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Study of the Effect of Cryogenically treated tools during Rapid Drill Electro-discharge machining of Ti-6Al-4V alloy

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Abstract

Now-a-days, alloys and super alloys viz. Titanium and Inconel have abundant applications in manufacturing complex parts in aircraft, automotive, and other industrial usages. Machining of these materials becomes extremely difficult with conventional machining process at precision level. These materials can be machined with ease; with desired accuracy with non-conventional machining process like electrical discharge machining (EDM) process. However, the high erosion of EDM tool during machining has emerged as the major obstacle for tool engineers to achieve productivity of the process. In view of this, the present work proposes an experimental investigation on cryogenically treated brass and copper electrodes which were used for machining of Ti-6Al-4V alloy workpiece. The effect of cryogenic treatment of tools on different performance measures like material removal rate (MRR), tool wear rate (TWR) and radial overcut is investigated. Experiments were conducted by full factorial design to find the outcome of important process parameters viz. current (I), pulse on-time (Ton), voltage(V) and pulse-off time (Toff) on responses viz. MRR, TWR and radial overcut. It has been observed that owing cryogenic treatment tool wear and radial overcut reduces considerably where as MRR remains unaffected.

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*Keywords:*EDM; Cryogenic treatment; Titanium alloy;TWR;Radial Over Cut

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1. Introduction

Electrical Discharge Machining (EDM) is commonly used for high-precision machining of extremely hard steels and exotic metals in mould and die making, particularly in the aerospace and electronics manufacturing units [1]. It is extensively used for machining of hard materials viz. Titanium, Tungsten, Inconel as well as brittle materials viz. ceramic mats: boron carbide, silicon carbide etc. and materials which are difficult to machine with traditional machining process. In material is removed owing to series of spark discharges is between both the tool and workpiece. Near about 8000°C to 12,000°C temperature is generated at the machining zone which is enough to melt the material from both tool and work piece. Finally, the molten metal is flushed away from the machining zone by flushing action of the dielectric fluid. Vinoth Kumar et al. [1] investigated the effect of cryogenic cooling on the electrode wear and they got 18% reduction in electrode wear. Surface roughness was also improved while machining with cryogenic electrode cooling. Sanjeev Kumar et al.(2017) [2] reported the effect of deep cryogenic treatment(DCT) on tool wear rate during electric discharge machining of Ti-5Al-2.5Sn titanium alloy by varying various process parameters namely cryogenic treatment of electrode material, peak current, pulse-on & off time and flushing pressure. Significant reduction in tool wear of copper-tungsten was observed. Srivastava and Pandey (2012) studied the effect of process parameters on the performance of EDM process with ultrasonic assisted cryogenically cooled electrode. Thus they found ultrasonic assisted cryogenically cooled electrode provide better tool life, tool shape retention ability and better surface integrity than conventional EDM [3]. Rahul et al. [4] investigated the surface integrity and metallurgical characteristics of the machined Inconel825 work surface in relation to Electrical Discharge Machining (EDM) using Cryogenically Treated Tool (CTT) in comparison with non-treated tool (NTT). They found Surface crack density was relatively less (73%) for the EDMed Inconel 825 work surface obtained by using CTT, as compared to the case of NTT. Anand Pandey et al.(2018) carried out study by using cryogenically treated Cu-tool electrode to fabricate hole on Ni-based super alloy (Inconel-718) using Taguchi s experimental design [5].Vinoth Kumar and Pradeep Kumar (2015) investigated machining of AISI D2 tool steel via conventional electrical discharge machining (CEDM) and Cryogenic cooled electrode in electrical discharge machining (CCEDM). They found surface roughness in CCEDM decreased by approximately 19% compared with that in CEDM. The results also indicated that the surface morphology of the workpiece machined via CCEDM was better than that of the workpiece machined via CEDM [6]. Mohanty, et al.(2016) proposed proposes an experimental investigation and optimization of various machining parameters for the die-sinking electrical discharge machining (EDM) process using a multi-objective particle swarm (MOPSO)algorithm. They observed that tool material, discharge current and pulse on- time have significant effect on machinability characteristics of Inconel 718[7]. Sahu, et al. (2015) studied Multi response optimisation of EDM parameters using data envelopment analysis [8].

