International Journal of Fluid Mechanics & Machinery– IJFMM
Volume 1 : Issue 2 [ISSN 2374-1481]
Publication Date : 25 June 2014

The Effect of Deep and Shallow Cryogenic Treated Wire Electrodes on the Performance Characteristics of WEDM

[Jatinder Kapoor[1] Sehijpal Singh[2]]

Abstract—***This paper describe the effect of deep and shallow cryogenic treated brass wire electrodes on the material removal rate (MRR) and the surface roughness (SR) of an EN-31 steel machined by WEDM. Full factorial experimental design strategy is used in the experimentation. Three process parameters, namely type of wire electrode (untreated, deep and shallow cryogenic treated brass wire electrodes), Pulse width, and Wire tension have been considered. Analysis of variance (ANOVA) results indicated that all the process parameters have significant effect on MRR and SR. Scanning electron microscopy (SEM) and Electron dispersive spectrograph (EDS) highlighted the important features of WEDMed surfaces with cryogenically treated and untreated brass wire electrode. MRR is enhanced and SR is improved with cryogenically treated wire electrodes.***

Keywords— ***WEDM, Brass wire, Cryogenic treated wire, Surface roughness***

I. INTRODUCTION

The wire electrical discharge machining (WEDM) process plays a significant role in certain manufacturing sectors; since it has the capability to cut complex and intricate shapes with superior surface finish and accuracy. High strength and low ductility conductive materials can easily be machined with high accuracy [1]. In this process, a continuously moving wire electrode made of metallic wire connected to a pulse generator, so as to generate an electrical discharge between a wire electrode and an electrically conductive work piece. The gap between travelling wire electrode and workpiece must always be filled with a dielectric fluid, which acts as cooling agent and promotes flushining of debris removed by discharge in an active machining area. Surface generated by includes many defects such as craters due to electrical sparks, alloying of tool electrode material on work piece surface. The surface characteristics of work piece machined by WEDM plays a vital role in determining the quality of the material. The quality of surfaces generated by various machining methods and machining parameters can be studied by scanning electron microscope (SEM) photographs.

1. Dr. Jatinder Kapoor
Associate professor,
Department of Mechanical Engineering, G.N.D.Engg. College, Ludhiana, India

2. Dr. Sehijpal Singh
Professor and Head,
Department of Mechanical Engineering, G.N.D.Engg. College, Ludhiana, India

Energy dispersive spectroscopy (EDS) revealed that some amount of the wire electrode material from WEDM gets deposited onto the workpiece surface. A mathematical model was constructed to predict the material removal rate and surface finish, when machining D2 tool steel material at different machining conditions [2]. The effect of various process parameters was analyzed and it was concluded that open circuit voltage and pulse duration are most effective parameters for surface roughness [3]. It was also investigated that when pulse energy per discharge is constant, short pulses and long pulses will produce the same surface roughness but different material removal rates[4]. It was also indicated that short pulse duration together with high peak value can improve surface roughness. Also reverse polarity has significant effect on surface roughness. Tosun et al., [5] further investigated that increasing the pulse duration, open circuit voltage, and wire speed increases the crater diameter and crater depth, whereas increasing the dielectric fluid pressure decreases these factors. It was concluded) that material removal rate and surface finish are influenced by feed and pulse rate [6]. Investigations into machining input parameters on the characteristics of surface produced by WEDM have been reported by Williams and Rajurkar [7]. Tarng et al. [8] used neural network system to find out optimal settings of process parameters (pulse duration, pulse interval, peak current and servo reference mean voltage) for the evaluation of surface finish and cutting speed. Greater discharge energy would produce large craters on the workpiece surface and hence more surface roughness [9]. It has been reported that shallow crater together with large diameters enhances the surface finish, so it is important to control electrical discharge energy at lower level by selecting shorter pulse[10]. High performance coated brass wire electrodes improves the cutting speed and surface finish significantly [11]. But these wires are not only costlier but also cause many impurities in dielectric fluid and other problems such as environmental hazards [12]. Cryogenic processing is the process of cooling the materials to temperature far below the room temperature. For many years, cryogenic processing has been acknowledged as a means of improving the surface hardness and thermal stability of the metals [13]. Cryogenic treatment affects the entire cross-section of the non ferrous materials also [14]. The literature survey indicates that most of the research has been directed towards material removal and surface characterization of WEDMed workpieces with plain brass or coated wire electrodes. Few attempts (Aoyama et al [15], kuroda et al. [16] have been made to study the performance of WEDM with high performance wire electrodes as these electrodes have high thermal and electrical conductivities as compared to plain brass wire electrodes. Machining speed of wire-EDM is related with conductivity of wire electrodes and cryogenic treatment enhances this property. The aim of this study is to investigate the effects of cryogenic treated brass wire electrode on material removal rate and surface roughness of the workpiece.

