International Journal of Mechanical and Production Engineering, ISSN(p): 2320-2092, ISSN(e): 2321-2071
Volume- 7, Issue-3, Mar.-2019, http://iraj.in

PERFORMANCE ENHANCEMENT OF MATERIAL REMOVAL RATE BY USING CRYOGENIC TREATMENT ON ZINC COATED DIFFUSED BRASS WIRE IN WIRE-CUT EDM PROCESS

[1]KULTAR SINGH, [2]SANDEEP SINGH

Assistant Professor, Department of Mechanical Engineering, UIET Sant Baba Bhag Singh University, Jalandhar, 144030, Punjab, India., Assistant Professor (Former), Department of Mechanical Engineering, GNIEM Nushehra, Hoshiarpur, 144208, Punjab, India.
E-mail: [1]Kultarsingh355@gmail.com, [2]Bajwa921@gmail.com

Abstract - The effect of cryogenic treatment of wire has been studied on material removal rate obtained by wire electrical discharge machining (WEDM). Two different wires have been used under the same input parameters. One wire was cryogenically treated and the other was simple and without any cryogenic treatment. AISI D3 die steel was used as work piece material. The performance of wires has been measured in terms of obtained material removal rate. Optimum set of input parameters for maximum material removal rate has also been determined. It is found that the cryogenically treated wire produces more material removal as compared to non-cryogenically treated wire for same material.

Key Words - Wire EDM, Material removal rate, Cryogenic Treatment, Optimization.

I. INTRODUCTION

Wire electrical discharge machining (WEDM) technology has advanced significantly since it was first used more than 30 years ago. In 1974, D.H. Dulebohn accomplished the optical line follower system to mechanically control the configuration of the components to be machined by the WEDM process. Its quality rapidly improved during further processing and its capabilities were better understood by the industry. In 1970s the computer numerical control system was presented into the WEDM, which brought about a major phylogeny of machining process. Its broad capabilities have allowed it to the encompass production industries and automotive industries and virtually all areas of conductive material machining. That’s why WEDM provides the best alternative or sometimes the only alternative for machining conductive, high strength and the temperature resistive materials, conductive ceramics with the scope of the generating complicated shapes and profiles. WEDM has enormous potential in its applicability in the present day metal cutting industry for achieving a considerable dimensional accuracy, surface finish and contour generation features of the products. The cost of wire contributes only 10% of operating cost of the WEDM process. The difficulties faced in the die sinking EDM area voided by wire electrical discharge machine, because complicated design tool is replaced by moving conductive wire and relative movement of wire guides. WEDM is generally utilized for machining of hard materials by using a wire of diameter ranging from 0.5 mm to 0.25 mm. WEDM process uses a conductive wire as an electrode and the moving wire cut the work piece. In this study, two different wires (a cryogenically treated wire and a non-cryogenically treated wire) have been used to cut AISI D3 die steel and the obtained material removal rate (MRR) with both the wires has been compared. The optimum set of parameters has been determined in order to get the maximum material removal rate with the cryogenically treated wire.

II. REVIEW OF LITERATURE

Mahapatra and Patnaik [1] described the optimization of WEDM process parameters by using Taguchi methods. The authors modified metal removal rate, surface finishing and the cutting width for a rough cut. The Taguchi’s L_{27} was utilized to optimize single response characteristic. Finally, genetic algorithm was employed to modify the wire electric discharge machining process with many types of objectives. The study demonstrates that wire EDM process parameters can be adjusted to attain the finer metal removal rate, surface finish and cutting width simultaneously. The confirmation experiments were carried out that shows the error associated with MRR, SR and kerf was less than 5%. Leskovsek et al. [2] investigated the influence of the deep-cryogenic treatment (DCT) on wear resistance of vacuum heat-treated high speed steel (HSS). The material used was electroslag remelting high-speed steel AISI M2 delivered in the shape of rolled, soft-annealed bar, and diameter 20 mm × 400 mm. The metallographic specimens diameter 20 mm × 9 mm prepared from the bar were heat treated in a horizontal vacuum furnace with uniform high-pressure gas quenching using nitrogen at a pressure of 5 bars. After the vacuum and deep-cryogenic treatments, the eight different types of samples were grounded and polished for further analysis and characterisation. The micro structural tests were performed. It was concluded that a moderate, but sufficient high, hardness and fracture toughness results in better wear resistance than the case when only one of the parameters in extremely high. Gill and Singh [3] investigated the effect of the deep cryogenic treatment on machinability of titanium alloy Ti-6246 in electrical discharge drilling. The material used was the alpha-beta titanium

