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Influence Of Process Parameters On Wire Electrical Discharge Machining Of SS17-4 (PH)

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Abstract
Wire electro-discharge machining (WEDM) is one of the important non-traditional machining processes, which is used for machining of difficult-to-machine materials and intricate profiles. This paper describes Selection of optimal values of different process parameters, such as pulse on, pulse off wire feed, wire tension and dielectric flow rate of wire electric discharge machining (WEDM) process. The major performance measures of WEDM process generally include material removal rate (MRR), cutting width (kerf) and dimensional deviation. The aim of this paper is to investigate the influence of the output performances of WEDM on stainless steel 17-4 (Precipitation Hardening). Brass wire was employed as the wire electrode in this study. The experimental results are presented and discussed.

Keywords: *Wire- Electrical Discharge Machining; Material Removal Rate; Kerf; Cutting width*

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Nomenclature

MRR	Material removal rate
DD	Dimentional deviation
PH	Precipitation Hardening
Cs	Cutting Speed
L	Thickness of the work piece
SNRA	Signal to Noise ratio

I. Introduction

Wire Electrical Discharge Machining (WEDM) is a nontraditional, thermoelectric process which erodes material from the work piece by a series of discrete sparks between a work piece and tool, with de-ionized water as the dielectric medium, produce complex two and three dimensional shapes according to a computer numerically controlled (CNC) path. The schematic representation of the WEDM cutting process is shown in Fig. 1.

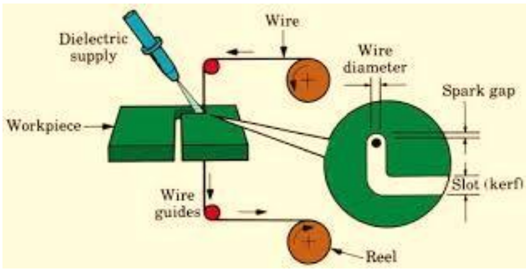

Fig. 1. Schematic Representation of WEDM process

WEDM is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining process. At present, WEDM is a widespread technique used in industry for high-precision machining of all types of conductive materials. The wire-cut electrical discharge machining plays an important role in manufacturing sectors especially industries like aerospace, ordinance, automobile and general engineering [J.A. Sanchez., 2007, R. Ramakrishnan and L. Karunamoorthy et al., 2006]. Conventional machining is more efficient than unconventional machining like wire-cut EDM process but it is difficult to obtain intricate and complex shapes of the components [K.K. Choi et al., 2008] as it is required in the above mentioned applications. Moreover machine tool tables provided by the manufacturer often do not meet the requirements in machining a particular material [A.Manna and B.Bhattacharya, 2006]. So, to obtain various shapes of structural components the wire-cut EDM process is important in many cases, but it requires the improved machining efficiency. Hence, for improving the machining efficiency it requires the models to predict optimum parametric combinations accurately. But wire-cut EDM consists of a number of parameters, which makes it difficult to obtain optimal parametric combinations for machining different materials for various responses like surface roughness, material removal rate, kerf etc. Taguchi's robust design has been used in various applications to obtain optimum parametric combinations [A.Manna and B.Bhattacharya et al., 2006, P.G.Benardos et al., 2002, J.A.Ghani et al., 2004, H.T Lee and J.P .Yur, 2000, S.S.Mahapatra et al.,2007, K .Kanlayasiri, et al., 2007]for desired responses. In many of the manufacturing processes, the surface roughness is one of the response performance measures. Several researchers were attempted previously to improve the surface roughness [Aminollah Mohammadit et al., 2008, P.G.Benardos, et al., 2003, U .Esme, A .Sagbas et al., 2009, Fuzhu Han et al., 2007, MI.Gokler et al., 2000, M. Kiyak and O. Cakir, 2007, H.T.Lee et al., 1996, YS.Liao et al., 2004, IPuertaset al., 2004, R.Ramakrishnan and L. Karunamoorthy, 2004, A.A. Khan, 2008] on various materials. MI.Gokler and AM.Ozanozgu [2000] were conducted the experiments on different materials namely aluminum alloy, brass, alloy steel, cemented carbide at the same conditions to obtain surface roughness. They found that the rigidity is a significant factor affecting the surface roughness. The surface roughness decreases accompanying an increase in material rigidity. Therefore high rigidity materials will produce finer surfaces and low rigidity materials like aluminum alloys produces high surface roughness. In addition, Khan [2008] presented his analysis on material removal rate during EDM of aluminum and mild steel using copper and brass electrodes. The highest material removal rate was observed during machining of aluminum due to high thermal conductivity and low melting point when compared to steel at low thermal conductivity and high melting point. As a result highest material removal rates were obtained during machining of aluminum alloy. It is well known fact that a high material removal rate and a very good surface finish can never be achieved simultaneously in WEDM process [A.B. Puri and B.Bhattacharyya, 2003, K.P.Rajurkar and W.M Wang 1993].. Analysis of variance (ANOVA) is carried out to determine significant factors and signal-to-noise (S/N) ratio is conducted to find the optimal settings and factor levels. To establish a relationship between factors and response variable multiple regression models was used. Finally, experimental confirmations were carried out to identify the effectiveness of this proposed method. In the Present work SS17-4(PH) is considered for measuring the output parameters like material removal rate, kerf and dimensional deviation using Taguchi method.

