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Analysis of the Research Potential of Electrical Discharge Machining Process

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Abstract

Electrical Discharge Machining (EDM) is a non-traditional machining process based on electro-thermal principles, where electrical energy is used to generate electrical spark. In this process, material removal mainly occurs due to thermal energy of the spark. The important challenges in electrical discharge machining process are low material removal rate (MRR), higher tool wear rate (TWR), lower finish of EDMed surfaces and high cost of dielectric fluid. It is evident that the overall efficiency of EDM process is quite low. There are newer technologies developed to overcome the limitations of the EDM process. It is known that most metals can burn in oxygen under normal conditions. Therefore, exploring this aspect leads to introduction of a new high-efficiency process known as EDM-induced ablation machining (EDM-AM) using multi-function electrode technology. Another emerging technology is dry electrical discharge machining. It is a technology that has the potential to replace conventional liquid based EDM, owing to its low tool electrode wear, thin recast layer, and eco-friendliness. Another process is EDM on cryogenically cooled workpiece, which brings out a balance between removal and finish of surfaces. The results of experimentation show an increase in the MRR of the cryogenically cooled workpiece technique, along with a decrease in the surface roughness value (Ra). Therefore, the advanced techniques investigated in this paper indicate newer methods to improve the material removal rate, at the same time surface roughness and overall process efficiency.

Keywords: Electrical Discharge..

Introduction

Electrical Discharge Machining (EDM) is the process of machining electrically conductive materials by using accurately controlled sparks that occur between an electrode and a workpiece under the occurrence of a dielectric fluid. The tool electrode is normally considered as the cutting tool [1]. In the EDM process, the electrode does not make physical contact with the work piece for material removal, hence known as a non-contact machining technology. In EDM, there are no forces related to the tool, since the electrode does not contact the workpiece. The material removal mechanisms in the EDM process are not completely known. Considering the cutting tool, nature of workpiece and mode of cutting, EDM can be classified into two: die sinking EDM and wire EDM processes. The electrode must always be spaced away from the workpiece by the distance required for sparking, known as the

sparking gap. If the electrode contacts the workpiece, sparking will finish and no material will be removed. Furthermore, in the EDM process, only one spark occurs at any moment. The range of spark frequency is from 5,000 to 500,000 number of sparks per second [2].

In conventional EDM, the sparks move from one point on the electrode to another as sparking takes place. The spark removes material from both the tool electrode and workpiece, which increases the distance between the electrode and the workpiece at that point. Further, the next spark occurs at the neighboring point between the tool electrode and workpiece. The mechanism of material removal in the EDM process is by heating. The flow of electrons between the tool electrode and workpiece causes the generation of a spark, thereby developing thermal energy. The outer layer of the work material is heated to the material vaporization point . The molten zone and the thermally affected zone by each spark is very small, and consequently the dielectric fluid rapidly cools the vaporized material, the surfaces of the electrode and workpiece [3]. The plasma formation and sparking which is an indicative of this energy causes heating of the workpiece material surfaces. Therefore, metallurgical properties of the workpiece

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can change as a result of this heating. The distance between tool electrode and workpiece is known as the inter-electrode gap or sparking gap.

The dielectric fluid is used to cool the tool and workpiece electrodes, to flush out eroded particles and to develop the necessary dielectric strength to begin sparking. The traditional EDM machines normally employ mineral oils, whereas micro-EDM machines and wirecut machined use de-ionized water as the dielectric media. The dielectric fluid works as an electrical insulator until enough electrical voltage is applied to cause it to change into an electrical conductor. The dielectric fluids used for EDM machining are able to remain as electrical insulators till dielectric breakdown occurs. The discharge voltage causes the dielectric fluid to change from an insulator to a conductor and the sparking phenomenon occurs between the tool electrode and the workpiece electrode [4]. Furthermore, when the electrical sparking action is turned off, the dielectric fluid de-ionizes and the fluid returns to its original condition of an electrical insulator. This physical phenomenon occurs during each sparking process. As each spark occurs, a small amount of the tool electrode material and relatively large amount of workpiece material gets evaporated. During the pulse off-time, the evaporated material gets solidified under the cooling action of the dielectric liquid [5]. A small debris particle (powdered form) is generated at the end of a sparking process and is washed away from the inter-electrode gap, at the end of the pulse on-time. Therefore, in this paper, a few of the recent developments in the areas related to the spark erosion processes are discussed. Taking into consideration the growth in the basic EDM process, the possible areas of scientific research in the process are identified. A detailed analysis has been carried out to assess the effectiveness of these technologies. The basic principle of the EDM process is discussed in the next section.

