Effect of Powder Mixed Electric Discharge Machining (PMEDM) on Various Materials with Different Powders: A Review

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Abstract

Electrical discharge machining (EDM) is a non-conventional machining process used to manufacture intricate profiles, complex shapes, process hard materials that are extremely difficult to machine by conventional machining processes. This thermo electric machining technique is continuously emerging from a mere tool and dies making process to a micro scale machining applications. In recent years, researches have emphasized on process performance like material removal rate (MRR), tool wear rate (TWR), surface roughness (SR). Powder mixed electrical discharge machining (PMEDM) has emerged as one of the advanced techniques in the direction of the enhancement of the capabilities of EDM. This article presents comprehensive history, mechanism of PMEDM process, and reviews research literature in this area. The last part of this article outlines trends for future AEDM research directions.
Keywords: Electric discharge machining (EDM), Powder mixed EDM (PMEDM); Material removal rate; Tool wear rate; Surface roughness Electrical discharge machining (EDM) is a non-conventional machining process used to manufacture intricate profiles, complex shapes, process hard materials that are extremely difficult to machine by conventional machining processes. This thermo electric machining technique is continuously emerging from a mere tool and dies making process to a micro scale machining applications. In recent years, researches have emphasized on process performance like material removal rate (MRR), tool wear rate (TWR), surface roughness (SR). Powder mixed electrical discharge machining (PMEDM) has emerged as one of the advanced techniques in the direction of the enhancement of the capabilities of EDM. This article presents comprehensive history, mechanism of PMEDM process, and reviews research literature in this area. The last part of this article outlines trends for future PMEDM research directions

I. INTRODUCTION

The machining of extremely hard and brittle materials by conventional machining processes like lathe, drilling and milling etc is difficult or almost impossible with traditional machining processes. To meet present needs and requirements a non-conventional machining processes are employed. The non-conventional machining processes can produce any complex shape on any work piece irrespective of hardness, brittleness of the material. Electrical discharge machining (EDM) is one of the most accepted methods in non-conventional machining process. Electrical Discharge Machining (EDM) is nontraditional, no physical cutting forces between the tool and the work piece, high precision metal removal process using thermal energy by generating a spark to erode the work piece. The work piece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. EDM machine has wide application in production of die cavity with large components, deep small diameter hole and various intricate holes and other precision part.

In the recent past, powder mixed EDM (PMEDM) has emerged as one of the advanced techniques in the direction of the enhancement of the capabilities of EDM. In this process, a suitable material in fine powder form is mixed into the dielectric fluid of EDM. The spark gap is filled up with additive particles. The added powder significantly affects the performance of EDM process. The electrically conductive powder reduces the insulating strength of the dielectric fluid and increases the spark gap distance between the tool electrode and work piece. As a result, the process becomes more stable, thereby improving machining rate (MR) and surface finish.

II. TECHNOLOGY AND PROCESS MECHANISM OF PMEDM

In powder mixed electric discharge machining (PMEDM) process, the experimental unit consists of a transparent bath similar to container, called machining tank. It is placed in the work tank EDM and the machining is performed in this container. For the better circulation of the powder mixed dielectric, a stirring system is engaged. For regular reuse of powder in the dielectric fluid, a modified circulation system (Fig.1) is used. For holding the work piece, a work piece fixture assembly is placed in it. The machining tank is filled up with dielectric fluid. A stirring system was included to avoid particle settling. A small dielectric circulation pump was installed for appropriate circulation of the powder mixed dielectric fluid into the discharge gap. The pump and the stirrer assembly are placed in the same tank in which machining is to be done. The minimum distance (10 in.) between powder mixed dielectric suction point and nozzle outlet should kept for better suspension of powder in the discharge gap. Magnetic forces were used to split the debris from the dielectric fluid. For this function, two permanent magnets are located at the bottom of machining tank. Powder particles fill up the spark gap. During the process, when the voltage of 80–320 V is applied between the electrode and the work piece facing each other with a gap of 25–50 m [1], an electric field in the range of 10^5–10^7 V/m is produced. Under the influence of high electric potential, the powder particles get energized and behave in a zigzag manner (Fig. 1).