II. EXPERIMENTAL

A. Materials and Methods

Workpiece used in this study was EN31 steel plate. The properties of work piece are depicted in Table1. A Robofil-290 CNC wire-EDM machine was used in this study. Three brass wire spools (one untreated and two cryogenic treated) were taken for experimentation. The properties of brass wire electrodes are mentioned in the Table 2.

Table 1 Properties of work piece material

Material	Chemical composition	Hardness (HRC)	Thickness mm
En-31	C-1.0% Si-0.31 % Mn-0.50 % P- 0.31 % S-0.042 % Cr-1.40%	58	11

Table 2 Properties of brass wire electrode

Material	Hardness (VHN)	Tensile strength	Conductivity (%IACS*)
Untreated brass wire	255	905N/mm^2	21%
Shallow cryogenic (-110°C) treated brass wire spool	220	850 N/mm^2	27.6%
Deep cryogenic(-180°C) treated brass wire spool	217	841N/mm^2	29.3%

* International annealed copper standard

B. Experimental Details

The primary aim of this experimentation was to study the effect of cryogenically treated brass wire electrodes on the performance characteristics, namely material removal rate (MRR), surface roughness (SR). Full factorial experimental design strategy was used in this experimentation. Three process parameters, namely Type of wire, Pulse width and Wire tension have been considered for experimentation, keeping remaining machining parameters constant. These machining conditions were chosen based on the preliminary experimentation. Three levels for each process parameters were selected for the full factorial experiment. Each machining condition has three replicates. Replications compute the variability of measurements within each unique combination of factors and also it allows estimating pure error in the experiments. An estimate of the pure error can be used to evaluate the size and statistical significance of the variability. The range and level of process parameters are shown in Table 3. The range of these parameters is selected on the basis of preliminary experiments. The experiments were conducted at different settings of control variables as specified in Table 4.

Table 3 Control and fixed parameters

Control Parameters	Levels		
	L 1	L2	L3
Type of wire	Untreated brass wire	Cryogenic treatment (-110^{0}C) brass wire	Cryogenic treatment (-184^{0}C) brass wire
Pulse width(µs)	0.4	0.8	1.2
Wire tension (daN)	0.6	1.3	2.0

Table 4 Full factorial experimental design

Exp. No. (Std. Order)	Run Order	Control parameters			Performance characteristics	
		A	B	C	MRR (mm^3/min)	SR (µm)
1	12	1	1	1	15.00	1.75
2	15	1	1	2	16.20	1.48
3	10	1	1	3	15.50	1.85
4	2	1	2	1	22.75	2.35
5	13	1	2	2	25.00	2.45
6	22	1	2	3	20.25	2.4
7	11	1	3	1	41.00	2.67
8	25	1	3	2	42.00	2.9
9	9	1	3	3	46.10	2.85
10	1	2	1	1	16.00	1.55
11	26	2	1	2	19.00	1.35
12	21	2	1	3	18.90	1.75
13	14	2	2	1	24.50	1.95
14	4	2	2	2	28.00	2.15
15	8	2	2	3	24.00	2.25
16	18	2	3	1	45.00	2.25
17	19	2	3	2	45.70	2.9
18	27	2	3	3	52.90	3.05
19	24	3	1	1	17.11	1.45
20	5	3	1	2	21.40	1.25
21	23	3	1	3	18.00	1.55
22	20	3	2	1	25.70	1.8
23	7	3	2	2	29.00	2.35
24	3	3	2	3	25.30	2.05
25	16	3	3	1	46.90	2.34
26	6	3	3	2	47.80	2.92
27	17	3	3	3	53.60	2.86

The material removal rate (MRR) is evaluate as,

$$MRR= K. T. V$$

Where K is the kerf width, T is the workpiece thickness and V is the cutting speed. The surface roughness (SR) values were measured with Surf Tester (SJ 201). Mean values of performance characteristics (MRR and SR) are given in Table 4.

