International Journal For Technological Research In Engineering
Volume 3, Issue 9, May-2016 *ISSN (Online): 2347 - 4718*

AN INVESTIGATION AND ANALYZE EXPERIMENT DATA FOR MATERIAL REMOVAL RATE, SURFACE ROUGHNESS, KERF WIDTH ON WIRE CUT EDM FOR 17-4 PH MATERIAL

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Abstract: The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Wire Electrical Discharge Machining (WEDM). It is a capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries medical, optical, dental, jewellery industries, and in the automotive and aerospace R & D areas. 17-4 PH martensitic stainless steel that is usually supplied in a high fracture toughness, flexural strength, and hardness and wear resistance and posses greater strength and toughness are usually known to create major challenges during conventional and non-conventional machining. The Wire Electric discharge machining process is finding out the effect of machining parameter such as discharge current, pulse on time, Pulse off time and diameter of tool of 17-4 PH tool steel material. Using brass wire tool with internal flushing. A well-designed experimental scheme was used to reduce the total number of experiments. Parts of the experiment were conducted with the L16 orthogonal array based on the Taguchi method. Moreover, the signal-to-noise ratios associated with the observed values in the experiments were determined by which factor is most affected by the Responses of Material Removal Rate (MRR), Surface Roughness (Ra) and Kerf Width (kw).

I. INTRODUCTION

The history of EDM Machining Techniques goes as far back as the 1770s when it was discovered by an English Scientist. However, Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes. When it was originally observed by Joseph Priestly in 1770, EDM Machining was very imprecise and riddled with failures. Commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped shape the metal working industry we see today. In the mid 1980s.The EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes. [16] Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. The applied to machine such difficult to machine materials. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and -aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface. [19]

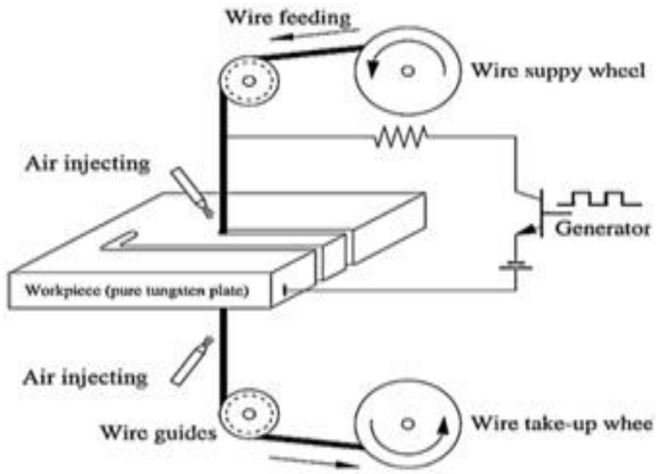

Fig. 1 the Basic Principle of WEDM Process

WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. WEDM are available with watertight work tanks to submerge and surround the part with dielectric during cutting operations. This assures a fully immersed spark gap and aids in temperature control of the work piece, tooling and machine components. Submersion also allows machines equipped with anti-electrolysis circuitry to better resist rust, corrosion and oxidation of sensitive work piece materials.

II. METHODOLOGY

A. SELECTION OF MACHINE TOOL

For this experiment the whole work can be done by CNC wire cut Electric Discharge Machine, model ELECTRONICA, ULTRACUT S2 as shown in fig 3.1. Wire cut type with servo-head (constant gap) and positive polarity for WIRE (as a tool) was used to conduct the experiments.

Figure 3.1- wire cut EDM,

Table 3.1: Specification of machine

Table traverse	600 X 400 mm
Table size	800 X 580 mm
Maximum work piece height	300 mm
Axes	5
Screen	LCD
Machine series	Ultracut s2
Company name	Electronica

III. SELECTION OF WORKPIECE

From the review of the literature it is found that the Precipitation hardened martensitic stainless steels (like 17-4 PH) materials increasingly being used in dies application by providing of its high fracture toughness, flexural strength, and hardness and wear resistance.

