The Effects of Cryogenic Cooling on Electrode Wear In Electric Discharge Machining Process

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Abstract
The work presented in this paper is carried out to study the effect of the cryogenic treatment on the electrode material to improve the tool life. The experiments were performed in H13 material using untreated electrode and cryogenic treated electrode. The input process parameter studied for different level of interactions are discharge current, Voltage and pulse on time. L9 Taguchi method of optimization was used for this input parameters to see their effect on the electrode wear with different treatments to the tool. Discharge current is found to be the most contributing factor for electrode wear in both untreated and treated electrode. The experiments has established an improvement of 29.77% in the life of the tool.

Keywords: Electric discharge machining, Cryogenic treatment, Taguchi optimization, and Electrode cooling

1. Introduction

In 1766, Joseph Priestley, an English theologian and chemist, first noted the craters formed on the cathode(metal) surface due to electric sparks. In 1943, two Russian brothers Boris and Natalya Lazarenko were the pioneers who used the electric spark to remove metal. Electrical Discharge Machining (EDM) is a non-conventional machining process used to remove metal by a controlled disintegration of electrically conductive materials by the commencement of fast and repetitive spark releases between the anode and work piece isolated by a little distance. EDM is a vital and powerful method of machining electrically conductive materials which are extremely difficult and fragile. In this process the electrode and work piece are always maintaining a distance between themselves, therefor operator need not have to worry about the cutting forces acting on work piece [1]. A slight gap about 0.025mm is kept by a servo system shown in Figure1 in between the EDM tool and work piece. Dielectric fluid is used to envelope the EDM tool and work piece in the work pan. EDM oil/

ISSN: 0971-1260

Vol-22-Issue-17-September-2019

Kerosene/deionized water are normal kind of dielectric liquids although gaseous dielectrics are additionally utilized in specific cases. At the point when a distinction of potential is applied between two conductors submerged in a dielectric liquid the liquid will ionize if the potential contrast arrives at a sufficiently high worth, a spark will happen [2].

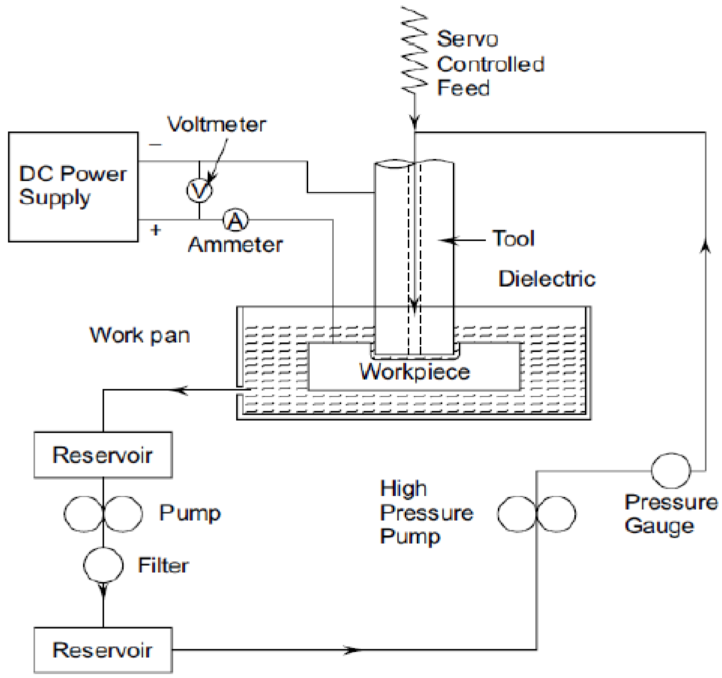

Figure 1: Set up of EDM. [1]

For tool and die industries which require working with hard material, EDM technique is the first choice and now it is turning a common approach to utilize EDM for prototyping and low volume production of parts especially in the aerospace and aircraft [3]. Any conductive material of any hardness can be easily machined [4]. EDM tool wear is a significant issue in EDM technique. In a large portion of the EDM tasks, the commitment of the electrode cost to the absolute activity cost is more than 70% [5]. While going for EDM operation the EDM tool wear should be cautiously considered. If the tool wear happens above a certain value then we are not going to get the mirror image and specified dimensional geometry on the work piece. The thermal and electrical properties of a material govern its machinability in EDM. Material's electrical resistivity is dependent on its temperature. Due to its low electric and thermal resistance, copper electrode is able to ensure the effective transfer of energy to the work piece [6].

