A Review on Hybrid Electrical Discharge Machining Processes

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Abstract

Electrical discharge machining (EDM) is extensively used unconventional machining process for making small holes, dies and cavity from past decades. Extremely hard material is easily machined without any vibration and chattering by EDM process.However, major problems encounter in the EDM process are poor surface quality and low material removal rate (MRR).These drawbacks have been overcome by progressive research in previous years. The paper aims about a review on the modern machining trends of EDM and to study the development of different hybrid EDM processes like ultrasonic assisted EDM, magnetic field assisted EDM, rheological fluid assisted EDM and powder mixed EDM. The study mainly prominences on aspects related to material removal rate, tool wear and surface quality. Discharge current, pulse on time, pulse off time, duty cycle, voltage and percentage of abrasive particles were reported as the input parameters in existing research.

Keywords: Electric, machining, hybrid, ultrasonic, rheological, fluid, magnetic.

I. Introduction

Materials such as super alloy die steel, composite and ceramics are used in aerospace, automobile and surgical industries. Machining of these materials is very difficult using conventional machining due to their high hardness. EDM is usually used for machining of these difficult-to-machine material. This process had been developed in late 1940s [1]. In which, the series of continuous discharge generate between electrical conductive workpiece and electrode in the presence of dielectric fluid. Both electrical and non-electrical parameters are used in EDM. Pulse on time, pulse off time, duty cycle and discharge current have been taken as electrical parameter by most of researchers [2]. Electrode and workpiece rotation, type of dielectric fluid, percentage of abrasive particles have been taken as non-electrical parameters in reported research [3, 4]. The parameters and performance measures of EDM are shown in Fig. 1.

Material removal mechanism in EDM

In EDM, the basic mechanism of material removal is melting and vaporization. The tool is moved towards workpiece by servo-controlled feed until the gap becomes small enough in the range of 10-100 μm [5]. Afterwards, the applied voltage ionizes the dielectric. Dielectric fluid plays a vital role in EDM. However, as sufficient voltage reach then its molecules break into ions and electrons and form a channel of plasma. The thermal energy is generated at temperature 8000°C to 12000°C between the electrode gap and workpiece due to plasma channel. When pulsating supply is turned off, the plasma channel breaks down and dielectric flush the molten metal from the surface in form of debris [6, 7]. The material removal mechanism in EDM is shown in Fig. 2.

