International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 4, No. 1, January 2015

Research Paper

STUDY OF RADIAL OVERCUT DURING EDM OF H-13 STEEL WITH CRYOGENIC COOLED ELECTRODE USING TAGUCHI METHOD

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Cryogenic treatment enhances the abrasion resistance and fatigue resistance of electrode material. It also increases the electrical and thermal conductivity by reducing its defects and inclusions. The cryogenic process also relieves residual stresses in metals and plastics. In this research work an effort has been made to compare the machining characteristics of one untreated and one cryogenically treated Cu electrode using Electron Discharge Machine (EDM). This study includes the three processing parameters such as peak current, voltage and pulse on time (T_{on}). The output parameter for study is Radial Overcut (ROC). A set of eighteen experiments (Taguchi design) were performed to develop relationships between input and output parameters. The results of the study suggest an overall improvement of 17% in Radial Overcut.

Keywords: Cryogenic treatment, Electrical discharge machining, Taguchi design, Radial overcut, ANOVA

INTRODUCTION

Electrical Discharge Machining (EDM) is a non-traditional machining process used to remove material by a controlled erosion of electrically conductive materials by the repetitive spark discharges between the electrode and work piece separated by a small gap. EDM is an important and cost effective method of machining extremely tough and fragile electrically conductive materials. In EDM there is no physical contact between the electrode and work piece and hence no cutting forces acting on the work piece (Rao, 2012). A thin gap about 0.025 mm is maintained between the electrode and work piece by a servo system shown in Figure 1.

Both electrode and work piece are submerged in a dielectric fluid, i.e., kerosene/ EDM oil/deionized water and sometime gaseous dielectrics are also used in certain cases. When a potential difference is applied between two conductors immersed in a

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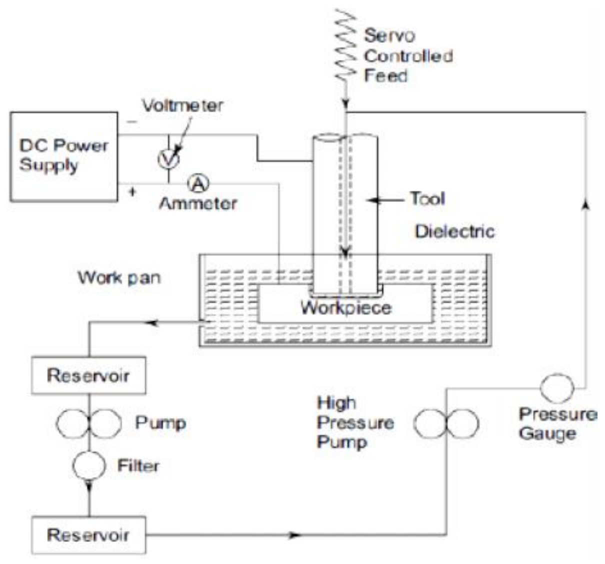
Figure 1: Set Up of EDM



dielectric fluid, the fluid will ionize if the potential difference reaches a high enough value and a spark will occur. Several hundred thousand sparks occur per second with the actual duty cycle carefully controlled by the setup parameters (Pandey Anand and Singh Shankar, 2010).

The EDM process was originally developed for machining carbides, hard nonferrous alloys, tool and die material and other difficult to machine material. Now a days the aerospace, automobile and electronics industries are using EDM for making prototype and production parts where production quantities are relatively low. Mahendran *et al.* (2010) first carried out the optimum process parameters for a high removal rate and a good surface quality for the ceramic material. Ramasawmy and Blunt (2004) proposed increasing the electrical conductivity of SiC by adding particles of TiB_2 and Tin in the EDN process. Ozgedik and Cogun (2006) investigated the EDM process of Al_2O_3 doped with TiC to improve its electrical conductivity. Onwubolu (2005) proposed to improve metal removal rates and for fine surface finish by optimizing the carbide contents on the ceramics ZrO_2 and Al_2O_3. Suleiman Abdulkareem *et al.* (2010) reported the increase in MRR, SR, ROC for higher values of pulse current by using a Cu-W tool electrode on AISI 1045 alloy steel. Mohandoss (2012) his research revealed that Cu electrode played a major role in improving material removal rate and radial overcut. Po Chen *et al.* (2010) research revealed the effect of DCT on machinability of Ti 6246 alloy in Electric Discharge Drilling (EDD) by doing experimental investigations on the electrolytic copper electrode. He revealed that there was a drilling time breakeven point beyond which the MRR increases for deep cryogenically treated Ti 6246 alloy than that of non-treated alloy. Our experimental work was focused on the electrical discharge machining of H-11 tool steel with Cu(99%) tool electrode when cryogenic cooled and without cryogenic cooled and an attempt has been made to obtain optimal setting of the process input parameters for minimum overcut with EDM oil as dielectric fluid. Taguchi methodology has been applied to plan and analyze the experiments.