II. Experimental Detials

All the experiments were conducted on the Joemars WT-655 wire electro-discharge machine (WEDM) as shown in Fig. 1. In this machine, all the axes are servo controlled and can be programmed to follow a CNC code which is fed through the control panel. All five axes have an accuracy of 1µm. Through an NC code, machining can be programmed.

Fig. 2. Joemars WT-655 CNC Wire cut EDM

2.1. Work piece Material

In the present research work, Stainless Steel 17-4 (PH) has been considered the work piece material to conduct the experiments. This material is extensively used for mould making, chemical and industry applications. The thickness of the work piece material is 24mm. The chemical composition of the work piece material is given in Table 1.

Table 1. Chemical composition of SS 17-4 (PH) Material

Material	C	S	O	N	P	Si	Cr	Ni	Cu	Mn	Mo	Cb
SS17-4(PH) (%)	0.011	0.005	0.23	0.018	0.009	0.86	17.34	4.61	3.92	0.20	0.02	0.26

2.2. Wire electrode

Brass is begun to be used in the late of the 1970's in wire electro-discharge machining. These conductive metal wires (diameter from 0.05mm to 0.35mm) are used in three-dimensional machining after programming the required shape and provide wire continuously. Plain Brass wire with 0.25mm diameter is used as a wire electrode material to conduct the experiments on WEDM. Table 2.shows the wire electrode properties.

Table 2. Wire electrode material properties.

Wire name	High-Speed Brass
Material	High Purity Brass Special Composition
Tensile Strength	900N/mm^2
Wire Diameter	0.25mm

2.3. Process Parameters and Design

Input parameters such as pulse on, pulse off, wire feed, wire tension and dielectric fluid pressure used in this study as shown in Table 3. Each factor is investigated at five levels to determine the optimum settings for WEDM process. These parameters and their levels are chosen based on the trail experiments and literature review. The experimental designs were done based on the Taguchi's method. According to the Taguchi's method for five factors and five levels L_{25} (5^6) orthogonal array (OA) is used.

Table 3. Parameter conditions in WEDM process

S.NO	Process Parameters	Units	symbol	Levels				
				L1	L2	L3	L4	L5
1.	Pulse On	μs	A	8	10	12	14	16
2.	Pulse Off	μs	B	18	22	26	30	34
3.	Wire Tension	Kg-f	C	4	6	8	10	12
4.	Wire feed	m/min	D	7	8	9	10	11
5.	Dielectric fluid pressure	Kg/cm^2	E	3	4	5	6	7

2.4. Evaluation of Process Performances

The experiments are conducted based on the Taguchi's L_{25} orthogonal array as per the process parameters shown in Table 3. The most important performance measures in WEDM are Material removal rate (MRR), kerf and dimensional deviation. In the present study these performance measures are measured as follows

2.4.1. Material Removal Rate (MRR)

The Material removal rate is calculated for each experiment of WEDM process. The following Equation is used to find out the MRR value.

Material removal rate (MRR) = Cs * L mm^3/min

Where Cs = Cutting Speed in mm/min

L = Thickness of the work piece in mm

2.4.2. Kerf (cutting width)

Kerf (cutting width) is also an important process performance measure of the wire electro-discharge machining process. The kerf was measured using the Mitutoyo Tool Makers Microscope (x100). The average of five measurements made from the work piece for 10mm along cut length.

