Influences of Powder mixed Dielectric Fluid on Machining Characteristics of EDM processed parts: A review

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Abstract: The effective application of any machining process relies on its ability to machine the part/material with high efficiency and with better surface finish. Electrical discharge machining is considered as a non-conventional method of machining which is well established and is used for the manufacture of parts which have geometrically complex shapes and intricate profiles. This machining technique came out for the process of making dies and mere tools for the other manufacturing process. From several years various researches are going on to ameliorate the process parameters which consists of characteristics such as surface roughness (SR), Material Removal Rate (MRR) and tool wear rate (TWR) etc. One of the process that came up with the advancement in capabilities of the EDM process is Powder Mixed Electrical Discharge Machining (PMEDM). The presence of fine metal particles in the dielectric fluid enhance its properties. It includes the increase in the spark gap between the tool electrode and the work and also the reduction in the insulating strength. This increases the surface finish and material removal rate and the process becomes more stable. The present paper brings in the review of research done by several authors across the world to enhance the capabilities of EDM by adding powder mixed dielectric as working fluid. The behaviour of several powders when mixed with the dielectric fluid (working fluid) have been studied and observed by many researchers.

Keywords: EDM, Powder mixed EDM, MRR, TWR, SR

1. Introduction

In the years passing by, an arise in the need of making use of components which are light weighted, slim and compact in the industries which includes medical, automobile, nuclear reactor and aerospace industry lead the way for the evolution of hard materials for innumerable application because of their properties like high strength and resistance to temperature. The machining of such tougher, harder materials which are less sensitive to heat is difficult. Press tools and dies of such materials are extensively manufactured by employing one of the most voguish nonconventional method of machining that is the electric discharge machining. EDM facilitates the machining of a material regardless of its hardness, strength and shape until material being used remains electrically conductive [1]. In this process of machining since the job and the tool does not come in contact with each other, even complex fine sections and materials which are weak can be machined without any deformity. EDM is an electro thermal process in which a dielectric fluid is used to submerge the work-piece. A high frequency continuous electric discharge is developed by making use of a DC pulse generator for the job to be shaped. Non-conventional methods of machining find its great use in machining of MMC’s for the reason it includes process of mixing of the reinforcing material which are relatively stiffer and harder to
that of the matrix onto the base material. However, its implementation is restricted owing to the fact that it has low efficiency and rough surface finish. There is another demerit i.e. the poor flushing of the debris of machining which affects this non-conventional process [2]. The outcome of which is the adhesion of the tool electrode and job. The process of adhesion occurs when the eroded material detached from the job gets attached to the tool electrode which results in the unstable discharge pulse and thereby condition of short circuit occurs between the job and the tool electrode. This increases the overall machining time [3]. To overcome this trouble the dielectric fluid is added with a powder [4]. This new hybrid process of removal of material is the powder mixed EDM. The outcome shows that surface finish and surface quality are improved by implementing PMEDM and at a comparatively high rate of machining [5] Furthermore, the surface produced by this process (EDM) is adhesion and corrosion resistant [6]. There are several materials used as powders, among them aluminum gives much better Material Removal Rate and provides good surface finish when compared to other powder materials which includes Cr, Cu and SiC because spark gap is increased due to low density and high electrical conductivity of Aluminum [7].

The breakdown characteristics of the fluid are enhanced upon the addition of powder to the dielectric fluid, that is, the reduction in the insulating strength and simultaneously increase in the distance of spark-gap in between the work and the tool electrode [8] Therefore there is the uniformity in the flushing of the eroded material (debris) due to enlargement of spark gap. This leads to the process turning out to be more stable and hence great surface finish is achieved with better MRR.

2. Influence of process parameters on EDM

The mechanism of removal of material in EDM process has not been perfectly discerned, it is the most established mechanism of removal of material. In this process wherein there is a transformation of electrical energy to thermal energy across several discrete electrical discharges in between the job and the electrode tool and both of them are immersed a dielectric fluid. Due to the potential difference emission of electrons takes place. There is a collision between the electrons and the dielectric fluid when the emitted electrons advance from cathode to anode and these electrons breaks in to electrons and ions. An ionized column of fluid molecules is produced between the job and tool electrode causing a spark. The principle of working is presented and shown in Figure 1.

