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CRYOGENIC TREATMENT IN ELECTRO-DISCHARGE MACHINING – A REVIEW

Dhruv Mulchandani[1], Devesh Patel[2], Jayal Gandhi[3], Sachin Pandya[4], Dhavalkumar Ghoghalia[5]

[1,2,3,4,5]*Mechanical Engineering Department, Navrachana University Vadodara, (India)*

ABSTRACT

Metals are easy to machine by using nontraditional machining such as Electric Discharge Machine (EDM). But, during machining done over EDM machine, with the workpiece, even the tool wears out. This tool wear is not desired as it changes the tool geometry. To overcome this hurdle, cryogenic treatment is carried out for tool material before machining. The machining performances of the process are concluded in terms of Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness values.

Keyword: Cryogenic Treatment, EDM, MRR, Surface Roughness, TWR.

I. INTRODUCTION

Conventional machining of metals and their alloys produce a very high temperature which leads to wear and plastic deformation of tool cutting edge because of low thermal conductivity of the material and for this reason non-conventional machining is more preferable for machining metals and alloys [1]. The best method for drilling hard material, for the intrusive machining of automotive parts and hard to machine materials, ELECTRIC DISCHARGE MACHINE is widely used. Pulsating spark occurs between the gap (10-100μm), between tool electrode and workpiece, needed to avoid short circuiting, filled with a dielectric liquid preferably hydrocarbon oil (EDM Oil). A plasma channel which is an ionized and electrically conductive gas with High temperature (8000℃-1000℃ [1]) is formed between the two electrically conductive electrodes because of the discharge [2]. For every spark, electrode materials are evaporated and a small crater is generated on the tool electrode and workpiece surfaces which erodes material that are re-solidified in the dielectric liquid forming spherical debris particles, which are then by means of flushing are removed with the help of dielectric flow from the gap. Plasma channel collapses resulting in a recombination of ions and electrons that recovers the dielectric strength [2].

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As the EDM has become an indispensable operation in the manufacturing processes, it has been a luring interest for the researchers. But there are some barriers that EDM face while machining hard materials such as high tool wear and low surface finish. To reduce the tool wear, cryogenic treatment can be performed on the tool. Cryogenics, is the science between temperatures -150° C to -273.15° C which is absolute zero. In cryogenic treatment process the tools is being dipped into the liquid nitrogen (LN_2) for certain time duration. The cryogenic treatment is carried out in 3 main stages namely cold down stage, soaking stage and warm up stage [3].

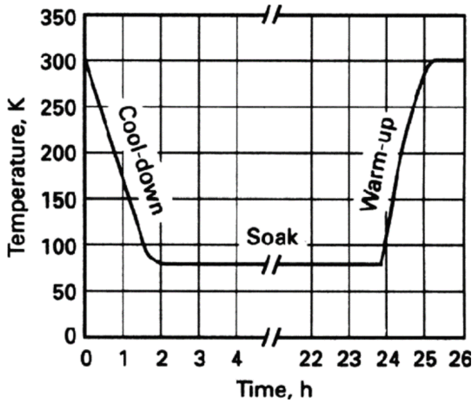

Figure 1: Stages of Cryogenic Treatment [3].

Cryogenic treatment relieves the stress when subjected for a period of time as the cryogenic treatment eliminates austenite via isothermal martensite phase transformation at low temperature. In addition to this, during the cryogenic treatment austenite and martensite endures high amount of contraction due to low temperature. The high degree of stress decompose martensite. The defect generated acts as a preferential site for wandering carbon atom. The retained austenite reduction, higher carbide percentage increase adhesive and erosive wear, hardness, fatigue strength and corrosion resistance [4, 5].

II. LITERATURE REVIEW

TOOL WEAR RATE (TWR)

Abdulkareem et al., (2010)

They have studied the effect of electrode cooling by liquid nitrogen at a temperature of −195°C on copper electrode. Electro discharge machining was carried out on titanium alloy (Ti-6Al-4V) workpiece.

