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Developments in Electrical Discharge Grinding process: A review

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Abstract

Electrical discharge grinding (EDG) is a hybrid process involving energy of sparking as well as mechanical grinding. The machining of thin and fragile material is very difficult for manufacturing industries and rapid demand of requirement could not be achieved. Electrical discharge machining is more acceptable machine tool for machining hard and brittle electrically conductive materials but its productivity is very low. In past decade, researchers have focused on EDG for machining these materials because there is no mechanical forces exerted on work piece during machining and it gives better performances than EDM due to the rotating speed of wheel. Therefore, the objective of this paper is to review the array of research works carried out on EDG process. It also focuses on recent developments for practical applications.

Keywords: EDG, material removal, mechanical forces, sparking action, abrasive particle, productivity.

Introduction

Electrical discharge grinding (EDG) is a non-traditional thermal process for machining hard and brittle electrically conductive materials. EDG has been developed by replacing the stationary electrode used in electrical discharge machining (EDM) with rotating electrode [1-3]. In EDG process, material is removed melting and vaporization as same as EDM process. But there are ample differences with EDM instead of mechanism of material. In EDG process, an electrically conductive wheel is used as a tool electrode instead of stationary tool electrode used in EDM. There is no contact with work piece and tool electrode (rotating wheel) except during electric discharge [4-6]. Due to the rotational motion of wheel electrode, the peripheral speed of wheel transmitted to the stationary dielectric into gap between work piece and wheel resulting flushing efficiency of process is enhanced. Therefore, the molten material is effectively ejected from gap and no debris accumulation take place into gap while in EDM debris accumulation is major problem which adverse effect on performances of process [1,2]. Due to the enhanced in flushing, higher material removal and better surface finish is obtained as compare to the conventional EDM process [3]. At the same machining condition, EDG gives better performances than EDM and it is machined extremely hard materials faster (2-3 times) as compare to the conventional grinding [6-8]. The high speed of wheel is not always beneficial and after a certain value of speed, the spark becomes instable and produces adverse effect on performance. There is no physical contact between work piece and wheel, so that the process becomes more advantageous for machining thin and fragile electrically conductive materials.

Principle of Working

The details of EDG process have been illustrated in Fig 1 and wheel-work piece interaction is shown in Fig. 2. In this process, a rotating electrically conductive metallic wheel is used which is known as grinding wheel. The grinding wheel used in this process, having no any abrasive particles and rotates its horizontal axis. Due to the similarities of process with conventional grinding and material is removed due to the electrical discharge, it is known as electrical discharge grinding (EDG).

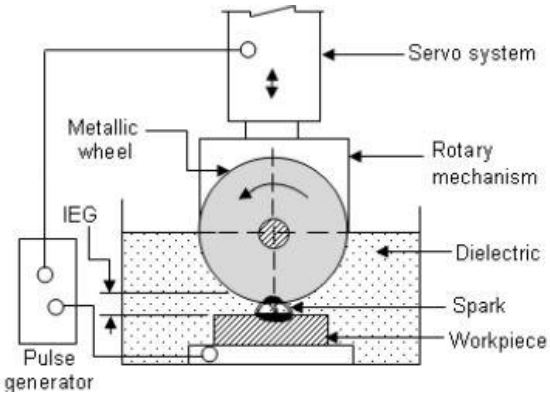

Fig. 1 Principle of working of EDG

In this process, the spark is generated between rotating wheel and work piece. The rotating wheel and workpiece both are separated by dielectric fluid and during machining both (workpiece and wheel) are continuously deeped into dielectric fluid. The dielectric fluids are mainly Kerosene oil, Paraffin oil, Transformer oil or de-ionized water. The main purpose of dielectric is to make a conductive channel during ionization when suitable breakdown voltage is applied. The servo control mechanism utilized to maintain the constant gap between workpiece and wheel in range of 0.013-0.075 mm.

