Experimental Studies on Effect of Wire Related Parameters in Wire Electrical Discharge Machining

S.R.Dhale[1], M. L. Kulkarni[2]
[1] Research scholar, Walchand Institute of Technology, Ashok Chowk , Solapur- 413 006
[2] Professor, JSPM Narhe Technical Campus, Pune- 411041

ABSTRACT

Wire electric discharge machining (WEDM) is marching towards proprietorship in non-traditional machining process for difficult-to-cut materials. Over the years since its inception lot of research work is done to improve its material removal rate, at better surface finish. More emphasis was on electrical parameters. Non electrical parameters related to wire are very crucial but unheeded in research. In this paper experimental studies are presented to focus on the effect of wire related parameters. The parameters like wire tension, wire feed, wire material, are varied individually and in combination with other parameters to study the effect on performance measures like surface finish, kerf width, MRR etc.

Keywords: **WEDM, MRR, SF, kerf width.**

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1. Introduction

Most of the research in wire EDM is attributed to only improving the Material Removal Rate (MRR) at high surface finish. MRR is a function of high pulse on time, high peak current and other energy parameters, however the high surface finish is a function acting reverse on MRR. If you compromise MRR you will get higher SF and if high MRR is desired you may end with low SF. It is obvious that achieving a high material removal rate and fine surface quality can never be achieved collectively in the WEDM process. Working of WEDM is governed by electrical, mechanical and, hydraulic systems. The MRR mechanism in WEDM is widely accepted as per Thermo-Electric theory so major contribution in MRR is of electrical parameters, however in this paper an attempt is made to highlight the other aspect which is closely related with the electrical parameters. The electrode wire is the only external element that is added in to the system, so it's all behavior during cutting is very important to decide the desired performance of WEDM. Wire electrodes thermal, mechanical,

chemical, and electrical, properties play an important role in performance of WEDM. The wire tension has the greatest effect on three dimensional accuracy characteristics. It is one of the most dominant factors that affect wire bending, vibration and the wire tightness in WEDM. Proper wire tension increases machining accuracy, wire lifetime, and reduces machine downtimes. Low wire tension causes wire vibration and wire slackness. However if the applied tension exceeds the tensile strength of the wire, it leads to wire breakage and hence machine breakdown. During WEDM cutting the wire is continuously advanced between the spools to present a constant diameter wire to the job. The high wire feed subjects the wire to low discharge energy per unit time due to less time spent in workpiece part. Higher wire feed means more sparks, greater energy per unit time more cutting speed. But very high wire feed will cause insignificant wire vibration and instability. Low wire feed means more time spent in workpiece part, reduces the wire diameter and has effects on the wire wear ratio. Also in the low wire feed, the wire wear ratio significantly increase which can cause wire breakage especially in rough machining. Coated wires were developed in an attempt to put more zinc on the surface of the wire while retaining a core wire material that could be successfully drawn. It combines the conductivity of a brass core with the flush ability of zinc. This consists of a thin around 5 microns zinc coating over a core. Increased percentage of zinc in the wire electrode increases the cutting rate due to low vaporization temperature of zinc and its assistance in quick ionization. However if zinc percentage increases beyond 40 %, it becomes more brittle and hence it should be controlled.

2. Relevant literature review

Kinoshita et al[1], in a first ever attempt, has explored the mechanical behavior of wire over wide range of machining conditions. The effect of wire feed rate, feed direction was explored. It was revealed that for cutting accurate profile it is important to estimate the width of groove which depends upon the behaviour of electrode wire. Jennes[2], proposed a method to model the thermal load on EDM- wire electrode. The occurrence of wire rupture is the main constraints in WEDM in today's era also. Thermal aspect seems to govern the rupture phenomenon. It was found that relatively large variation of temperature along the wire axis, and time and space concentration of discharges can cause wire rupture. After conducting a number of experiments it was confirmed that wire EDM imprecision is influenced by physio-mechanical interactions during EDM machining. The EDM wire behaves like a vibrating string. [3].

