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Cryogenic Treatment and Cryogenic Cooling in Die Sink Electric Discharge Machining Process: An Experimental Set Up

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ABSTRACT
Integration of Cryogenic Treatment and Cryogenic Cooling with EDM process results in a newer process called as the Cryogenically Assisted Electric Discharge Machining (CEDM) process. It is one of very recent developments for the enhancement of process capabilities of EDM. In this technique, either the tool or the workpiece, or tool and workpiece both, may be, cryogenically treated down to sub zero temperatures or the EDM tool is cryogenically cooled with an objective to modify their properties. The modifications in properties result in the reduction of tool wear rate (TWR) and surface roughness (SR) and to increase material removal rate (MRR). An experimental set up for both the variants of CEDM has been discussed in the presented paper.
Keywords: Cryogenically Assisted Electric Discharge Machining (CEDM) process; Cryogenic Cooing; Cryogenic Treatment; Experimental Set up

I. INTRODUCTION

Electrical Discharge Machining (EDM) is one of the prominent machining processes amongst all non conventional machining processes. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in the manufacture of mould, die, automotive, aerospace and surgical components [1]. It is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys with difficult geometries in small batches or even on job-shop basis. Physical, mechanical and metallurgical properties of the workpiece do not significantly influence the performance of the process. EDM is one of the most popular machining methods for the manufacturing of press tools and various dies [2]. Matte finish obtained during EDM process minimizes the polishing time required.

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]. Similarly, Electrode used for the purpose should be electrically conductive. In EDM, electrode also gets worn out by the impingement of highly accelerated ions. In most of the EDM operations, the contribution of the tool cost to the total operation cost is more than 70% [5]. Thus, the electrode wear is a major problem in EDM process. Some effective measures need to be devised, so as to lower down this electrode wear.

Many attempts have been made using different research methodologies, to optimize the parameters which affect the EDM, to attain maxim MRR, surface finish etc. Many methods like Dry EDM, EDM using pure water as dielectric fluid, Powder Mixed EDM (PMEDM), electrode rotation etc., have been used for this, but very less attempts are available in literature about the minimization of electrode wear.

Cryogenics is a branch of physics which deals with the phenomenon taking place at very low temperatures (in the range of -196^{0}C or even less), called as cryogenic temperatures. Engineering materials behave differently at cryogenic temperatures than the normal temperatures and they exhibit modified mechanical, thermal, physical and electrical properties at cryogenic temperatures. Thus, the benefits of cryogenics can be integrated with various machining techniques, so as to modify the output machining parameters like material removal rate and surface finish etc. Many researchers have worked on the hybrid machining process using cryogenic conditions in conjunction with various conventional machining processes like turning, milling and grinding etc. [6]. But, the role of different cryogenic conditions viz. cryogenic cooling and cryogenic treatment have not been exploited in the case of non conventional machining processes especially EDM, where tool wear is found to be very serious problem. This area needs to be fully explored and the benefits of cryogenics need to be integrated with the conventional EDM. The resultant hybrid machining process is called as Cryogenically Assisted Electric Discharge Machining (CEDM) process.

II. CRYOGENICALLY ASSISTED ELECTRIC DISCHARGE MACHINING (CEDM) PROCESS

CEDM is an emerging hybrid machining process. In this technique, either the tool or the workpiece, or tool and workpiece both, may be, cryogenically treated down to sub zero temperatures or the EDM tool is cryogenically cooled with an objective to modify their metallurgical, mechanical, electrical and thermal properties. The modifications in properties lead to reduction of tool wear rate (TWR) and surface roughness (SR) and to increase material removal rate (MRR). Moreover, CEDM also helps in shape retention of tool.