EXPERIMENTAL PROCEDURE AND PARAMETERS

All the experiments have been conducted on Sparkonix machine which is servo controlled by a Numerically Controlled code programming and the servo control feedback is dependent on the gap voltage between the electrode and workpiece. The gap distance cannot be independently controlled on this machine. The X and Y axes are manually controlled. All three axes have an accuracy of 5ìm. Alternately the spark can be controlled manually after the desired interval of time for machining has elapsed. The workpiece used in the experiments is H-13 Tool Steel. Tool steels for hot work applications, designated as group "H-13, EN, D3, D2" steels in the AISI classification system, have the capacity to resist softening during long or repeated exposures to high temperatures needed to hot work or for die-casting other materials. The outstanding characteristics of these tool steels are high toughness and shock resistance. They have air hardening capability from relatively low austenitizing temperatures and minimum scaling tendency during air cooling. Alloying elements of the workpiece is listed in the Table 1.

Table 1: The Chemical Composition of H-13 (Tool Steel) Workpiece

Elements	Weight Limit %	Actual Weight %
C	0.32-0.40	0.35
Cr	5.13-5.25	0.40
Mo	1.33-1.5	1.50
Si	1.0	1.0
V	1.0	0.45
Mn	0.40-0.50	0.40

Electrode material used in EDM can be of a variety of metals like Cu, Zn, Al alloys, Ag alloys, etc. The mechanical properties of H-13 (Tool Steel) Workpiece are listed in Table 2.

Table 2: Mechanical Properties of H-13 (Tool Steel) Workpiece

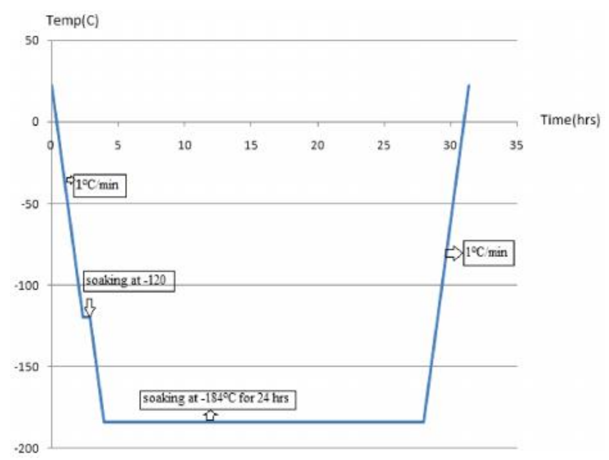
Properties	Conditions T (°C)
Hardness, Rockwell C	52-54 (Tempered at 510 °C)
Tensile strength ultimate	1990 MPA at HRC = 54 (Tempered at 995-1025 °C)
Modulus of elasticity	201 GPA (Tempered at 990 °C)
Bulk modulus	140 GPA (Tempered at 990 °C)

Electrode used in this experiment is pure Cu. Electrode shape is cylindrical having a diameter of 12.5 mm in which one is cryogenically treated and other is non cryogenically treated. Copper has low electrical and thermal resistance which results in a more efficient energy transfer to the workpiece. Chemical Composition of copper electrode is listed in the Table 3.

Table 3: The Chemical Composition (Wt. %) of Cu Electrode

Cu	Zn	Pb
99.5	0.165	0.0216
Sn	P	Mn
0.0772	0.014	0.004
Fe	Si	Mi
0.0894	0.0069	0.0055
Cr	Al	S
0.0010	0.0020	0.0079
As	Be	Ag
0.0033	0.0050	0.0088
Sg	Co	Bi
0.0013	0.0122	0.0026

Figure 2: Cryogenic Cycle



Deep cryogenically treatment of copper electrodes was done in a cryogenic chamber.

Liquid nitrogen gas is used to perform the deep cryogenically treatment. Same set of parameters are used to perform the experiment on two different (cryogenically treated and non-cryogenically treated) Cu electrodes. While doing the machining by EDM the cavities are produced somewhat greater than the electrode size, which result in Radial Overcut (ROC). ROC is important when close tolerance is required in production of components. ROC is expressed as half the difference of diameter of the hole produced to the tool diameter that is shown by the equation.

In Taguchi experimental designs we usually require only a fraction of the full factorial combinations. In this combination the arrays are designed to handle as many factors as possible in a certain number of runs compared to those by full factorial experimental design. The columns of the arrays are balanced and orthogonal as shown in Table 4. This means that in each pair of columns, all factor combinations occurs at same number of times.