III. ANALYSIS AND DISCUSSION OF EXPERIMENTAL RESULTS

In full factorial experiments, all the possible combinations of the variables are utilized to carry out the experiments. The total number of experiments is the product of the number of variables and their levels. In this randomized block design technique, the treatment amalgamations are randomly assigned to the experimental units by unraveling them into different blocks. The precision of experiments is improved by minimizing the variation between blocks.

A. ANOVA for MRR

Analysis of variance (ANOVA) was performed to determine the factors affecting the performance characteristics. The ANOVA result of MRR data is given in Table 5. The p- value tests the statistical significance of each of all the factors. The factors; Type of wire (A), Pulse width(B) and Wire tension(C) have significant effect on MRR at the 95% confidence interval. It can be observed from Figure 1 that more MRR is removed from deep and shallow cryogenic treated wire electrodes. This could be attributed to the fact that high conductive wires give more energy to the process as additional conductivity promotes more electron emission.

Table 5 ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	100.40	100.40	50.20	104.42	0.000
B	2	4177.47	4177.47	2088.73	4344.83	0.000
C	2	30.73	30.73	15.37	31.96	0.000
A*B	4	8.98	8.98	2.24	4.67	0.031
A*C	4	5.29	5.29	1.32	2.75	0.104
B*C	4	85.25	85.25	21.31	44.33	0.000
Error	8	3.85	3.85	0.48		
Total	26	4411.96				

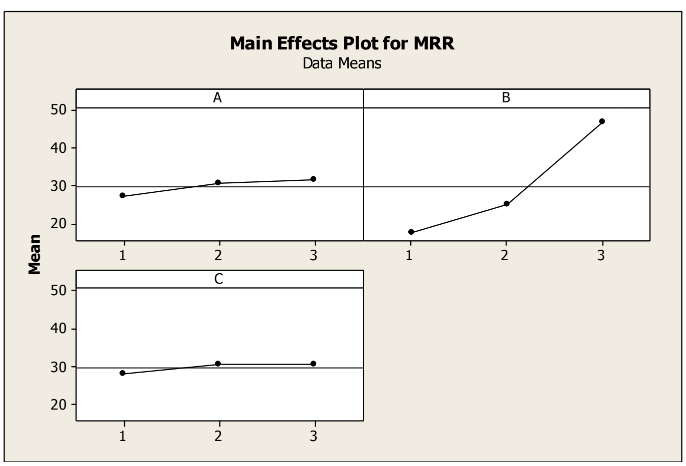

Fig. 1 Main effects plot for MRR

B. Analysis of varance(ANOVA) for SR

The analysis of varaiance has been performed in order to discern the contribution of signifiacnt parameters towards response (SR). The ANOVA for SR data is shown in Table 6.

Table 6 ANOVA for SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	0.26607	0.26607	0.13303	16.58	0.001
B	2	6.44336	6.44336	3.22168	401.59	0.000
C	2	0.35849	0.35849	0.17924	22.34	0.001
A*B	4	0.05878	0.05878	0.01469	1.83	0.216
A*C	4	0.12438	0.12438	0.03109	3.88	0.049
B*C	4	0.45062	0.45062	0.11266	14.04	0.001
Error	8	0.06418	0.06418	0.00802		
Total	26	7.76587				

The ANOVA Table 6 indicates that Type of wire (A), Pulse width (B) and Wire tension(C) are the significant factors, which control the surface characteristics of work piece. Statistical analysis reveals the interaction between type of wire (A) and wire tension(C), Pulse width (B) and Wire tension(C). From Figure 2, it is clear that surface roughness increases with increase in pulse width and wire tension whereas, both shallow and deep cryogenic treated wire exhibit improved surface finish due to uniform craters.

