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Study of the Cryogenically Cooled Electrode Shape in Electric Discharge Machining Process

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Abstract**—**Electrical discharge machining (EDM) is well established machining technique mainly used to machine complex geometries on difficult-to-machine materials and high strength temperature resistant alloys. In the present research, the objective is to study the shape of the electrode and establish the application of liquid nitrogen in reducing distortion of the electrode during electrical discharge machining of M2 grade high speed steel using copper electrodes. Study of roundness was performed on the electrode to observe the shape of the electrode for both conventional EDM and EDM with cryogenically cooled electrode. Scanning Electron Microscope (SEM) has been used to study the shape of electrode tip. The effect of various parameters such as discharge current and pulse on time has been studied to understand the behavior of distortion of electrode. It has been concluded that the shape retention is better in case of liquid nitrogen cooled electrode.

Keywords**—**cryogenic cooling, EDM, electrode shape, out of roundness.

I. Introduction

ELECTRICAL Discharge Machining (EDM) is a thermoelectric process that is based on removing material from a conducting workpiece by means of a series of repeated electrical discharges between tool electrode (cathode) and the workpiece (anode) in the presence of a dielectric fluid. The electrode is moved towards the workpiece by servo controlled feed until the gap is small enough in the region of 25-50 μm, so that the applied voltage ionizes the dielectric. Short duration discharges of the order of 0.5 μs to 4000 μs are generated in a liquid dielectric gap. The material is removed with the erosive effect of the electrical discharges from electrode and workpiece. Thermal energy generates a channel of plasma between the cathode and anode at a temperature in the range of 8000 to 20000°C initializing a substantial amount of heating and melting of material at the surface of each pole [1]. When the pulsating direct current supply is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten material from the pole surfaces in the form of microscopic debris [2]. In EDM, there is no direct contact between the electrode and the workpiece so mechanical stresses, chatter and vibration problems during machining are eliminated [3]. Materials of any hardness can be machined as long as the material can conduct electricity [4].

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Electrode wear is a major problem in EDM process. In most of the EDM operations, the contribution of the tool cost to the total operation cost is more than 70% [5]. Due to this reason, the wear of the tool has to be carefully taken into consideration in planning EDM operations. When electrode wear occurs, the required geometrical dimensions and form of the electrode are not reproduced on the workpiece. The machinability of a material is a factor of its thermal and electrical properties in EDM. Material's electrical resistivity is dependent on its temperature. Copper electrode has low electrical and thermal resistance, resulting in a more effective energy transfer to the work piece [6].

Significant contributions have been made in evaluating the effect of cryogenic cooling on various materials during machining. Dhar et al. [7] investigated the role of cryogenic cooling by liquid nitrogen jet on cutting temperature in turning plain carbon steel under varying cutting speed and feed. Silva et al. [8] studied on cryogenically treated high speed steel tools showing micro-structural changes in the material that can influence tool lives and productivity significantly. The study was aimed to verify the effect of cryogenic treatment on M2 grade high speed steel tools after using either laboratory or shop floor tests in an automotive industry. Improvements were found for the treated tools in some of these tests. Paul and Chattopadhyay [9] employed liquid nitrogen in the form of jet in the surface grinding of various steel specimens and compared it with the surface ground under dry conditions and with soluble oil. They found appreciable improvement in the chip formation mechanism and reduction in specific energy requirement, grinding temperature and residual stress in cryo-grinding when compared with dry grinding and grinding with soluble oil. Kumar and Choudhury [10] investigated dry cutting conditions and cryogenic LN2 spraying in machining of stainless steel 202 with a carbide insert in terms of tool wear. They observed an improvement of about 37.39% in the flank wear with cryogenic machining over the dry cutting. They also observed about 14.83% improvement over dry cutting with cryogenic LN2 spraying by a nozzle in machining of stainless steel 202. Ahmed et al. [11] modified a tool to apply liquid nitrogen as coolant through a hole made in the tool so that liquid nitrogen can be directly applied to the machining zone during machining of stainless steel with carbide tools coated with titanium carbonitride. It was found that the tool life increased by more than four times on the application of liquid nitrogen using the modified tool. 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. Kim and Ramulu [12] used cryogenically treated carbide tools in drilling thermoplastic composites for investigating machinability in terms of the drilled hole quality and tool wear. The cryogenically treated carbide tools produced better hole qualities than the conventional carbide tools but the conventional carbide tools showed better wear resistance than the cryogenic treated carbide tools. Abdulkareem et al. [13] studied the cooling effect of copper electrode on the die-sinking of electrical discharge machining of titanium alloy (Ti-6Al-4V). Current intensity, pulse on-time, pulse off-time and gap voltage were considered as the machining parameters, while electrode wear and surface roughness were the responses. Analysis of the influence of cooling on the responses was carried out and presented in their work. It was found that electrode wear ratio reduced up to 27% by electrode cooling. Surface roughness was also reduced while machining with electrode cooling.

