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Study of Effect of machining parameters of WireEDM on the Surface Finish of H11 tool steel using Correlation - Regression and ANOVA

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***Abstract* - Wire Electro Discharge Machining (WEDM) is a process which takes into account multiple input conditions for machining of materials. It has multiple measurable outputs which is dependent on one or more of the machining conditions. A lot of study is to be undertaken before the correct set of machining parameters can be selected. The output responses of the WEDM is dependent upon a set of input parameters and what makes this machining process very interesting is that the output responses are the result of a combination of the Input conditions and is not dependent upon one single condition.**

Machining of H11 tool steels using WEDM is an area in which not much of research has been carried out. Machining of H11 tool steels using WIRE EDM is an area in which not much of research has been carried out. H11 is one of the most commonly used chromium hot work steels. These steels are suitable for designing highly stressed structural parts such as aircraft landing gear which makes it even more important to machine using stress free machining processes.

This work deals with the study of influence of the input parameters selected, i.e Pulse on time (Ton), Pulse off time (Toff), Peak Current (Ip) and Wire feed (Wf) on the surface finish using Correlation-Regression analysis and ANOVA.

A L16 orthogonal array based on Taguchi method was designed. The relationship was studied using ANOVA and linear regression.

Index Terms: ANOVA, Orthogonal array, Regression, EDM, WEDM

I. INTRODUCTION

Manufacturers of WEDM and the users have been striving for achievement of higher machining productivity with also a desired accuracy and surface finish. In order to achieve it there must be a proper understanding of the effect of the input parameters towards the output responses. This is however a very difficult task as WEDM itself is a very complex machining process as it is controlled by a large number of parameters. Many researchers have constantly been trying to calculate and predict the relationship between the Input and the output parameters.

Figure 1 Factors Influencing the Wire EDM process [1]

II. *RELATED WORKS*

H.Singh et al [3] concluded that the material removal rate (MRR) was directly increasing with the increase in the pulse on time (Ton) and also the peak current while it also decreased with the increase in the (Toff) pulse off time and the (SV) Servo Voltage.

Nihat Tosun et.al [2] had investigated the effect and had also optimsed the machining parameters on the cutting width also known as kerf and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. They had conducted the experiments under varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. Taguchi Experimental design was used for designing of the experiments.

Sonum Dhiman et al [4] in their experiment on S7 steel using WEDM found out that the cutting rate (CR) increased with the pulse on time but only upto a certain range after which the MRR started decreasing. It also decreased with the increase of pulse duration and the servo voltage. There was also an increase in CR with the increase in the peak current. There however was not effect of Wire Feed and Wire Tension on the CR.

Trezise [5] in the report had concluded that the fundamental limit on machining accuracy depends solely on the dimensional consistency of the wire and also on the positional accuracy of the worktable.

Jeenes et.al [6] had found a relation between the wire vibrations which occur during the machining processes in the wire and the occurrence of short circuits, which resulted in lower cutting speeds and an increased possibility of wire rupture.

Sho et al. [7] reported that the machining rates increase with increase in zinc (Zn) content in the wire. This was due to the 'heat sink' effect produced in the wire by the zinc coating thereby cooling the core of the wire.

Hatchek [1] in his research had reported that the thickness of the workpiece had a major influence on the cutting speed, whereby thicker the material faster the cut. He had concluded that the longer length of wire electrode in a thicker work piece provided more of an opportunitiy for the occurrence of the spark.

It is being observed that the process parameters like voltage, current, Ton and Toff dominate the output parameters namely MRR, surface roughness etc.

III. EXPERIMENTAL WORK

A. *Experimental Setup*

1. Workpiece - H11 tool steel was chosen as the material for the study and optimisation. The reasons for the same being:-
- Not much research has been made for study of H11 steel in wire EDM process
- It is suitable for designing highly stressed structural parts such as aircraft landing gear
- It is one of the most predominantly used Chromium Hot Work tool steels
2. Machine used – Electronica Sprintcut – 734 was used with the electrode/wire being soft brass of 0.25 mm diameter and the dielectric used was de-ionised or distilled water.
3. Input Variables Selected :-
   - Ton – Pulse On Time
   - Toff – Pulse Off Time
   - Ip – Peak Current
   - Wf – Wire Feed
4. Output response – Surface Roughness (SR) measured in Ra (µm)

B. *Design of Experiments*

For the present work a 4 level 4 factor L16 factorial design was developed. **MINITAB** software has been used to design the orthogonal array for the present work.