![Figure 1. Schematic of electrical discharge machining showing working of the process [31]](image)

This is the reason for increase in the temperature ranging between 8000oC to 20000oC and this results in the melting of both the work and the tool and simultaneously evaporation of these two takes place and on the surface of the work-piece crater is formed. When the pulse is turned off the channel of
plasma breaks down and the eroded material is flushed out by the circulating dielectric fluid in debris form from the gap between the work and the tool [1-4].

2.1. Mechanism of Material removal in EDM

Ignition Phase: In between the tool and the job a high potential difference is created. The voltage increases in the gap between the electrodes as the electrode moves through the apparatus before the breakdown voltage is reached. In between the tool electrode and the work, the output usually occurs at the closest point on the job and the tool electrode. Because of the presence of debris or any impurities the location where the output occurs may change. Plasma Phase: As soon as the channel of plasma is formed the current starts to flow between the channel and as the ionization takes place the voltage drops. Discharge phase: The job is continuously heated due to the constant collision of electron and the ions on to the electrodes. On the surface of the electrodes there forms a molten pool of metal as the temperature increases due to the flow of current. As the channel of plasma is widened molten pool of metal increases.

Ejection Phase: In this phase dielectric fluid exerts pressure and there is a drop in the voltage due to this the channel of plasma collapses. This results in the formation of cavity on the work surface and the dielectric fluid powerfully draws the molten metal pool. The material of the job in small quantities is removed in the form of molten metal and forms debris upon solidification. The impurities or the debris is washed away from the gap between the electrodes by dielectric flushing.

3. Powder mixed EDM process (PMEDM)

Powder mixed Electric Discharge Machining (PMEDM) is an advanced version of process of EDM. In this process fine abrasive particles which are electrically conductive or non-conductive is added in the form of powder in the dielectric fluid. The abrasive particles which are suspended in the Dielectric fluid generally increases the gap between the two electrodes and insulating strength is reduced. With this the performance of the EDM process is improved. This provides better surface finish when compare to that of the conventional EDM. The principle of PMEDM includes the setting up of the electric field upon the application of suitable voltage, this results in the powdered particles being charged. The powder particles are energized. These particles get accelerated and further moves in zigzag manner resulting in the improved spark gap between the tool electrode and job as shown in Figure 2. Interlocking between the flow particles occurs in the direction of flow of current.

![Figure 2. Schematic representation of EDM process with powder particles in the dielectric fluid](image)
3.1. Influence powder mixed EDM process

In PMEDM, when a voltage ranging from 80-320 volt is applied across the tool electrode and the work an electric field (105-107V/m) is developed and due to this charges are accumulated around the fine metal particles used as powder and is mixed with the working fluid[9]. The breakdown of the voltage takes place at the point where there is maximum density of electric field. This breakdown may occur in between the particles of powder or between the powder particles and the work or the tool electrode. Spark keeps on developing depending on the intensity of electric field. A chain is formed due to the interlocking different particles of powder. This results in easy short circuiting and thereby resulting in an early explosion between the tool electrode and the work gap. The size of the discharge gap is mainly dependent on the electrical and physical properties of particles of powder. The dielectric resistance is reduced when powder particles consist of free electrons at a condition of high temperature. Therefore the spark can be developed from a certain longer distance which reasonably extend the discharge gap.[10]. Particles of powder when get energized gets accelerated along with the electrons and ions surrounding the powder particle after the first discharge. As and when these particles get collide with the working fluid that is the dielectric fluid, more generation of numbers of electrons and the ions is seen and when compared to the conventional EDM more electric charges are being produced. This phenomenon increases the discharge gap as the hydrostatic pressure on the channel gets reduced. The discharge column which is now widened forms cavities on the job surface. In a single pulse multiple craters are formed on the surface of the work. This is seen as a result of energy being uniformly distributed due to rapid movement of the particles in zigzag manner. Due to the multiple discharges in the duration of single pulse the voltage fluctuates hastily [11].