It can be observed from the literature survey that many attempts have been made to use cryogenic liquid in conventional machining processes like turning, grinding etc., however only one attempt [13] appears to be made in EDM where the fluid has been introduced into the electrode (tool) as coolant, but no literature was found regarding the effect of cryogenic fluid on the shape of the electrode.

In the present research, the objective is to study the shape of the electrode and establish the application of liquid nitrogen in reducing distortion of the electrode during electrical discharge machining of M2 grade high speed steel using copper electrodes. Study of roundness was performed on the electrode to observe the shape of the electrode for both conventional EDM and EDM with cryogenically cooled electrode. Scanning Electron Microscope (SEM) has been used to study the shape of electrode tip. The effect of various parameters such as discharge current, pulse on time, duty cycle and gap voltage has been studied to understand the behavior of distortion of electrode.

II. Planning Of Experiments

A. Details of work piece and tool assembly

M2 grade high speed steel work pieces have been spark eroded using copper as electrode material. The workpiece used for this study was high speed steel having the dimension of 15×15×15 mm. The hardness of the work piece was 35 HRC. The chemical composition of the workpiece is given in Table I. Circular holes of 7 mm diameter were machined on the workpiece.

TABLE I
CHEMICAL COMPOSITION (WT. %) OF HIGH SPEED STEEL

C	V	Cr	Mo	W	Fe
0.99	2.06	4.21	5.03	6.10	Rest

Copper has been chosen as the electrode material because of its lower electrical and thermal resistance. The electrode tip diameter was chosen suitably as 7 mm. The length of the electrode was kept 70 mm to ensure maximum heat transfer from the electrode tip. The electrode attachment was made of copper to maintain its conductivity. The upper part was made to fit the attachment into the electrode collet. The central part was the container in which heat exchange between liquid nitrogen and the electrode took place. The liquid nitrogen was stored in a Dewar and passed into the container through an attachment. The electrode setup has been shown in fig 1.

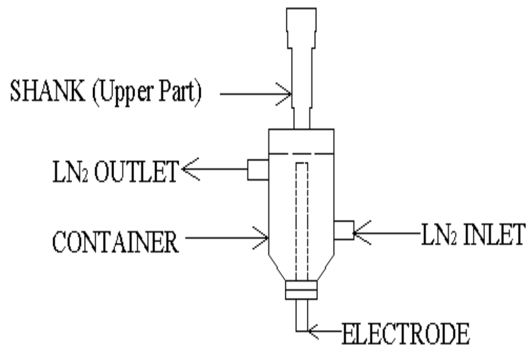


Fig. 1 The schematic diagram of electrode attachment [14]

B. Selection of process parameters

Die sinking EDM experiments have been carried out on EDM machine (Model PS LEADER ZNC, Electronica, India). In all the experiments, kerosene oil was used as dielectric medium. The performance of EDM on steel is governed by a large number of interactive variables [15], [16]. However to facilitate the experimental work, four controllable variables have been considered namely discharge current, pulse-on time, duty cycle and gap voltage. The experiments were conducted keeping these process parameters at various levels. The range for each of the process parameter was selected based on the review of past literature [17], capabilities of the EDM machine and preliminary experiments conducted. The range of the discharge current was selected from 3 to 7 A, pulse-on time was selected from 100 to 500 µs, duty cycle was fixed from 0.24 to 0.88 and gap voltage has been selected from 50 to 70 V respectively. The machining time was fixed suitably and kept 25 minutes for all the experiments. The range of process parameters have been given in Table II. Total 31 experiments have been carried out in this study.

TABLE II
RANGE OF PROCESS PARAMETERS

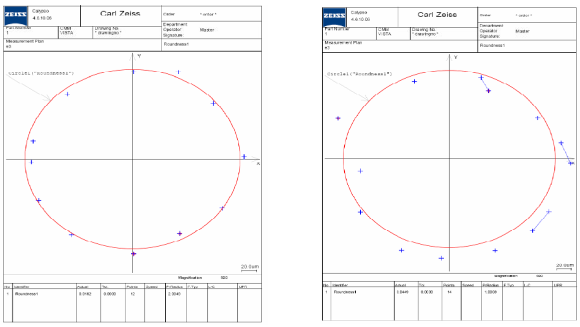
Parameters	Symbol	Range
Discharge Current (A)	Ip	3,4,5,6,7
Pulse On Time (µs)	Ton	100,200,300,400,500
Duty Cycle	DC	0.24, 0.40,0.56,0.72,0.88
Gap Voltage (V)	Vg	50,55,60,65,70

Measurement of the electrodes was performed so as to determine the change in the shape of the electrode after machining in both EDM process and cryogenic assisted EDM process. This measurement was performed on Carl Zeiss Coordinate Measuring Machine and Calypso software. The change in roundness of the tool has been considered as the response in the study to represent the shape of the electrode. A Scanning Electron Microscope (SEM) (model EVO 50) has been used for observing surface topography of the electrode to study the shape of electrode tip.