Table 3.2: Composition of Material

Contents	C	Mn	P	S	Si	Cr	Ni	Cu	Cb+Ta
Max %	0.07	1	0.040	0.030	1	15-17.5	3-5	3-5	0.15-0.45

Fig. 3.2 17-4 ph material

3.4.1 Cryo treated Precipitation hardened martensitic stainless steels (like 17-4 PH) materials

It is the process of treating material to cryogenic temperatures (i.e. below -190°C) to remove residual stresses and improve wear resistance on steels. The process has a wide range of applications from industrial tooling to improvement of musical signal transmission. The range of all the process parameters is selected for the present study based on the results obtained from preliminary experiments.

3.5 SELECTION OF TOOL (WIRE) MATERIAL

In this Wire cut EDM used wire as the cutting tool. There are two types of material used in wire Copper and brass. We choose the material tool of brass wire as shown in fig.3.3

Fig. 3.3 Spool brass wire

3.5.1 Importance of the Brass wire

- Copper wire and is still the most commonly used wire today. Brass, which is an alloy of Copper and Zinc, delivers a powerful combination of low cost, reasonable conductivity, high tensile strength, and improved flush ability. It should be noted that even a small amount of Zinc added to Copper wire drastically reduces the conductivity.
- Hard Brass wire typically has conductivity only 20% of Copper wire. Since it is the Zinc that gives Brass Wire its improved flush ability, some manufacturers now offer a "high zinc" brass which is Cu 60%, Zn 40%.
- Experimental Reading

NO.	T_{on} [µs]	T_{off} [µs]	Voltage [V]	Wire Feed [mm/sec]	MRR [mm^3/min]	SR [µm]	KW [mm]
1	90	28	24	5	2.45	1.36	0.6803
2	90	34	30	9	2.97	1.96	0.7477
3	90	40	36	13	3.97	2.66	0.7547
4	90	46	42	17	4.97	3.15	0.7846
5	110	28	30	13	2.57	1.04	0.7083
6	110	34	24	17	3.32	1.73	0.7284
7	110	40	42	5	4.46	2.14	0.7221
8	110	46	36	9	5.27	2.64	0.7534
9	120	28	36	17	3.27	1.03	0.6917
10	120	34	42	13	4.97	1.01	0.7083
11	120	40	24	9	4.73	1.75	0.7284
12	120	46	30	5	5.71	1.01	0.7477
13	130	28	42	9	5.37	1.25	0.6724
14	130	34	36	5	5.45	0.84	0.6658
15	130	40	30	17	6.21	1.15	0.7284
16	130	46	24	13	6.73	1.11	0.7394

5 S/N RATIO CALCULATION FOR MATERIAL REMOVAL RATE, SURFACE ROUGHNESS AND KERF WIDTH

In this the observe value of for Material removal rate, Surface roughness, kerf width are transform in S/N ratio values t
o find out the optimum combination of parameters for response variable. In Surface roughness and Kerf Width response “smaller is better” is objective characteristics, where as in Material removal rate response should be “ higher is the better”. Since the minimization of the quality characteristic is interested and it can be expressed by equation in chapter no.3.The value of S/N ratio for all response by use of above described equation is shown in table.

Table 4.5:– SN ratio calculation

No	SNR MRR	SNR SR	SNR KW
1	7.7833	-2.67078	3.34599
2	9.4551	-5.84512	2.52545
3	11.9758	-8.49763	2.44451
4	13.9271	-9.96621	2.10703
5	8.1987	-0.34067	2.99566
6	10.4228	-4.76092	2.75260
7	12.9867	-6.60828	2.82805
8	14.4362	-8.43208	2.45949
9	10.2910	-0.25674	3.20164
10	13.9271	-0.08643	2.99566
11	13.4972	-4.86076	2.75260
12	15.1327	-0.08643	2.52545
13	14.5995	-1.93820	3.44745
14	14.7279	1.51441	3.53312
15	15.8618	-1.21396	2.75260
16	16.5603	-0.90646	2.62241

4.5.1 Main Effects Plot for SNR of material removal rate

The main effects plot for S/N ratio of material removal rate versus Pulse on time, Pulse off time, voltage and wire feed are shown in fig.4.1,