2. Literature Review

Suleiman Abdulkareem et al. [7] studied the effect of electrode cooling during the EDM of Titanium alloy (Ti-6Al-4V). Investigation on the effect of electrode cooling on electrode wear was carried out. Current, pulse on-time, pause off-time, and gap voltage were considered as the machining parameters while electrode wear (EW) is the response. Analysis of the influence of electrode cooling on the response has been carried out and it was possible to reduce EWR by 27% using this method. R Mohandas [8] in his study describes the cryogenic treatment application to EN-19 gear material to improve its mechanical properties. Material war first case carburized and after it is cryogenically treated. After it tensile testing is done on Rockwell hardness tester using C scale and impact testing is also done. His results showed that there is a good increase in tensile strength due to deep cryogenic treatment. But the material loses its ductility and becomes brittle which may not be suitable for handling impact loads and therefore depending upon the load applications it has to be determined whether cryogenic treatment is necessary for particular steel. Po Chen et al [9] studied the effect of cryogenic treatment on the tensile strength, hardness fatigue life and stress erosion cracking (SCC) for aerospace aluminium (Al) alloys. He deducted the tests with non-destructive techniques. He used fusion welding for welding the alloys. He concluded in his research that residual stresses are reduced upto 12 ksi in the HAZ of the weld specimen material and upto 9 ksi in parent material. Significant improvements were seen in SCC performances for weld specimen. Minor increase in tensile strength is seen in weld specimen after cryogenic treatment and no change in significant properties were seen in fatigue properties of parent material. Ahmed et al. [10] modified a electrode to apply liquid nitrogen as coolant through a hole made in the electrode so that liquid nitrogen can be directly applied to the machining zone during machining of stainless steel with carbide electrodes coated with titanium carbonitride. It was found that the electrode life increased by more than four times on the application of liquid nitrogen using the modified electrode. Application of this cryogenic cooling was found to be more effective at higher cutting speeds. It was also observed that cryogenic cooling is efficient at a higher feed rate rather than a higher depth of cut. Simarpreet Singh et al. [11] investigated the effect of DCT on machinability of Ti 6246 alloy in electric discharge drilling (EDD) by conducting experimental investigations on the production of

ISSN: 0971-1260

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10mm diameter blind holes with electrolytic copper electrode. His research 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.

3. Experiment Details.

3.1 Substrate Materials

The substrate material selected for the study was commercially pure Cu (cooper) of 15mm diameter as electrodes. The electrode samples were cut into 15mm diameter and 40mm length for the experiments. The work piece material is H13 electrode steel. The workpiece material is cut into 150mm×100mm×20mm.

Table 1: Chemical Composition (Wt. %) of Copper Electrode

Cu	Zn	Pb	Sn	P	Mn	Fe	Ni	Si	Mg	Cr	Al
99.5	0.165	0.216	0.0772	0.014	0.004	0.0894	0.006	0.0055	0.0013	.0020	.0079

3.2 Input-Output Parameters

This research was carried out with selected combinations of electrodes and workpiece by selecting different levels of current, voltage and pulse on time using L9 orthogonal array of Taguchi design approach. Cryogenic treatment was performed at -180°C. EDM experiments were carried on SPARKONIX 25A EDM machine. In all the experiments kerosene oil was used as dielectric medium. The experiments have been carried out maintaining those system parameters at diverse levels. The range for every of the system parameter was decided on based totally at the evaluation of past literature and competencies of the EDM system and initial experiments carried out. The range of the discharge current become decided on from 5A to 8A, pulse-on-time was decided on from 4μs to 6 μs and gap voltage decided from 30V to 50 V. The variety of method parameters had been given in table 2.Total 36 experiments has been carried out in this study.

ISSN: 0971-1260

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Table 2: Range Of Process Parameters

Parameters	Level 1	Level 2	Level 3
Discharge current(A)	5	8	12
Voltage(V)	30	40	50
Pulse on time(μs)	4	5	6

The thin line represents the cooling rate. Cooling rate is one of the most crucial parameter which should never again surpass 20-30 °C/hr with the aim to spare you the burst of the segments due to the cooling stresses. The ramp down time is 1°C/ hr. A temperature of –180 °C is achieved in 7 hours. After cryogenic treatment tempering is done at 140°C for 4 hours and after it is air cooled to room temperature. Figure 2: shows the cryogenically cycle which is used for cryogenic treatment of copper.

