Review of State of Art and Process Parameter Influence in EDM Technology

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Abstract- *Electric Discharge Machining (EDM) is a non-conventional machining process in which material is removed electrically by the application of a high voltage. Over the years the EDM process has cast itself into various specialized forms such as Wire cut EDM, EDM drilling etc. This paper presents a study of all the major improvements that have been implemented on EDM machining in the recent years. Various techniques proposed by researchers to improve the machining characteristics and to increase versatility of the EDM process have discussed in this paper. It should be noted that there is no well-defined relations between the electrical process parameters of an EDM process and the output variables like surface roughness, material removal rate etc. The influence of these material vary widely with material being machined. Hence, a study has been done on the influence of these parameters on the various process characteristics of EDM process.*

Keywords – *EDM, State of Art, Electrical Process Parameters.*

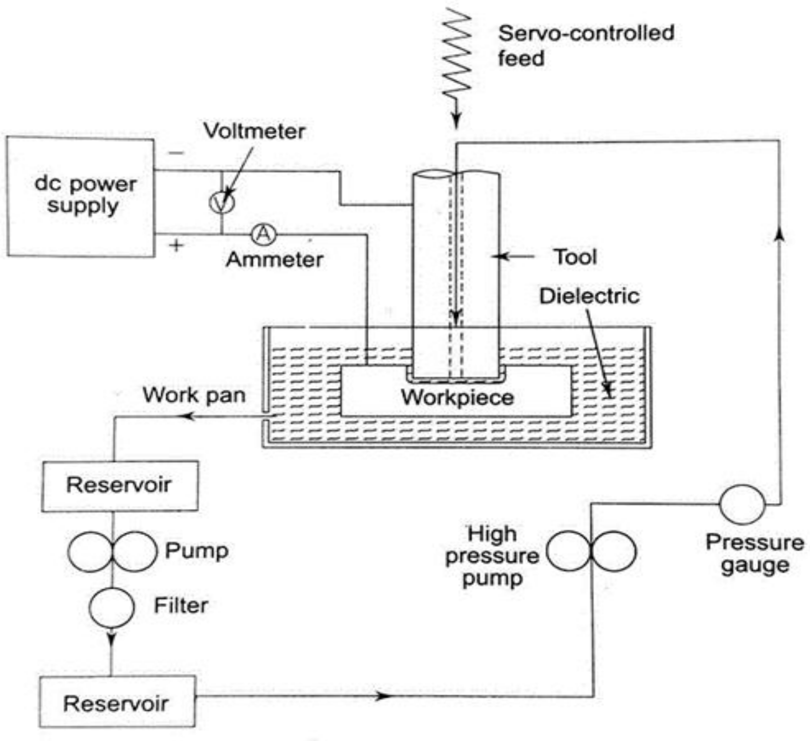

Fig.1 Basic EDM Setup (*Source: Manufacturing Technology – Volume II by P N Rao*)

I. INTRODUCTION

Electric Discharge Machining commonly known as (EDM), is one of the most popular non-conventional machining process. In fact it has become so common and widely used that it can no longer be termed 'Non- Conventional'. The machining is done electrically by inducing repetitive and controlled sparks of high energy between the workpiece and the tool electrode. It is a non-contact method of machining in which there is no contact between the tool and the workpiece and hence the issue of residual mechanical stresses can be forgotten. When an appropriate voltage is applied between the tool and workpiece separated by a specified distance, an electric field builds up. When the applied potential exceed the breakdown potential of the dielectric, ionisation takes place. A high current flow resulting in a spark which consequently removes the metal by partially melting and partially vaporising it. This discharge takes place at the point of smallest separation where the resistance is least. Progressively these sparks produce cavities on the surface of the workpiece resulting in the formation of a contour complementary to that of the tool.

The debris consisting of tiny metal globules is flushed out from the machining spot by the dielectric. EDM process is highly efficient for the machining of hard metals since the hardness of the workpiece has little effect on the process. It should be noted that the work material should be sufficiently conductive to machine it by EDM. The setup of a general EDM machine is shown in Fig.1. It gives an insight into the various elements involved in spark generation and the flushing of dielectric. Material removal occurs due to the conversion of electrical energy into heat energy and hence a considerably high amount of energy is required than that needed for conventional machining.