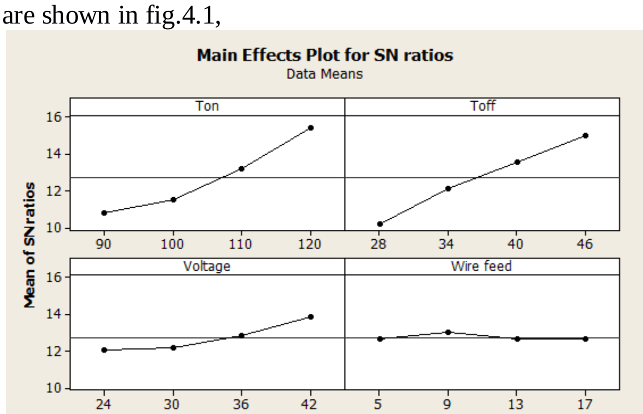

Fig. 4.1 - Effect of control factor on material removal rate which is generate from the value of S/N ratio of material removal rate as per table in minitab-16 statistical software is useful to find out optimum parameter value for response variable.

Fig.4.1 shows that higher material removal rate will meet at Pulse on time 120 µs, Pulse off time 46 µs, Voltage 42 V and wire feed 9 mm/sec. The graph generate by use of minitab-16 statistical software for material removal rate is shown in fig.4.1

From the fig.4.1, it has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at Pulse on time [A4], Pulse off time [B4], Voltage [C4] and wire feed [D2].

4.5.2 Main Effects Plot of Surface roughness

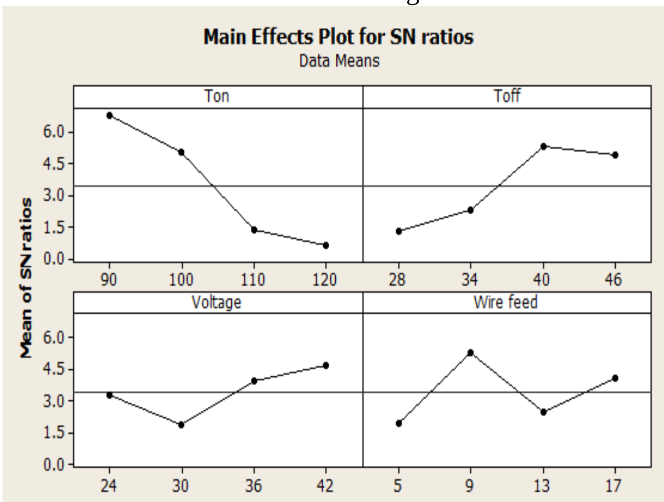

Fig. 4.2 - Effect of control factor on surface roughness

Fig.4.2 shows that lower Surface roughness will meet at Pulse on time 120 µs, Pulse off time 28 µs0, Voltage 30 V and wire feed 5 mm/sec From the fig.4.2, it has been conclude that the optimum combination of each process parameter for lower surface roughness is meeting at Pulse on time [A4], Pulse off time [B1], Voltage [C2] and wire feed [D1].

4.5.3 Main Effects Plot for SNR for kerf width

Fig.4.3 shows that lower kerf width will meet at Pulse on time 60 µs, Pulse off time 28 µs, Voltage 36 V and wire feed 17 mm/sec From the fig.4.3, it has been conclude that the optimum combination of each process parameter for lower surface roughness is meeting at Pulse on time [A4], Pulse off time [B1], Voltage [C3] and wire feed [D1].