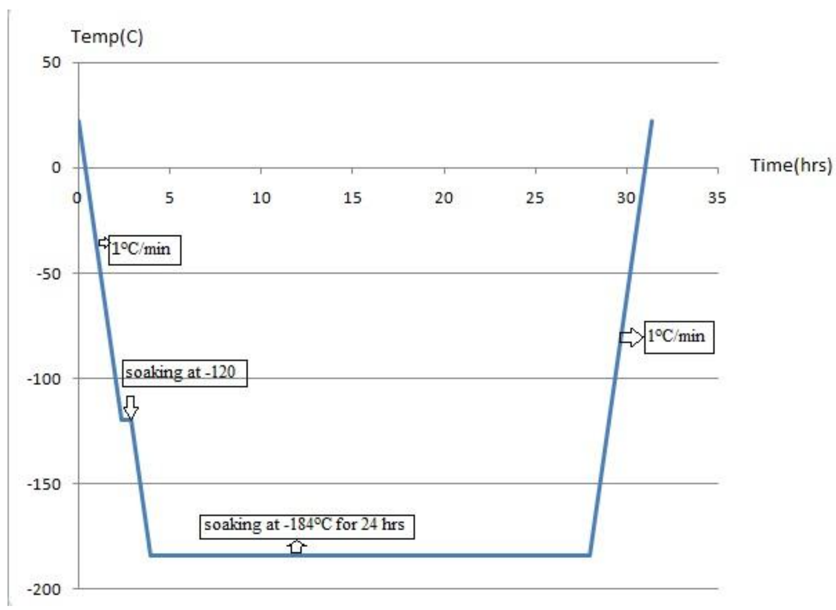

Figure 2: Cryogenic Cycle

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3.3Experiment Procedure

Electrode wear is crucial thing because if impact on dimensional accuracy and the form produced. Electrode wear is associated with the melting point of the materials. Electrode wear is stricken by the precipitation of carbon from the hydrocarbon dielectric at the electrode surface throughout sparking. EW is communicated as the proportion of the distinction of weight of the terminal when machining to the machining time. That can be explained by this equation.

$$EW = \frac{Etb - Eta}{T}$$

Table 3: Experimental Observations for Non Cryogenic Cooled Electrodes

Run	Peak current(Amp)	Voltage(V)	T_{on}	Wt. of Electrode(gm)		EW
				Etb	*Eta*	
1	5	30	4	71.02	70.75	4.25
2	5	40	5	70.75	70.54	5.52
3	5	50	6	70.54	70.31	8.21
4	8	30	5	70.31	70.06	12.4
5	8	40	6	70.06	69.80	15.2
6	8	50	4	69.80	69.53	13.5
7	12	30	6	69.53	69.19	34.1
8	12	40	4	69.19	68.85	48.5
9	12	50	5	68.85	68.44	23.1

The values of EW have been put up to two decimal place by using the concept of significant figures. The accuracy of weighing balance was up to 10^{-3} gm.

Table 4: Experimental Observations for Cryogenic Cooled Electrode

Run	Peak current(Amp)	Voltage(V)	T_{on}	Wt. of Electrode(gm)		EW
				Etb	*Eta*	
1	5	30	4	73.58	73.56	0.57
2	5	40	5	73.56	73.53	1.00
3	5	50	6	73.53	73.51	0.80
4	8	30	5	73.51	73.44	4.37
5	8	40	6	73.44	73.36	4.21
6	8	50	4	73.36	73.27	4.09
7	12	30	6	73.27	73.14	24.40
8	12	40	4	73.14	73.03	18.80
9	12	50	5	73.03	72.91	13.70