Extensive study of past literature indicates that limited number of studies have been reported until now to study the machinability investigation on a relatively difficult to machine work material viz.Ti-6Al-4V material. Mostly researchers have focussed on a MRR, TWR as the responses and less attention has been given to radial overcut as the performance measure. It also shows that, limited numbers of studies have been reported till now when a relative low conductive and hard material like Ti-6Al-4V work piece is machined with a variety of tool materials viz. copper and brass. Ti-6Al-4V finds extensive application in manufacturing aeroplane, automotive body and engine components. Therefore, there exists a vital need to study the machinability investigation with a variety of electrodes in order to know the compatibility of the material with different electrodes. Hence, in this work,an attempt has been made to study the machinability of Ti-6Al-4V work piece with copper and brass electrodes on a rapid drill EDM machine. Both the electrodes were cryogenically treated in order to enhance the wearing resistance ability and performances of both the electrodes were compared with an objective to obtain the best combination of work-tool pair. Open circuit voltage, discharge current, pulse-on-time, pulse- of-time are selected as the important process parameters whereas, MRR, TWR and radial overcut as the important performance measure.

2. Experimental Details

2.1 Experimental Design

In present study current (I), pulse on time (T_{on}), voltage (V) and pulse off time (Toff) were considered as a input parameters and material removal rate (MRR), tool wear rate (TWR) and radial overcut were taken as response parameters. Full Factorial design 2^4 with four center points was used to carry out a total number of 20 experiments for each electrode. Table 2 presents the design factors and their selected variation levels. Twenty experiments were conducted while other parameters like sensitivity and rotational speed (48 rpm) kept constant.

Material removal rate was calculated by taking difference of weight before and after the machining and dividing it by machining time and density. Tool wear rate was calculated by taking difference of weight before and after the machining and dividing it by machining time. Similarly radial overcut was calculated by taking the half of the difference of diameter of the hole produced to the diameter of the tool as shown in below Table 1.

Table 1. Machining parameters and level selected

Factor Level	Current(A)	T_{on} (μs)	Voltage(V)	T_{off} (μs)
High Level(1)	5	5	30	6
Low Level(-1)	3	3	20	4

2.2 Cryogenic treatment

The experiments were conducted on rapid drill EDM machine as shown in Fig 1. This EDM machine is specially used to drill the hole having small diameter on hard metals. Machine is consisted of cross table, ram, rotating device, generator, fluid system, control panel, display centre and column. Machine has capability to use tap water as dielectric medium. It can drill from 0.3 to 3mm diameter hole up to large depth. The work piece used in this experiment was Ti-6Al-4V with 60 mm×60 mm×20 mm dimension. Through holes were machined on the workpiece. In present study tubular brass and copper electrodes with 1mm outside diameter (OD) and 0.3mm inside diameter (ID) were used during the experiments. Commercially available copper and brass are selected as the EDM tool material with an aim to improve the thermal and mechanical property by virtue of cryogenic treatment.

In this study cryogenic treatment were performed with the copper and brass electrodes. For this the electrodes are placed in the cryogenic chamber at -185^{0}C for 24 hours. The set up for the cryogenic treatment shown infig 2.

Table 2. Properties of the Brass and Copper electrodes before and after cryogenic treatment

Property	Untreated Brass	Cryogenically treated brass	Untreated copper	Cryogenically treated copper
Thermal conductivity (W/m.K)	109	114	386	405
Micro hardness (VHN)	212	230	369	390

3. Result and Discussions

Effect of Cryogenic Treatment on MRR, TWR and radial overcut with Copper Electrodes

Table3.Observations obtained for MRR, TWR &Radial overcut using Non cryogenic and cryogenic copper as tool electrode.