Srivastava and Pandey studied the cryogenically cooled electrode shape in electric discharge machining process [7]. They concluded that the out of roundness of the cryogenically cooled electrode is lesser than the out of roundness of electrode used in conventional EDM. They found very little distortion in electrode shape as compared to the electrode which was used for experiment without liquid nitrogen. Very recently Abdulkareem et. al. studied the effects of cryogenic cooling during electrical discharge machining of titanium alloy (Ti-6Al-4V) with copper electrode [8]. Experiments showed the highest reduction (27%) of Electrode Wear and an improvement of 8% in surface roughness with cryogenic cooling of electrode. Yildiz et. al. [9] studied the effects of cold and cryogenic treatments on the machinability of beryllium-copper alloy in electro discharge machining. Experimental results showed about 20-30% increase in material removal rate by cold and cryogenic treatment processes. Gill and Singh [10] studied effect of deep cryogenic treatment on machinability of titanium alloy Ti-6Al-2Sn-4Zr-6Mo (Ti-6246) Electric Discharge Drilling. The improvement up to 8.5% for MRR, 34.78% for TWR, and 30.16% for WR had been observed for different drilling times. The improvement up to 9.01% for surface roughness at base of blind hole, 6.69% for surface roughness at side walls of holes, and 16.09% for overcut was also observed.

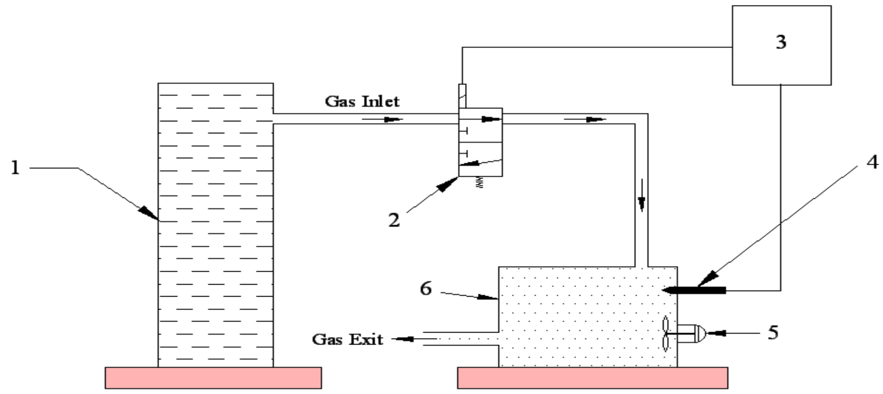
Keeping in consideration the remarkable effects of CEDM process an experimental set up has been prepared for carrying out various studies on CEDM process and has been discussed in the presented paper. There are two major variants of CEDM process viz. Cryogenic Cooling and Cryogenic Treatment. In order to fully understand the mechanism of set up prepared for CEDM it is of utmost importance that the basics of both the variants of CEDM are well understood.

III. CRYOGENIC TREATMENT IN CEDM

Cryogenic treatment is an inexpensive, one time, permanent treatment, affecting the entire section of the component unlike coatings. It is a supplementary process to conventional heat treatment process. The prime aim of cryogenic treatment is to transform retained austenite into martensite and to precipitate fine carbides into martensite matrix [11]. Retained austenite is a softer grain structure always present after heat treatment. By using cryogenic treatment, retained austenite is transformed into the harder, more durable grain structure - martensite. The range of retained austenite in a material after heat treating may be as high as 50% or as low as 3%. The amount depends on the heat treating operator and the accuracy of the heat treating equipment. Cryogenic treatment simply continues the conversion initiated by heat treatment, whereby almost 100% of the retained austenite is converted to martensite. As greater amounts of retained austenite are transformed, and wear resistant martensite is increased, the material obtains a more uniform hardness.

Fine carbide particles (precipitates) are formed during the long cryogenic soak. These are in addition to the larger carbide particles present before cryogenic treatment. These fine particles or "fillers", along with the larger particles, form a denser, more coherent and much tougher matrix in the material.

A Cryoprocessor (as shown in fig. 1) is used for treatment of components. It comprises of an insulated box for accommodating components, called as cryo box. A motor with a circulating fan is fitted at the lower end of cryo box for providing the uniform circulation of nitrogen (in the gaseous form) in the cryo box. The cryogenic temperature inside the cryo box is constantly measured with the help of a thermocouple which is further connected to a temperature controller and programmer which in turn operate the solenoid valve to regulate the supply of nitrogen in the box by permitting the gas inlet. Tool and/or work (depending upon the type of study) may be placed inside the insulated box and it can be treated based on a pre planned cryogenic cycle by ramping up and down the temperature for planned duration of times.