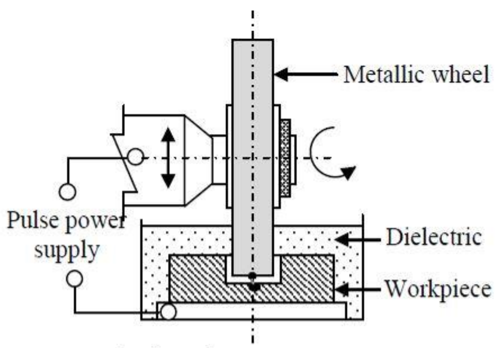

Fig. 2 The phenomena of wheel-workpiece interaction in EDG

A pulse generator is used for maintaining the DC pulse power supply in ranges of voltage, current and frequency are 30-400V, 30-100A and 2-500 kHz respectively. When pulse power supply is applied, the spark takes place into gap due to the ionization and striking of ions and electrons at their respective electrodes. Due to spark, high temperature generated between ranges of 8000 °C to 12000° C or as so high up to 20000^{0}C by each spark resulting material is meted from both the electrodes. Simultaneously DC pulse power supply switch is deactivated resulting the breakdown of spark occurs and fresh dielectric fluid entering into gap. Due to the high flushing efficiency, the molten materials flush away in form of micro debris from gap and formed the crater on work surface.

Many research and developments [1-8] have been done in field of EDG for machining difficult machine materials. In this process, a rotating electrically conductive wheel is used for spark erosion and simultaneously enhances the flushing due to the rotational motion of wheel. There is many developments are found in particular process, depending on type of wheel and its rotation that are used in EDG process. These developments are implemented with two types of grinding wheels. Firstly, grinding wheel without abrasive particles while others is grinding wheel with abrasive particles.

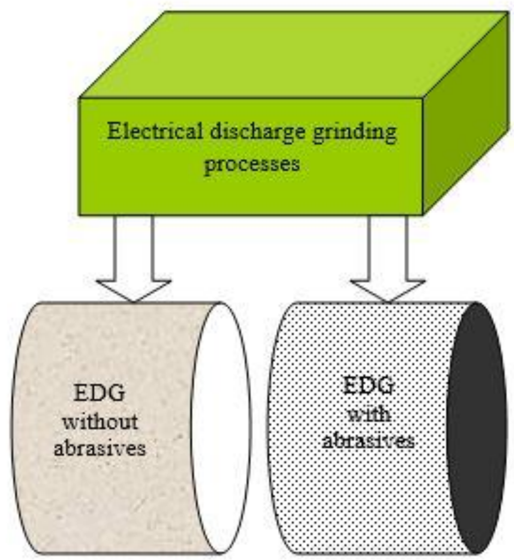

Fig. 3 Classification of EDG processes

In EDG without abrasive particle, the wheel is made of graphite which rotates on is horizontal axis but instead of graphite wheel, some other materials are used for making wheel for EDG process such as copper, brass and mild steel. Due to the high wear resistance, the mild steel wheel gives low wheel wear as compare to the copper and brass wheel, see Fig. 3. The main developments in EDG without abrasives are: electro-discharge grinding and electro-discharge milling (ED milling) [8]. In EDG process with abrasive particle, the rotating wheel replaced with metal bonded abrasive wheel or and such types of wheel is known as composite wheel. In composite wheel, the main purposes of abrasive particles are: to enhanced the material removal, to achieve better surface finish and requirement of low grinding forces [1]. Electro-discharge abrasive grinding (EDAG) is the main development of EDG process with abrasive wheel. It is further developed in three different grinding configurations such as

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electro-discharge abrasive cut-off grinding, electro-discharge abrasive face grinding and electro-discharge abrasive surface grinding.

Analysis of Experimental Techniques and Improvement Methods in EDG Processes

The experimental techniques are very important in the EDG process. The EDG machine tools are developed by incorporating a dielectric system for de ionized water. Fig. 4 shows the scheme of the machine and experimental system.