II. STATE OF THE ART

The field of EDM has witnessed several improvements andupgradation since the advent of computer numerical control. The EDM now manifests itself in various forms such as die sinking EDM, wire EDM, EDM drilling, EDM grinding etc. Various new techniques and methodologies have been suggest to overcome the minor difficulties and fine tune the EDM process. Some interesting experimental concepts have also been put forth by various researchers to tackle various problems.

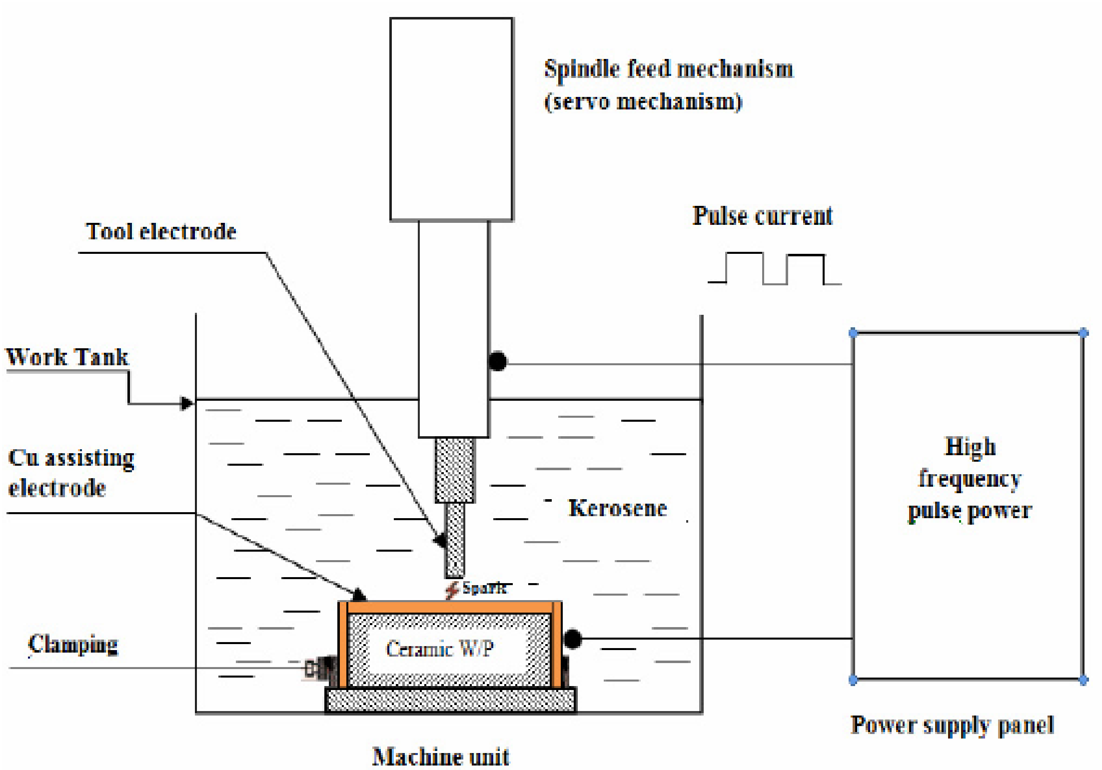

Fig.2 Experimental Setup for machining Ceramics (*Source: AbdusSabur*)

A. Machining Non-Conductive Materials

The general conception is that only electrically conductive materials can be machined using electric discharge machining. But in recent times, methods have been developed to machine non-conductive materials too with Electric Discharge Machining. AbdusSabur et al. have investigated the material removal characteristics of non-conductive ZrO_2 in EDM using an assisting electrode [1]. Adhesive copper or aluminium foil, coating of graphite or carbon, silver varnish and copper, silver or gold can be sputtered on the surface of the workpiece to provide a metallic coating as shown in the Fig.2. As the discharge occurs pyrolytic carbon is formed on the surface of the workpiece due to the disassociation of kerosene molecules. This carbonic layer provides the necessary electrical conductivity to carry on the process. The tool electrode was made of copper and an adhesive copper foil is used as the assisting electrode. It has been observed that the main mechanism of material removal is spalling and only a small amount of material is removed by vaporization and melting. The material removal rate has been found to increase with increasing values of power.