Kumar et al. (2017) [12] reported the outcome of the experiment performed with an aim to know the mechanism of removal of material in PMEDM. Authors used Al-10% SiCp MMC to understand the role of silicon powder to get the picture of mechanism of material removal using PMEDM. In this paper authors reported how the suspended particles effect the process performance, using Taguchi method they obtained the optimal setting of the process variables. For the experimentation a Die sinking EDM machine was used. In the kerosene oil which was commercially available silicon powder was suspended. The size of the suspended particle was of the order 20-30 micron. Using stir casting method Al-10% SiCp MMC was produced. To machine Al-10% SiCp MMC, electrode made of copper of diameter 5 mm was used. The conclusion made by the authors indicate surface roughness and machining rate is highly affected by the concentration of silicon powder added and the peak current. The surface roughness is lowered to as much as 33% and the machining rate is doubled by adding the optimum amount of silicon powder (4g/L) into the working fluid (dielectric fluid)[12]. Talla et al. [13] Achieved the fabrication and machining of aluminium/alumina MMC in the presence of aluminium powder in kerosene oil used as dielectric fluid in EDM. Semi empirical models were also established for material removal rate based on the parameters of machining and the important thermophysical properties using dimensional and regression analysis. The size of aluminium and alumina particles is about 15mm and 90mm and with a weight ratio of 80:20. For process control agent liquid toluene was used. Sintering technique was used for the fabrication of MMCs. For the prevention of agglomeration of the particles the lubricant used was acetone. Die sinking EDM setup was used for the machining of MMC and the experiment was performed by making use of Taguchi L18 orthogonal array. Electrode of copper with a diameter of 12mm was used to machine Al/AI2O3 MMC. An improvement in the productivity and also the surface quality was reported when the MMC were machined by suspending particle of powder. From the model equations, it was noted that with thermal conductivity, machining parameters and density of material a significant change in MRR was seen. The experiment resulted in better MRR [13]. Prihandava et al. [14], worked in order to enhance the accuracy and precision of the PMD-μ-EDM process and this was achieved by the suspension of nano graphite powder into the dielectric fluid. The process of suspending the nano graphite powder with a particle size of 55nm into the working fluid was done using the ultrasonic vibration of the working fluid and also using the number of discharge pulses. The process was performed by making use of Panasonic MG-ED72 micro-EDM with the positioning accuracy of 0.1 μm. The dielectric fluid used was the kerosene oil. An ultrasonic bath was used in order to avoid the accumulation of the nano
graphite powder at the bottom and also to reduce the adhesion that is because of the eroded material in the form of debris. Silver-tungsten work-piece was machined. Electrode made of tungsten with a diameter of 300 μm used. The main goal of this experimentation was to make blind holes having a depth of 50 μm. Authors noticed that the machining time was significantly reduced up to 35% by the introduction of nano-powder into the working fluid. The problem of inaccuracy was resolved by counting the number of discharge pulse. The additional benefit by adding Nano-powder into the dielectric fluid was the elimination of micro cracks on the machined surface and therefore the surface quality was improved [14]. Yeo et al. [15] observed the effects of adding the powder particles in the working fluid on the characteristics of crater for PSD micro-EDM. Stainless steel was used for the single discharge experiments. To reduce the irregularities from the surface of the work to achieve the mirror surface the work surface was pre polished. Pure tungsten with diameter 125 μm was used as electrode. Daphne Cut HL-25 which is a synthetic electric spark oil was used as the working fluid and 15-55nm diameter spheres of silicon carbide Nano powder was used as an additive. The experiment was conducted at low discharge energies of 2.5 μJ, 5 μJ and 25 μJ and with the working fluid with additive and without additive. The authors observed a difference in the morphology of crater produced with and without using additive in the dielectric fluid. They noticed that when the additive was used craters with more consistent shapes and small diameters were produced and also this effect was less when additive was not added. [15]. Pivaprakasan et al. [16] Observed the effect when graphite nano powder was suspended in the working fluid of Micro wire EDM process. Investigation of machining characteristics of kerf width (KW), MRR and surface roughness was done. The tool electrode material was a cylindrical copper wire with coated zinc with an electrode diameter of 70μm.Inconel alloy metal plate with a thickness of 1mm, width of 10mm and length of 50mm was taken as a work-piece. The EDM oil served as a dielectric fluid. To filter the debris a magnetic filter was used and a pump continuously re-circulated the filtered nano powder to avoid the sedimentation and accumulation of nano powders mechanical stirring was used. The results indicated that when the graphite nano powder is used at a concentration of0.5 g/l at a 100V voltage and at a capacitance of 0.01mF higher material removal rate 0.00544 mm3/min was achieved. Surface roughness was reduced as the single spark brakes into many small sparks which are uniformly distributed. kerf width is significantly affected by the voltage, capacitance and powder concentration [16].