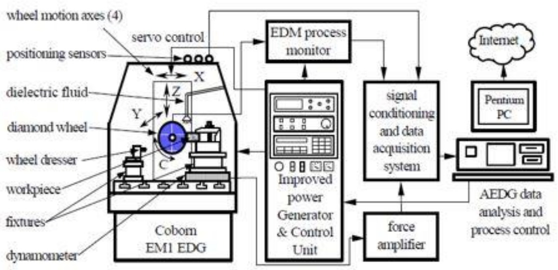

Fig. 4 Experimental set-up for electrical discharge abrasive grinding [8]

In most of the research works on EDG, de ionized water is used as the dielectric fluid. A separate tank with a pump is used along with de ionizing chambers and a filter [8]. Material Removal Rate (MRR) is measured by the difference of weight of the workpiece before and after the machining. The surface roughness can be measured by a stylus type profilometer.

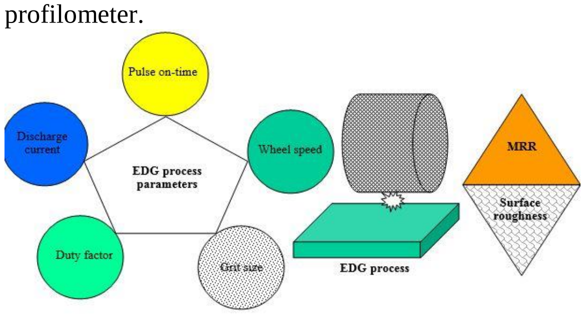

Fig. 5 Input parameters and process outputs for EDG process

The selected parameters and process outputs for a comprehensive experimental investigation on EDG is shown in Fig. 5. The effect of pulse frequency is presented by the duty factor defined as the ratio of pulse on-time to pulse period. At the same time, in the grinding process, the metal-bonded wheel loses its cutting ability after certain number of operations [2]. Hence, to resume the efficient grinding process, frequent re-dressing of wheel becomes essential. The conventional dressing methods of metal bonded grinding wheels are time consuming and lead to severe wear of the tool [3]. The EDG process itself has several benefits such as self-dressing, where the electrical discharges simultaneously wear away the workpiece and wheel. A schematic diagram of the mechanism of workpiece and wheel contact region with abrasive grits, metallic bond and embedded or lodged workpiece chips in the wheel are shown in Fig. 6.

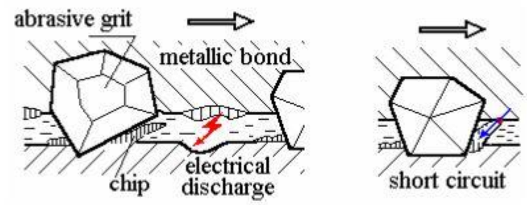

Fig.6 The mechanisms of electrical discharge and occurrence of short circuit during EDG process [4]

Similar to the EDM process, many parameters affected the performances of EDG. These are classified into two categories: electrical parameters and non-electrical parameters. The electrical parameters are discharge voltage, pulse current, pulse duration, pulse interval, pulse frequency, duty factor and polarity while non-electrical parameters are types of dielectric and wheel rotational speed while the flushing method and flushing pressure of dielectric are not significantly affects the performances of EDG [5]. The performance measures are MRR, tool wear rate (TWR), and average surface roughness (Ra). When the abrasive is added into metallic wheel then size of abrasive, types of abrasive, bond materials and concentrations also affects the performance measured.

In EDG process, a rotating metallic wheel is used in machining which may rotates either its horizontal axis or vertical axis. Based on the rotation of wheel, the EDG process developed in three different configurations [7]. These are: electro-discharge cut-off grinding, electro-discharge face grinding and electro-discharge surface grinding. In cut-off grinding configuration, the metallic wheel rotates about its horizontal axis and fed into perpendicular direction to the machine table. It is used to cut workpiece into pieces or making grooves into workpiece. In face grinding configuration, the metallic wheel rotates about vertical spindle axis and fed into perpendicular direction to the machine table [4]. It is more suitable for end machining of cylindrical work surface. In the surface grinding mode, the wheel also rotates its horizontal axis and fed into perpendicular direction to the machine table. It is mostly applicable for machining of the flat surfaces.