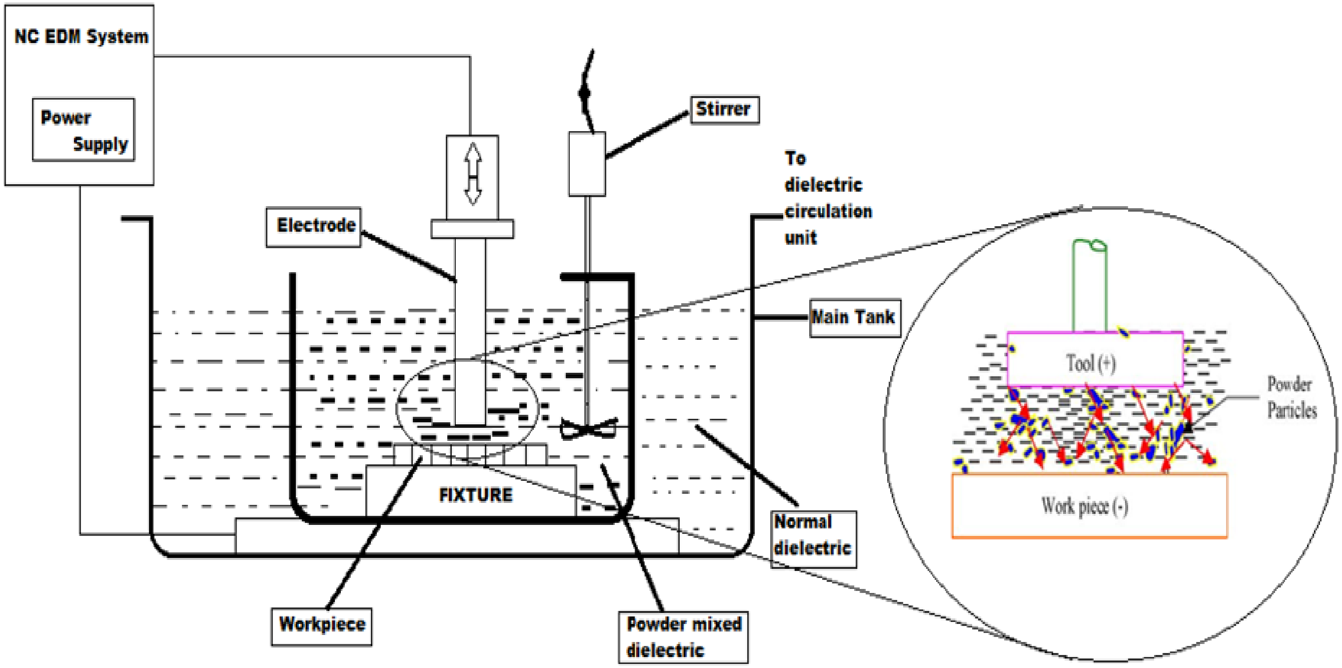

Fig. 1: Schematic diagram of machining set-up and principle of powder-mixed EDM

These charged particles are accelerated by the electric field and serve as conductors. The conductive particles help breakdown in the gap and increase the spark gap between tool and the work-piece. In the region of sparking area, the particles come close to each other and organize themselves in the form of chain like structures between both the electrodes. In the direction of flow of current, there is occurring of interlocking between the different powder particles. The chain arrangement helps in bridging the discharge gap between both the electrodes. Because of bridging effect, the insulating strength of the dielectric fluid decreases. As process goes on short circuit takes place, which causes early explosion in the gap. Therefore, a series discharge starts below the electrode area. The faster sparking within a discharge takes place causing faster erosion from the work piece surface and hence the material removal rate (MRR) increases. Simultaneously, the adding of powder modifies the plasma channel. The plasma channel becomes enlarged and opened [2]. The sparking is evenly distributed among the powder particles, therefore electric density of the spark decreases. Due to uniform distribution of sparking among the powder particles, shallow craters are formed on the work piece surface. This results in improvement of surface finish.

III. PROCESS PARAMETERS

The performance of PMEDM depends upon electrical parameters, non-electrical parameters, powder concentration and its type, material and size of electrode, workpiece material and their properties. The process parameters in EDM are used to regulate the performance methods of the machining process. Process parameters are generally well-disciplined machining input factors that decide the conditions in which machining is carried out. These machining situations will affect the process performance result, which are gauged using various performance methods. There are two types of process parameters i:e electrical parameters like peak current, voltage, duty cycle, pulse on, pulse off etc and non-electrical parameters like flushing, powder mixed dielectric, tool rotation etc. The Fig.2 shows the cause and effect on PMEDM process performance like MRR, TWR, SR.