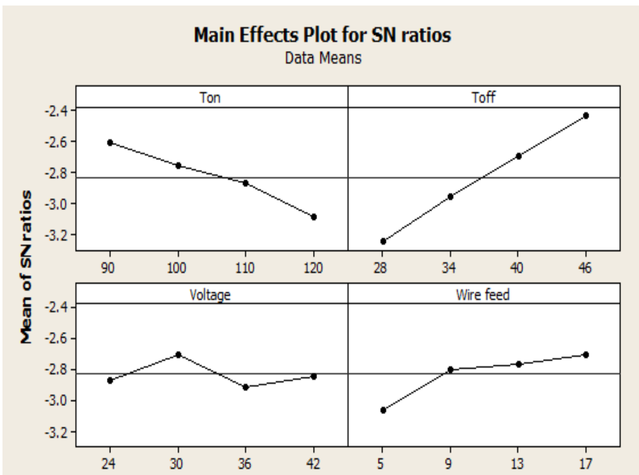

Fig. 4.3 - Effect of control factor on kerf width 4.6 Analysis of Variance

Table 4.6 General Linear Model: MRR [gm/min] versus Ton [µs], Toff [µs], ...

Factor	Type	Levels	Values 1	Values 2	Values 3	Values 4
T_{ON} [µs]	Fixed	4	90	100	110	120
T_{OFF} [µs]	Fixed	4	28	34	40	46
Voltage [V]	Fixed	4	24	30	36	42
Wire feed [mm/sec]	Fixed	4	5	9	13	17

Table 4.7 Analysis of Variance for MRR [gm/min],

Source	DF	Adj SS	Adj MS	F	P
Ton [µs]	3	13.1275	4.3758	40.20	0.006
Toff [µs]	3	11.0587	3.6862	33.87	0.008
Voltage [V]	3	0.9937	0.3312	3.04	0.193
Wire feed [mm/sec]	3	0.0467	0.0156	0.14	0.928
Error	3	0.3265	0.1088		
Total	15	25.5532			

S = 0.329912 R-Sq = 98.72% R-Sq(adj) = 93.61%

From ANOVA result it is observed that Pulse on time and Pulse off time influencing parameter for MRR, while the value of p for voltage and wire feed is 0.193 and 0.928 which is greater than 0.05 p value so they are not influencing parameter for MRR.

4.6.2 Analysis of variance for Surface Roughness

Table 4.8 General Linear Model: SR [µm] versus Ton [µs], Toff [µs], ...

Factor	Type	Levels	Values 1	Values 2	Values 3	Values 4
T_{ON} [µs]	Fixed	4	90	100	110	120
T_{OFF} [µs]	Fixed	4	28	34	40	46
Voltage [V]	Fixed	4	24	30	36	42
Wire feed [mm/sec]	Fixed	4	5	9	13	17

Table 4.9 Analysis of Variance for SR [µm],

Source	DF	Adj SS	Adj MS	F	P
Ton [µs]	3	3.88117	1.29372	56.07	0.004
Toff [µs]	3	1.91372	0.63791	27.65	0.011
Voltage [V]	3	0.91057	0.30352	13.15	0.031
Wire feed [mm/sec]	3	0.82532	0.27511	11.92	0.036
Error	3	0.06922	0.02307		
Total	15	7.59999			

S = 0.151898 R-Sq = 99.09% R-Sq(adj) = 95.45%

From ANOVA result it is observed that the Pulse on time, Pulse off time, wire feed and voltage influencing parameter for SR. So, it is not influencing parameter for Surface roughness.

4.6.3 Analysis of variance for Kerf Width

From ANOVA result it is observed that the Pulse on time, Pulse off time and wire feed are influencing parameter for Kerf Width, while the value of p for voltage is 0.154 which is greater than 0.05 p values. So, it is not influencing parameter for Kerf Width.

Table 4.10 General Linear Model: Kerf Width [mm] versus T on [µs], T off [µs], ...

Factor	Type	Levels	Values 1	Values 2	Values 3	Values 4
T_{ON} [µs]	Fixed	4	90	100	110	120
T_{OFF} [µs]	Fixed	4	28	34	40	46
Voltage [V]	Fixed	4	24	30	36	42
Wire feed [mm/sec]	Fixed	4	5	9	13	17

Table 4.11 Analysis of Variance for Kerf Width [mm]

Source	DF	Adj SS	Adj MS	F	P
Ton [µs]	3	0.003429	0.001143	20.02	0.017
Toff [µs]	3	0.010147	0.003382	59.25	0.004
Voltage [V]	3	0.000639	0.000213	3.73	0.154
Wire feed [mm/sec]	3	0.001979	0.000660	11.56	0.037
Error	3	0.000171	0.000057		
Total	15	0.016366			