Zhao et al. [17] Performed an experimental research on the surface roughness and mechanical efficiency of PMEDM in rough machining. Copper electrode was used and steel workpiece with diameter of 25mm was used. Aluminium powder with 40g/l in density and 10mm in granularity was mixed with Mobil which was used as special working fluid in EDM. The reduction in the ejecting force on the melted material and the loss of discharge energy is also responsible for the lowering of machining efficiency and reduction in surface roughness [17]. Kolli et al. [18] Observed the effect of suspending graphite powder in dielectric fluid on the surface roughness (SR), tool wear rate (TWR), material removal rate (MRR) and recast layer thickness (RLT). The process parameters included the discharge current, powder concentration and the surface concentration and were changed to know the effect. To observe the influence of graphite powder and surfactant on the machining process Scanning Electron Microscope was used. Titanium (Ti-6Al-4V) of alloy grade 5 was used as the job in the form of rectangular samples dimensioning 100mm in length, 5mm in thickness and 50mm in width. The electrode material was copper with a diameter of 14mm and length of 70mm. It was observed that as the surfactant concentration increase from 4 to 6g/l MRR and RLT increases and these two reduces after 6g/l. Also with increase in concentration of graphite powder and discharge current MRR increased at optimum condition [18]. Hu et al. [19] observed the effect on the surface properties when SiC particle with 40% of volume fraction is reinforced with Aluminium matrix composites. ASP-23 alloy steel was used as the work piece. The results verified that the surface roughness decreases by 31.5%, hardness was increased by about 40% and the wear resistance also increased by 100% [19]. S. Tripathy et al. [20] investigated how process variables such as peak current (Ip), Duty cycle (DC), powder concentration (Cp), gap voltage (Vg) and peak current (Ip) on Tool wear rate, Electrode wear Ratio and Material Removal Rate using chromium powder mixed dielectric fluid. Taguchi method in combination with TOPSIS and GRA
was adopted for the evaluation of effectiveness of optimizing parameters of PMEDM. Commercial grade EDM oil was used as dielectric fluid. H-11 die steel served as a work piece the dimensions being 120 × 60 × 25 mm. The electrode was the electrolytic copper measuring 20 × 60 × 25 mm. The optimal values of process parameters were found to be Ip=6Amp, DC= 90%, Vg= 50V and Cp=6g/l from TOPSIS and Ip=3Amp, DC=70%, Cp=6g/l and Vg=30V from GRA. The experimental result claims that there is a variation on the surface roughness within a range of 3.8 μm to 9.2 μm. When the Cr powder concentration was increased to 6g/l the roughness got reduced from 2.4 μm to 5.04 μm. Thus, it can be said that on the addition of powder particles in proper concentration and size reduces the surface roughness during machining. It was also noticed that on the addition of conductive powder to the dielectric fluid, the surface topography improves with less cracks, defects and surface roughness which has a direct relation with the size of crater formed [20].