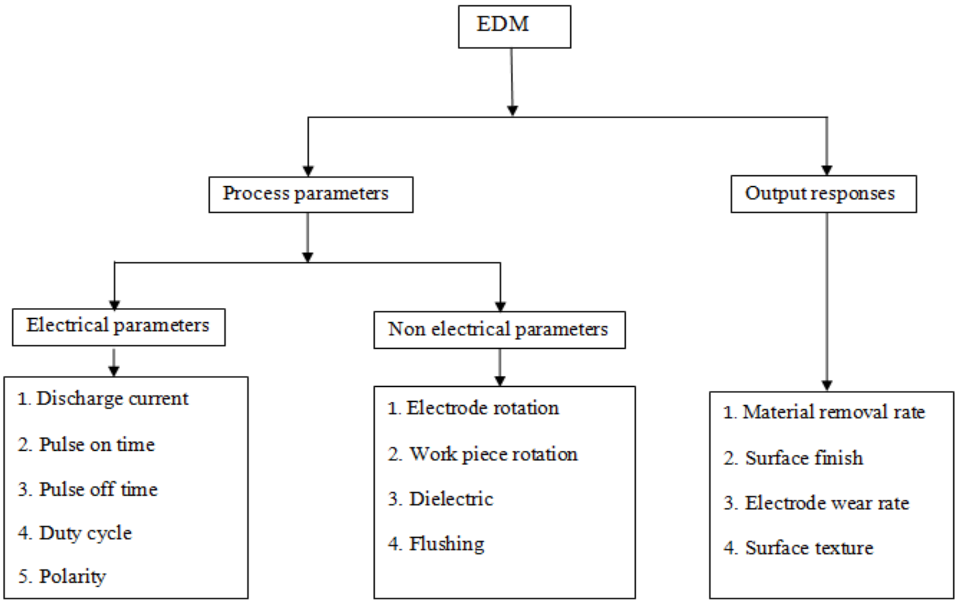

Fig. 1 EDM process parameters and output responses

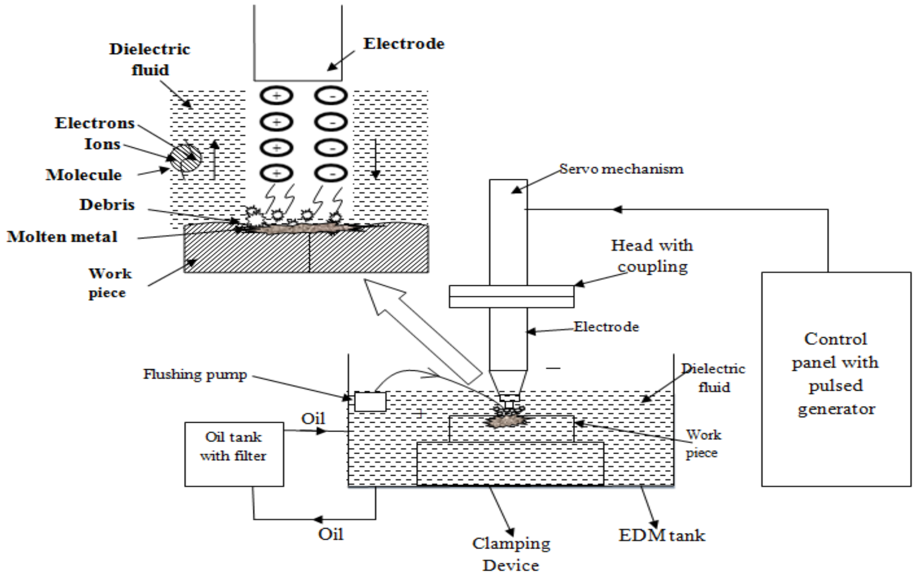

Fig. 2 Mechanism of material removal in EDM

II. Literature review

The performance of EDM has been investigated over the last five decades. A broad look of literature reveals that hybrid EDM has received maximum attention. In hybrid EDM, the material removal mechanism of EDM combined with the additional source of material removal process to enhance the performance of EDM. The ultrasonic assisted electrical discharge machining (UEDM), magnetic field assisted electrical discharge machining (MEDM), powder mixed electrical discharge machining (PEDM) and rheological fluid assisted electrical discharge machining (REDM) have been the recent development in form of hybrid EDM process reviewed in this article. The hybrid EDM processes are shown in Fig. 3

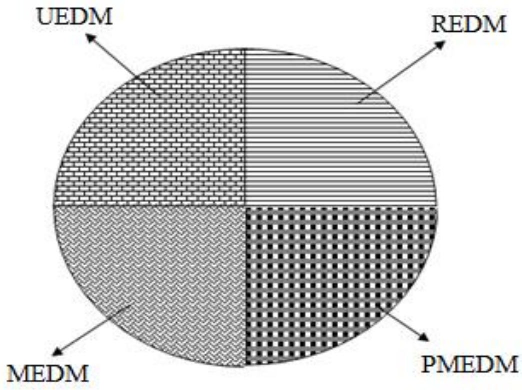

Fig.3 Hybrid EDM processes

Ultrasonic assisted electrical discharge machining (UEDM)