Mayank Srivastava has studied the EDM machining of non-conductive ceramics using different electrodes namely graphite, copper and brass [2]. A lacquer based assisting electrode was applied on the workpiece surface using Doctor's knife and screen print techniques. It was noted that material removal, wear rate and process stability were deeply influenced by the choice of the electrode used. Copper electrodes have shown a stable behaviour and produced better surface quality. Graphite electrodes were found to produce the highest material removal rates.

Andreas Schubertet al. studied the ablation behaviour of the ceramic composites Alumina Toughened Zirconia (ZrO_2-Al_2O_3) and Titanium Nitride toughened Silicon Nitride (Si_3N_4-TiN) [3]. Amaximum aspect ratio of 6 for ZrO_2-$Al_2O_3$and 5 for Si_3N_4-TiN was obtained. It was observed that the resistance increases with increasing bore depth. In addition to the conventional problems encountered in deep holedrilling, the influence of conductive carbon layer formation holds a major drawback for drilling holes of higher aspects. Their experiment also reveals that material removal rate, tool wear, and surface roughness are influenced by the ceramic composite composition itself and the discharge energy.

Li Xiaopenget al. have formulated a novel technique called Double Electrode Synchronous Servo Electrical Discharge Grinding for machining of non-conductive ceramics [4]. This method integrates the advantages of Electrical Discharge Machining and mechanical grinding. A conductive grinding wheel which acts as the tool electrode is made to rotate at high speeds at the surface of the workpiece. When a thin conductive sheet is inserted in between them, discharge take place and material removal take place on both the sheet and the workpiece due to the very thin nature of the sheet. This method is stated to provide material removal rate significantly better than of conventional machining.

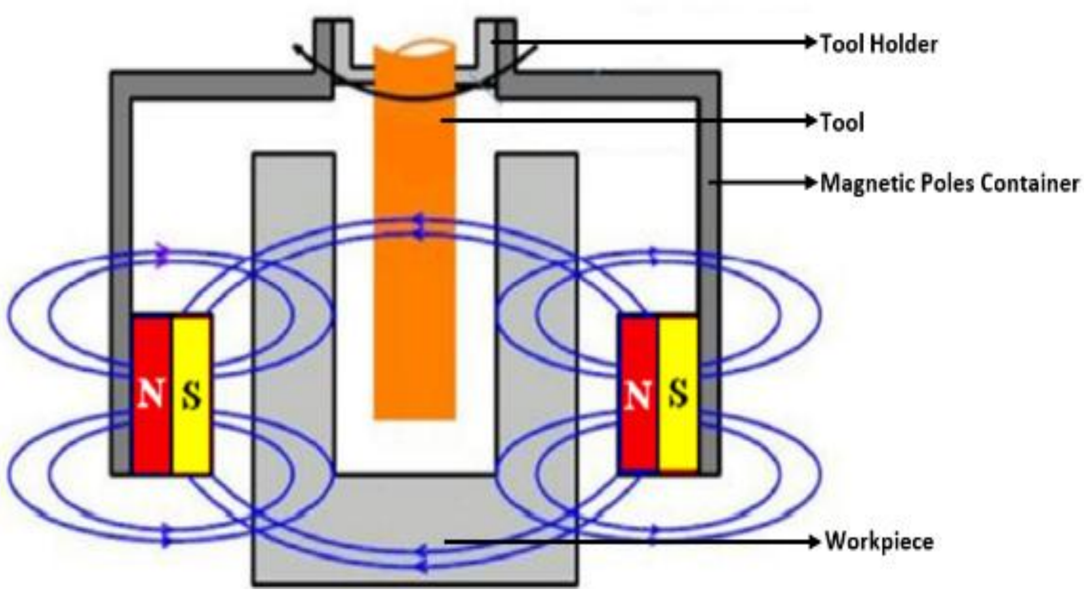

Fig.3 Magnetic Force Assisted EDM Setup (Source:R.Teimouri)