Principle

Electrical Discharge Machining (EDM) is a metal erosion process in a controlled manner to remove metal by means of a number of electric sparks, see Fig. 1. In this process, considering the basic principle, an electric spark is used as the cutting tool to cut the workpiece to generate the finished component to the desired size and shape. The erosion process is carried out by applying a pulsating electrical discharge of a current of high frequency from the electrode to the workpiece surface. This repetitive action of sparking removes very tiny pieces of metal in the form of debris particles from the workpiece at a controlled rate.

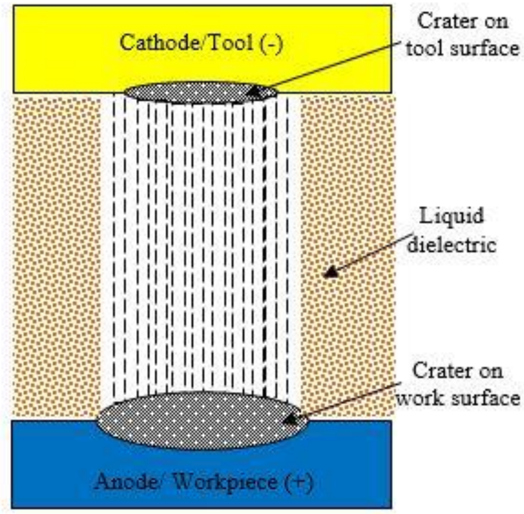

Figure 1: General principle of EDM

In electrical discharge machining process, both tool and workpiece must be conductors of electricity. EDM spark erosion is identical to that having an electrical short that burns a small hole in a piece of metal it contacts. Based on the fundamental physics of sparking action and the machining actions to generate cavities on metal surfaces, the applications of EDM process can be in the following areas:

- A previously generated tool electrode, usually made from copper/copper-tungsten/graphite, is shaped to the negative form of the product to be generated. The generated electrode is fed vertically down and the reverse shape of the electrode is eroded (burned) into the solid workpiece.
- A long thin wire electrode which is continuously fed is applied, the diameter of a small needle or less, is controlled by the computer programming to follow a path to erode or cut a narrow slot (similar to a band saw) through the workpiece to produce the required shape. The I-t characteristic and V-t characteristic for the EDM process are shown in Figs. 2 and 3 respectively. The interaction of the plasma with the electrodes is shown in Fig. 4.

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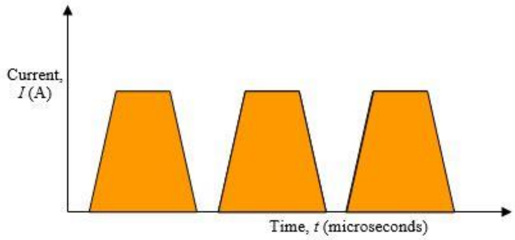

Fig. 2 Current-time (*I-t*) characteristic for a typical EDM process independent of the dielectrics

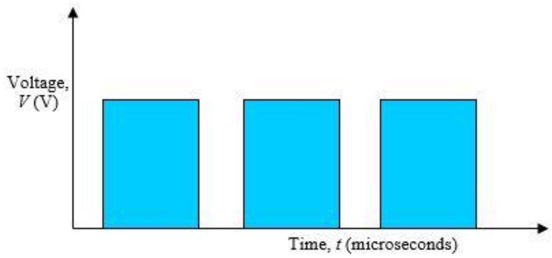

Fig. 3 Current-time (*V-t*) characteristic for a typical EDM process independent of the dielectrics