Ti-6Al-2Sn-4Zr-6Mo alloy and used for a die sink EDM machining. There were two work pieces used one was deep cryogenically treated titanium Ti-6246 alloy and other was non-treated Ti-6246 alloy. The results of study revealed the higher material removal rate and lower tool wear rate in case of electric discharge drilling of DCT Ti 6246 alloy work piece as compared with non-treated Ti-6246 alloy work piece. It was concluded that deep cryogenic treated of Ti-6246 alloy also greatly improved the production of the drilled holes. Jaganathan et al. [4] investigated the machining parameters optimization of WEDM process using Taguchi method. The machine was ST CNC-E3 (MCJ) wire cut electrical discharge machine. The experiments were conducted on EN 31 alloy steel material. The work piece was in the shape of rectangle plate and work piece had been machined utilizing molybdenum wire was utilized as a tool having 0.20 mm diameter and the de-ionized water as a dielectric fluid. All the samples were machined for a length of the 4 mm. The significant machining parameters for the performance measures like material removal rate and surface were determined. Patel et al. [5] investigated the parametric analysis and mathematical modelling of material removal rate and surface roughness for H-11 material on wire cut EDM by DOE approach. The selected material was H-11 die tool steel and used for the wire-cut EDM machining. The process parameters were: pulse duration, specific energy, discharge frequency and discharge current intensity. The output parameters were material removal rate, surface roughness and kerf width. The molybdenum coated brass wire having 0.25 mm diameter was used. It was found that the process parameters affect different response in different ways and a model was developed for improving the surface roughness, kerf width, material removal rate. Alias et al. [6] analyzed the WEDM: influence of machine feed rate in the machining titanium Ti-6AL-4V using the brass wire and a constant current of 4A. The process parameters were: machine feed rate, wire speed, voltage, and wire tension. Before and after machining, all the specimens were cleaned in an alcohol bath using mini ultrasonic cleaner modal MUC-100 and then dried up. The best settings of machining parameter were determined for kerfs width, material removal rate and surface roughness. Singh et al. [7] experimentally analyzed the effect of two cryogenically treated dissimilar material wires on material removal rate obtained by machining on a wire EDM. The work piece material was AISI D3 die steel and the machine was Charmilles Model 290 wire EDM machine. Two different wire electrodes of brass wire and zinc coated diffused wire were used. The various machining parameters were: pulse width, time between two pulses, wire tension and wire feed rate. It was observed that the cryogenically treated zinc coated diffused brass wire gives 22.55% more MRR as compared to the cryogenically-treated plain brass wire. Gubencu and Pop-Calimanu [8] investigated the factors influence on the objective functions of wire EDM of AA2124/SiC/25p material. The systemic analysis was on the basis of detailed experimental research. The input parameters such as pulse-on time, pulse-off time, peak current, table feed rate, offset correction, wire tension and wire speed were used. The influence of thickness of the material laminate and the wire material on the material removal rate was studied.. The experiment was carried out on 3 values for the material thickness. These samples were machined by wire EDM cutting, using the same straight pattern, each of 200 mm length. The authors was used the two types of brass wire, uncoated brass wire and coated brass wire. The objective function chosen was the material removal rate, as a representative evaluation of the process performance, especially for roughing applications. A bi-factorial ANOVA was considered to be an appropriate assessment method. The results of the bi-factorial analysis were to determine which factors have a statistically significant effect on material removal rate [mm^3/min] using Fisher tests. It was concluded that the thickness laminate doesn’t have a significant influence on the material removal rate of wire EDM of AA2124/SiC/25P at the 95.0% confidence level.