B. Magnetic Field Assisted EDM

Flushing is the process in which the dielectric fluid washes away the debris in between tool and workpiece. Reza Teimouri et al. have studied the effect of using a rotating magnetic field in dry EDM machine assisted with ultrasonic vibration of the workpiece [5]. A rotary magnetic disk containing four magnets is attached along with the tool holder and rotates along with the tool in a planetary fashion. Experiments were carried without and under the influence of magnetic fields. It was revealed that the magnetic field highly aids in increasing the material removal rates. This is because the magnetic force assists in flushing out the eroded particles between the tool and the work piece. It was also uncovered that establishing a magnetic field at the machining gap causes better ionisation. Thus the migration of ions is accelerated which in turns helps in quick formation of the plasma channel reducing the ignition delay. The effect of the magnetic field is predominant in the cases of high current and pulse on time. In these conditions the enormous suspended particles in the machining gap that lead to abnormal discharges are expelled efficiently thereby improving the stability of the process dramatically.

Optimizationof EDM employing rotary tool assisted with a rotating magnetic field was studied by R. Teimouri and H. Baseri[6]. The Fig.3 shows the experimental setup consisting of an electro motor and belt mechanism mounted on a machine. The rotational speed of the machine is being controlled by LS600 inverter. Two magnetic poles with various intensities were attached onto the inner surface of a cylinder with a central through hole which establishes the magnetic field around the work and tool electrode. It was found that high magnetic field intensity caused expansion of plasma channel that affects the MRR, but provides a better surface finish. Lower field intensities were found to provide better ionization by resisting the expansion of the plasma channel providing better MRR and on the other hand affecting the surface roughness. At higher rotational speeds there was an improvement in MRR as the accumulation of debris in the machining gap was lowered which in turn lowered the surface roughness. Hence, a better surface finish can be achieved.

Ahsan Ali Khan et al. have studied the effect of an external magnetic field on the surface roughness of SUS 304 Stainless Steel[7]. The amount of solid debris formed was comparatively less than that of conventional EDM. Better surface finish (up to 7 µm) was observed at lower values of current and the quality degraded with higher currents. The optimum duty factor was found to be 50%. The craters formed were smaller and less micro cracks.

C. Dry EDM

Dry EDM is an environmental friendly method in which the liquid dielectric medium is replaced with a gaseous medium which is injected into the machining gap at high pressure through a tubular tool. This eliminates the use of toxic flammable non eco-friendly dielectrics. EckartUhlmannet al. have analysed comparatively the dry EDM and conventional EDM process for manufacturing of micro holes in Si_3N_4-TiN [8]. The conventional dielectric, deionised water was compared with two different gaseous dielectrics, oxygen and argon. It was concluded that oxygen could be used for roughing as it has the highest MRR. Deionised water provided a low MRR but had lower electrode wear and showed smaller recast and white layers. Argon showed a very poor MRR but resulted in smaller recast and white layers with sharp edges. It possessed the least electrode wear of the three due to the chemical inertness of argon.

GrzegorzSkrabalak and Jerzy Kozak mathematically modelled the dry EDM process and compared it with kerosene bases EDM process [9]. Serious troubles were encountered in evacuating the eroded particles from the machining gap. The particles attached themselves to the electrode and the machined surface, thus slowing down the process. The situation can be improved by providing additional gas nozzles from the sides. Suction nozzles were also suggested. The dry EDM process to be effective for machining thin layers as the removal of the debris is much easier in these cases. Since tool wear is also minimal, it proved to very efficient for micro-scale machining.