They observed that it was possible to reduce electrode wear ratio up to 27% by electrode cooling. The TWR increases with the current and pulse on time. It means that high current and long pulse duration results in high TWR. Also, TWR decreases as pulse off-time increases from 4μs to 5μs. But as pulse off-time increases to 6μs, a sharp increase is observed in the TWR during machining without electrode cooling as against sharp reduction

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in the TWR during the EDM with electrode cooling by liquid nitrogen. The gap voltage resulted in a gradual reduction in TWR for the two conditions during EDM process [6].

Abdulkareem et al., (2009)

In their investigation they have supplied liquid nitrogen to flow through the electrode as coolant during the EDM machining. They conducted experiment on EDM of titanium alloy (Ti-6Al-4V) using copper electrodes. The response factors investigated are the electrode wear and surface finish of the workpiece. They observed that it was possible to reduce electrode wear ratio up to 27% by electrode cooling. The cooling effect of liquid nitrogen improves thermal conductivity of the electrode materials thereby minimizing heat trapped in electrode. As a result, melting and vaporization of electrode material minimizes and, thus, wear rate of electrode is reduced [7].

Ahmad and Lajis, (2013)

They have conducted experiments on the Inconel 718. Electrode was of copper material. They have concluded that the longer pulse duration used may improve the EWR but affect adversely when higher peak current is used [8]

Gill and Singh (2010)

They have investigated the Effect of deep cryogenic treatment (DCT) on machinability of Ti 6246 alloy in electric discharge drilling (EDD) by conducting experimental investigations on the production of 10mm diameter blind holes with electrolytic copper tool. Result shows that the Tool wear rate of copper electrode is less when drilling DCT Ti 6246 alloy workpiece as compare to tool wear rate of non-treated tool. The material being machined takes a significant role in electrode wear rate. Electric sparks generated during EDD decompose the kerosene dielectric into carbon and hydrogen and the carbon penetrates into the machined surface depending on the microstructure of material to be machined to form TiC layer. The melting point of TiC is reasonably high than that of Ti 6246 alloy, hence large discharge energy is required for breaking this layer before the actual drilling. That is why the presence of TiC layer increases the TWR and reduces the MRR [3].

Kumar et al., (2012)

Experimental investigations have been carried to evaluate machining efficiency with additive powder mixed in dielectric fluid of electrical discharge machining on Inconel 718 with copper and cryogenically treated copper electrodes. They found that both TWR and WR are minimum with the use of cryogenically treated copper electrode. This may be due to increase in wear resistance, hardness, toughness, and improvement in thermal and electric properties of the electrode after cryogenic treatment [9].

Mathai V.J.,Vaghela R.V.,Dave H.K.,Raval H.K.,And Desai K.P. (2013)

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They observed that cryogenic process increases the homogeneity of the crystal structure, dissolving gaps and dislocations of the alloying elements and consequently, the resulting improved structural compactness improves electrical conductivity. When thermal conductivity increases, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear [10].

R. Thanigaivelan et al. (2015)

This study observed that copper is subjected to more wear compared to other electrodes. The cryogenic treated copper electrode shows significant improvement in TWR. TWR for copper electrode is found to increase up to half way in the beginning but then starts decreasing with further increase in voltage.

The cryogenic treated copper and brass electrode produces lower TWR compared with other electrodes. The hardness test using Rockwell hardness at HRB scales is performed on the untreated and cryogenic treated tools. The HRB value for cryogenic treated brass and brass was 95 and 78, respectively and for cryogenic treated copper and copper, it was 88 and 72, respectively. Hence, the HRB values of cryogenic treated tools justify the lower TWR.

The cryogenic treated copper electrode is found to have less TWR compared to other electrodes. The cryogenic treated copper electrode improves the TWR by 24 times compared to copper electrode at pulse on time of 150µs, current of 3A and voltage of 70V [11]

Singh and Abbas (2013)

They have been conducted experiments on the workpieces are 3 types of Alloy Steel, 2 samples of each, out of which one is cryogenically treated and other is non-cryogenically treated): (1) High Carbon High Chromium (HCHCr), (2) WC 6 and (3) WC 9. Electrodes used of graphite material. They have concluded that cryogenic treatment majorly improves the tool wear. The best improvement in Tool Wear (72.22%) is reported by WC 9 followed by HCHCr (47.12%) and then WC 6 (30.07%) [12].