III. Results And Discussion

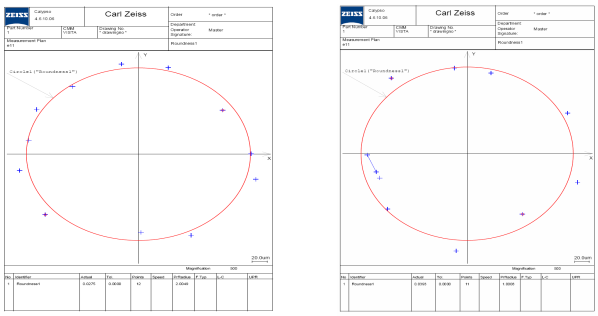
An ideal EDM electrode should not only remove the maximum amount of material from the workpiece, but should also be capable of resisting self erosion. The electrical erosion resistance of EDM electrodes is determined by a combination of thermo-physical and mechanical characteristics [18]. The effect of cooling through 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 electrode wear rate and electrode distortion is reduced.Measurement of the roundness of the electrode has been performed, both before and after machining, to determine the out of roundness of the electrode after machining, both in conventional EDM and cryogenic assisted EDM process using coordinate measuring machine. 14 random points were marked on the periphery of the electrode tip as shown in fig 2. Calypso software was used to evaluate the selected points in order to determine the out of roundness of the electrode.

(a) **(b)**



discharge current of 7 A, pulse-on time of 300 µs, duty cycle of 0.56 and gap voltage of 60 V

(a) **(b)**



discharge current of 5 A, pulse-on time of 100 µs, duty cycle of 0.56 and gap voltage of 60 V

Fig. 2 Graphs showing the values of out of roundness for the electrode at same processing conditions (a) with cryogenic assistance (b) without cryogenic assistance

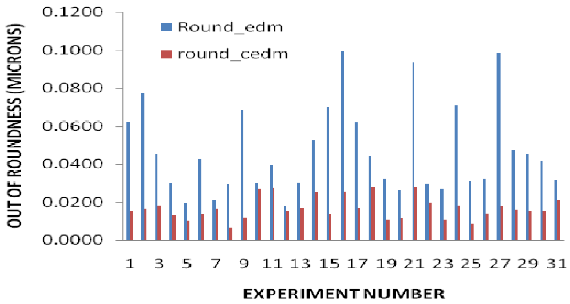


Fig. 3 Comparison of out of roundness values for EDM and cryogenic assisted EDM

It can be observed from fig. 3 that the out of roundness values of the cryogenically cooled electrode used in EDM is significantly lower as compared to the out of roundness values of electrode used in conventional EDM. The improvement in out of roundness varied from 10.30% in experiment 10 to 82.94% in experiment 9.

It can be seen from fig. 4 that discharge current and pulse on time have the most significant effect on the out of roundness for EDM with cryogenically cooled electrode.

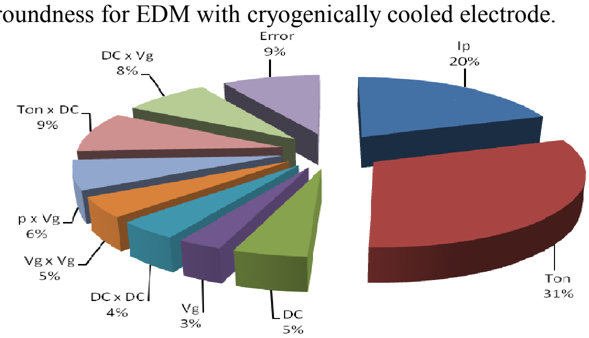


Fig. 4 Percentage contribution of the factors for out of roundness in EDM with cryogenically cooled electrode

Fig 5 shows the effect of discharge current for different values of pulse on time on out of roundness of EDM process with cryogenically cooled electrode. It has been observed that out of roundness increases with increase in discharge current. This may be due to the formation of the electrical discharge column in the machining gap, which not only removes the unwanted workpiece material but it also wears out the electrode. Increase in the discharge current causes more electrical discharge energy to be conducted into the machining gap, thereby increasing the distortion of the electrode [19].