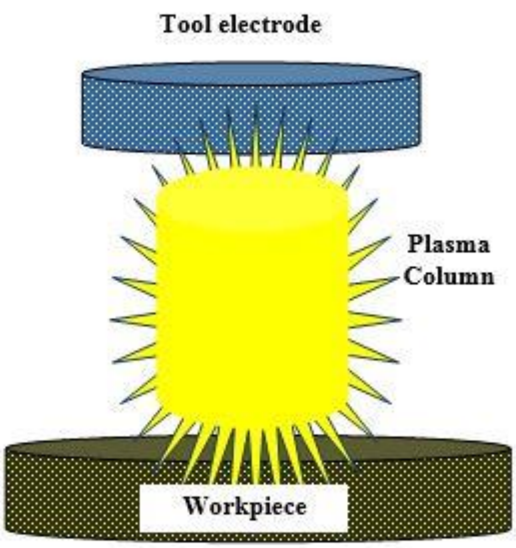

Figure 4 Interaction of plasma column with the tool and workpiece electrodes

Methodology for Investigations

In the EDM process, a potential difference (V) is applied between the tool and workpiece. As discussed, both the tool and the work material are to be conductors of electricity. I n the process, the tool and the work material are immersed in a dielectric medium. Generally kerosene or deionized water is used as the dielectric medium. A gap is maintained between the tool and the workpiece (d). Considering the applied potential difference and the gap between the tool and workpiece, an electric field would be established, mathematically expressed as:

$$E=V/d \text{ V/m} \quad \ldots\ldots\ldots\ldots (1)$$

In the EDM process, the tool electrode is connected to the negative terminal (-) of the generator and the workpiece is connected to positive terminal (+). As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces (F_{ES}), see Fig. 5.

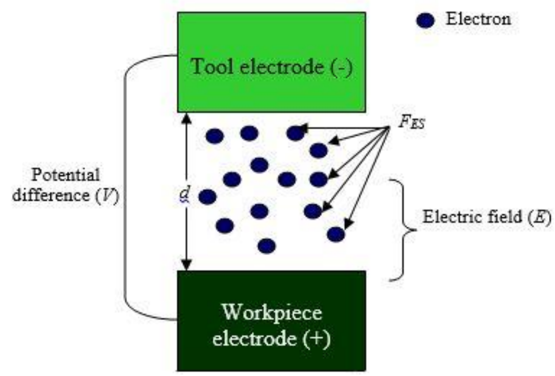

Fig.5 Forces acting on electron particles in EDM process

Assuming that the tool is connected to negative terminal and if the work function or the bonding energy of the electrons is less, electrons would be emitted from the tool. Such emission of electrons are called or termed as cold emission. These electrons are then accelerated towards the workpiece electrode through the dielectric medium. As they gain velocity and energy, and start moving towards the work, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionization of the dielectric molecule depending upon the work function or ionization energy of the dielectric molecule and the energy of the electron.

Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions. This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap. The electrical resistance of the formed plasma channel would be very less. The kinetic energy of the electrons and ions on impact with the surface of the job and tool would be transformed into thermal energy. Further, the mechanism of material removal in the EDM process is characterized by formation of shock waves in accordance with the collapse of the plasma channel during the process.

The dielectric used in the EDM process have enough dielectric resistance so that it does not breakdown electrically too easily. At the same time, the dielectric gets ionized when electrons collide with its molecule. In liquid dielectric EDM, mineral oil or deionized water is used as dielectric. Furthermore, this investigation involves introduction of two novel EDM variants with interesting features and characteristics. They are:

- Electrical discharge machining-induced ablation machining
- Electrical discharge machining using cryogenically cooled workpiece

These two methods are discussed below:

Electrical discharge machining induced ablation machining: It is evident that the process efficiency of electrical discharge machining is very low. The objective of EDM-induced ablation machining is to apply the concept of using multi-function electrode technology. In this work, in the EDM process oxygen is injected and dielectric fluid into the processing area. The chemical energy caused by the reaction of metal and oxygen can much improve the MRR as well as the material removal efficiency. In general, the combustion of metal must meet the three following conditions: the metal is combustible, oxygen contacts the combustible metal, and the ignition temperature is reached. Most of the materials that can be processed by normal EDM can burn in oxygen. The temperature in the center of the discharge channel is about 8,000–10,000 °C, which is far higher than the ignition point of most metals. So, the requirements of combustibility and ignition temperature are met. Then when oxygen is injected into the working area, the EDM-induced ablation machining process begins. A high MRR can be achieved through the metal material consumption by combustion and melting caused by the generated heat.