2.4.3. Dimensional Deviation

The specimen cross-section is measured with the help of a Mitutoyo's digital micrometer having the least count of 0.001 mm and the deviation of the measured dimension is calculated in percentage using the following expression.

$$\text{Dimensional deviation} = \frac{(\text{observed value} - \text{Actual value})}{\text{Actual value}} \times 100$$

III. Results and discussions

Any of the manufacturing process generally measured in terms of surface roughness achieved and how fast material is removed. In the present work the experiments were conducted to measure the MRR, Kerf and dimensional deviation.

3.1. Selection of best Parametric Combination for MRR and Kerf

The analysis of variance (ANOVA) of experimental data and S/N data is carried out to identify the significant variables and to quantify their effects on the response characteristics. The most favorable values (optimal settings) of process variables in terms of mean response characteristics are established by analyzing the response curves and the ANOVA tables.

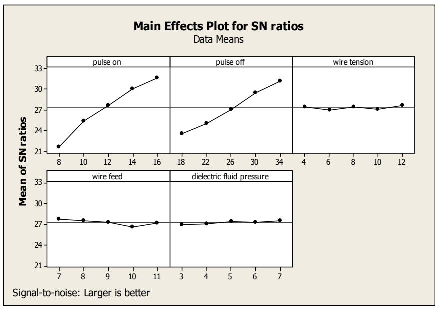

Fig. 3. S/N response graphs for MRR

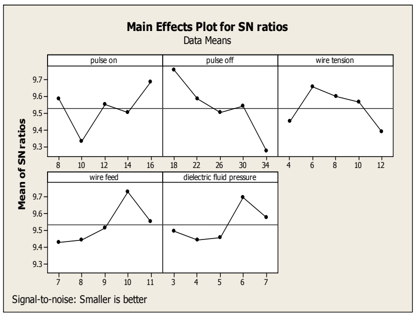

Fig. 4. S/N response graphs for Kerf

Fig.2 shows the main effects of plot for MRR vs. all input factors for the tabled in Table 3. Since it is always desirable to maximize the MRR larger is better option is selected. From the above graph it can be seen that maximum MRR is achieved at pulse on 14 µs, pulse off 34µs, wire tension 8 Kg-f, wire feed 7mm/min, dielectric fluid pressure 7kg/cm^2.

Table 4. Experimental results and S/N ratios for MRR and Kerf

S. No	Cutting Speed mm/min	MRR (mm^2/min)	SNRA for MRR	Kerf (mm)	SNRA for Kerf	Dimensional Deviation (%)
1.	0.326	7.824	17.8686	0.337	9.44740	0.0054
2.	0.382	9.168	19.2455	0.324	9.78910	0.0028
3.	0.484	11.616	21.3011	0.335	9.49910	0.0050
4.	0.604	14.496	23.2250	0.321	9.86990	0.0022
5.	0.872	20.928	26.4146	0.342	9.31948	0.0064
6.	0.504	12.096	21.6528	0.320	9.89700	0.0020
7.	0.562	13.488	22.5990	0.333	9.55112	0.0046
8.	0.712	17.088	24.6538	0.334	9.52507	0.0048
9.	1.042	25.008	27.9616	0.356	8.97100	0.0040
10.	1.326	31.824	30.0551	0.367	8.70668	0.0096
11.	0.662	15.888	24.0214	0.329	9.65608	0.0016
12.	0.832	19.968	26.0067	0.334	9.52507	0.0038
13.	1.004	24.968	27.9477	0.342	9.31948	0.0048
14.	1.362	32.688	30.2878	0.327	9.70904	0.0072
15.	1.302	31.248	29.8964	0.333	9.55112	0.0034
16.	0.862	20.688	26.3144	0.328	9.68252	0.0046
17.	1.046	25.104	27.9949	0.345	9.24362	0.0036
18.	1.232	29.568	29.4164	0.332	9.44740	0.0006
19.	1.624	38.976	31.8159	0.337	9.78910	0.0044
20.	2.274	54.576	34.7400	0.332	9.49910	0.0054
21.	1.042	25.008	27.9616	0.313	9.86990	0.0044
22.	1.206	28.944	29.2312	0.323	9.31948	0.0006
23.	1.662	39.888	32.0168	0.331	9.89700	0.0026
24.	2.146	51.504	34.2368	0.327	9.55112	0.0042
25.	2.352	56.448	35.0330	0.346	9.52507	0.0034