The levels for the Input parameters selected, Pulse on Time (Ton), Pulse off time (Toff), Peak Current (Ip) and Wire Tension (WT) are shown in the Table 1 and the design matrix is depicted in Table 2

Table 1 Levels used for Input parameters

S. No	Machining Parameter	Unit	Level			
			1	2	3	4
1	Ton	µsec	15	20	25	30
2	Toff	µsec	30	40	50	60
3	Ip	mA	140	160	180	200
4	Wf	Machine units	5	6	7	8

C. *Conduction Of Experiments*

The experiments were conducted adhering strictly to the orthogonal array design. The roughness of surface was measured using **Mitutoyo's Surftest J210.**

D. *Design Matrix*

Table 2 Design matrix and Observation Table

Expt. Number	Input Process parameters				Output
	Ton	Toff	Ip	Wf	Ra
C1	1	1	1	1	2.928
C2	1	2	2	2	2.919
C3	1	3	3	3	2.232
C4	1	4	4	4	2.322
C5	2	1	2	3	3.770
C6	2	2	1	4	3.139
C7	2	3	4	1	2.798
C8	2	4	3	2	2.882
C9	3	1	3	4	2.690
C10	3	2	4	3	3.409
C11	3	3	1	2	3.254
C12	3	4	2	1	2.026
C13	4	1	4	2	3.514
C14	4	2	3	1	3.713
C15	4	3	2	4	3.216
C16	4	4	1	3	3.033

IV. RESULT AND DISCUSSION

A. *Response Table*

Table 3 shows the response table for the experiment conducted

Table 3 Response Table

Expt. Number	Input Process parameters				Output
	Ton	Toff	Ip	Wf	Ra
C1	15	30	140	5	2.928
C2	15	40	160	6	2.919
C3	15	50	180	7	2.232
C4	15	60	200	8	2.322
C5	20	30	160	7	3.770
C6	20	40	140	8	3.139
C7	20	50	200	5	2.798
C8	20	60	180	6	2.882
C9	25	30	180	8	2.690
C10	25	40	200	7	3.409
C11	25	50	140	6	3.254
C12	25	60	160	5	2.026
C13	30	30	200	6	3.514
C14	30	40	180	5	3.713
C15	30	50	160	8	3.216
C16	30	60	140	7	3.033