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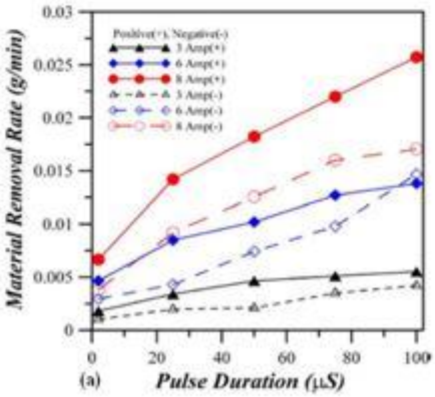

Fig. 7 Effect of pulse on-time on material removal rate (MRR) [2]

Many researchers have made effort to identify the factors that affects the performance of EDG process. It has been experimentally proved that material removal rate (MRR) and surface quality improved by properly selecting of process parameters by Aoyama et al. Sato et al. have claimed that electrode rotation served as an effective gap flushing technique resulting better material removal [6]. The edge quality of various grades of polycrystalline diamond (PCD) cutting tool blanks after EDG on either the face or periphery of a rotating graphite wheel has investigated by Thoe et al. and found that as compare to the coarse grain, the fine grain blank has higher MRR, grinding ratio and lower roughness of surface and edge. To obtain high material removal, higher peak current and longer pulse duration with positive polarity of electrode are suggested by Shih and Shu as shown in Fig. 7 while the negative tool polarity gives better surface finish as shown in Fig. 8 at same machining conditions.

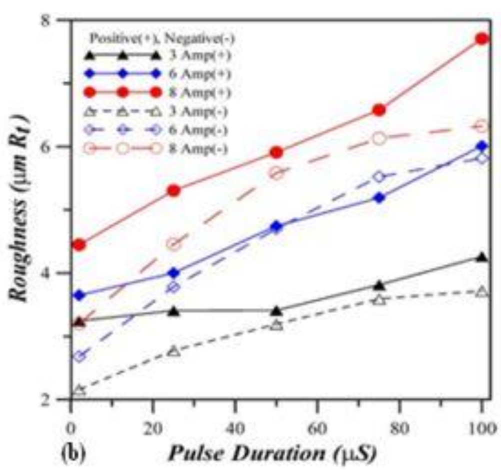

Fig. 8 Effect of pulse on-time on surface roughness [2]

It was observed that the orbital motion of the electrode for improving the machining rate and the results were compared with stationary electrode. They have found that orbital motion of the electrode enhanced the performance and MRR increases with rotation of electrode due to improved flushing action and sparking efficiency; however the surface roughness is increased. It has been experimentally proved that rotating workpiece gives two times more MRR as compare to the conventional EDM but this process is most suitable for axial-symmetrical die and mold work. Further, MRR, TWR, relative electrode wear, corner reproduction accuracy and surface finish aspects of a rotary electrode are better as compare to stationary electrode. This is because the rotation speed of electrode would convey a velocity to the dielectric in the gap hence more effectively flushing take place in the gap but at higher rotating speeds result in discharge instability resulting lower MRR with improve in surface roughness.

The EDG process can be modified by locating the rotating electrode below workpiece as shown in Fig. 9. It is evident that due to gravitational force debris removal rate was significantly improved resulting higher MRR with better finish with rotating workpiece below workpiece. The effect of vibration-rotary EDM as compare to the vibration EDM on MRR is high with higher surface finish has been obtained. It is found that the combination of ultrasonic vibration enhanced the performances of rotary EDM and rotation of electrode leads to increase the MRR but simultaneously TWR and Ra values is also increased. The angle speed of workpiece and tool electrode should not be too high otherwise working fluid cannot enter into discharge gap under centrifugal effect of rotating wheel which plays adverse effect on the performances.