In UEDM process, ultrasonic vibrations of electrode coupled in EDM that raised feed rate by better flushing and lower destruction due to heating [8]. Research efforts, carried out in the past to investigate experimentally the effect of ultrasonic vibrations in EDM, and has been discussed in this review. Kremer et al. [9, 10] studied the influence of ultrasonic vibrations on the performance in EDM. They observed that the vibrating surface of the electrode accelerates the dielectric circulation. Further, they observed that more efficient discharges due to pressure variations in the gap. So additional melted metal removed from every crater. The exaggerated layer was reduced thermal residual stresses were modified. Less micro-crack were observed. The fatigue resistance was originate to be increased by ratio up to 6 times.Srivastava and Pandey [11] observed the influence of process parameters on the performance of EDM with ultrasonic based cryogenically cooled electrode. It was noticed that surface integrity was found better in case UACEDM process as compared with conventional EDM. The MRR was modified in UACEDM process due to ultrasonic vibrating motion of the electrode. The surface of UACEDM was found abundance of cracks. Murti et al. [12] investigated the effect of ultrasonic irradiation of the spark gap on EDM debris. Most of the particles were globular in shape with slight ellipticity showed by scanning electron microscopy (SEM). The effect of ultrasonic vibrations was highly significant with size and incidence of collision.

Jia et al. [13, 14] established a technique to produce holes in engineering ceramics using electro discharge machining. Study revealed that the technique was effective in obtaining the high MRR. Lin et al. [15] demonstrated the machining characteristics of hybrid EDM with ultrasonic vibration. The study reported the greater MRR and finer surface integrity. The hybrid EDM process enabled the migration of debris from machining gap with the help of magnetic force and ultrasonic vibrational force.Higher surface roughness was reported in positive polarity machining.

Shabgard et al. [16] used the fuzzy based algorithm for prediction of MRR, EWR and surface roughness.The study revealed that the fuzzy model was developed based on the EDM of tungsten carbide and modelling UEDM were able to forecast the experimental results with accuracy more than 90 %. Zhang et al. [17] suggested spark erosion with ultrasonic frequency using a DC power supply. They indicated that it is easy to produce a combined hybrid technology, which benefits from the virtues of ultrasonic machining and EDM. Liew et al. [18] produced the deep micro holes using ultrasonic cavitation based micro-EDM. The proposed EDM process to be beneficial for fabricating micro holes on hard brittle ceramic materials. Goiogana et al. [19] developed the pulsed UEDM for finishing operation. The copper tool was used for machining of alloy steel in proposed research. Pulsed ultrasonic vibrations in EDM achieved homogeneous distribution of debris layer. Therefore, homogeneous surface roughness was obtained. The study proven that pulsed ultrasonic vibrations combined with EDM was the best suited method to achieve the better surface finish.

Xie et al. [20] studied the debris distribution in UEDM of hole array under different amplitude and frequency. This research proposed the two-dimensional model of flow field and found the mechanism of debris distribution for the bottom and side gap in UEDM process by computational fluid dynamics.The effect of amplitude and frequency of ultrasonic vibrations of tool on debris distribution was examined through numerical simulation. Shabgard et al. [21] exposed that ultrasonic vibrations of the workpiece can significantly decrease the inactive pulses and improve the stability of process. It has been elucidated that UEDM is effective in achieving the high MRR in finishing regime.Yeo and Tan [22] investigated the limitations of micro holes machining capabilities and current, while attempting to improve micro hole drilling in UEDM. A method of introducing ultrasonic vibrations into micro EDM processes was developed based on theories in fluidization engineering.Yu et al. [23] explicated the influence of ultrasonic vibration on EDM process. The results indicated that ultrasonic waves and cavitation played an important role in improving the machining efficiency.