Run Order	I	Ton	V	Toff	Non cryogenic treated MRR	cryogenic treated MRR	Non cryogenic treated TWR	cryogenic treated TWR	Non cryogenic treated Radial overcut	cryogenic treated Radial overcut
1	5	3	30	4	0.00291	0.00305	0.005172	0.00466	0.1775	0.1655
2	5	5	30	6	0.00478	0.004322	0.004651	0.004166	0.397	0.2445
3	4	4	25	5	0.002935	0.002926	0.003913	0.00372	0.2795	0.2165
4	5	5	30	4	0.004958	0.004691	0.005208	0.00475	0.3265	0.245
5	5	3	20	4	0.002339	0.0025	0.00433	0.004	0.295	0.231
6	3	5	30	6	0.00183	0.001699	0.00275	0.002714	0.2758	0.1125
7	3	3	30	6	0.001456	0.001586	0.002272	0.001733	0.0675	0.067
8	5	3	30	6	0.003127	0.003947	0.00433	0.00425	0.239	0.123
9	3	3	20	6	0.001176	0.001401	0.0019	0.00125	0.1025	0.094
10	3	3	20	4	0.001716	0.00183	0.002857	0.002714	0.1315	0.1525
11	3	5	20	6	0.0016	0.00163	0.0025	0.00225	0.2095	0.1015
12	4	4	25	5	0.00286	0.003146	0.004	0.00375	0.2375	0.2465
13	4	4	25	5	0.00305	0.002837	0.00377	0.0036	0.245	0.237
14	3	5	20	4	0.001067	0.001177	0.00244	0.002384	0.2865	0.184
15	3	3	30	4	0.001544	0.001324	0.002125	0.002757	0.1605	0.1155
16	4	4	25	5	0.00291	0.002929	0.00409	0.004	0.2245	0.2155
17	5	5	20	4	0.00399	0.003974	0.005636	0.005526	0.3605	0.295
18	5	3	20	6	0.002974	0.00284	0.00375	0.003695	0.1765	0.1815
19	3	5	30	4	0.001782	0.001958	0.003274	0.00296	0.1995	0.1695
20	5	5	20	6	0.00337	0.003613	0.00545	0.00526	0.295	0.2205

Table 3 shows the experimental table along with obtained performance measures observations obtained for MRR, TWR and radial overcut using non cryogenic and cryogenic treated copper as tool electrode. Similarly, to the above table the observations are obtained for non-cryogenic treated and cryogenic treated brass electrodes. The effects of discharge current, pulse on time, voltage and pulse off time on MRR, TWR and radial overcut have been studied. Figure 3 and 4. shows the variation of MRR and TWR with respect to process parameters for cryogenic treated copper electrodes. MRR and TWR show highest value at 5A current. As current and Ton increases, TWR for both the cryogenic and non-cryogenic electrodes increases and with Voltage and Toff it increase first and then start decreasing. MRR increases with the increase in discharge current as shown in fig. 3. This could be due to an increase in discharge energy with increase in discharge current, which improves the rate of melting and evaporation. It is observed that cryogenic treated copper and brass electrodes contribute in slow TWR as compared to without cryogenic treatment. More refinement of grain particles observed in case of cryogenic treated tool electrodes. During cryogenic treatment as temperature goes down thermal vibration of atoms become weaker resulting in easy movement of electrons in metal. Due to this phenomenon electrical conductivity of tool electrodes increases which reduces bulk electrical heating of metal [1].

Figure1. Rapid Drill EDM

Figure 2.Cryogenic equipment

As the maximum material removal is given by the copper electrode among the four different electrodes used, as copper electrode has higher thermal conductivity as compared to the brass electrode further the MRR of cryogenic treated copper electrode and brass electrode are less than the non-cryogenic treated electrodes. In the cryogenic treatment of electrodes, the thermal conductivity of the electrodes increases. Due to increase in thermal conductivity of the electrode, heat applied during machining gets dissipated at a faster rate, which results in decrease in heat input at the inter-electrode gap [9]. This further resulted in decrease in MRR. In the EDM process heat is applied for every discharge pulse and rate at which the material is removed depend upon how fast the applied heat is absorbed or dissipated.

When the current increases from 3A to 5A, then more ionization of the dielectric fluid occurs. This means that more number of the ions and electrons are striking on the tool surface. The experiments show that TWR of cryogenic treated electrode is less than the non-treated electrode. The cryogenic treatment improve the thermal conductivity of electrode material and due to good thermal conductivity there is a reduction is the heat entrapment at the electrode & work piece interface, due to less heat at the interface, there is less volume of metal which gets melted and evaporated, which results in reduction in the tool wear rate [4]. Results obtained during experiments shows the radial overcut is also decreased in cryogenic treated tool electrodes than non-treated tool electrodes.
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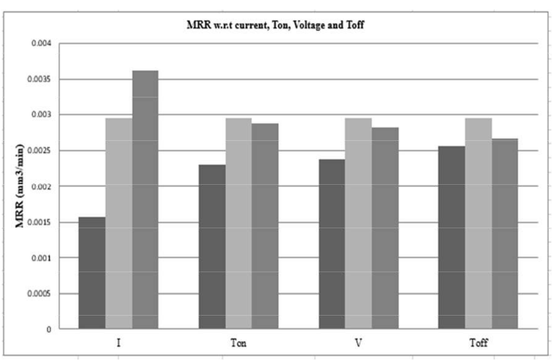