Table 5. S/N response table for MRR

S.No	Level	A	B	C	D	E
1	1	21.61	23.56	27.37	27.72	26.93
2	2	25.38	25.02	26.93	27.56	27.14
3	3	27.63	27.07	27.38	27.25	27.43
4	4	30.06	29.51	27.05	26.62	27.36
5	5	31.70	31.23	27.66	27.23	27.53
6	Delta	10.08	7.66	0.73	1.10	0.60
7	Rank	1	2	4	3	5

Table 6. S/N response table for Kerf

S.No	Level	A	B	C	D	E
1	1	9.585	9.754	9.451	9.425	9.495
2	2	9.330	9.585	9.658	9.441	9.442
3	3	9.552	9.505	9.599	9.513	9.453
4	4	9.506	9.541	9.564	9.728	9.696
5	5	9.687	9.275	9.389	9.553	9.573
6	Delta	0.357	0.480	0.269	0.303	0.254
7	Rank	2	1	4	3	5

Table 7. Optimal Parameter Combination for MRR and Kerf

S.No.	Process parameters	Optimum Combination for MRR	Optimum Combination for Kerf
1.	Pulse On	A4	A5
2.	Pulse Off	B5	B1
3.	Wire Tension	C3	C2
4.	Wire feed	D1	D4
5.	Dielectric fluid pressure	E5	E4

3.2. Mathematical Model

In the present work, mathematical model expressions are developed to predict the material removal rate and kerf. In this model MRR and kerf is a function of pulse on, pulse off, wire feed, wire tension and dielectric fluid pressure. The mathematical model for MRR and kerf is as follows

MRR = - 36.7 + 3.45 pulse on + 1.47 pulse off - 0.224 wire tension - 1.50 wire feed - 0.224 dielectric fluid pressure

Kerf = 0.341 - 0.000740 pulse on + 0.000975 pulse off + 0.000420 wire tension- 0.00212 wire feed - 0.00158 dielectric fluid pressure

With the help of mathematical equation the predicted values of MRR and kerf is estimated and their deviation is tabulated. It is observed that the predicted values are closer to experimental values as in Table-9 and shown in graphical form in figure-5.

Table 8. Comparison between predicted and experimental values.

S.No.	MRR	Predicted MRR	Deviation	Kerf	Predicted Kerf	Deviation
1.	7.824	5.292	-2.532	0.337	0.33473	-0.00227
2.	9.168	9	-0.168	0.324	0.33577	0.01177
3.	11.616	12.708	1.092	0.335	0.33681	0.00181
4.	14.496	16.416	1.92	0.321	0.33785	0.01685
5.	20.928	20.124	-0.804	0.342	0.33889	-0.00311
6.	12.096	8.072	-4.024	0.320	0.32511	0.00511
7.	13.488	11.78	-1.708	0.333	0.32615	-0.00685
8.	17.088	16.608	-0.48	0.334	0.33509	0.00109
9.	25.008	27.816	2.808	0.356	0.34673	-0.00927
10.	31.824	33.764	1.94	0.367	0.34357	-0.02343
11.	15.888	11.972	-3.916	0.329	0.32339	-0.00561
12.	19.968	23.18	3.212	0.334	0.33503	0.00103

13.	24.968	26.888	1.92	0.342	0.33607	-0.00593
14.	32.688	32.836	0.148	0.327	0.33291	0.00591
15.	31.248	37.664	6.416	0.333	0.34185	0.00885
16.	20.688	22.252	1.564	0.328	0.32437	-0.00363
17.	25.104	27.08	1.976	0.345	0.33331	-0.01169
18.	29.568	33.028	3.46	0.332	0.33015	-0.00185
19.	38.976	36.736	-2.24	0.337	0.33119	-0.00581
20.	54.576	47.944	-6.632	0.332	0.34283	0.01083
21.	25.008	26.152	1.144	0.313	0.32265	0.00965
22.	28.944	32.1	3.156	0.323	0.31949	-0.00351
23.	39.888	43.308	3.42	0.331	0.33113	0.00013
24.	51.504	48.136	-3.368	0.327	0.34007	0.01307
25.	56.448	51.844	-4.604	0.346	0.34111	-0.00489

The above Table 8. is show the experimental and predicted values of the material removal rate and kerf values. Using these results the comparision graphs are ploted for the MRR and kerf.