1- Liquid Nitrogen Tank 2- Solenoid Valve
3- Temperature Controller and Programmer 4- Thermocouple
5- Motor and Fan Assembly 6- Cryo- Box

Fig. 1: A schematic diagram of cryoprocessor used for cryogenic treatment

It is not possible to recommend a single process for every tool material, nor even a single cycle for all tools manufactured from the same material. Each tool needs to be separately assessed and an individual process route devised for it that will depend on the combination of hardness, toughness, and wear resistance required in service. A typical Cryogenic Cycle [12] includes following stages:

- RAMP DOWN: Lowering the temperature of the workpiece at a rate which must not exceed 20-30 °C/h in order to prevent the rupture of the components because of the cooling stresses.
- SOAK: Hold/Soaked for an appropriate time generally 24 hrs.
- RAMP UP: Bringing the temperature back up to room temperature at a rate of 20-30°C/h.
- TEMPER RAMP UP: Elevating the temperature to 150 °C (form room temp.) at rate 80-85 °C /h.
- TEMPER HOLD: Holding the elevated temperature for 4-6 hours.
- DOWN TO NORMAL: The material is brought back to room temperature at a rate 80-85 °C /h.

A typical Plot (as shown in fig. 2) of temperature versus time for the Cryogenic process has been shown as follows:

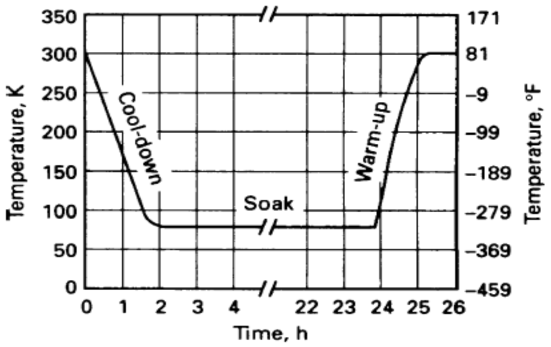
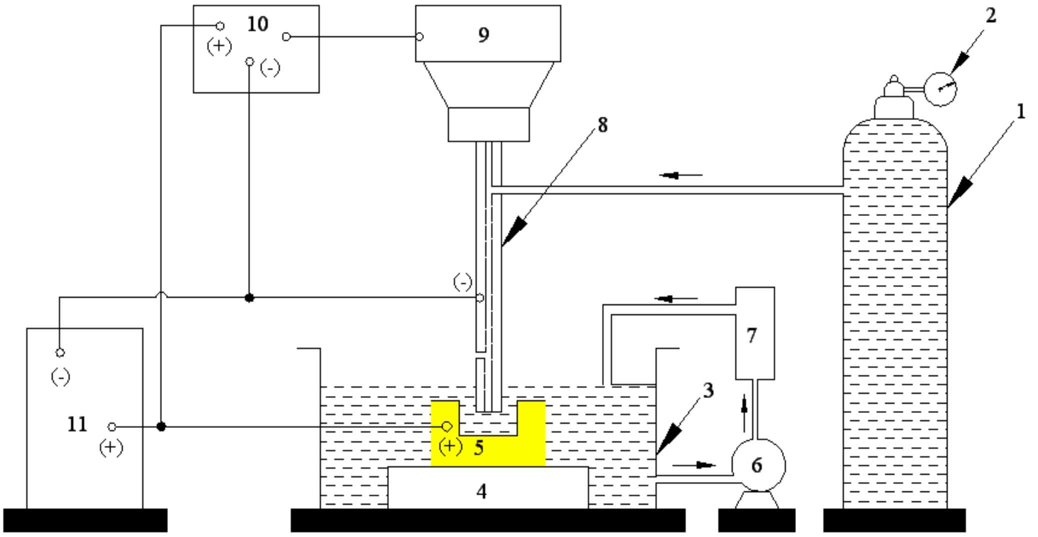


Fig. 2: A typical plot of temperature versus time for the cryogenic process [13]

It is a continuous process of approximately 2 days to cryogenically treat a component. It is worthwhile to mention here that a lot of components (depending on the capacity of Cryoprocessor) can be treated at a time. It helps in reducing the cost of treatment/component.