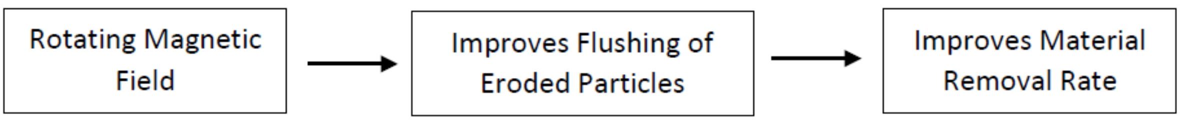

Fig.4 Effect of Magnetic Fields in EDM Process

L. Liqing et al. have studied dry EDM with oxygen mixed dielectric and cryogenic cooling. Experiments with oxygen, nitrogen, argon and compressed air revealed that oxygen provided the highest. MRR [10]. Cryogenically cooled work pieces were resulted in a slight improvement in surface roughness and a considerable rise in MRR for both positive and negative polarities. Overcooling must be avoided as it forms a frost layer and produces excessive water vapour during machining which negatively influences the process.

D. Ultrasonic Assisted EDM

EDM process equipped with an ultrasonic assisted cryogenically cooled copper electrode for the machining of M2 grade high speed steel was studied by Vineet Srivastava et al.[11]. The MRR, Electrode Wear Rate (EWR) and surface roughness achieved with normal electrode, cryogenically cooled (CEDM) and Ultrasonic Assisted Cryogenically Cooled Electrode (UACEDM) have been compared. The MRR of UACEDM was comparable to that of conventional EDM and higher than that of CEDM. The surface roughness was significantly higher in the convention EDM and in all three, SR tends to increase with increasing discharge current and pulse ON time. UACEDM provides better surface integrity. Material removal in UACEDM occurred also due to oxidation and decomposition. Though cryogenic cooling lowers the effective heat transferred, the ultrasonic vibration acts as a pump and propels the debris out, thus improving the discharge energization.

The outcomes of applying ultrasonic vibration to the machining dielectric fluid of micro EDM was studied by T. Ichikawa et al.[12]. The application of ultrasonic vibration to the machining fluid has a pumping effect and aid in debris removal. It also evens out the debris and carbon particle distribution in the machining gap and reduces the short circuits and abnormal discharges. Thus machining speed was greatly increased. The tool wear ratio was also found to be less. It was also concluded that the vibration amplitude had no major influence on the machining characteristics.

E. Other Advanced Methods

Y. Shenet al.studied the machining of AISI 304 stainless steel (AISI 304 SS) using high-efficient hybrid machining with a high-speed air dielectric [13]. This high speed dry EDM method improved the MRR of dry EDM to a considerable extent. Arc machining is characterised by high material removal rates and Electric Discharge Machining by better surface quality. The hybrid method suggested incorporates the advantages of the two. The EDM module causes the dielectric breakdown producing higher voltages and the arc machining module provides the necessary energy for machining. The high voltage produced allows for higher machining gap than that of arc machining thus tremendously improving debris disposal. Results showed that machining rates upto 100 times better than EDM were obtained. This is because more energy is dispended continuously in the process than in conventional EDM. The Relative Electrode Wear Rate(REWR) was also found to be less than that of EDM. The surface roughness was much higher than that of EDM but was half of that of the arc machining process. Also the MRR increased with high values of air flow rate, peak voltage and electrode rotation speed. REWR decreases with high values of air flow rate and lower values of peak current. The work piece was found to be work hardened.

Anand Prakash Dwivedi et al. has increased the performance of EDM Process using Tool Rotation methodology for machining AISI D3 Steel [14]. The rotating tool produces a pumping effect improving the flushing efficiency. MRR and quality of holes are improved. Y S Liaoa and H W Liangetal.have carried out vibration assisted EDM Drilling with electrode feed in the horizontal direction [15]. Inclining the direction of feed by 15^{o} upwards was observed to provide best results. A 75% increase in the depth of the hole was achieved in drilling of aluminium 6061 alloy by inclining the workpiece.

III INFLUENCE OF ELECTRICAL PROCESS PARAMETERS

Electrical process parameters play an important role in the process and performance measures of EDM. Various, research works have been conducted on electrical discharge machining to analyze the electrical process parameters of EDM. The research works mainly focus on material removal rate, tool wear rate, surface finish, Pulse ON time of the electrical discharge machining process.Xiuzhuo Fu et al. have implemented a high resolution and high response frequency piezoelectric actuator in EDM process which can regulate discharge gap based upon the discharge condition and even eliminate the short circuit [16]. The electrode wear rate can be improved by this technique.