The review of available literature revels that the cryogenic treatment can improve the hardness of the cutting tools. Less work has been reported on the use of cryogenic treatment of wires in WEDM machine to enhance the MRR. Therefore, in this paper the effect cryogenic treatment of wire used in WEDM has been studied on the material removal rate of the machined surface. The following objectives have been decided for this research work:

1. To investigate the effect of cryogenically treated wire on material removal rate in WEDM.
2. To compare the material removal rate achieved by machining with cryogenically treated wire and non-cryogenically treated (NCT) wire.
3. To find the optimal set of parameters for cryogenic treated wire to obtain maximum material removal rate.

III. EXPERIMENTATION

A wire EDM of make Charmilles Technologies and model Robofil 290 was used to carry out the experiments using 0.25 mm diameter zinc coated diffused brass wire as the tool electrode. This machine allows the operator to choose input parameters and change their values during machining. AISI D3 steel has been used as the work piece material. AISI D3 tool steel is a high-carbon, high chromium, oil-hardening tool steel that is characterized by a relatively high attainable hardness. Applications for this material include blanking, stamping, and cold forming dies and punches for long runs; lamination dies, bending, forming, and seaming rolls, cold trimmer dies or rolls, plug gauges, and drawing dies for bars or wire.

Cryogenically treatment of one wire was done in a cryogenic processor (Model: CP220LH). In cryogenic treatment the following steps were followed.

1. The temperature was decreased at the rate 0.51˚C per minute from room temperature. This is known as ramp down.
2. The temperature was decreased up to -184˚C in 6 hour in cryogenic processor.
3. The temperature was held at -184˚C for a period of 12 hours.
4. Temperature was increased at the rate of 0.51˚C per minute in a ramp up stage for a period of 6 hours and the temperature is bought to room temperature.

Taguchi method has been used for design of experiments. The L9 orthogonal array (OA) has been used to accommodate four input parameters having three levels of each. The selected input machining parameters are: pulse width, time between two pulses, wire mechanical tension and wire feed rate. The three levels of the each parameter have been taken. The parameter and levels selected are shown in Table 1.

Table 1: Input factors and their levels

S. No.	Level	Units	Symbol	Level I	Level II	Level III
I.	Pulse width	μs	A	0.5	0.7	0.9
II.	Time b/w two pulses	μs	B	10	12	14
III.	Wire mechanical tension	daN	C	0.70	1.20	1.80
IV.	Wire feed rate	m/min	D	5.0	7.0	9.0

Sixty work pieces of length 40 mm width 25 mm and thickness 11 mm were taken for the research work. A close view of three work pieces before machining is shown in Fig. 1.

Fig. 1 Photographic view of work pieces

Three repetitions of nine experiments were conducted with the cryogenically treated wire and three repetitions of nine experiments were conducted with non-cryogenically treated wires, after setting the machining parameters according to the design of experiments.

IV. RESULTS AND DISCUSSION

Experiments were conducted according to values of different input parameters and their levels according to design of experiments. The material removal rate was measured by taking difference of initial weight and final weight of the work piece divided by time and it is represented in g/min. The average values of MRR and the S/N ratio obtained by using CT wire have been shown in Table 2, whereas, the average values of MRR and S/N ratio obtained by using non-CT wire have been represented in Table 3. The S/N ratio has been calculated by using the 'larger is better' option.