Electrical discharge machining using cryogenically cooled workpiece: In conventional metal cutting, Cryogenic machining presents a more sustainable alternative due to its increased stability and the resultant productivity of the process. Similarly, a preliminary investigation on EDM with cryogenic cooled workpiece are able to reduce the electrode wear by up to 27% by using electrode cooling while simultaneously reducing the surface roughness of the workpiece. In conventional EDM, the workpiece is cooled by a liquid, and debris is speedily cooled and expelled. In some cases, lower thermal conductivity of air (0.0241 W/mK) vs. that of a liquid (for kerosene: 5 W/mK), cooling of a workpiece is much reduced in EDM. We supposed that cryogenically cooled workpiece might lead to an improvement in dry EDM performance.

A comparison of removal mechanisms in the newer EDM processes are presented in Fig. 6.

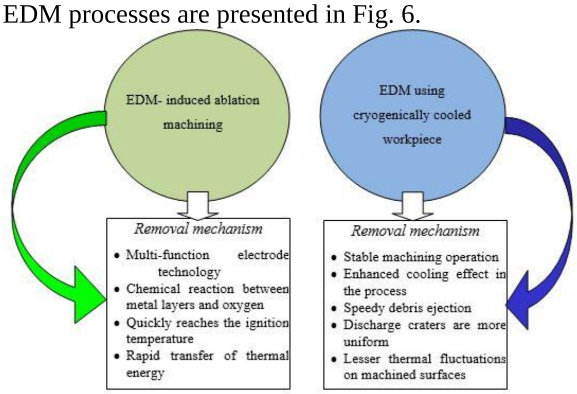

Fig. 6 A comparison of phenomena associated with removal mechanisms in newer EDM processes

Results and Discussion

The results of this investigation and discussion on the results obtained are presented in this section.

The maximum MRR achievable for ablation machining can be much higher than that of the normal EDM for the same processing conditions. The higher MRR could be attributed to higher utilization rate of electrical discharge energy, removal of material by ablation (see Fig. 6) and melting effect of heat generated at the surface. In addition to these mechanisms, a localized explosive force is expected.

A comparative evaluation of material removal rates in three processes viz. electrical discharge machining, electrical discharge machining with multi-functional electrode and electrical discharge machining with ablation machining are presented in Fig. 7.

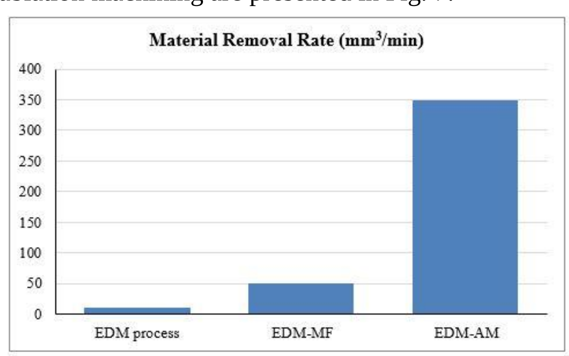

Fig. 7 A comparative analysis of EDM process, EDM with multifunctional electrode and EDM with ablation machining

It is observed that for the same input parametric conditions, the removal rate of normal EDM with the single- function electrode is 9

mm^3/min, the removal rate of normal EDM with the multi- function electrode (EDM-MF) is 49 mm^3/min, and the removal rate of EDM with ablation processing is 351 mm^3/min. Therefore, the following are observed:

- The MRR in EDM-MF is 5.4 times that of the MRR in conventional EDM process. This indicates that the process of introducing multi-functional electrodes is highly beneficial in improving the MRR of the process.
- The MRR in the case of ablation-assisted EDM (EDM-AM) is 39 times that of the MRR in conventional EDM process. Therefore, the mechanisms such as mechanism, heating and rapid removal of large amount of material supports the EDM system, hence causing a higher removal.