M P Jahanet al. looked into the effects of electrical process parameters in EDM process using an RC pulse generator while machining tungsten carbide workpiece with brass tool electrode[17]. A smoother surface finish was obtained when the transistor pulse generator was replaced by a RC pulse generator.Ayesta et al. has tested the influence of electric discharge current and pulse ON time, material removal rate and tool wear rate of EDM process while machining the C1023 Aeronautic alloy with POCO tool electrode [18]. They concluded that electrode wear reduces when the input current and surface roughness increases. RiamaoZouet al. investigated the parameters of micro EDM process of porous stainless steel 304 with tungsten electrode [19]. They have found that as the pore size increases the tool wear ratio increased. David Carolos etal.analyzed the performance of the die-sinking EDM machining of high resistance material such as Nickel base alloy with graphite as tool [20]. They revealed that vibration assisted EDM machining improves machining time and reduces the material removal rate. Amplitude of vibration plays an important role in this process. Roberto Perez et al. investigated the perspective of zero defect manufacturing with the scope to detect the defects generated in WEDM by advanced sensor signal feature [21]. They found that the sensorical data related to the signals of voltage and current and feed rate.

Sanjay Agarwal et al. inquired into the surface integrity in EDM process with AISI 4340 Steel and copper tungsten electrode [22]. They infer that reduced pulse current increases the surface crack density. Induced residual stresses also depends upon the pulse current and pulse duration.Durairajetal.analysed the process parameter ofwire EDM with stainless steel using Taguchi method and Grey relational Grade [23]. They deduced that pulse ON time plays major role on surface roughness and kerf width. They used ANNOVA for study of the parameter relationships.KapilGupta et al. examined the micro-geometry of miniature spur gears of bronze and aluminium machined by wire EDM process[24]. They found that the profile deviation and irregular shapes and craters are formed due to high electric discharge and wire lag in wire EDM process. Uhlmannidentifiedthe development and optimized the die sinking EDM technology for machining nickel alloy MAR-M247 [25]. They found that machining time has been increased by 50% due to variation in discharge current , discharge duration, pulse duration and ignition voltage and duty factor. Vikas et al. analyzed the effect of process parameters on the surface roughness in EDM for EN41 materials using Grey-Taguchi method [26]. They found that the discharge current has a larger impact over the surface roughness. The effect of other process parameters are significantly less and ignored. Feng Yerui et al. investigated the EDM parameters for TiC/Ni Cermet machining [27]. They concluded that pulse ON time increases the material removal rate and increase the surface roughness. Gasification and melting are the main material removal methods observed.

Kliuev et al. studied the EDM-Drilling and Shaping of SiSiC and SiC materials [28]. They found that best technology for SiC is high ignition voltage to material removal rate and low pulse duration and high current. J.F.Liu et al. studied the white layer formation in the EDM process [29]. They proposed that the high voltage and high discharge duration makes more white layer formation on the ASP 2023 tool steel and also found that the upper layer is porous and lower layer is solid.

RavindranandhBobbili et al analyzed the multi response optimization of wire EDM process parameters of ballistic grade aluminium alloy [30]. Experiments have been performed with four machining variables, pulse on time, pulse off time, spark voltage, peak current. Ganesh Dongre et al. investigates the optimization of silicon wafer slicing by wire EDM process [31]. They deduced that work piece height, wire diameter, duty cycle and current are the control parameters of wafer slicing. VineetSrivastav et al. examines the effect of process parameters on the performance of EDM process with ultrasonic assisted cryogenically cooled copper electrode on M2 grade High speed steel [32]. They inferred that the abundance of cracks formed are due to high discharge current. Electrode wear ratio and surface roughness are lower in ultrasonic assisted EDM. Dastagiri et al. investigated EDM process parameters on stainless steel & En41b [33]. Material removal rate, tool wear rate, surface roughness, hardness parameters are controlled. As current increases the discharge power is increased.