S = 0.00755524 R-Sq = 98.95% R-Sq(adj) = 94.77%

1 Regression Equation for material removal rate

The regression equation is

MRR [mm3/min] = -7.33 + 0.05536 Ton [µs] + 0.1238 Toff [µs] + 0.0338 Voltage [V] - 0.0063 Wire Feed [mm/sec]

Table 4.12 Regression Coefficient for material removal rate

Predictor	Coefficient	SE Coef	T	P
Constant	-7.33	1.42	-5.18	0.000
Ton [µs]	0.05536	0.00875	6.32	0.000
Toff [µs]	0.1238	0.0193	6.42	0.000
Voltage [V]	0.0338	0.0193	1.75	0.107
Wire Feed [mm/sec	-0.0063	0.0289	-0.22	0.833

R-Sq = 88.46% R-Sq(adj) = 84.26%

Show in above table 4.12, the p value of pulse on time, pulse off time and voltage process parameters are less than 0.05, therefore all these factor are significant. But wire feed has 0.765, thus it is not effective for material removal rate. The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 88.46% which is indicates that model is fit for prediction

4.7.2 Regression Equation for Surface Roughness

The regression equation is

SR [µm] = 2.23 - 0.03205 Ton [µs] + 0.0494 Toff [µs] + 0.0284 Voltage [V] + 0.0209 Wire Feed [mm/sec]

Table 4.13 Regression Coefficient for surface roughness

Predictor	Coefficient	SE Coef	T	P
Constant	2.23	1.02	2.18	0.051
Ton [µs]	0.03205	0.00630	-5.08	0.000
Toff [µs]	0.0494	0.0139	3.55	0.005
Voltage [V]	0.0284	0.0139	2.04	0.066
Wire Feed [mm/sec	0.0209	0.0208	1.00	0.337

R-Sq = 79.87% R-Sq(adj) = 72.56%

The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 79.87 % which is indicates that model is fit for prediction with high accuracy.

4.7.3 Regression Equation for Kerf Width

The regression equation is

KW [mm] = 0.6719 - 0.000963 Ton [µs] + 0.003752 Toff [µs] - 0.000141 Voltage [V] + 0.002253 Wire Feed [mm/sec]

Table 4.14 Regression Coefficient for kerf width

Predictor	Coefficient	SE Coef	T	P
Constant	0.6719	0.0302	22.22	0.000
Ton [µs]	0.000963	0.000187	-5.15	0.000
Toff [µs]	0.003752	0.000412	9.10	0.000
Voltage [V]	-0.000141	0.000412	-0.34	0.739
Wire Feed [mm/sec	0.002253	0.000619	3.64	0.004

R-Sq = 91.77% R-Sq(adj) = 88.78%

The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 91.77 % which is indicates that model is fit for prediction with high accuracy.

IV. CONCLUSION

Experimental investigation on wire electrical discharge machining of 17-4 PH material has been done using brass wire of 0.25mm. The following conclusions are made.

- From the S/N ratio plot the optimum parameter settings for material removal rate at, ie. Ton = 120µs, Toff = 46 µs, Voltage = 42 V and wire speed = 9 mm/sec.
- It can also observed that Ton and Toff is the most prominent factor affecting the Material removal rate.
- From the S/N ratio plot the optimum parameter setting for surface roughness at, ie. Ton = 120 µs, Toff = 28 µs, Voltage = 30 V and wire speed = 5 mm/sec.
- From the S/N ratio plot the optimum parameter setting for kerf width at, ie. Ton = 120 µs, Toff = 28 µs, Voltage = 36 V and wire speed = 5 mm/sec.
- The Analysis of Variance resulted that the Ton and Toff has major influence on the material removal rate (mm^3/min,)surface roughness (µm) and kerf width (mm) in both the Taguchi optimization method. Whereas the pulse on time has significant effect on the material removal rate.
- The objectives such as material removal rete, surface roughness and kerf width are optimized using a single objective taguchi method.

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