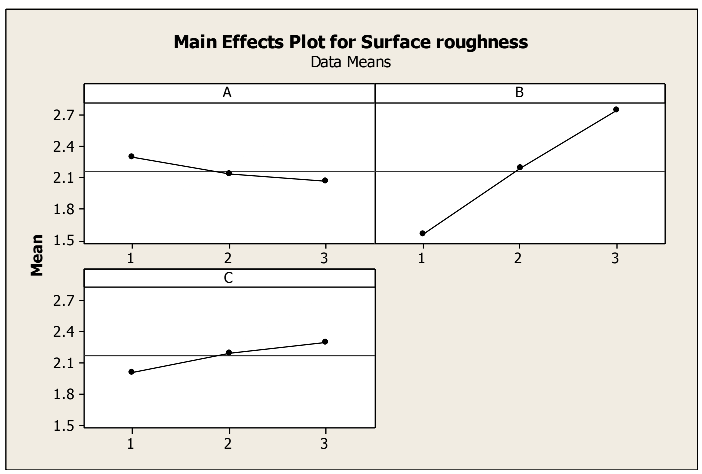

Fig. 2 Main effects plot for SR

C. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS)

The work pieces were observed with SEM (JOEL, JSM-6610lv, detector-Everhart Thornley). The scanning electron gun operated with accelerating voltage of 0.3-30kv with a pre-centered tungsten hairpin filament. The effect of untreated, shallow and deep cryogenically treated wire on SR is evident from the SEM photographs shown in Figures 3, 4 and 5 respectively. These photographs were taken at pulse width of

International Journal of Fluid Mechanics & Machinery– IJFMM
Volume 1 : Issue 2 [ISSN 2374-1481]
Publication Date : 25 June 2014

0.4µs and wire tension of 0.6daN. Figure 3 shows the work piece surface machined by untreated wire. The machined surface exhibits non-uniform craters. The craters are uneven, distinct and deep.

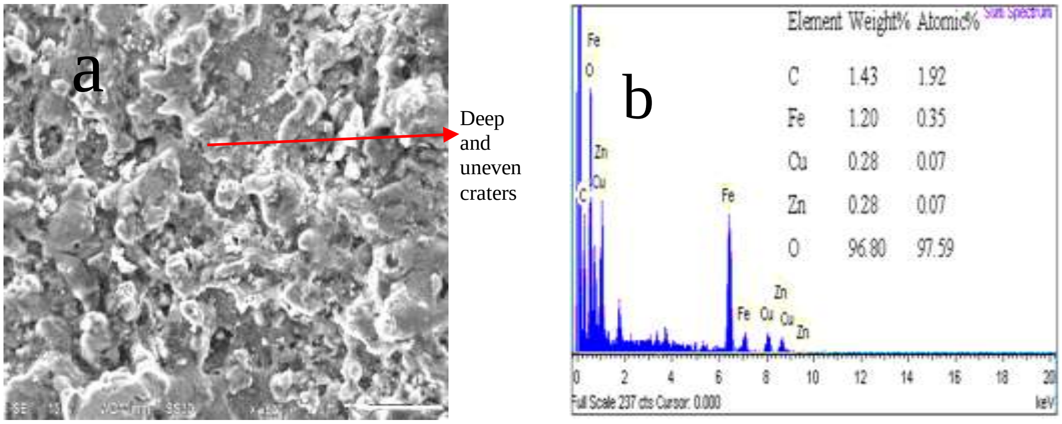

Fig. 3 SEM (X 500) (a) and EDS (b) Photograph of Workpiece Surface Machined by Untreated Wire (Pulse Width- 0.4 µs and Wire Tension -0.6daN)