Dauw[4], compared several types of wire from their metallurgical aspect. Their physical composition and relative performance was analysed. Wire properties such as electrical, geometrical, mechanical and physical are studied. And it was revealed that wire tool influence substantially cutting speed. Prohaszka[5] specifically considered the effect of wire material on machinability. Negative polarity rods of pure magnesium, tin and zinc of 5.00 mm were used as the tool electrode. It was revealed that machinability of WEDM is considerably increased by proper combination of mechanical, physical and geometrical properties of wire electrode. The coating of wire considerably increases the cutting efficiency of WEDM. Tosun., et al[6], studied the effect of cutting parameters on the size of erosion craters diameter and depth on wire electrode. Investigation of wire electrode craters is crucial for understanding of wire rupture. Larger sizes of craters on the wire increase the risk of wire rupture and also result in poor workpiece surface quality and machining accuracy. It was found that increasing wire speed increases the depth and diameter of the wire crater.

Han et al[7], constructed the wire temperature measurement system. The system developed was used to measure and record the changing history of wire resistance when the wire is heated by the discharging energy. The temperature increment of the wire rises considerably when the wire is hidden inside the kerf. It is effective to prevent the wire from overheat by flushing the coolant toward the wire. The convective heat transfer coefficient which is an important parameter for heat transfer analysis of WEDM is experimentally determined.

3.Plan of Experiments

Four experiments are conducted to understand the effect of wire related parameters under different combinations of parameters, different machines, and different work piece materials. The first experiment was conducted based on one factor at a time experimental strategy to understand the individual effect of wire feed and wire tension if at all present on the response variables like material removal rate and surface finish. The experiment was performed on Electronica Sprint cut model with HcHcr, as workpiece material. The second experiment was performed to know the interaction effect of pulse on and pulse off with variation in wire feed. In the third experimental run wire feed and wire material was taken as process parameters and response parameters were M.R.R. The second and third experiment was performed on Eco cut WEDM with tool steel (D2) as workpiece material. In last fourth experiment run seven parameters were taken to understand the effect of interaction of process parameters in the performance of wire EDM. This experiment was performed on Ultra cut WEDM with Inconel-718 as workpiece material.

3.1 Experiment 1: Effect of Coatings

The experiment was performed on an ELECTRONICA SPRINTCUT Wire EDM machine. The experiments are based on one factor at a time experiment strategy. One input parameter was varied while keeping all other input parameters at constant level. And the effect of parameters was studied on the performance measures that are Material removal rate, surface finish, and kerf width.

Electrode and Work piece Materials:

Work piece material used was 30x30 mm square block of HcHCr(D2] tool steel. And the electrodes used are Brass and Zinc coated wires of 250 micron diameter. The approximate values of their properties received from recognized lab are as tabulated in the Table.1

TABLE 1
WIRE ELECTRODE MATERIAL PROPERTIES

Wire Name	Plain Brass	Zinc Coated
Material	Brass	Zinc coated Brass
Diameter	0.25 mm	0.25 mm
Tensile strength	500 N/mm^2	500 N/mm^2

Composition	Cu 59.88 % Zn 40.03 %	Cu 59.92 % Zn 39.96 %

3.2 RESULTS AND ANALYSIS:

In the first phase of experiment wire tension is varied from 2 to 14, in machine units, with coated and brass wire separately and the performance measures were measured. While wire tension is varied all other parameters wire feed (6), peak current (230), Servo voltage (20) and pulse on (114), pulse off (46), dielectric flow rate (1), are kept constant. The experimental results are plotted in the graph using Microsoft office excels. Figure1. shows the variation of M.R.R, kerf width, and surface finish with increment in wire tension respectively**.**

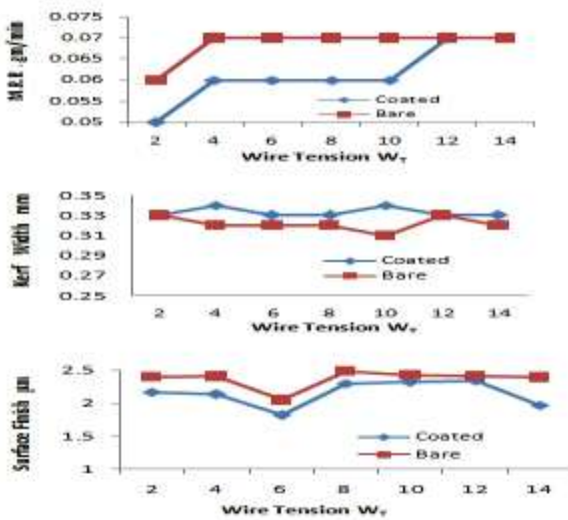

Figure 1. Wire tension V/s performance measures.