Srivastava and Pandey (2012)

They performed experiments to find the effect of ultrasonic assisted cryogenically cooled copper electrode during electro discharge machining of M2 grade high speed steel. Results shows that TWR increases with increase in discharge current. Tool wear rate were found to be lower in ultrasonic assisted cryogenically cooled copper electrode as compared to conventional EDM for the same set of process parameters.

The shape of the electrode has also been measured and it was found that the shape retention was better when cryogenically cooled electrode as compared to conventional EDM process. An increase in pulse-on time decreases the values of electrode wear ratio. This is due to the fact that the diameter of the discharge column increases with the pulse duration which eventually reduces the energy density of the electrical discharge on the discharge spot. The value of TWR increases with an increase of the duty cycle [13].

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Yildiz et al., (2010)

They have studied effect of cryogenic treatment on beryllium-copper alloy as a workpiece subjected to around -150° F for cold treatment and to around -300° F for cryogenic treatment. And the effects of these cold and cryogenic treatments on the machinability of beryllium-copper workpieces in electro discharge machining have been investigated. TWR was increased by about 50% between 10 A and 25 A working currents. However, there was a decrease about 14% in EWR between 20 µsec and 80 µsec pulse durations. On the other hand, alterations in TWR results in using of cold and cryogenically treated Be-Cu workpieces are negligible [14]

II MATERIAL REMOVAL RATE (MRR)

Ahmad and Lajis, (2013)

They have been conducted experiments on the Inconel 718. Electrodes used of copper material. They have concluded that the peak current is the most influence parameter for achieving high MRR while for pulse duration it shows insignificant for improving MRR [8].

Gill and Singh (2010)

They have investigated the Effect of deep cryogenic treatment (DCT) on machinability of Ti 6246 alloy in electric discharge drilling (EDD) by conducting experimental investigations on the production of 10mm diameter blind holes with electrolytic copper tool. The MRR for both the workpieces decreases as with longer drilling operations. It may be due to inability of the flushing jet to wash away debris from the holes of higher depth.

Also it is interesting to note that MRR of DCT workpiece is less than the MRR for non-treated workpiece for 30 min and 60 min drilling time, but for longer durations of drilling (90 min, 120 min, 150 min, and 180 min) the trend is reversed. So, it is very much evident that there exist a breakeven drilling time beyond which the deep cryogenic treatment of workpiece can enhance the MRR resulting in relatively productive [3].

Kulwinder and Dinesh, (2015)

They have studied the effect of copper tungsten and cryogenic copper tungsten electrode on material removal rate during electrical discharge machining of H11 tool steel at straight polarity.

MRR increases with the increase in peak current for both electrode, but MRR is more with the cryogenic copper tungsten (CuW) electrode as compared with the copper tungsten electrode. MRR decreases with the increase in gap voltage from 40 to 50 volt and when gap voltage increases from 50 to 60 volt material removal rate increases for copper tungsten electrode and in the case of cryogenic copper tungsten electrode MRR increases with increase in gap voltage from 40 to 50 volt and further decrease with increases in gap voltage from 50 to 60 volt.

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MRR decreases when duty cycle increases from 0.72 to 0.82 and MRR also decreases with further increase in duty cycle from 0.82 to 0.92 for copper tungsten electrode. MRR remains same when duty cycle increase from 0.72 to 0.82 and when duty cycle increases from 0.82 to 0.92 MRR decreases for cryogenic copper tungsten electrode [15].

Kuppan et al., (2008)

This paper reports on an experimental investigation of small deep hole drilling of Inconel 718 using the EDM process. The parameters such as peak current, pulse on-time, duty factor and electrode speed were chosen to study the machining characteristics. Results shows that the individual and higher-order effects of factors, such as peak current, duty factor, electrode rotation and higher order effects of pulse on-time, and the interaction effects between peak current and duty factor, and peak current and electrode rotation have significant contributions in MRR. The MRR increases with the increase in peak current, duty factor and electrode speed [16].

