	2	2
11	2	0.5	2	0.5	4	4
12	2	0.5	4	2	0.5	0.5
13	2	2	0.5	2	0.5	0.5
14	2	2	2	4	2	2
15	2	2	4	0.5	4	4
16	2	4	0.5	4	4	4
17	2	4	2	0.5	0.5	0.5
18	2	4	4	2	2	2

3.4 Experimental Procedure

The working tank of EDM machine is of 800 x 500 x 350 mm dimension. As per the experimental plan, concentration of powder is to be varied as 0 g/l, 4 g/l and 8 g/l. But in such a large working tank's the process will be costly in making the desired powder concentration in dielectric. To avoid problem and to obtain the desired powder concentration, a small tank of 7 liter capacity was made in the workshop & is placed in the working tank. An external dielectric pump with two nozzles was placed in this tank to maintain the circulation of powder suspended dielectric fluid in the discharge gap between tool electrode and workpiece surface.



Fig- 3 Small working tank and jet flushing system used in the EDM process

Two nozzles of dielectric pump were placed in such away so that these do not come beneath the tool tip moved downward by the servo system of machine tool. The downward movement of tool electrode towards workpiece surface has been controlled by servo feed control system of EDM machine tool, which maintained uniform sparking gap between the adjacent surfaces of work piece and tool electrode. Guide wheels on the EDM machine tool tank helped to position the workpiece with respect to the axis of approaching tool electrode. All the experiments in which 4g/l and 8g/l powder concentration used are performed in this small tank. Experiments in which pure EDM oil (0 g/l concentration of silicon powder) used are performed in machine tool working tank.

4. RESULTS & DISCUSSIONS

By testing the workpiece at right angles under the tip of stylus of surface roughness tester, three values of Ra were taken into consideration at the bottom for each machined hole. Then the average of values was taken as Ra value. Table 6 shows variation of actual values of each input parameter and experimental results obtained in all eighteen experiments.

The results as per table 6 were then put to Minitab 16.1 software for further analysis. ANOVA tables are used to summarize the results to see the significance of input machining parameters on the output measure i.e. SR.

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

Exp No.	A: Polarity	B: Peak current (A)	C: Pulse On Time (μ s)	D: Duty Cycle	E: Gap Voltage (V)	F: Concentration of Powder (g/l)	R _s : Surface Roughness (μ m)
1	Positive	0.5	50	9	40	0	3.45
2	Positive	0.5	75	10	70	4	2.22
3	Positive	0.5	100	11	100	8	1.53
4	Positive	2	50	9	70	4	4.55
5	Positive	2	75	10	100	8	4.34
6	Positive	2	100	11	40	0	5.56
7	Positive	4	50	10	40	8	5.26
8	Positive	4	75	11	70	0	7.11
9	Positive	4	100	9	100	4	7.22
10	Negative	0.5	50	11	100	4	3.22
11	Negative	0.5	75	9	40	8	2.25
12	Negative	0.5	100	10	70	0	3.74
13	Negative	2	50	10	100	0	2.54
14	Negative	2	75	11	40	4	2.17
15	Negative	2	100	9	70	8	1.90
16	Negative	4	50	11	70	8	3.13
17	Negative	4	75	9	100	0	2.72
18	Negative	4	100	10	40	4	2.87

This table concludes in formation of analysis of variance and case statistics for further interpretation. After the ANOVA procedure, further analysis was performed with graphic plots. The main effects plots of the means for the output response parameter are obtained using Minitab 16.1 software.

A. Analysis of Surface Roughness (SR)

The main effect plots for means for SR at different levels of particular machining parameters are plotted in figure 4 keeping the objective as “Smaller is better”. ANOVA was performed to study the significance of each input machining parameters in effecting the SR. The ANOVA for SR is given in table 7.

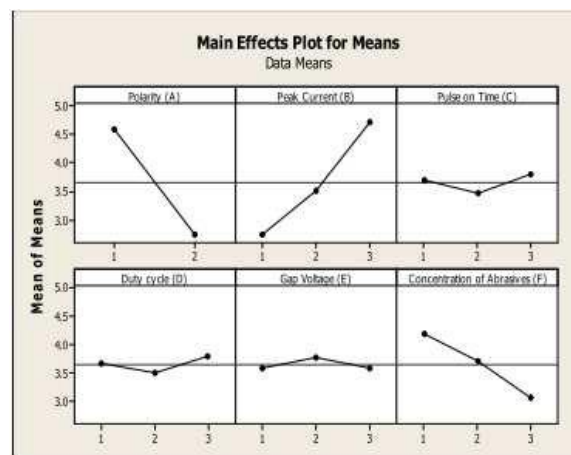


Fig-4 Main effect plot for means for SR

Based on this plot the effect of each factor can be graphically assessed. It is clear from figure 4 that SR is minimum at the 2nd level of polarity, 1st level of peak current, 2nd level of pulse on time, 2nd level of duty cycle, 1st level of gap voltage and 3rd level of abrasive powder concentration. This main effect plot for means for SR suggests the same levels of the parameters (A2, B1, C2, D2, E1 and F3) as the best levels for minimum SR.

Table 7: ANOVA for 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				

The results of ANOVA indicate that all the input machining parameters affect the output response characteristics i.e. SR.

5. CONCLUSIONS

Following are the conclusions which can be taken out by varying each input parameters during machining of H11 specimen with aluminium electrode.

- Negative polarity of tool electrode is desirable lowering of surface roughness.
- Suspension of powder particles in dielectric fluid improves surface roughness.
- Higher peak currents produce more rough surfaces in EDM process.

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