Table 2: S/N ratios for CT wire

Exp. No.	Input Parameter A	B	C	D	MRR (g/min)	S/N ratio (dB)
I	0.5	10	0.7	5	0.071	-22.950
II	0.5	12	1.2	7	0.059	-24.582
III	0.5	14	1.8	9	0.029	-30.515
IV	0.7	10	1.2	9	0.08	-21.938
V	0.7	12	1.8	5	0.069	-23.197
VI	0.7	14	0.7	7	0.038	-28.245
VII	0.9	10	1.8	7	0.156	-16.137
VIII	0.9	12	0.7	9	0.099	-20.034
XI	0.9	14	1.2	5	0.088	-21.031

Table 3: S/N ratios for non-CT wire

Exp. No.	Input Parameter				MRR (g/min)	S/N ratio (dB)
	A	B	C	D		
I	0.5	10	0.7	5	0.061	-24.180
II	0.5	12	1.2	7	0.051	-25.814
III	0.5	14	1.8	9	0.024	-32.181
IV	0.7	10	1.2	9	0.068	-23.349
V	0.7	12	1.8	5	0.059	-24.553
VI	0.7	14	0.7	7	0.032	-29.735
VII	0.9	10	1.8	7	0.126	-17.992
VIII	0.9	12	0.7	9	0.082	-21.660
XI	0.9	14	1.2	5	0.072	-22.757

A perusal of Table 2 and 3 shows that the values of MRR obtained by using CT wire is more than the MRR obtained by using non CT wire. Therefore, it can be concluded that the CT wire is better than non CT wire for material removal rate. The comparison of MRR for both the wires is shown in Fig. 2.

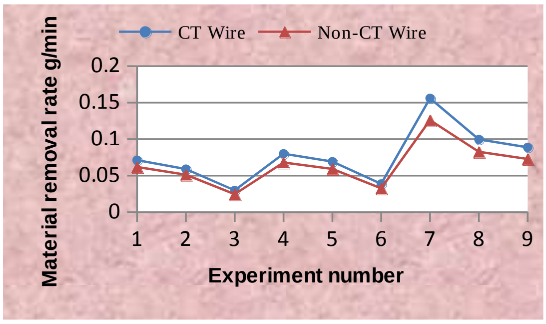

Fig. 2 Comparison of wires for MRR

The graph in Fig. 2 shows that the material removal rate achieved by using the cryogenically treated wire is higher as compared to non-cryogenically treated wire for all the experiments.

A. Analysis of S/N Ratio

The response table for S/N ratios for all the variables is given in Table 4 for CT wire.

Table 4: Response table for S/N ratio for MRR for CT wire

Level	Input Parameter			
	A	B	C	D
I	-26.02	-20.34*	-23.74	-22.39*
II	-24.46	-22.61	-22.52*	-22.99
III	-19.07*	-26.60	-23.28	-24.16
Delta	6.95	6.26	1.23	1.77
Rank	I	II	IV	III

*indicates higher S/N ratio

In the last row of the Table 4 ranks have been given to the various factors. Higher is the rank, higher is the significance. It has been found that pulse width has the highest rank 1 and is the most significant factor followed by the time between two pulses at rank 2 and wire feed rate at rank 3. Wire mechanical tension has lowest rank and is least affecting the material removal rate. The ranks represent the relative importance of each factor to the response. The main effect plots for S/N ratio for CT wire are shown in Fig. 3. The X-axis indicates the level of input parameter and Y-axis indicates the mean of S/N ratio.