Powder mixed electrical discharge machining (PMEDM)

In PMEDM, mechanical abrasion caused by the abrasive particles suspended in dielectric in form of powder to assist the EDM action and enhance the further material removal, surface finish. Singh and Sharma [24] investigated the effect of different dielectric on environmentally conscious PMEDM. Three dielectric namely EDM oil, kerosene oil and distilled water were used in the study. The work material of tungsten carbide and graphite powder (Particle size: 55µm) were selected for the study.The machining characteristics material removal and tool wear rate (TWR) were found contradictory in nature in single variable study.Both have different requirements to obtain significant output responses. Their research has suggested to use the multi-objective optimization for find the optimal solution. Tripathy and Tripathi [25] optimized PMEDM using TOPSIS and grey relational analysis. The study revealed that the TWR decreased and MRR increased with addition of 3 gm/l chromium powder in dielectric fluid due to the bridging effect. Muttamara and Mesce [26] noted the effect of titanium nitride powder mixed in EDM. The machined surface with titanium nitride mixed kerosene was found rougher than that in conventional EDM. Furutani et al. [27] studied the effect of accretion of titanium carbide (TiC) powder by EDM. The titanium powder layer on the machined surface grew up the thickness of 150 µm after accretion of titanium powder. The study exposed that nozzle flushing was not significantly affect the MRR at the interface between tool and workpiece.

Kumar et al. [28] studied the parametric optimization of PMEDM for Inconel – 800 using response surface methodology. Tungsten carbide, cobalt and boron carbide and three electrodes i.e. copper, copper-chromium and graphite have been used for experimentation. Singh et al. [29] investigated the effect of conductive powder on the surface properties of super alloy machined by EDM process.Graphite powder was used to mix in EDM oil, which affected the energy distribution and sparking efficiency by lowering the dielectric strength. The graphite tool was used in experimentation. The study revealed that the improvement in micro hardness was found to be lower whereas surface finish improved significantly with powder mixed EDM.

Amorim et al. [30] reported about the influence of various size of fine molybdenum powder particles, suspended in dielectric fluid in several EDM finishing regime. The resolidify layer of surface has been identified by an addition of molybdenum powder in the dielectric. The optimum value of discharge current and particle size were found as 1A as and more than 15μm respectively to achieve the resolidify layer free from micro cracks. Pecas and Henriques [31] examined the effect of silicon powder mixed dielectric on EDM.The polishing performance of EDM was improved using silicon powder. Smooth and high reflective craters were achieved at 2g/l silicon carbide concentration.

Kumar and Batra [32] explained that the tungsten powder mixed dielectric was improved the plasma channel. The substantial amount of material was removed using tungsten powder mixed dielectric under suitable machining condition. The presence of tungsten carbide in dielectric increased the micro hardness of the machined surface. Singh et al. [33] did aluminum powder mixed EDM. The study was carried out using copper electrode. The high material removal with low TWR was reported in the research. The surface finish of hastelloy was also improved using powder mixed dielectric.

Wang et al. [34] studied the characteristics of plasma channel in PMEDM. The aluminum powder mixed in kerosene was used for the experimentation. The study revealed that the formation of plasma channel was stable in powder mixed kerosene oil in mono pulse discharge. Their stability was increased with an increase in discharge current. The aluminum particles formed a bridge that compressed the discharge column. Therefore, the discharge column was narrow and plasma channel became stable. Behera et al. [35] studied the parametric optimization of powder mixed EDM of aluminum based metal matrix composite. Taguhi and grey relational analysis were used in the reported research. The SiC reinforced ZA-27 metal matrix composite was used as workpiece material.The study revealed that largest value of grey relation grade (GRG) was obtained in PMEDM. Therefore, powder concentration had strongest effect among other process parameters. The highest GRG was found at lowest concentration powder at 6A peak current and 0.5 duty cycle.

Magnetic field assisted electrical discharge machining (MEDM)

In MEDM, the magnetic field is applied around the machining zone that enhances the process stability and increases the efficiency of the EDM. The use of magnetic field also helps in increasing the MRR due to reduction in the inactive pulses such as arcing, open circuit and short circuit due to Lorentz force [36, 37]. Jafferson et al. [38] studied the cumulative effect of ultrasonic vibration and magnetic force during micro EDM milling. The study reported the poor material removal was found. MRR was improved in EDM either separately using ultrasonic vibration or magnetic field. For better MRR, the range of tool rotation speed and horizontal feed rate were 1500 rpm and 100 mm/min respectively.