B. Influences On Surface Roughness

Graphs depicting the relationship between Input parameters and the response

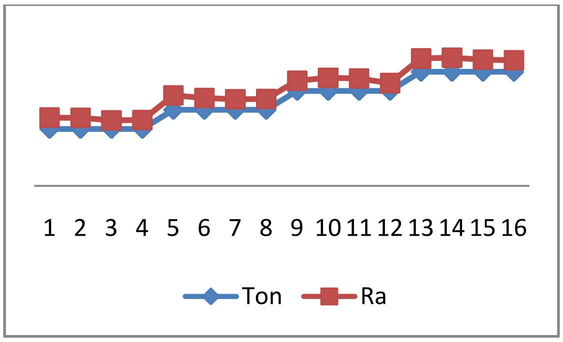

Figure 2 Ton vs Ra

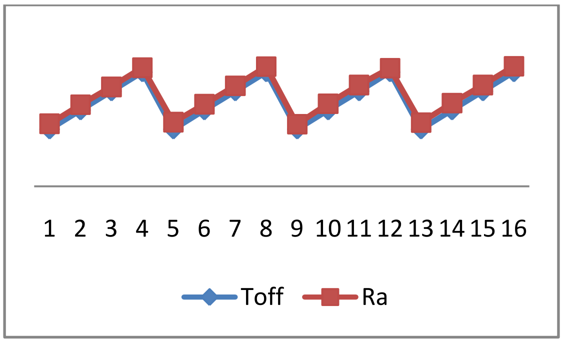

Figure. 3 Toff vs Ra

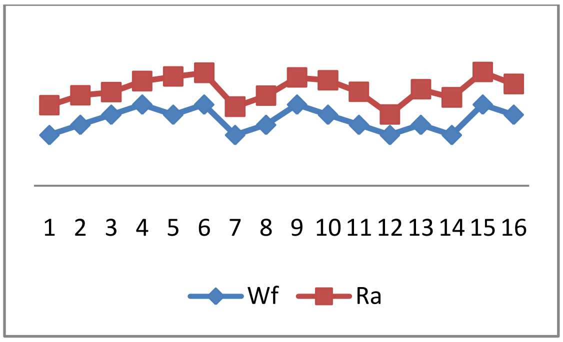

Fig. 4 Wf vs Ra

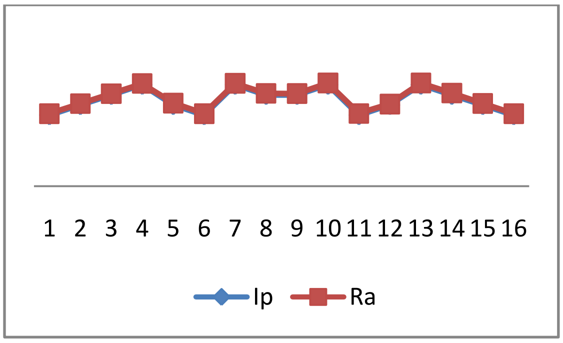

Figure. 5 Ip vs Ra

Corelation Analysis

The Corelation Coefficient for Gap Current against the Input Parameters is calculated using the following formula:-

$$r = \frac{\sum_i (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_i (x_i - \overline{x})^2}\sqrt{\sum_i (y_i - \overline{y})^2}}$$

The following is a table of the correlation between the Gap Current and the Input Parameters. The table also gives a brief description of the result

Table 4 Correlation between Surface Roughness and Input Parameters

Sl. No	Input Parameters	Corelation Coeficient (r)	Coefficient of Determination (r^2)	Remarks
1	Ton	0.458272	0.210013	The value of R is 0.4583. Although technically a positive correlation, the relationship between your variables is weak (*nb.* the

				nearer the value is to zero, the weaker the relationship).
2	**Toff**	-0.54873	0.3011	The value of R is -0.5487. This is a moderate negative correlation, which means there is a tendency for high X variable scores to go with low Y variable scores (and vice versa).
3	Ip	-0.07702	0.005932	The value of R is -0.077. Although technically a negative correlation, the relationship between your variables is only weak (*nb.* the nearer the value is to zero, the weaker the relationship).
4	WT	-0.02396	0.000574	The value of R is -0.024. Although technically a negative correlation, the relationship between your variables is only weak (*nb.* the nearer the value is to zero, the weaker the relationship).

It was observed that the most influential parameter for Surface Roughness is Pulse Off Time (Toff)

The following figure depicts that the influence of Toff is the strongest for Surface Roughness

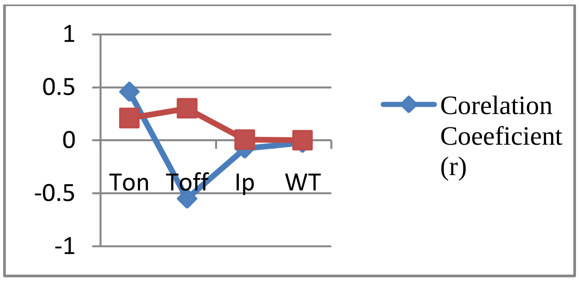

Fig. 6 Correlation of Input parameters v/s Cutting Speed

Regression analysis

Using MINITAB software the regression equation was determined and the plot of actual to the predicted value was made.

The regression formula was found using the MINITAB software and the Regression equation is given below:-

Ra = 3.52 + 0.0401 Ton - 0.0240 Toff - 0.00168 Ip - 0.0105 Wf

Based upon the equation, the table number 5 shows the Predicted and the Actual value.