P. Chaudhury et al. [21] observed the influence of parameters such as powder concentration, peak current and powder type while machining EN-19 work piece using PMEDM. Taguchi method was used for analyzing the experimental results. Pure kerosene was used as the dielectric fluid. Tungsten powder was added to the working fluid the optimum values of process parameters obtained were Peak current= 7A, Powder concentration= 10g/l, duty cycle =50% and pulse on time= 100 μs. It was observed that when compared to the conventional EDM process larger MRR was achieved in PMEDM. With increase in pulse on time and current values TWR first increase then decreases [21]. Chow et al. [7] examined the revised EDM process. The revised EDM process was developed in order to minimize the discharge current by modifying the discharging circuit. A new driven mechanism was added with horizontal rotating electrode. The process was qualitatively and quantitatively analyzed using different dielectric fluids. Titanium alloy (Ti-6Al-4V) was machined using micro-slit EDM by applying copper diskette electrode. Kerosene, Kerosene mixed with aluminium and kerosene mixed with SiC powder were the three-dielectric fluid. Surface roughness and Material removal depth can be increased by adding Al or SiC with kerosene. SiC gives better material removal depth than when Al is added to kerosene. The gap between the tool electrode and the job extends when kerosene added with either SiC or Al. In case when Al powder is added to kerosene it gives the largest gap between the tool electrode and the job. Based on this it can be perceived that it gives the largest slit expansion. [7]. P. Peças et al. [22] studied the improvement in performance of conventional EDM when powder-mixed dielectric fluid was used. Silicon powder was mixed with the working fluid and the assessment of the improvement in performance was done through process time measurement and quality surface indicators over different processing area. It resulted in the reduction of operating time and the decrease in the surface roughness which allowed for the formation of mirror like surfaces. Even though the influence of electrode area was reduced by using silicon powder on the surface area, we can observe the increase in the electrode area roughness. The observation noted was smooth and high reflective craters were obtained for the concentration of 2g/l of silicon powder. [22]. K. L. Wu et al. [23] examined the effect of Aluminium powder and surfactant when mixed with the dielectric fluid on the surface status of the job when machined through EDM. SKD11 steel was adopted as the job with dimensions of 50x50x6 mm3. High purity electrolytic copper was used as the electrode with diameter of 25mm and 80mm in length. For the optimized surface roughness, the dominant EDM working parameters were taken as 0.1g/L of Al powder, positive polarity, surfactant concentration of 0.25g/L and peak current of 0.3A. Due to the addition of surfactant in dielectric the surface status of the job improves effectively. Aluminium powder with dielectric fluid lowers the insulation and the distance between the electrode increases. The value of surface roughness is also improved to more than 50 than when machined under pure dielectric.[23]. M. Kolli et al. [24] evaluated Tool wear rate, Material Removal Rate and the surface roughness for the Machining of Ti-6Al-4V through EDM. B4C powder mixed with spark ignition 450EDM oil served as the dielectric fluid for the machining. Electrolytic copper with 14mm of diameter and 70mm length was used as the electrode. The results showed that the spark gap and electrical discharge density were improved and hence simultaneously improving the Material Removal Rate. The optimum value of MRR was obtained at 15gm/L. Increase in the concentration of B4C powder significantly increased tool wear rate. It was also noted that at 15g/L the lowest surface roughness was achieved which can be said as the surface roughness was improved [24]. K. Furutani et al. [25] studied...
the influence of the pulse duration and the discharge current on the deposition process by EDM. The work-piece involved is the Carbon steel. Copper rod is used as an electrode with 1mm of diameter. Ti powder was mixed with the dielectric fluid. The result shows that if the power density and the discharge energy is small then TiC could be deposited. The depositable condition range was affected by the discharge energy. It was seen that matrix surface was hardened and the hardness of the deposition obtained was 2000HV[25]. M. Kumar et al. [26] examined the machinability of titanium alloy (Ti-6Al-4V) when machined through EDM. By varying the pulse on duration and peak discharge the experiment was performed. The assessment of the performance of EDM was in terms of rate of tool wear and material removal efficiency. The evaluation of surface integrity was also done. 99.8% pure carbon was used as an electrode. The dielectric fluid employed was the kerosene oil. To determine the elemental analysis of the electrode and work-piece inductively coupled plasma optical emission spectroscopy was performed. It was found that the surface morphology was indeed disappointing due to the presence of pockmarks, crater, globules of debris and uneven fusion structure. However, with the variation of pulse on duration and peak discharge there is a variation in intensity of these irregularities. It was also noted that the peak current has a positive effect on Tool wear Rate, MRR and surface roughness. When the pulse on duration and peak discharge there is an increase in surface crack density [26].

Powder mixed EDM process is better technique to optimize the response parameters in EDM. In manufacturing process, EDM has major advantages over the other machining techniques because of the non-contact technique [27-36].

4. Summary/ Concluding remark

Comprehensive literature survey on powder mixed electrical discharge machining is done. It can be observed that the EDM process response variables are greatly influenced by the input process variables. MRR is significantly affected by the peak current and Ton time. It is well reported by various authors that addition of powder in the dielectric fluid is influenced the MRR and surface roughness of the machined surface. Use of powder in dielectric fluid significantly improves the MRR and surface quality of the machined surface. The concentration of the powder particle in the die electric fluid also influenced the response variables. Increase in the concentration increases the MRR whereas recast layer found improved with concentration.

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