L. Liqing, S. Yingjie (2013)

This paper listed the result as, for a peak current of 29A, the MRR was improved by 54%, and for a peak current 20A, MRR was improved by 29.7%, in relation to the EDM results for non-cryogenically treated work pieces [17]

Mathai V.J.,Vaghela R.V.,Dave H.K.,Raval H.K.,And Desai K.P. (2013)

This study paper derived that material removal rate increases with increase in current and pulse ON time irrespective of the cryogenic treatment condition applied on the tool. After performing cryogenic treatment, the electrical and thermal conductivity of the electrode material increases, which reduces the bulk heating and thereby excessive melting of the tool and the work piece and resulting in relatively lower MRR [10]

R. Thanigaivelan et al. (2015)

In this study, for copper electrode, the machining rate slowly increases. At higher voltage, large discharge takes place in gaseous zone resulting in impaired material removal. The Cryogenic Treated Brass electrode shows no significant change and in Brass electrode, the chance for recast layer is minimal [11].

Raghu et al., (2014)

They have studied effect of cryogenic treatment on EN 31 steel as a workpiece subjected to around -120° C for cold treatment and to around -180° C for cryogenic treatment. And the effects of these cold and cryogenic treatments on the machinability of EN 31 steel workpieces in electro discharge machining have been investigated. Hear graphite material was used as electrode. They had conclude that the optimized parameters for the EDM process for the graphite electrode and both the work pieces in common for MRR are current 20A,

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voltage 30V, duty factor 40, and for surface roughness are current 10A, voltage 50V and duty factor 30. Significant increase in MRR had been observed on cryogenically treated work piece at most of the levels [18].

Singh and Abbas (2013)

They have been conducted experiments on the workpieces are 3 types of Alloy Steel (2 samples of each, out of which one is cryogenically treated and other is non-cryogenically treated): (1) High Carbon High Chromium (HCHCr), (2) WC 6 and (3) WC 9. Electrodes Used Graphite electrode (12 mm in diameter) and Diectric Used EDM oil SEO 450. Some increment is reported in Material Removal Rate (MRR) in all the three types of alloy steels after cryogenic treatment but in case of WC 6, it is comparatively less affected [12]

Srivastava and Pandey (2012)

They performed experiments to find the effect of ultrasonic assisted cryogenically cooled copper electrode during electro discharge machining of M2 grade high speed steel. Results shows that the MRR increases with the increase in discharge current. This could be due to an increase in discharge energy with increase in discharge current, which improves the rate of melting and evaporation. Also it can be seen that MRR decreases with the increase in pulse-on time initially but after a certain value of pulse-on time, it increases. This is due to re-solidification of some of the molten metal on the workpiece due to lower discharge energy initially, which leads to decrease in MRR. Results also shows that an increase in the duty cycle leads to increase of the MRR [13].

Yildiz et al., (2010)

They have studied effect of cryogenic treatment on beryllium-copper alloy as a workpiece subjected to around -150° F for cold treatment and to around -300° F for cryogenic treatment. And the effects of these cold and cryogenic treatments on the machinability of beryllium-copper workpieces in electro discharge machining have been investigated. Hear C-122 copper material was used as electrode, and Commonwealth oil EDM-244 as a dielectric medium. Experimental results showed about 20-30 % increase in material removal rate of cold and cryogenic treated workpieces. Current is the most effective parameter affecting the MRR. Reason for this behavior is, when the working current is increased, more energy is supplied to the machining process and therefore, more material is removed. The MRR variations could be assumed negligible depending on pulse durations. In the case of using treated workpieces, MRR increased averagely by about 19% with cold treatment and by about 20% with cryogenic treatment according to data means. It should be noted that MRR differences between EDM of non-treated, cold-treated and cryogenically treated Be-Cu workpieces are increased remarkably by increasing working current. On the other hand, melting point of a material can decrease by reduction in hardness, which can be result of a cold or cryogenic treatment and the reduction in melting point will increase MRR [14].