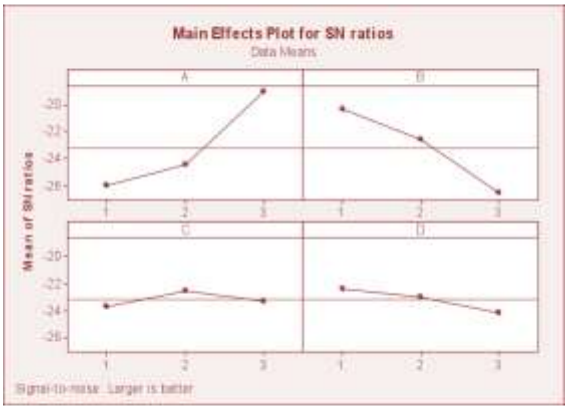

Fig. 3 Main effect plots for S/N ratio for CT wire

The main effect plots in Fig. 3 show that when the pulse width (A) increases, the value of material removal rate also increases. The discharge energy increases with the pulse width step-up and the larger discharge energy produces a larger crater. Then larger crater produces more MRR. The increase in time between two pulses (B) decreases the value of material removal rate. It is due to the fact that each pulse is responsible for material removal rate and less number of pulses per minute would produce less MRR. The effect of wire mechanical tension (C) is negligible. With increase in wire feed rate (D) the value of material removal rate decreases. However the effect of wire feed rate is very less and insignificant. Similar results have been reported by Singh et al. [7] and Rao et al. [10].

B. Analysis of Variance

The analysis of variance (ANOVA) was carried out to study the relative influence of the machining parameters on the MRR of the WEDM machined material. The sum of degree of freedom (DOF) of all the parameter is 8 which is equal to the DOF of the model. The DOF of residual error is zero. Therefore, F and P-values cannot be calculated and a pooling is required. The factor C has minimum value and it can be pooled in error. After pooling the parameter (C) in the error, the pooled ANOVA table has drawn as shown in Table 5.

Table 5: Analysis of variance for S/N ratio for MRR for CT wire

Source	DOF	Sum of square	Mean square	F-value	Status	%age Contri.
A	2	79.780	39.890	34.66	Sig.	54.21%
B	2	60.196	30.098	26.15	Sig.	40.91%
C	0	-	-	-	-	-
D	2	4.864	2.432	2.11	Insig.	3.30%
Error (pooled)	2	2.302	1.151			1.58%
Total	8	147.142				100

The F-value given in the Table 5 suggests the significance of the factors on the desired characteristics. The principle of F-test is that larger the F-value more is the significance of factor. The pulse width and time between two pulses are significant factors.

The wire feed rate is insignificant factor. In these experiments the $F_{0.05,2,2}$ = 19.00. This F-table value finds significance of a factor at 95% confidence level, if it is greater than 19.00. The F-value for pulse width is greater than 19.00. Therefore it's significant. It has been observed that the percentage contribution of pulse width is very high in this case (i.e. 54.21%). The time between two pulses is also significant parameter at 95% confidence level. The error in this case is 1.58%. The rank order based on percentage contribution is same as that obtained earlier through S/N ratio analysis.

C. Optimum Set of Parameters for CT wire

The optimum values of machine parameters for CT wire were formed from the experiments and the obtained S/N ratios. The higher S/N ratio represents the more favourable effect of input variable on the output. From Table 4 the optimum levels (parameter levels with highest mean S/N ratio) have been taken for most significant parameters in order to achieve maximum material removal rate. These optimum levels and their corresponding values are shown in Table 6.

Table 6: Optimum set of parameters for CT wire

Factor	Highest mean S/N ratio	Optimum level	Optimum value
Pulse width	-19.07	III	0.9
Wire mechanical tension	-20.34	I	0.70
Wire feed rate	-22.39	I	5

D. Prediction of MRR for CT wire

In this work there are four input parameters and the parameters A, B, D scored the highest ranks as shown in Table 4. The predicted optimum response in terms of S/N ratio (η_{pre}) can be calculated by using the following equation [11].

$$(\eta_{pre}) = \bar{\eta} + (\bar{A}_3 - \bar{\eta}) + (\bar{B}_1 - \bar{\eta}) + (\bar{D}_1 - \bar{\eta}) \quad (1)$$

In this equation $\bar{\eta}$ is the average of S/N ratio for all the observations as given in Table 4.3, whereas $\bar{A}_3$, $\bar{B}_1$ and $\bar{D}_1$ are highest mean S/N ratios for most significant parameters A, B and D as shown in Table 4.

$$\eta_{pre} = (\bar{A}_3) + (\bar{B}_1) + (\bar{D}_1) - 2(\bar{\eta})$$

= (-19.07) + (-20.34) + (-22.39) - 2(-23.18)
= - 61.8 + 46.362
= - 15.438 dB

By using predicted optimum S/N ratio in Eq. (1), the value of predicted material removal rate for CT wire by using optimum set of parameters is 0.169 g/min.