IV. CRYOGENIC COOLING IN CEDM

In this variant of CEDM i.e., cryogenic cooling a jet of cryogenic fluid which is thin but at high speed is passed through the EDM tool specially designed nozzle by using various mechanisms. Helium, hydrogen, neon, nitrogen, oxygen and normal air can work as cryogens gases. These cryogenic gases have a wide variety of applications in industry such as health, electronics, manufacturing, automotive and aerospace industry particularly for cooling purposes.



1. Liquid Nitrogen Tank 2. Pressure Gauge 3. Machining Tank 4. Fixture
5. Workpiece 6. Pump 7. Filter 8. Electrode
9. EDM Control System 10. Servo Motor 11. Pulse Generator

Fig. 3: An experimental set up for cryogenic cooling of tool

Liquid nitrogen has been used as cryogenic fluid. It is produced industrially by fractional distillation of liquid air and is referred as LN_2. Nitrogen in gaseous state melts at -210.01 ^{0}C and boils at -198.79 ^{0}C, it is the most abundant gas, composes about four-fifths (78.03%) by volume of the atmosphere. It is a colourless, odourless, tasteless and non-toxic gas. These characteristics of liquid nitrogen have made it as a preferred coolant.

An experimental set up as shown in Fig. 3 has been prepared for carrying out studies on effects of cryogenic cooling on the performance of EDM process. It consists of a liquid nitrogen tank (at a temperature of about -196^{0}C). It has been placed near work tank of EDM. A cryogenically non-treated copper electrode of circular cross section of 15 mm diameter has been prepared. A well defined tubular passage, as shown in Fig. 4, of 5 mm diameter has been drilled through it. This passage has been designed to allow the flow of liquid nitrogen through it, at a specified rate. The electrode is clamped onto the machine ram. The stainless steel pipe has been used to carry liquid nitrogen from tank to the inlet of the electrode though a brass adaptor [14].

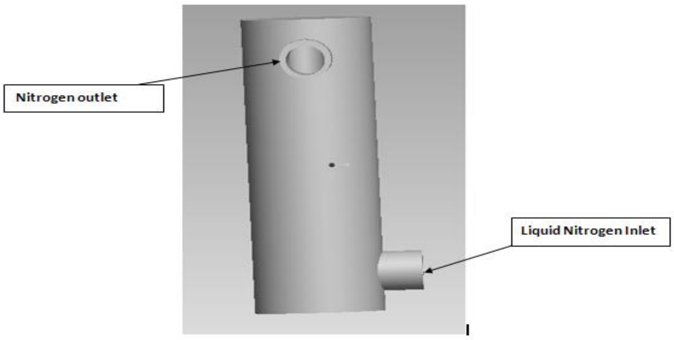


Fig. 4: Cryogenically non-treated copper electrode

The main objective of cryogenic cooling is to lower the temperature of the electrode (tool) so as to prevent the self erosion. The effect of cooling improves thermal conductivity of the electrode materials thereby minimizing the heat trapped in the electrode. As a result, electrode wear rate and electrode distortion is reduced.

V. CONCLUSIONS

Based on the need of reduction of cost associated with conventional EDM process and improvements witnessed with the integration of cryogenics with the conventional machining processes, a newer category of non conventional process has been recently emerged called as cryogenically assisted EDM (CEDM) process. An experimental set has been designed and developed for studies of cryogenic treatment and cryogenic cooling used in CEDM. The new experimental set up is able to accommodate all kinds of attachments necessary to provide required cryogenic conditions to the process. The presented set up is capable of performing the studies like investigation of effect of cryogenic cooling and treatment on the process characteristics such as MRR, TWR and surface finish etc and consequently optimization of the CEDM process.

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