Table 4: Orthogonal Array L_9 Matrix

Exp. No.	Current (A)	Voltage (V)	Pulse on Time (µs)
1	5	30	4
2	5	40	5
3	5	50	6
4	8	30	5
5	8	40	6
6	8	50	4
7	12	30	6
8	12	40	4
9	12	50	5

The observed values of ROC for the12.5 mm non-cryogenic cooled cooper electrode and the cryogenic cooled cooper electrode are listed in Tables 5 and 6. Parameters are Peak current (Amp), Voltage (V), T_{on}(µs).

RESULTS AND DISCUSSION

The mean effect plots of the S/N ratios for the overcut were obtained using Minitab 14.1 software. Plots with the steeper slope and longer lines shows that the factor has significant impact on overcut. The average

Table 5: Observed Values of ROC with Non-Cryogenic Cooled Electrode

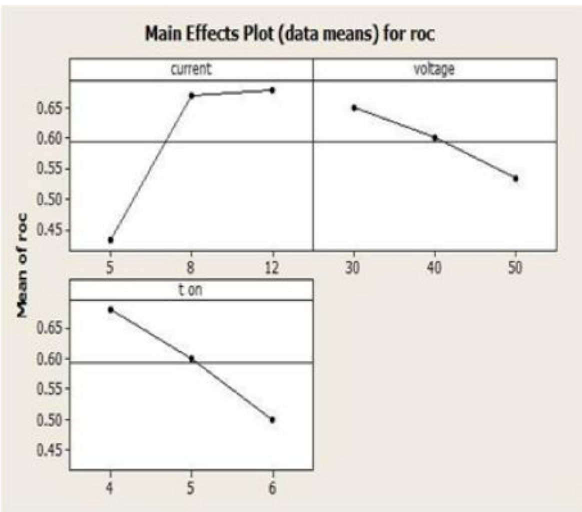
Run	Peak current(Amp)	Voltage(V)	T_{on}	Wt. of Tool(gm)		Cavity Dia	ROC	With 12.5mm Electrode
				Wtb	Wta	D_{jt}		
1	5	30	4	32.84	32.82	13.724	0.612	
2	5	40	5	32.82	32.81	13.393	0.446	
3	5	50	6	32.81	32.76	12.736	0.236	
4	8	30	5	32.76	32.74	13.882	0.691	
5	8	40	6	32.74	32.69	13.743	0.621	
6	8	50	4	32.69	32.67	13.895	0.697	
7	12	30	6	32.67	32.62	13.785	0.642	
8	12	40	4	32.62	32.57	13.964	0.732	
9	12	50	5	32.57	32.52	13.826	0.663	

Table 6: Observed Values of ROC with Cryogenic Cooled Electrode

Run	Peak current(Amp)	Voltage(V)	T_{on}	Wt. of Tool(gm)		Cavity Dia	ROC	
				Wtb	Wta	D_{jt}		
1	5	30	4	40.78	40.77	13.106	0.3032	With 12.5mm Electrode
2	5	40	5	40.77	40.76	12.893	0.3333	
3	5	50	6	40.76	40.74	12.621	0.1212	
4	8	30	5	40.74	40.73	12.982	0.4820	
5	8	40	6	40.73	40.70	13.212	0.7120	
6	8	50	4	40.70	40.69	13.124	0.6240	
7	12	30	6	40.69	40.66	13.285	0.7850	
8	12	40	4	40.66	40.64	13.324	0.8240	
9	12	50	5	40.64	40.62	13.198	0.3490	

values of S/N ratios for overcut at different levels are plotted in Figure 3. It is clear from the Figure 3 that the radial over cut increases with the increase in Peak current. Peak current is the most significant on the radial over cut. The ROC is unavoidable though adequate compensation is provided at the time of tool design. We have to reduce the value of radial over cut to achieve accuracy; therefore factors affecting the ROC are essential to measure. The graph represents that current is directly proportional to the ROC. Increasing in the discharge current from 5 to 8A the ROC is increasing sharply and after increasing the current from 8 to 12A there is slight increase in the ROC. Where the ROC is decreases with the increase in gap voltage because with increase in the gap voltage the average discharge gap gets widened resulting into better surface accuracy due to stable machining.