ISSN: 0971-1260

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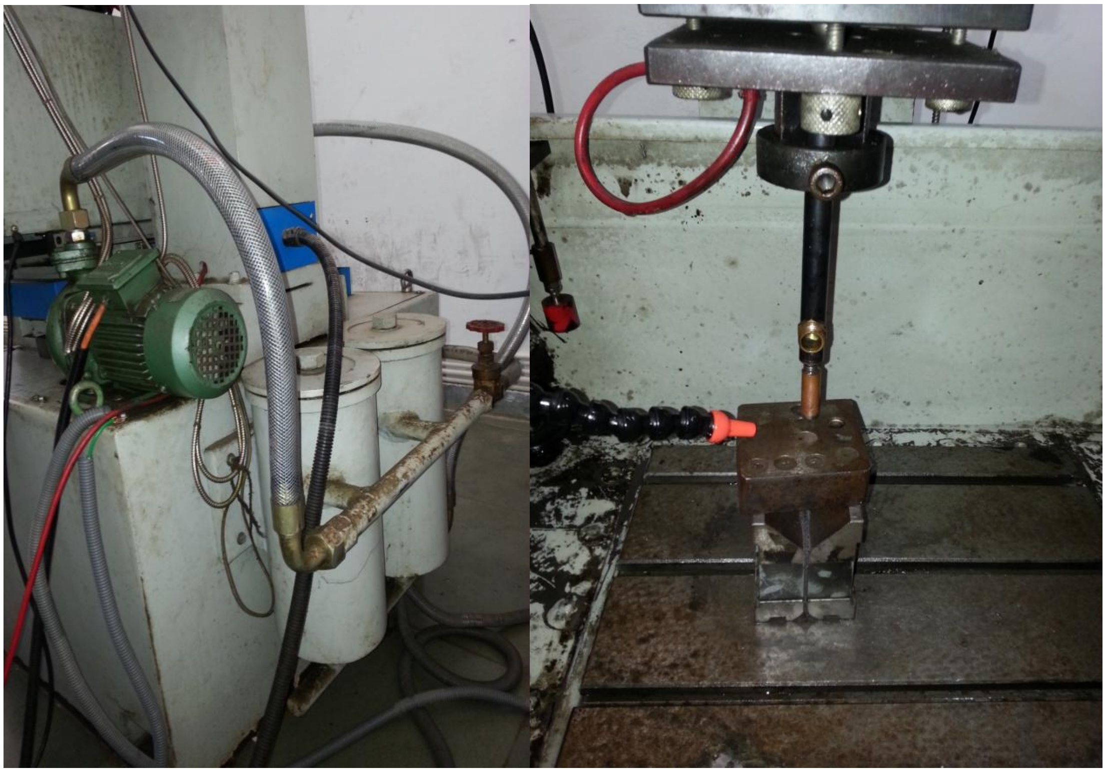

Figure 3: Electric Discharge Machine and Machining of Component

4. Results and Discussions

The results obtained from pilot experimental data were optimized using Taguchi L9 orthogonal array to get optimized conditions of EW. With the help of MINITAB 14 software the ANOVA analysis of the above data was performed to attain the plots for EW. The results are valid with 95% accuracy level.

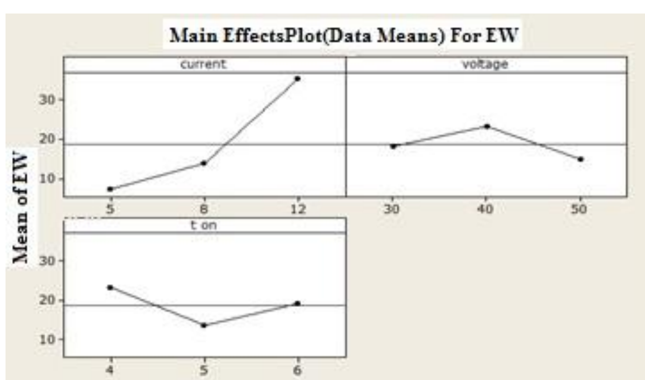

Figure 4: Effects of Process Parameters on EW of Non-Cryogenic Cooled Electrode

ISSN: 0971-1260

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Figures 4 display that the electrode wears rate for non-cryogenic cooled electrodes increases with the growth of peak current, voltage and pulse- on-time. That is due to the fact the discharge energy increases with the growth in peak current and pulse-on-time consequently leading to quicker electrode wear rate. It is also evident that electrode wear rate is minimum at first level of peak current and voltage. It very well may be seen from the figures that voltage had impact on electrode. But current is most significant factor affecting EW in both the cases. Investigation of ANOVA table for a given assessment empowers to choose which of the parameters wanted to be overseen.