A similar process is the cryogenic-assisted EDM process. It is observed that the MRR and surface roughness can be improved for cryogenically cooled workpiece with both positive and negative polarities, see Fig. 8. For positive polarity machining, the MRR was improved by approximately 30-50%, while the surface roughness was improved only slightly over that of an uncooled workpiece, see Fig. 9. The surface morphology of the cooled workpiece was found to be uniform and regular, due to the decreased probability of debris reattachment on the surface as debris was cooled and ejected, see Fig. 10. With the debris ejected, the state of the discharge passage was improved, which consequently contributed to the desirable MRR values.

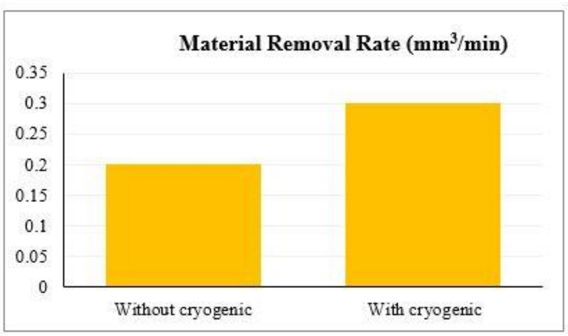

Fig. 8 Relationship between MRR and EDM without and with cryogenic cooling

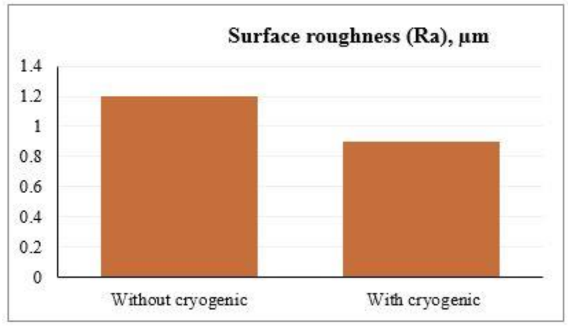

Fig. 9 A comparative analysis of surface roughness without and with cryogenic cooling

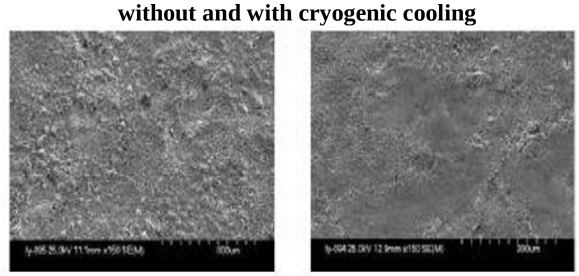

Fig. 10 A comparison of surface morphology for uncooled workpiece surface and cryogenically cooled surface

Newer techniques like application of a small amount of water mist (minimum quantity lubrication) would cause an increase in the MRR. For higher energy parameters, the MRR and SR were improved greatly when the workpiece was at a lower temperature. However, the workpiece must not be overcooled, as this leads to a layer of frost and excessive water vapour produced during machining, which negatively affect the machining. These comparative studies have helped to characterize the newer EDM processes at different parametric conditions.

Conclusions

This paper has presented newer methods for improvement of MRR in the EDM process. The research potential of the EDM process is considering the fundamental aspects of material removal mechanisms in the EDM process. Based on this work, the following conclusions can be drawn:

- The MRR of the EDM process can be greatly improved by the ablative effect, which is 39 times that of normal EDM.
- In the ablation process, the discharge gap region is in good condition. EDM is mainly carried out in the presence of liquid dielectric accessible to all regions.
- The removal effect of the electric spark is both steady and highly efficient, and the utilization ratio of the discharge energy is high.

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• A higher MRR in ablation machining was observed because there is a combination of the high discharge energy utilization, the material consumption by combustion, the melting effect of the heat of combustion, and the forced chip removal caused by the local explosion.

• It is observed that dry EDM with cryogenically cooled workpiece helps improve both the MRR and surface finish to a large extent.

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