E. Confirmatory Experiments

Two confirmatory experiments were conducted by using the optimal levels of the input parameters and the obtained material removal rate is 0.160 g/min and 0.165 g/min which are quite closer to the predicted value of material removal rate.

CONCLUSIONS

The effect of cryogenic treatment of wire in WEDM has been studied on the material removal rate of the machined workpieces. Four independent variables (pulse width, time between two pulses, wire mechanical tension and wire feed rate) were selected for machining and the experiments were conducted by using a CT wire and a non-CT wire as electrodes in a WEDM machine. The main conclusions are given below:

1. The material removal rate obtained was found to be more with cryogenically treated wire as compared to non-cryogenically treated wire.
2. The pulse width and time between two pulses found to be most significant factors for material removal rate.
3. The material removal rate increases when the pulse width was increased and it decreases with increase in time between two pulses.
4. The effect of wire mechanical tension and wire feed rate was negligible.
5. It can be concluded that the cryogenically treated wire produces more material removal rate than non-cryogenically treated wire.

REFERENCES

[1] S.S. Mahapatra and A. Patnaik, 'Optimization of wire electrical discharge machining (WEDM) process parameters using taguchi method', International Journal of Computers and Industrial Engineering, Vol. 50, 2006, pp. 15-34.

[2] V. Leskovsek and M. Kalin, 'Influence of deep cryogenic treatment on wear resistance of vacuum heat treated HSS', Surface Instrumentation & Vacuum Technology, Vol. 80, 2006, pp. 507-518.

[3] S.S. Gill and R. Singh, 'Wear behavior of cryogenically treated tungsten carbide inserts under dry and wet turning conditions', International Journal of Machine Tool and Manufacturing, Vol. 49, 2009, pp. 256-269.

[4] P. Jaganathan, N.T. Kumar and R. Sivasubramanian, 'Machining parameters optimization of WEDM process using taguchi method', International Journal of Scientific and Research Publications, Vol. 2, No. 12, 2012, pp. 1-4.

[5] C.H Patel, M.D. Patel and R. Prajapti, 'Parametric analysis and mathematical modelling of MRR and surface roughness for H-11 material on wire cut EDM by DOE approach', International Journal of Engineering Research and Applications, Vol. 2, 2012, pp. 1919-1924.

[6] A. Alias and B. Abdullah, 'WEDM: influence machine feed rate in machining titanium Ti-6Al-4v using brass wire and constant current (4v)', Procedia Engineering Vol.41, 2012, pp. 1812-1817.

[7] N. Singh, P. Kumar and K. Goyal, 'Effect of two different cryogenic treated wires in wire electrical discharge machining of AISI D3 die steel', Journal of Mechanical Engineering, Vol. 43, No. 2, 2013, pp. 54-60.

[8] D. Gubencu and M. Pop-Calimanu, (2013) 'Study of factors influence on the objective functions of wire EDM of AA2124/SiC/25p', Czech republic, EU.

[9] H. Singh and A. Singh, 'Wear behaviour of AISI D3 die steel using cryogenic copper and brass electrode in electric discharge machining', International Journal of Modern Engineering Research, Vol. 2, No. 6, 2012, pp. 4462-4464.

[10] P.S. Rao, 'Effect of WEDM conditions on surface roughness: a parametric optimization using Taguchi method', International Journal of Advance Engineering Science and Technologies, Vol. 6, 2011, pp. 041-048.

[11] Krishnaiah K, Shahabudeen P. Applied Design of Experiments and Taguchi methods. 4th ed. New Delhi: PHI Learning Pvt. Ltd; 2012. p. 248.

★★★