In the Second phase of experiment wire feed is varied from 2 to 14, in machine units, with coated and brass wire separately and the performance measures were measured.

While wire feed is varied all other parameters wire Tension(6), peak current(230), Servo voltage(20) and pulse on(114), pulse off(46), dielectric flow rate(1), are kept constant. The experimental results are plotted in the graph. Figure2. Shows the variation of M.R.R, kerf width, and surface finish with increment in wire feed respectively. The effect on performance measures can be discussed as

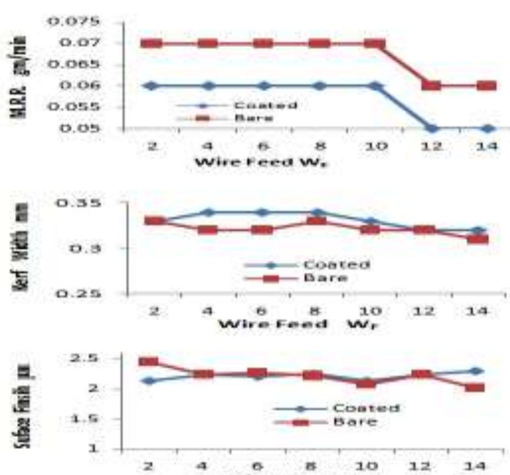

Figure 2. Wire Feed V/s performance measures.

M.R.R : M.R.R. for brass wire is more than the M.R.R. for Coated wire for the variation of wire tension and wire feed. M.R.R. remains constant with changes in wire tension and feed, indicating that there is negligible effect of wire tension and feed on material removal rate. But there is considerable effect of material of wire.

Kerf Width : kerf width is is less for bare wire than the coated wire for both the cases of wire tension and wire feed variation. Kerf width remains fluctuating within the permissible range.

Surface Finish: surface finish is much better in case of coated wire than bare wire. There is no considerable variation with respect to changes in wire tension and feed, but like M.R.R., also there is considerable influence of wire material in surface finish. This may be due to the effect of added flush ability of the zinc present in the coating of the zinc coated wire.

So from the above experimental results it is clear that there is a considerable effect of wire material parameter. Next four set of experiments were performed as per Taguchi, and analysis was carried out using ANOVA and signal to noise ratios.

Design of Experiments based on Taguchi method.

Taguchi method is a methodical and efficient approach to find the optimal combination of input parameters to reduce the number of experiments in any process[10]. The interactions among the input parameters have not been considered for choosing number of orthogonal array in the present study. The second experiment and fourth experiment is performed with Taguchi L18, mixed array as with mixed array we can keep the desired levels of any one parameter. Wire material can have only two levels as coated and brass and hence we must use Taguchi L18 mixed orthogonal array. The third experiment was performed with L16, mixed orthogonal array where we can have eight levels of wire feed and two levels of wire material.

4 Experiment 2: Wire feed, Ton, Toff

The Electronica Eco Cut machine was used for these experiments. The workpiece was D2 tool steel. Taguchi L18 mixed level orthogonal array is followed to know the effect of pulse on (Ton], and pulse off (Toff], in combination with wire related parameter wire feed. The peak current was 230 and Spark gap voltage at 20. The parameters levels are shown in Table.2.

TABLE 2
PARAMETER LEVLES FOR L18 DESIGN

Parameter	Unit	Level					
		L1	L2	L3	L4	L5	L6
Wire Feed	m/ min	1	2	3	4	5	6
Pulse On	µs	L1 = 4		L2=6		L3=8	
Pulse Off	µs	L1= 7		L3=5		L4=3	

4.1 Result and analysis:

The performance measures were statistically analyzed using analysis of variance. As per ANOVA for kerf width, it is observed that with this process parameter configuration, wire feed is the most significant process parameter with F-value of 17.20, and P-Val of 0.00<0.05.