III SURFACE ROUGHNESS (R_A)

Abdulkareem et al., (2009)

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In this investigation they have concluded that surface roughness was also reduced while machining with electrode cooling. 8% improvement in surface roughness with cooling by liquid nitrogen. They have also concluded that the current and pulse and pulse on time are most significant parameters which affect to surface roughness. The high temperature during the EDM reduces the thermal conductivity of the electrode material and the heat generated during the process cannot pass easily through the electrode. This results in melting and vaporization of electrode material. But during cryogenic cooling, the low temperature of liquid nitrogen cools the electrode and reduces its melting and vaporization resulting in smoother surface of the electrode with a uniformly distributed sparks. This reproduces a better surface of the workpiece [7]

Gill and Singh (2010)

They have investigated the Effect of deep cryogenic treatment (DCT) on machinability of Ti 6246 alloy in electric discharge drilling (EDD) with electrolyte copper electrode. The roughness values for DCT Ti 6246 alloy workpiece are less as compared with the non-treated workpiece on both the base of the blind hole as well as side walls, irrespective of the drilling time. So the surface finish produced on the DCT Ti 6246 alloy workpiece is better than the non-treated workpiece. Overall, the surface roughness increases as we go for longer durations of drilling for both the workpieces [3].

L. Liqing, S. Yingjie (2013)

This paper suggested that the Surface Roughness improvements were 0.7% and 4% for runs with peak currents of 29A and 20A, respectively for cryogenically treated workpiece then their anti-parts [17].

Mathai V.J.,Vaghela R.V.,Dave H.K.,Raval H.K.,And Desai K.P. (2013)

From this paper, it is worth noting that no significant effect of cryogenic treatment has been observed on improvement of surface quality of the workpiece. For lower current settings, the electrode treated for 24 hours yielded relatively good surface quality when compared when compared with other two electrode variations [10]

Singh and Abbas (2013)

They have been conducted experiments on the workpieces are 3 types of Alloy Steel (1) High Carbon High Chromium (HCHCr), (2) WC 6 and (3) WC 9. Electrode material was graphite. They have concluded that cryogenic treatment majorly improves surface roughness as compared to material removal rate. The best improvement in surface finish (57.36%) is reported by WC 6 followed by WC 9 (42.40%) and then HCHCr (41.53%). The optimum input parameters also get altered due to cryogenic treatment. It is observed that for the best value of surface roughness, voltage undergoes a shift to the higher side for HCHCr [12].

Srivastava and Pandey (2012)

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They performed experiments to find the effect of ultrasonic assisted cryogenically cooled copper electrode during electro discharge machining of M2 grade high speed steel. Result shows that surface roughness increases with discharge current up to 6 A and then slightly decreases for all the processes. As the discharge current increases, the discharge energy density and the impulsive force increase and results in the formation of deeper and larger discharge craters, which in turn increases surface roughness. It can be observed that increase in pulse-on time results in an increase in the surface roughness. This is due to the expansion of plasma channel with an increase in pulse-on time.

Yildiz et al., (2010)

They have studied effect of cryogenic treatment on beryllium-copper alloy as a workpiece subjected to around -150° F for cold treatment and to around -300° F for cryogenic treatment. Results shows that the surface roughness is affected by both current and pulse duration, roughness increases with the current and pulse on time in all the cases. The differences between results of cold and cryogenically treated workpieces are negligible. Variation in surface roughness value of the non-treated workpiece with respect to current is more as compare to cold and cryogenically treated workpiece [14].

IV MATERIAL PROPERTIES

Collins and Dormer (1997)

He stated that the variable cryogenic holding times did not affect hardness of D2 tool steel, but hardness of H13 tool steel increased with the time. However, it also revealed that increased time at cryogenic temperatures improved wear resistance of D2 tool steel. A minimum soaking time of 24 hours at cryogenic temperature has been recommended to derive maximum benefit from cryogenic treatment in terms of carbide count and consequently wear resistance. The conclusion is that the longer the holding time at the cryogenic temperature, the finer the carbide distribution is and the greater the increase in wear resistance for tool steels [19].