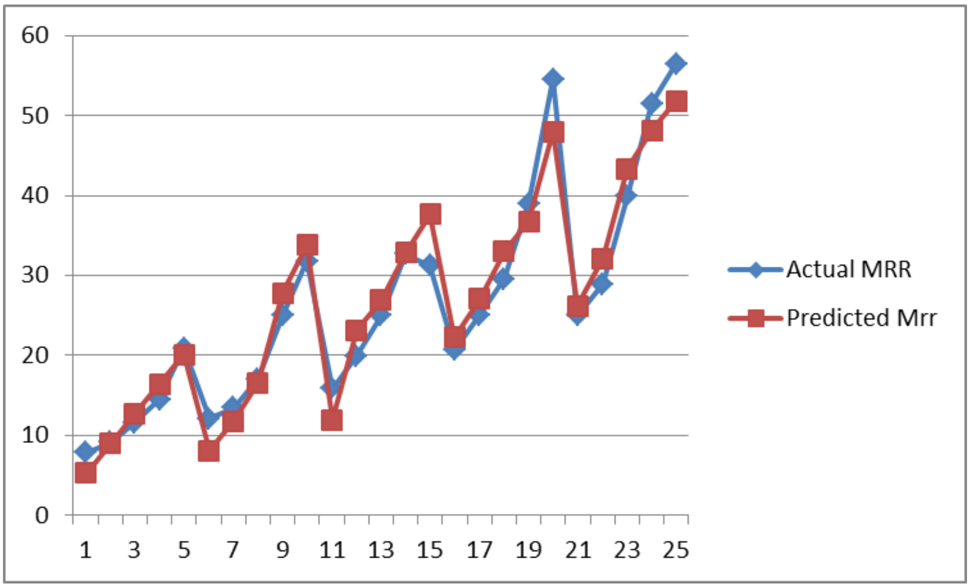

Fig. 5. Comparison graph between predicted and experimental values of MRR.

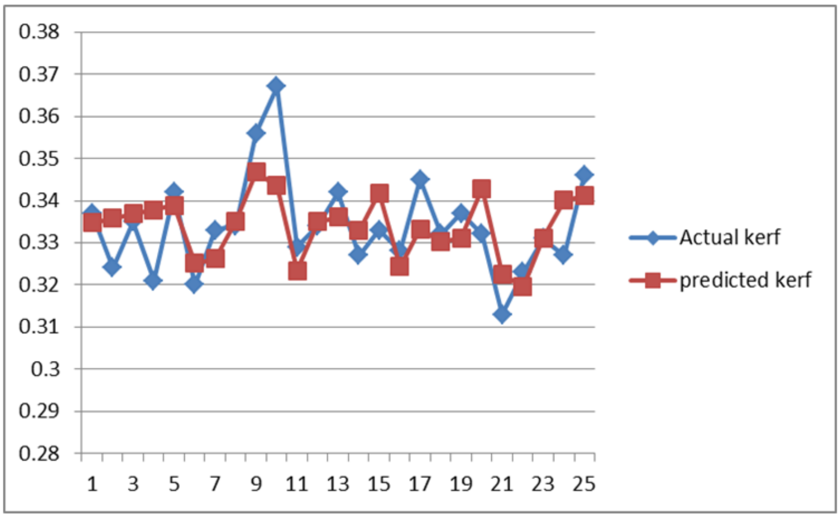

Fig. 6. Comparison graph between predicted and experimental values of Kerf.

IV. Conclusions

The experimental results show the maximum MRR at pulse on 14 µs, pulse off 34µs, wire tension 8 Kg-f, wire feed 7mm/min, dielectric fluid pressure 7kg/cm^2. The experimental results show the minimum kerf at pulse on 14 µs, pulse off 18µs, wire tension 6 Kg-f, wire feed 8mm/min, dielectric fluid pressure 6kg/cm^2. The mathematical model is developed for the MRR and kerf. Using these equations the deviation is calculated for MRR and kerf. From the graphs it is observed that the experimental and predicted values the deviation percentage is less.

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