TABLE 3
ANOVA FOR KERF WIDTH

Control Factors	DF	Adj SS	Adj MS	F-Val	P-Val
Wire Feed	5	0.035780	0.007156	17.20	0.000
Pulse on	2	0.00441	0.002208	5.31	0.03

		6			4
Pulse off	2	0.002998	0.001499	3.60	0.077
Error	8	0.003329	0.000416		
Total	17	0.046523			
S	R-sq	R-sq(adj)	R-sq(pred)		
0.0203985	92.84 %	84.80 %	63.78 %		

5 Experiment set 3: Wire Feed and Wire Material

Taguchi L16 mixed level orthogonal array is used to know the most influencing process parameter out of two wire related parameters i.e wire feed and wire material. The parameter setting of different parameters is as shown in the Table 4.

TABLE 4
PARAMETER SETTING FOR L16 DESIGN

Parameter	unit	Level							
		L1	L2	L3	L4	L5	L6	L7	L8
Wire Feed	m/min	1	2	3	4	5	6	7	8
Wire material		L1 = Brass				L2=Zinc coated			

And out of wire material and wire feed with L16, orthogonal array Wire material is the most significant parameter[11] having F-value of 203.06, for material removal rate. Also the model is statistically significant ad P-value is <0.05 for wire material

TABLE 5
ANOVA FOR M.R.R

Control Factors	DF	Adj SS	Adj MS	F-Val	P-Val
Wire Feed	7	0.004010	0.000573	3.78	0.050
Wire Material	1	0.030800	0.030800	203.06	0.000
Error	7	0.001062	0.000152		
Total	15	0.035872			
S	R-sq	R-sq (Adj)	R-Sq (Pred)		
0.0123158	97.04 %	93.66 %	84.54 %		

From the above two sets of experiments again it is clear that there is considerable effect of coating, and wire feed so in next experiment all the parameters are varied to know the rank of wire related parameters considering interaction effects of other process parameters.

6 Experiment 4: Rank of coatings effect

These experiments are performed on Electronica ultra cut machine. The workpiece material used here is hard material known that is superalloy Inconel-718. Current employed in the complete machining process has to be kept constant, also we can't change the dielectric fluid used. The commonly used dielectric fluid is deionised water; Servo voltage is also maintained at constant level

TABLE 6

PROCESS PARAMETER LEVELS L18 OA

Parameters	levels	Values		
Wire Material	2	Brass	Zinc coated	
Pulse on	3	110	112	115
Pulse off	3	49	50	51
wire feed	3	3	4	5
wire tension	3	2	3	4
flushing pressure	3	4	5	6

6.1 Result and analysis

ANOVA: The experimental results are collected for Material removal rate (M.R.R.), kerf width and for surface finish respectively.

TABLE 7

ANOVA FOR M.R.R

Control Factors	DF	Adj SS	Adj MS	F-Val	P-Val
Wire Material	1	0.029	0.029	2.4	0.172
Pulse On	2	0.84527	0.42264	34.98	0.000
Pulse Off	2	0.00856	0.00428	0.35	0.716
Wire Feed	2	0.00852	0.00426	0.35	0.716
Wire Tension	2	0.0263	0.01315	1.09	0.395
Flushing Pressure	2	0.03627	0.01813	1.50	0.296
Error	6	0.0725	0.012083		
Total	17	1.02642			
S	R-sq		R-sq(adj)	R-sq(pred)	
0.109925	92.94 %		79.99%	36.43 %	

TABLE 8

ANOVA FOR SURFACE FINISH

Control Factors	DF	Adj SS	Adj MS	F- Val	P-Val
Wire Material	1	0.002450	0.002450	23.21	0.003
Pulse On	2	0.287433	0.143717	1361.53	0.000
Pulse Off	2	0.000933	0.000467	4.42	0.066
Wire Feed	2	0.000133	0.000067	0.63	0.564
Wire Tension	2	0.000033	0.000017	0.16	0.857
Flushing Pressure	2	0.000033	0.000017	0.16	0.857
Error	6	0.000633	0.000106		
Total	17	0.291650			
S	R-sq		R-sq(adj)	R-sq(pred)	
0.010274	99.78 %		99.98 %	98.05 %	

As per ANOVA for M.R.R., surface finish and kerf width it is observed that with this process parameter configuration, Pulse On is the most significant process parameter with F-value of 34.98, 1361.53, and219.00, respectively

However it is important to note that out of other all parameters wire material is next significant parameter with F-value of 2.4, 23.21, and 7.26 respectively indicating the effect of coating.