Das et al. (2008)

They have carried out series of wear tests on material AISI D2 steel samples subjected to cryogenic treatment at 77K for different durations.

The wear resistance of the AISI D2 steel gets considerably enhanced by cryogenic treatment, compared to that of the conventionally treated one, irrespective of the time of holding at 77 K. It is also marked improvement in wear resistance of the cryogenic treated specimens compared to the conventionally treated [20].

Singh et al., (2010)

Cryogenic treatment improves mechanical properties like wear resistance, toughness and resistance to fatigue cracking. This is due to the, transformation of retained austenite into stable martensite. The phase transformation leads to the increase in density of dislocations and vacancies which in turns enhance the diffusion coefficient of

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carbon. This microstructure evolution induces the precipitation of very tiny carbides during the cryogenic treatment [3].

V CRYOGENIC TREATMENT METHODS

Abdulkareem et al. (2009)

The electrode is 100mm long with inlet hole of 16mm diameter above 10mm solid end for liquid N2. The outlet for liquid nitrogen is a 3mm hole located opposite the inlet hole. Twenty-seven percent reduction in EW was obtained during the EDM of titanium alloy with electrodes cooled by liquid nitrogen compared to the EDM of the same material without cooling of electrode [7]

Kumar and Kumar (2015)

The electrode was modified to allow LN2 to flow in from the lower region and exit at the upper region of the electrode. The electrode was 140 mm long. It had an inlet hole with a diameter of 12 mm that was located 90 mm from its top surface. The bottom 12 mm was solid, and a hole with a diameter of 3 mm was made at a depth of 0.08 mm at the center of the solid end. The outlet for LN2 was a 5 mm-hole located opposite the inlet hole.

Carbon is reduced by 11% in the elemental composition of the workpiece specimen because of the cryogenic cooling of the electrode. The average surface roughness in LN2 cooling of the electrode is reduced by 5%-10% compared with that in EDM. The results indicate that wear is reduced by 10%-21% under LN2 cooling of the electrode compared with under EDM.

Singh Jaspreet et al.

Experimental investigations have been made to compare the machining characteristics of three die steel materials, before and after deep cryogenic treatment using EDM

Deep cryogenically treatment of electrodes is done using 9-18-14 cycle. The temperature of cryogenically chamber is ramp down from atmospheric temperature to -184 °C in 9 hrs. The soaking period is 18 hrs. The temperature of cryogenically chamber is ramp up from -184 °C to atmospheric temperature in another 14 hrs. In this way 9-18-14 cycle is complete.

The results of study suggest that cryogenic treatment has a significant positive effect on the performance of work pieces, tool wear decreases and surface finish of the work piece after machining improves sharply for all three die steels

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VI CONCLUSION

From literature review it is understood that cryogenic treatment has a significant positive effect on the performance of EDM. Observation made from literature review is as describe below.

1. Application of Cryogenic treatment to EDM is also one of efficient process for improving the output parameters of EDM process like MRR, TWR and surface roughness.
2. It is observed that major work has been concentrated on cryogenic treatment of tool.
3. Studies have been carried out on the materials Titanium Alloy (Ti-6246, Ti-6Al-4V, Ti-6246), alloy steels (High Carbon High Chromium (HCHCr), WC 6, WC 9), AISI D2 steel, Al-10%SiCP, M2 grade high speed steel.
4. Maximum improvement is achieved when cryogenic treatment is applied for 24 hours.
5. Mostly copper and graphite are used as electrode.

The review of literature indicates that there is limited published work on the effect of variation in current, pulse on time when cryogenic treatment is applied to only tool or tool and workpiece both. This study shall be carried out in cryogenic treated tool & workpiece during EDM. The result shall be compared with those observed under non cryogenic-treatment condition. Effectiveness of cryogenic treatment shall be critically analyzed and discussed.

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