Figure 3.Variation of MRR with I, Ton, V and Toff for Cryogenic treated Copper electrodes

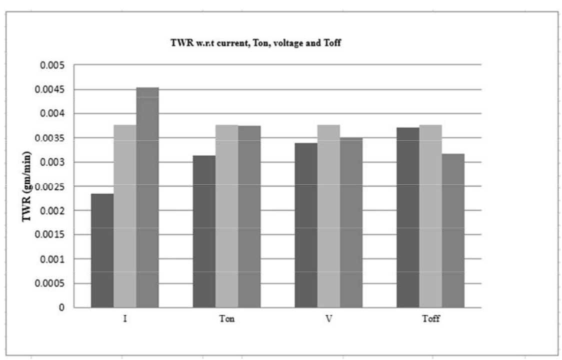

Figure 4. Variation of TWR with I, Ton, V and Toff for Cryogenic treated copper electrode

4. Conclusions

In this paper effect of cryogenic treatment of tool, current, pulse on time, voltage and pulse off time on MRR, TWR, radial overcut of Ti-6Al-4V is investigated. Full Factorial Design is used for design of experiments. The following conclusions were drawn from the study.

- Cryogenic treatment reduces the TWR. The reduction in TWR may be attributed due to increase in thermal and electrical conductivities of the tool material due to cryogenic treatment. Brass electrodes show more TWR than copper electrodes.
- Effect of cryogenic treatment on radial overcut for both the electrodes shows the improvement. Compared to brass electrode decrease in radial overcut is more significant for copper electrode. As the process of cryogenic treatment shows significant improvement in radial overcut, process can be thought to give better results in drilling hole with higher aspect ratio.
- Current has highest influence on MRR & TWR. Marginal increase in MRR occurred because increase in current produces strong spark, which produces the high temperature, causing more material to melt and erode from the work piece. TWR increases as current increases. When the current increase more ionization of the dielectric fluid occur which means that more number of the ions and electrons are striking on the tool surface, due to which more TWR occur.
- TWR increases as Ton increases Ton is 2^{nd} highest influence on MRR & TWR. Voltage and T_{off} having less influence on MRR &TWR. As Current and Ton increases, TWR for both cryogenic and Non- cryogenic electrodes increases and with Voltage & T_{off} TWR firstly increase and then start decreasing.

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References

[1] Kumar, S. V., & Kumar, M. P. (2015), Machining process parameter and surface integrity in conventional EDM and cryogenic EDM of Al SiCp MMC. *Journal of Manufacturing Processes* , *20*, 70-78.
[2] Kumar, S., Batish, A., Singh, R., & Bhattacharya, A. (2017), Effect of cryogenically treated copper-tungsten electrode on tool wear rate during electro-discharge machining of Ti-5Al-2.5 Sn alloy , *Wear*, *386*, 223-229.
[3] Srivastava, V., & Pandey, P. M. (2012). Effect of process parameters on the performance of EDM process with ultrasonic assisted cryogenically cooled electrode. *Journal of Manufacturing Processes*, *14*(3), 393-402.
[4] Datta, S., Biswal, B. B., & Mahapatra, S. S. (2017), Electrical discharge machining of Inconel 825 using cryogenically treated copper electrode: Emphasis on surface integrity and metallurgical characteristics , *Journal of Manufacturing Processes*, *26*, 188-202.
[5] Pandey, A., & Kumar, R. (2018), Some studies using Cryogenically treated Rotary Cu-tool electrode Electrical Discharge Machining , *Materials Today: Proceedings*, *5*(2), 7635-7639.
[6] Kumar, V., & Kumar, P. (2015), Experimental investigation of the process parameters in cryogenic cooled electrode in EDM , *Journal of Mechanical Science and Technology*, *29*(9), 3865-3871.
[7] Mohanty, C. P., Mahapatra, S. S., & Singh, M. R. (2016), A particle swarm approach for multi-objective optimization of electrical discharge machining process , *Journal of Intelligent Manufacturing*, *27*(6), 1171-1190.
[8] Sahu, J., Mahapatra, S. S., & Mohanty, C. P. (2015), Multi response optimisation of EDM parameters using data envelopment analysis , *International Journal of Productivity and Quality Management*, *15*(3), 309-334.
[9] Gill, S. S., & Singh, J. (2010), Effect of deep cryogenic treatment on machinability of titanium alloy (Ti-6246) in electric discharge drilling , *Materials and Manufacturing Processes*, *25*(6), 378-385.