Table 5 Table showing values of Ra (Predicted) and Ra (Actual)

Expt. No.	Ra (Predicted)	Ra (Actual)
C1	3.114	2.928
C2	2.830	2.919
C3	2.546	2.232
C4	2.262	2.322
C5	3.260	3.770
C6	3.043	3.139
C7	2.734	2.798
C8	2.517	2.882
C9	3.416	2.690
C10	3.153	3.409
C11	3.024	3.254
C12	2.761	2.026
C13	3.604	3.514
C14	3.408	3.713
C15	3.170	3.216
C16	2.974	3.033

The following figures, 7 and 8 shows the residual plots for Surface Roughness (Ra) and the Graph plot for predicted v/s Actual values of Ra respectively

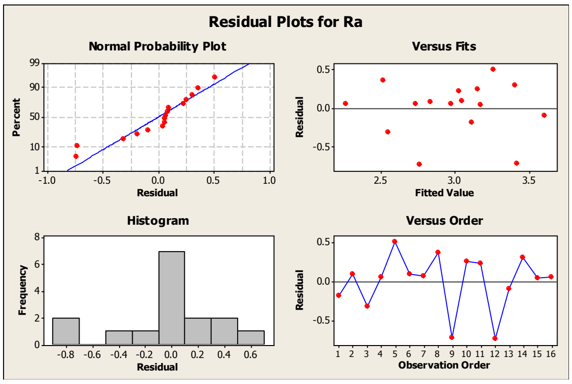

Figure 7 Residual Plots for Cutting Speed (CS)

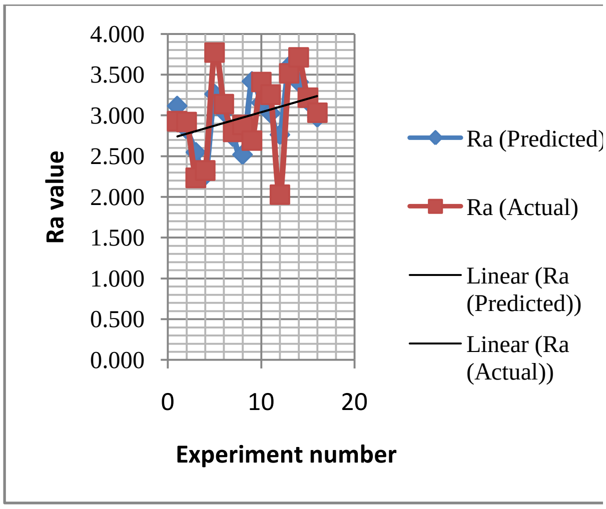

Figure 8 Graph for Predicted v/s Actual values for Ra

ANOVA

ANOVA was performed using MINITAB software. A GLM was performed for which the following is the result.The **ANOVA** shows that T_{on} and T_{off} has the largest influence on the Surface Roughness.

General Linear Model: Ra versus Ton, Toff, Ip, Wf

```
Factor  Type   Levels  Values
Ton     fixed       4  15, 20, 25, 30
Toff    fixed       4  30, 40, 50, 60
Ip      fixed       4  140, 160, 180, 200
Wf      fixed       4  5, 6, 7, 8

Analysis of Variance for Ra, using Adjusted SS
for Tests
Source  DF  Seq SS  Adj SS  Adj MS     F      P
Ton      3  1.3655  1.3655  0.4552  1.95  0.299
Toff     3  1.3668  1.3668  0.4556  1.95  0.299
Ip       3  0.0898  0.0898  0.0299  0.13  0.937
Wf       3  0.3005  0.3005  0.1002  0.43  0.748
Error    3  0.7011  0.7011  0.2337
Total   15  3.8236

S = 0.483410   R-Sq = 81.66%   R-Sq(adj) =
8.32%
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Figure 9 ANOVA for Surface Roughness

V. CONCLUSION

This paper investigated the effects of the important input parameters on the Surface finish of the material H11 in WEDM process.

The effect of Toff was found to be the highest for the Surface Roughness with Ton also having an influence on the outcome.

It also showed that the Surface roughness had linear relationship with only the pulse parameters viz Ton and Toff, and thus can be concluded that there is a this particular response has dependence on the combination of the pulse parameters.

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