Lin et al. [39] dealt with optimization of machining parameters in magnetic force assisted EDM. The Taguchi L18 orthogonal array was adopted for design the experiments. The study revealed that thin and clear surface was obtained in magnetic force assisted EDM. In magnetic force assisted EDM, the peak current was found as the significant parameter that affects MRR and surface roughness. Joshi et al. [40] investigated the dry EDM performance in a pulsating magnetic field. The pulsating magnetic field was enhanced the degree of ionization of plasma. It was noted that the productivity of EDM was improved by 130% at zero tool wear using this hybrid EDM as compared to normal EDM. Govindan et al. [41] analyzed the removal phenomenon in MEDM. Lorentz force was confined the plasma and reduced the mean free path of electron due to magnetic field. The crater depths were increased by 27% and 37% for dry and liquid EDM respectively. The maximum reduction of crater diameter was reported as 81% in dry EDM and 67% in liquid dielectric EDM.

Yeo et al. [42] revealed that efficient debris removal was achieved by implementing magnetic field perpendicular to the electrode rotational force. The net resultant force easily expelled the debris out of the hole during machining. The study stated that higher hole depth was achieved by magnetic field assisted micro EDM as compared to normal EDM. The magnetic field was not affected the surface roughness significantly. Heinz et al. [43] investigated the material removal in micro EDM for non-magnetic workpiece material. The additional Lorentz force normal to the workpiece was used to enhance the material removal by utilizing the workpiece directional current regardless the magnetic properties of workpiece material. The material removal was increased up to 50 % by micro EDM.

Zilong et al. [44] designed a magnetic field generator for compression plasma discharge channel in micro EDM. The study revealed that magnetic generator enhanced the self-magnetic field for compressing the discharge plasma channel, resulted in improvement in the performance of EDM. Chu et al. [45] studied the magnetic field assisted micro EDM. The study elucidated that the crater was formed larger and shallower from MEDM as compared to normal EDM.

Rheological fluid assisted electrical discharge machining

The very limited study has been reported for electro rheological and magneto rheological fluid assisted EDM. The rheological fluid has the property to change its viscosity under the application of magnetic or electric field [46, 47].The combined approach of EDM with magneto rheological fluid is investigated in limited reported research.Tsai et al. [48] firstly used electro rheological fluid as a dielectric medium in EDM. The results elucidated that the surface roughness and material removal was increased. There was same waveform of single discharge pulse at different starch concentration in electro rheological fluid. The study revealed that the electro rheological fluid of starch particles improved the surface finish significantly with the use of abrasive particles in ER fluid as compared to normal EDM. Upadhyay et al. [49] dealt with the capabilities of a newly developed method of EDM in which magneto rheological (MR) fluid was used as the dielectric. The viscoelastic nature of MR fluid was utilized to provide polishing effect as well as high material removal.The research reported that performance of EDM with MR fluid was improved as compared to normal EDM. Upadhyay et al. [50] investigated the rotary tool and magnetic field assisted EDM using magneto rheological fluid. Copper tool was selected for machining of M2 grade high speed steel. The study reported that MRR was increased and surface finish was improved using MR fluid.

III. Conclusion

The performance of EDM has improved in recent years. EDM is most popular method to produce the intricate and complicated shape. There are constant demand of this machining in the industries due to cutting of new hard material.The review of research trend in EDM on ultrasonic assisted, magnetic field assisted and powder mixed and rheological fluid assisted EDM performance is reported.The powder mixed EDM is suitable for achieving the best surface finish. UEDM is used for micro machining. Higher MRR is a concern MEDM. The rheological fluid assisted EDM is recently developed hybrid-machining process, which gives high MRR is achieved with better surface finish. For the same objective, each method introduced and implemented in hybrid EDM process to enhance the capability of machining performance. The better output response is carried out in hybrid EDM.

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