Jagdeep Singh et al. has discussed the implementation of Taquchi method with hybrid decision making tools for prediction of surface characteristics for powder-mixed EDM of WC [34]. They proposed that pulse-ON time is most influencing input parameter. Higher value of current and pulse on-time are found to be significant in the work whereas graphite powder to be more useful and efficient. K.Zakariaet al. investigated the effect of wire EDM cutting parameters for evaluating of additive manufacturing of hybrid metal material [35]. They proposed that pulse ON time and pulse OFF time and voltage have significant impact on surface hardness. High pulse ON time, current and high voltage produced poor surface quality. Surface roughness with sand polish is much less than without sand polish. Cheo-SooLee etal.analysed the electrode wear estimation for EDM drilling on a model [36]. They concluded that discharge parameters affect the wear rate.L.Selvarajan et al. examined the optimization of the EDM process parameters in machining Si3N4−TiN conductive ceramic composites to improve form and orientation [37]. They found that there was considerable improvement in material removal rate, tool wear rate, wear ratio, surface roughness during spark erosion.AmiteshGoswami et al. optimized wire EDM of Nimonic − 80A using Taguchi's approach [38]. They deduced that high cutting speed gives high surface roughness. Increasing pulse ON time and peak current increase the number of electrons striking the work piece(material removal rate is increased). F.L.Amorim et al. investigated the influence of generator action mode and process parameters on the performance finish of tool steel in EDM [39]. They concluded that the maximum material removal rate is obtained using positively charged electrode and generator under iso-energetic mode, minimum surface roughness is achieved by negatively charged electrode and generator under iso-energetic mode. Yan cherng Lin et al.analyzed the machining parameters in magnetic force assisted EDM based on Taguchi method [40]. They concluded that material removal rate of magnetic force assisted EDM is almost three times as large as value of the standard EDM. The peak current affects surface roughness in this method. Ming Zhou investigated the fast and stable EDM machining by two step ahead predict control [41]. They concluded that Two Step Prediction(TSP) control achieves a faster machining rate.Minimum Variance Pole Placement (MVMP) control law and minimum variance control lawswere used for two-step -ahead predicted control.

M.R. Shabgard have applied the fuzzy approach to optimize the process parameters in Ultra Sonic Assisted EDM (UAEDM) [42]. The variations of MRR, Surface Roughness (SR) and Tool Wear Ratio (TWR) with discharge current, pulse duration and ultrasonic vibration of the tool has been observed. Increasing values of discharge current and pulse duration improved the MRR but on the other hand the TWR and SR were increased.Fredrik Vogeleret al. examines the effect of Wire EDM processing on the flexural strength of ZrO2- TiN on large scale [43]. They concluded that there is not a correlation between surface roughness, surface integrity, and as a consequences of flexural strength. J.W.Murray etal.examines the physical and electrical characteristics of EDM debris [44].They finalized that the electrical debris particles are present in all sides of components and it does not depend upon the discharge current.It has been concludes that the surface roughness, material removal rate, tool wear ratio have been increased with pulse duration and input current and voltage.

IV CONCLUSION

This paper has provided insight into the various state of the art methodologies followed in EDM in detail. It has also discussed the influence of various electrical process parameters on the performance of Electric Discharge Machining. The scope of this study has not been limited to die sinking EDM alone but also covers EDM drilling, wire EDM, dry EDM etc. The following are the conclusions of the above discussions:

(i) The general notion that ‘EDM is feasible only for non-conductive materials’ is no longer valid since many non-conductive ceramics like ZrO2,Si3N4-TiNetc have been successfully machined using EDM process.

(ii) Magnetic field assisted EDM provides better MRR. This is because the rotating magnetic fields aid in the removal of the debris from the machining site, thus improving the flushing characteristics significantly.

(iii) Dry EDM is a prospective technique as it is environment friendly (as the dielectric is replaced by a gaseous medium). It also causes significantly less electrode wear.

(iv) From study of various literatures, it has been revealed that peak current and the pulse ON time are dominant parameters in influencing process performance.

(v) It has been observed that little focus has been shown on machining of composite materials using EDM. Composites, being able to meet the demands of modern engineering, are a prospective field where EDM machining can be employed.

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