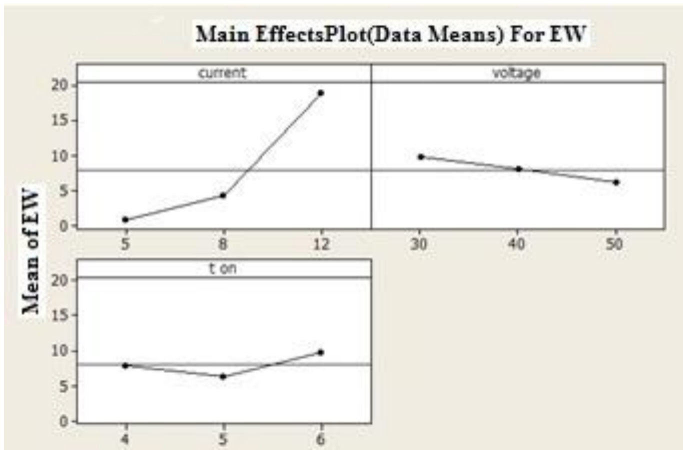

Figure 5: Effects of Process Parameters on EW of Cryogenic Cooled Electrode

Figures 5 shows the electrode wear for cryogenic cooled electrodes increases with the increase of peak current and voltage and pulse on time. This is because the discharge energy increases with the increase in peak current and pulse on time thus leading to faster electrode wear rate but due to cryogenic treatment the thermal conductivity of the electrode increases due to which heat entrapped in the electrode decreases and therefore there is less electrode wear rate because melting and vaporization in cryogenic cooled electrode is less.

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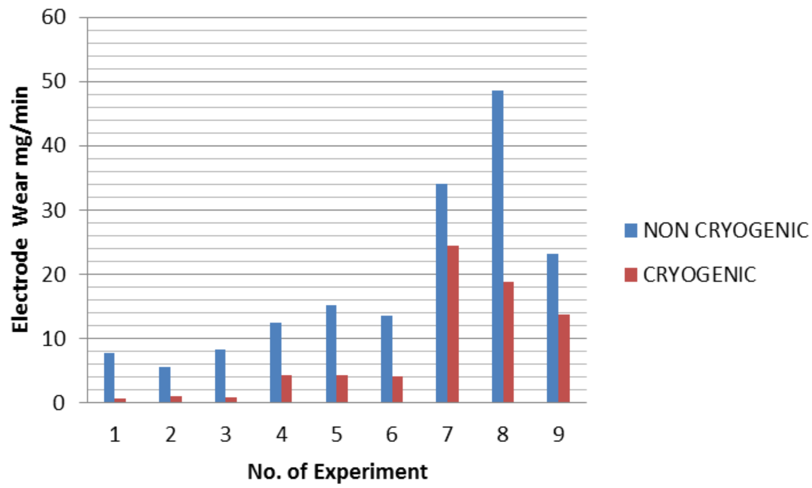

Figure 6: Comparison of EW for Non Cryogenic Electrode and Cryogenic Cooled Electrode

It is observed from the figure 6 that the EW values of the cryogenic cooled electrode utilized in EDM is notably decrease in comparison to the EW values of electrode utilized in traditional EDM.

The effects have been analyzed the use of ANOVA for figuring out the large elements affecting the overall performance measures. The analysis of Variance (ANOVA) for the imply electrode put on fee at 95% confidence level. In table 5 and table 6 the variant information for each factor and their interactions had been similarly tested to locate importance of each.

Table 5: Analysis of Variance for EW of Non-Cryogenic Cooled Electrode

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F_0	P	% Contribution
Current	2	0.0015232	0.0007616	2.10	0.323	81%
Voltage	2	0.0131435	0.0065718	18.10	0.052	15.5%
Ton	2	0.0034212	0.0017106	4.71	0.871	3.4%
Error	2	0.0007262	0.0003631			
Total	8	0.0188140				

Table 6: Analysis of Variance for EW of Cryogenic Cooled Electrode

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F_0	P	% Contribution
Current	2	558.09	279.05	27.13	0.036	90.6%
Voltage	2	19.27	9.63	0.94	0.516	3.1%
Ton	2	17.63	8.81	0.86	0.538	2.8%
Error	2	20.57	10.28			
Total	8	615.56				

5. Conclusion

- It can be clearly seen in figures 6 that EW achieved with cryogenic cooled electrode is lesser than the EW achieved with Non-cryogenic cooled electrode.
- Cryogenic treatment improves thermal conductivity of the electrode material subsequently limiting heat caught in it.
- Accordingly the melting and vaporization of the electrode minimizes and in this manner electrode wear rate is diminished.
- The results of the study show that there is 29.77% improvement in EWR while machining with cryogenic cooled electrodes.
- Finding the result of Electrode Wear Rate (EWR) peak current is most influencing factor and then gap voltage and after pulse on time.
- For good surface finish, sharp corner, tight tolerances and less EW cryogenic cooling of electrode is recommended.

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