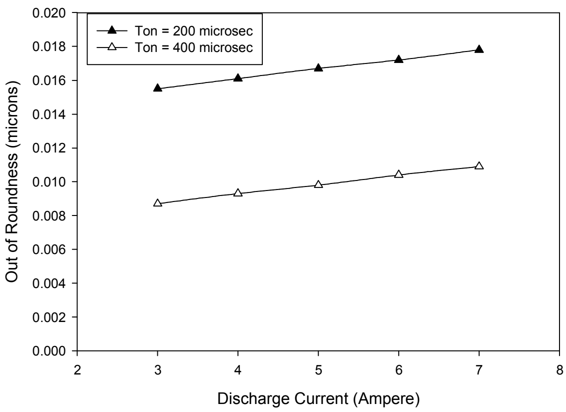


Fig. 5 Variation of Out of Roundness with discharge current (DC = 0.56, V_g = 60V).

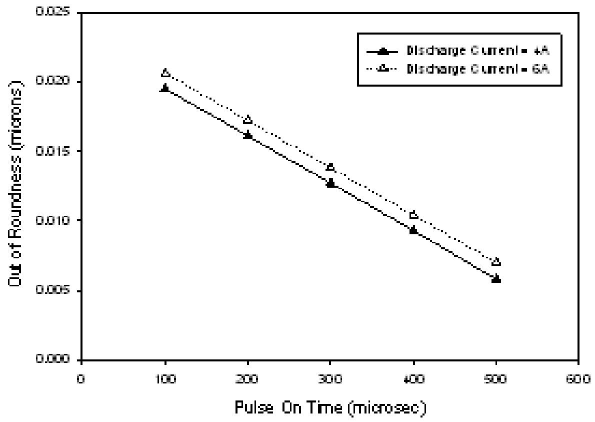


Fig. 6 Variation of Out of Roundness with pulse on time (DC = 0.56, V_g = 60V).

The effect of increase in pulse-on time for different values of discharge current on out of roundness for EDM process with cryogenically cooled electrode is shown in fig 6. The out of roundness has been found to decrease with increase in pulse on time. This is due to the fact that the diameter of the discharge column increases with the pulse duration which reduces the energy density of the electrical discharge on the discharge spot [16]. It has also been reported that at longer pulse-on time, the carbon from the decomposition of hydrocarbon-based dielectric liquid deposits on the surface of the electrode [4], [20]. This deposited layer increases the wear resistance of the electrode and reduces out of roundness.

The topography of electrode used in conventional EDM process and EDM with cryogenically cooled electrode at magnification of 60X for various processing conditions is shown in Fig. 7. The fig. 7 shows that the electrode surface profile is less distorted in case of EDM with cryogenically cooled electrode. The shape of electrode tip changes in case of conventional EDM process. The better shape of electrode tip with the use of cryogenic cooling can be attributed to the fact that use of cryogenic fluid leads to less melting of the electrode tip as the temperature reduces because of liquid nitrogen. Since, the volume of electrode melted is less; it leads to better retention of the initial profile of the electrode tip.

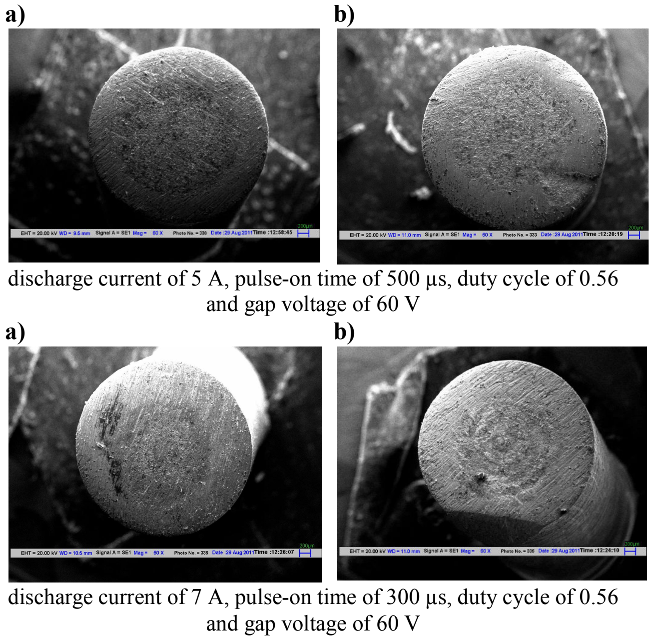


Fig. 7 SEM image of electrode at 60X magnification used under different processing conditions (a) with cryogenic assistance (b) without cryogenic assistance

IV. Conclusion

The effect of cryogenic cooling of electrode in electric discharge machining of M2 grade high speed steel with copper electrode can be summarized as follows

1. The out of roundness of the cryogenically cooled electrode is lesser than the out of roundness of electrode used in conventional EDM.
2. The out of roundness increases with increase in discharge current. It is also observed that out of roundness reduces with increase in pulse on time.
3. The scanning electron microscopy images also give an insight into the changes in the profile of electrode with the use of liquid nitrogen. The electrode retains its shape by using liquid nitrogen. There is very little distortion in electrode shape as compared to the electrode which is used for experiment without liquid nitrogen.

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