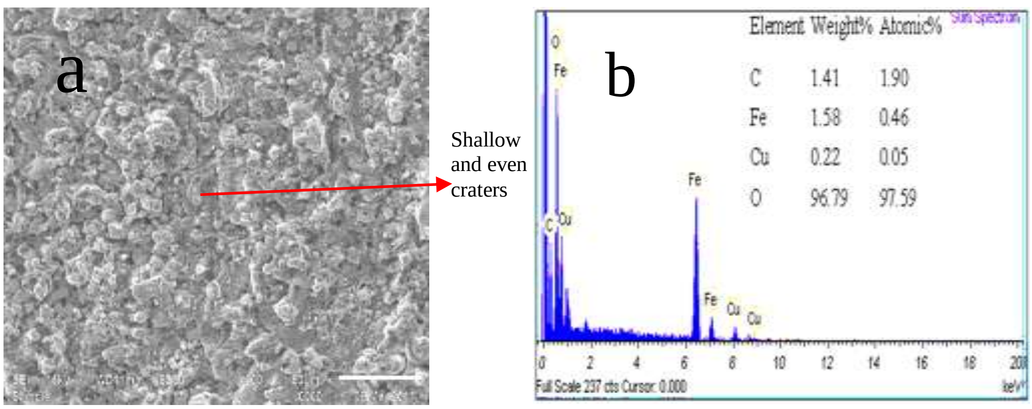

Fig. 4 (a) SEM (X 500) and(b) EDS Photograph of Workpiece Surface Machined by Shallow Cryogenic Treated Wire (Pulse Width- 0.4 µs and Wire Tension -0.6daN)

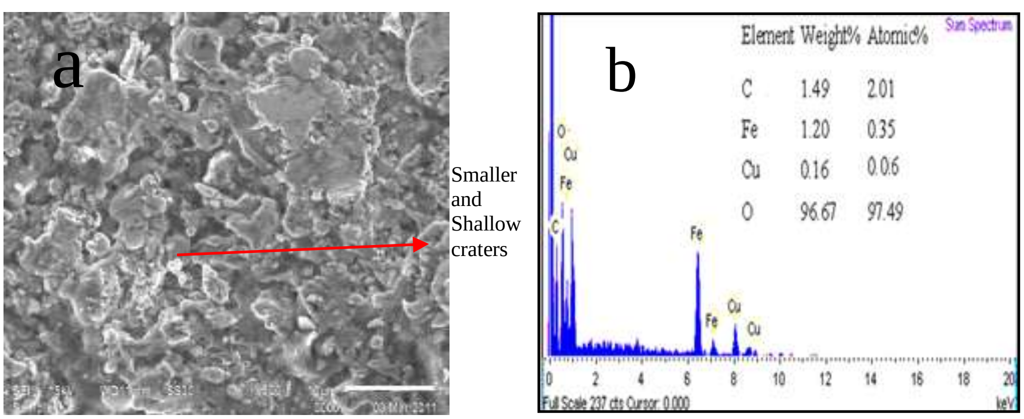

Fig. 5 (a) SEM (X 500) and(b) EDS Photograph of Workpiece Surface Machined by Deep Cryogenic Treated Wire (Pulse Width- 0.4 µs and Wire Tension- 0.6daN)

The Figures 4 and 5 clearly exhibits that craters are even, shallow and well defined overlapped. The explanation for the possible reason for improvement in SR is explained as follows:

The machining with more conductive cryogenic treated wire electrodes makes the discharge passage enlarged and widened. The generated debris from the spark gap is easily evacuated. The discharge is uniformly distributed in the discharge channel in the gap, which results into reduction in the relative difference in electric field between micro-peaks. The smaller and shallow craters are produced due to discharge of micro- current at each potential discharge point. The surface quality of WEDM is associated with the material removal per discharge, which is determined by the pulse energy per discharge. The value of surface roughness increases as the pulse width increases. The increased pulse width results into longer discharge time, which leads to higher discharge energy. The machined surface gets deteriorated owing to increased diameter and larger depth of craters. Increase in wire tension causes slight increase in surface roughness but further increase causes improvement in surface roughness due to decrease in cut width.

Energy dispersive spectroscopy (EDS) was used to identify the elements on the machined surface. EDS analysis (Fig. 3b) reveals that some amount of wire material elements (Cu and Zn) gets deposited on the workpiece surface. The transfer of Cu and Zn elements occurs during sparking, which were deposited on the machined workpiece surface in addition to C and Fe. Shock impulses cause the welding of the detached elements on the worpiece. Figure 4b and 5b reveals that Zn is eliminated, where as Cu remains present on the machined surface. The possible reason may be owing to more discharge energy by cryogenically treated wire. The electrode boils off the Zn, which is flushed with dielectric fluid during machining. There was clearly less Cu accreting on the surface machined by shallow and deep cryogenically treated wire electrode. The machined surface properties are affected by the transportation of tool material elements on to the workpiece.