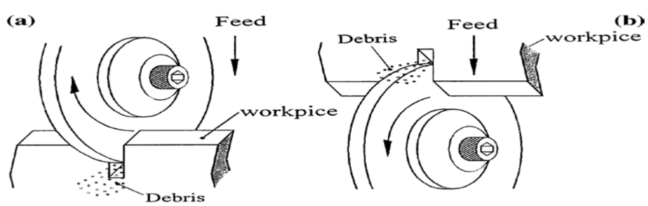

Fig. 9 Relative position of workpiece; (a) Conventional EDG, (b) Modified EDG

Machining of metal matrix composites (MMCs) are very difficult due to the presence of hard and brittle ceramic particles which leads to the rapid tool wear. But the MMCs are effectively machined with EDG due to the performances of EDG is not affected by mechanical or physical properties of materials. Yan and Wang have study on machining characteristics of Al_2O_3/6061Al composite using with copper tube electrode and they have found that current and volume fraction of Al_2O_3 were have significant affects the performances but the flushing pressure and electrode rotational speed have minor effect on performance parameters. Wang and Yan claimed that the electrical parameters more significant effect on performances as compare to the non-electrical parameters. The effects of electrode material, electrode rotation, volume percentage of SiCp and electrical parameters have been investigated by Mohan et al. They compared the performances of brass and copper electrode and found that brass electrode gives higher MRR than copper electrode with positive polarity electrode. They also claimed that the higher percentage volume of SiCp means lower value of MRR with good surface finish due to SiC particles protect the matrix. It has been also found that the rotating tube electrode gives higher MRR than the rotating solid electrode, when they were tested at same machining conditions.

Process Improvement Methods

To improve the efficiency of the EDG process, the metallic or graphite electrode has been replaced with metal bond abrasive wheel and the developed is known as electrical discharge abrasive grinding (EDAG). In this process, the material is removed by the combined effect of electro-erosion of EDM and micro-cutting of grinding process as shown in Fig.10. Due to the combined effect of EDG and grinding, the overall performances of the process have been improved. This process becomes evident when machining super-hard materials, engineering ceramics, sintered carbides and metal composites. The electrical discharge interactions on the metal bond abrasive grinding wheel lead to its self dressing in process. The theoretical analysis and experimental investigation of self-dressing mechanism of EDAG process has been investigated by Kozak [8]. They have also claimed that electro-erosion process could be applied in profiling of super-hard metal bonded wheel.

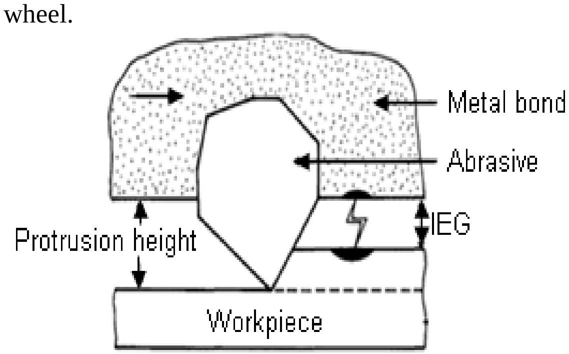

Fig. 10 Combined effect of EDG and grinding in EDAG process [8]

In recent past, several attempts have been carried out for employing the feasibility of EDAG process with different named proposed by researchers such as abrasive electro-discharge grinding (AEDG) and electro-discharge diamond grinding (EDDG). The enhancement of the MRR on introducing abrasion into the process has been studied in comparison to conventional EDM and EDG with rotating graphite has been done by Rajurkar et al. [8] during machining of Al-SiC composite and titanium alloy with copper bonded diamond wheel. They have found that MRR obtained by EDAG process is about five times more than EDM and about two times more than EDG process. It is found that the normal and tangential grinding forces decrease with an increased in the applied voltage at the expenses of wheel wear. The compound effect of electrical discharge and mechanical grinding process of SiC with segmented wheel is developed. They have found that the developed process effectively machine the large surface area with higher MRR and good surface finish.

It is observed that for effectively performance of EDAG process, the protrusion height of abrasive particles is approximately 30% of the grain size is more suitable. It was found that the spark discharges thermally soften the work material in grinding zone, hence soften material easily removed by grinding action and consequently decrease the normal forces. In an experimental investigation, tangential grinding force decreases with increase in voltage and duty factor for a particular value of current. The specific energy required in EDAG process is less than EDG. It has been investigated that the wheels speed and current are most significant factors that affecting performances of EDAG. The EDAG process is developed in face grinding mode for machining end surface of cylindrical workpiece and study the effects of process parameters. The EDAG process is developed in surface grinding mode for machining flat surface of workpiece and also study the effects of process parameters on performance measures.