Figure 3: Effects of Process Parameters on Radial Overcut for 12.5 mm Non-Cryogenic Cooled Electrode



From the Figure 3 it can be seen that the most significant factor is peak current. In Table 7 the variation data for each factor and their interactions were F-tested to find significance of each. Higher the value find out by F-test for a particular parameter the greater will be the effect on the performance characteristic due to the change in that process parameter. ANOVA table shows that the peak current (F 12.58 value), voltage (F 2.18 value), pulse on time (F 5.21 value) are the factors that

Table 7: ANOVA for Radial Overcut of 12.5 mm Non-Cryogenic Cooled Electrode

Source	D.O.F	SS	Variance	F	P	% Contribution
Current	2	0.118467	0.059234	12.58	0.074	60.06
Voltage	2	0.020481	0.010240	2.18	0.035	10.37
Ton	2	0.049060	0.024530	5.21	0.061	24.8
Error	2	0.009416	0.004708			
Total	**8**	**0.197424**				

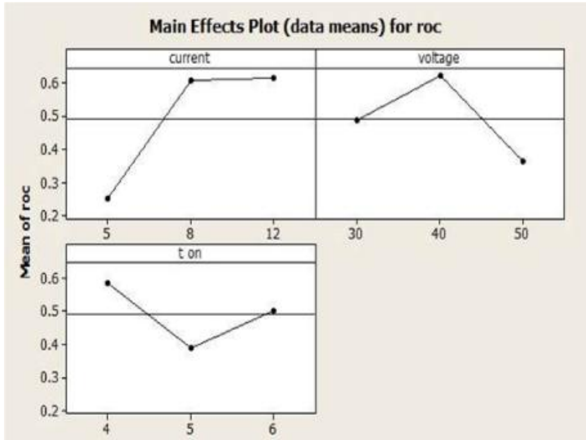
Note: S = 0.0686155; R-Sq. = 95.23%; R-Sq.(adj.) = 80.92%. DF-Degrees of Freedom, SS-Sum of Squares, MS-Mean Squares (Variance) F-Ratio of Variance of a Source to Variance of Error, P < 0.05 Determines Significance of a Factor at 95% Confidence Level.

significantly affect the ROC. It is seen in Figure 4 peak current is the most significant on the ROC. The graph represents that current is directly proportional to the ROC.

Increase in the peak current from 5 to 8A the ROC is. It is seen in Figure 4 peak current is the most significant on the ROC. The graph represents that current is directly proportional to the ROC. Increase in the peak current from 5 to 8A the ROC is increasing sharply and after increasing the current from 8 to 12A there is slight increase in the ROC. When the voltage is at level 1 and further increased to level 2 there is increase in ROC and when the voltage is increased from level 2 to level 3 the ROC is decreased with the increase in gap voltage because with increase in the gap voltage the average discharge gap gets widened resulting into better surface accuracy due to stable machining.

Significant effect of pulse on time is also seen in Figure 4 when the pulse on time is increased from level 1 to level 2 there is decrease in ROC further increase in pulse on time decrease ROC because due to plasma form between the gap of electrode and workpiece the lesser energy is transferred to workpiece due to which ROC decreases with increase in pulse on time.

Figure 4: Effects of Process Parameters on Radial Overcut for 12.5 mm Cryogenic Cooled Electrode



In ANOVA table it is clear that the significant factors are peak current and voltage. In Table 8 the variation data for each factor and their interactions were F-tested to find significance of each.

ANOVA Table 8 shows that the peak current (F 19.67 value), voltage (F 7.65 value), pulse on time (F 4.43 value) are the factors that significantly affect the SR. The parameter R^2 (amount of variation) = 96.95%, Adj. R^2 = 87.79%, and the standard deviation of error in the modeling S = 0.0809039. The second level of pulse on time (i.e., 5 µs) seems to be optimal. Figure 4 further suggest that third level of gap voltage (i.e., 50 V) gives optimal results.

Table 8: ANOVA for Radial Overcut of 12.5 mm Cryogenic Cooled Electrode

Source	D.O.F	SS	Variance	F	P	% Contribution
Current	2	0.257434	0.128717	19.67	.048	60.046
Voltage	2	0.100207	0.050103	7.65	.016	23.3
Ton	2	0.057995	0.028997	4.43	.018	13.5
Error	2	0.013091	0.006545			
Total	**8**	**0.428726**				

Note: S = 0.0809039; R-Sq. = 96.95%; R-Sq.(adj.) = 87.79%. DF-Degrees of Freedom, SS-Sum of Squares, MS-Mean Squares (Variance) F-Ratio of Variance of a Source to Variance of Error, $P < 0.05$ Determines Significance of a Factor at 95% Confidence Level.

CONCLUSION

1. In the measurement of radial overcut the most important factor is discharge current then voltage and after that pulse on time.
2. Radial overcut is critical parameter in EDM. Since cryogenic treatment has a significant positive effect on this parameter.
3. The optimum condition for machining by 12.5 mm non-cryogenic Cu electrode is at 5A current and at 50V whereas the effect of pulse on time is almost negligible for 12.5 mm electrode.
4. The optimum condition for machining the 12.5 mm cryogenic Cu electrode is at 5A current and at 50 V and at pulse on time of 5 µs.

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