S.N Ratios: The results of SN ratios are graphically represented with main effects plot for material removal rate, kerf width and surface finish. It shows that with zinc coated wire MRR is considerably increased. Also with the increase pulse on and pulse off there is increase in MRR. However for wire feed and wire tension there is no considerable change in the material removal rate. Flushing pressure is considered here as one of the process parameter showed increase in MRR with increase in its value from 4 to 6.

However from the main effects plot for kerf width figure 4, it is found that, kerf width is lower with brass wire than coated wire, and also lower with flushing pressure. However it increases with pulse on time and wire feed and wire tension are not significant in controlling the kerf width

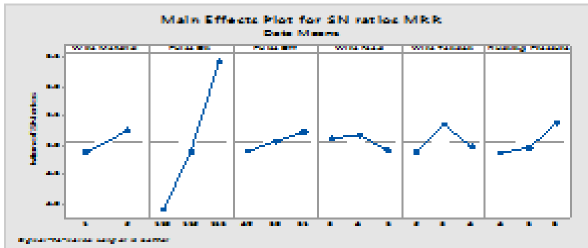

Fig. 3 Main Effect Plot for S/N for M.R.R.

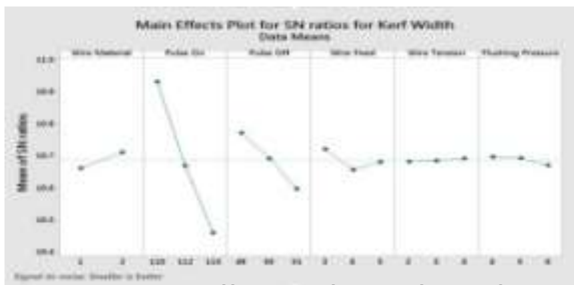

Fig. 4 Main Effect Plot for S/N for kerf width

From the main effects plot for surface finish figure 5, it is found that, surface finish is lower with brass wire than coated wire, and also lower with flushing pressure. However it increases with pulse on time and wire feed and wire tension are not significant in controlling the surface finish.

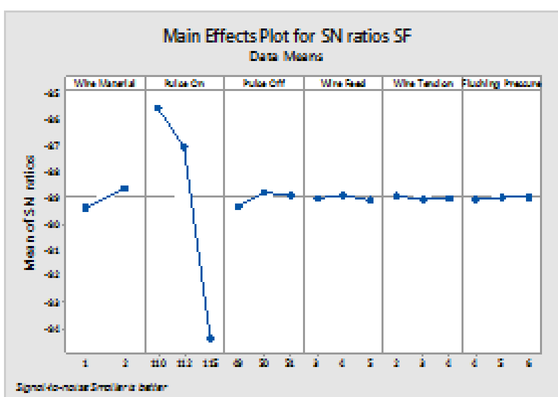

Fig. 5 Main Effect Plot for S/N for Surface finish

7.DISCUSSION:

In the first experiment instead of coated wire brass wire giving more M.R.R. this can be due to the constant Pulse on and other energy parameters. In the preceding experiments M.R.R. and Surface finish was better with coated wire as the electrode coating plays significant role in MRR and surface finish. The zinc coated wire sustains high discharge energy and improves flushability due to low melting and evaporation temperature of zinc layer the conductivity in the melting zone increases. Additionally, the vaporization of zinc coating helps to maintain lower temperature of wire core, which permits use of more intensive pulse power and results in increased cutting speed.

Due the effect of zinc coating surface finish is considerably increased. The zinc-coated brass wire can produce smoother surface in comparison with brass[12]. The uniform zinc layer on coated wire provides good discharge characteristics. A finer discharge can be created with good discharge characteristics and higher tensile strength. As a result, the quality of work piece surface is improved. Higher flushability leads to higher material removal, the zinc coated brass wire electrode has provided higher kerf width than the brass wire electrode in first, second and fourth experiment.

8.CONCLUSIONS

In this study, the influence of zinc-coated brass wire on the performance of WEDM is compared with brass. under different machining conditions. Based on the experimental results and analysis, the following conclusions are put forth.

1. Experiments result confirms influence of wire material, brass and zinc coated brass.
2. Pulse on time and wire material is the most significant parameters affecting material removal rate.
3. Compared with brass wire, zinc-coated brass wire results in higher material removal rate.

Zinc coated brass wire give better surface finish as compared to brass wire.

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