The main objective of investigation in this field is to study the Abrasive Electro discharge Grinding (AEDG) process performance while machining such advanced materials as polycrystalline diamond (PCD), metal matrix composite Al-SiC, polycrystalline cubic boron nitride (PCBN) and electric conductive ceramics. AEDG machining characteristics obtained with oil and deionized water has been compared. The effects of current, pulse on-time and wheel speed on the grinding have been studied [3-6]. Application of neural network modeling for determination of performance characteristics of AEDG and the comparison of neural network prediction with multiple regression analysis are presented. The study also sheds light on self-dressing effect in AEDG process. AEDG process, where synergistic interactive effect of combination of electrical discharge machining and grinding process is employed to increase machining productivity. The contribution of conventional grinding and electro discharge grinding (EDG) to AEDG illustrates Fig. 11. In the AEDG process, metallic or graphite electrode used in electrical discharge grinding (EDG) process has been replaced with metallic bond grinding wheel. Therefore, material is removed by the combined effect of electro-erosion and micro-cutting process (mechanical effect of abrasives). An increase in performance measures of the AEDG process becomes evident when machining super-hard materials, engineering ceramics, sintered carbides and metal composites.

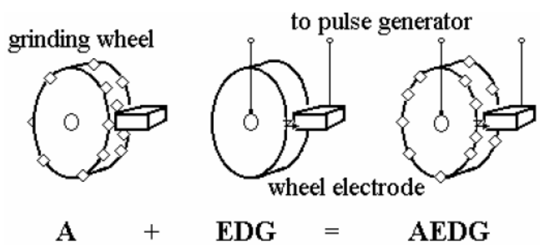

Fig.11 Principle of Abrasive Electrical Discharge Grinding (AEDG) [7]

Thus, the AEDG is a controlled electro discharge process assisted by mechanical grinding. In order to achieve mechanical grinding action in the rotary EDM, grits in the wheel are in contact with the workpiece, but this contact does not result in short circuits between the tool and the workpiece because of the non-conductive diamond grits [7]. The abrasion action in this process helps to speed up the removal of electrically non-conductive components when machining electrical conductive composites like PCD and PCBN. The abrasion can also smooth off the protrusions of the non-conductive ingredients, which insulate the inter electrode gap, so that the electro erosion can be accelerated [4]. The process can be controlled either in grinding dominant state with a relatively less contribution of electrical erosion to acquire a reduced heat-affected surface layer, or in EDM dominant state with a relatively less contribution of grinding to reduce machining force, or in a well balanced state between the grinding and the erosion. Simultaneously electrical discharge interactions on the metal bond super abrasive-grinding wheel lead to its self-dressing in process.

Applications: Additional benefits include grinding forces, lower grinding wheel wear, and an effective method for dressing of grinding wheel during machining process. Electro-erosion process could also be applied in profiling of super-hard metal bonded wheel. This process has also been found to be effective in preventing chipping of the brittle work pieces. AEDG of titanium alloy (Ti-6Al-4V), Inconel 601, Al-SiC (DURALCAN F3S.20D), PCD, and PCBN have been reported in references [1-8]. Main parameters influencing the process were peak current, pulse on-time and wheel speed. The enhancement of the material removal rate on introducing abrasion into the process has been studied in comparison to conventional EDM and EDM with a rotating graphite electrode (EDG).

Conclusions

In this paper, the published research works on EDG process along with the process parameters and their effects on performances are analyzed.The following conclusions can be drawn from this review of research works on the EDG process:

- It is evident from the published papers that wheel speed enhanced the flushing resulting performances of process is also enhanced.
- The ED milling is the unique development in EDG process for machining insulating materials such as Al2O3. Adding the abrasive into metallic wheel means unique changes in performances.
- This study helpful for researchers and developers, who works in field of advanced manufacturing technology and making efforts for machining difficult to machine materials at low cost.
- This paper reports a review of theoretical analysis as well as the experimental investigations of self-dressing mechanism in Abrasive Electro discharges Grinding (AEDG).
- A visual inspection of debris and quantitative comparison of material removal variation with grinding process support the theoretical analysis. This study has indicated a possibility to explore the feasibility and application of deionized water as dielectric medium instead of water to address the environmental aspects of the AEDG process.

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