IV. CONCLUSION

Within the range of parameters selected for study, following conclusions can be made;

1) All the three process parameters, namely Type of wire, pulse width and wire tension significantly affect the MRR, SR in WEDM.
2) Deep and shallow cryogenic treated wire electrodes appreciably enhance the MRR.
3) Scanning electron microscope (SEM) photographs confirm that cryogenically treated wires gives smoother surface than untreated wire electrode.
4) EDS analysis revealed that cu and zn elements from brass wire electrode were deposited on the machined surface of workpiece

REFERENCES

1. Ho K.S., Newman S.T., Rahimifard S. and Allen R.D. "State of the art in wire electrical discharge machining (WEDM)", International Journal of Machine Tools and Manufacture, 2004, Vol 44 (12–13), pp 1247–1259.
2. Scott, D., Boyina, S. and Rajurkar, K.P. Analysis and optimization of parameter combination in wire electrical discharge machining, *International Journal of Production Research*, 1991, 29(11): 2189–2207.
3. Tosun, N., Cogun, C. and Inan, A. The effect of cutting parameters on work piece surface roughness in wire EDM, *Machining Science Technology*, 2003a, 7(2):209–219.
4. Han, F., Jiang, J. and Yu, D. Influence of machining parameters on surface roughness in finish cut of WEDM, *The International Journal of Advanced Manufacturing Technology, 2007,* 34(5–6) : 538–546.
5. Tosun, N., Cogun, C. and Pihtili, H. The effect of cutting parameters on wire crater sizes in wire EDM, *International Journal of Advanced Manufacturing Technology*, 2003b, 21(10/11) : 857–865.
6. Liao, Y.S., Huang, J.T. and Su, H.C. A study on the machining parameters optimization of wire electrical discharge machining, *Journal of Material Processing Technology,1997,* 71(3), pp.487–493.
7. Wlliams R.E and Rajurkar K.P. "study of wire electrical discharge machined surface characteristics", journal of materials processing technology, 1991, Vol. 28 pp 127-138.
8. Tarng, Y.S., Ma, S.C. and Chung, L.K. Determination of optimal cutting parameters in wire electrical discharge machining, *International Journal of Machine Tools Manufacturing*, 1995, 35(12):1693–1701.
9. Rebelo, J., Morao, A., Kremer, D. and Lebrun, J. Influence of EDM pulse energy on the surface integrity of martensite steels, *Journal of Materials Processing Technology*, 1998, 84(1–3) : 90–96.
10. Liao, Y.S., Huang, J.T. and Chen, Y.H. A study to achieve fine surface finish in wire-EDM, *Journal of Material Processing Technology,* 2004, 149 (1): 165–171.
11. Kapoor, J., Singh, S.P. and Khamba, J.S. Recent developments in wire electrodes for high performance WEDM, *Proceedings of the World Congress on Engineering* (WCE2010), 30 June to 2 July, London, UK, pp.1065–1068, 2011.
12. Kern, R. "Improving wire EDM productivity", EDM Today, March/April Issue, 2007.
13. Molinari A., Pellizzari M., Gialenella S., Straffelini G and, Stiasny KH."Effect of deep cryogenic treatment on the mechanical properties of tool steels", Journal of Materials Processing Technology, 2001, Vol. 118, pp. 350–355.
14. Reitz W. and Pendray, J. ' Cryo- processing of materials- A review of current status', Materials and Manufacturing Processes,2001, Vol.16(6), pp. 829 – 840.
15. Aoyama, S., Tamura, K. and Sato, T. "High-performance coated wire electrodes for high-speed cutting and accurate machining", Hitachi Cable Review No.18, 1999.
16. Kuroda, H., Aoyama, S., kimura, T., Sawahata, K., Sato, T., Kimura, T., Sawahata, K., Nagai, T (2007), "Development of high performance coated wire electrodes for high-speed cutting and accurate machining", Hitachi Cable Review No. 22, 2007.