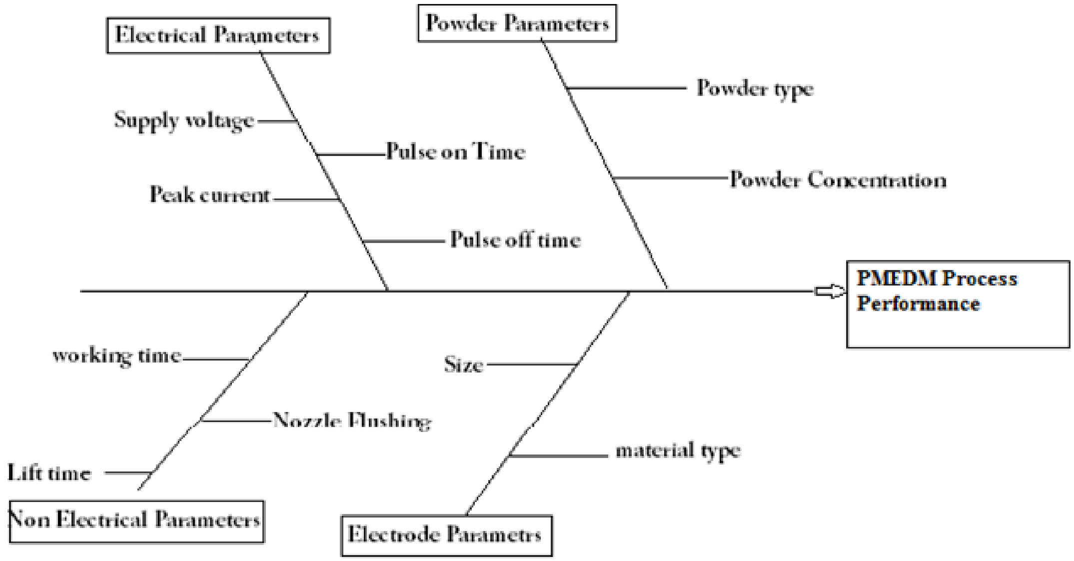

Fig. 3: Cause and effect diagram

IV. RESEARCH TRENDS IN PMEDM

Erden and Bilgin et al. [3] were the first to introduce the concept of powder mixed EDM. They the investigated the influence of adding copper, iron, carbon and aluminium powder into the kerosene dielectric on brass-steel and copper – steel workpiece. It has been observed that addition of powder results in improvement of breakdown characteristics of the EDM dielectric fluid. High concentration causes decrease in time lags resulted in an increase in machining rate. At high powder concentration, short circuiting leads to inefficient and unstable machining.

Jeswani et al. [4] determined the influence of suspending fine graphite powder into kerosene oil and achieved 60% improvement in MRR. He observed with the addition of 4 g/L fine graphite powder increases the space for electric discharge initiation and drastically lowered the breakdown voltage resulting in improvement in machining process stability.

Kansal H.K., et al. [5] establishes optimum process conditions for PMEDM of Al–10%SiCP metal matrix by an experimental investigation using response surface methodology. Aluminium powder was suspended into the dielectric fluid of EDM. MR tends to increase, considerably with an increase in peak current for any value of pulse duration due to their dominant control over the input energy. He observed that with increase in concentration of the powder, the MR tends to increase. This is because the added additive causes bridging effect between both the electrodes, facilitates the dispersion of discharge into several increments and hence increases the MR. The maximum MR is obtained at medium level of concentration of added aluminium powder (3 g/l) and high value of peak current (5A).

Gunawan Setia Prihandana., Muslim Mahardika , M. Hamdi , Y.S. Wong , Kimiyuki Mitsui., et al.[6] investigated the effect of Molybdenum disulfide powder in micro EDM process. They investigated that micro powder concentration is important factor of increasing in MRR. There is significant increase in MRR when 5g/l is added in dielectric fluid followed by 2g/l in dielectric fluid. This is because of concentration level of 5g/l causes stable discharge in continuous machining. The suspended micro-powder accelerates the increase in the frequency of sparks during machining processes and causes a higher material removal rate.

Y.F. Tzeng, C.Y. Lee., et al [7] studied the effects of various powder characteristics on the efficiency of electro discharge machining (EDM) SKD-11. He observed the effects of three Al particle sizes with various volumetric concentrations on TWR. At a low discharge current of 1.5 A, it was seen that TWR generally decreased with the introduction of foreign particles to the dielectric fluid. When the current discharge was increased to 4.0 A, the difference in TWR became slight because of the higher MRR effects. However, there was an appreciable rise in TWR for the largest Al particles (100 mm) at a particle concentration of 0.25 cm3 l-1, and an applied current of 1.5 A.

W.S Zhao et al [8] investigated that PMEDM improves the machining efficiency and surface roughness by selecting proper discharging parameters. He observed PMEDM makes discharge breakdown easier and enlarges the discharge gap which widens the discharge passage, because of this there is loss of discharge energy in the gaps and reduction of ejecting force on melted material, surface roughness becomes lower. Further, when peak current increases the surface roughness becomes lower.

S. Assarzadeh , M. Ghoreishi., et al. [9] examined that when Aluminium oxide(Al2O3) fine abrasive powders with particle concentration and size of 2.5–2.8 g/L and 45–50 μm, respectively, were added into the kerosene dielectric liquid of a die-sinking electrical discharge machine. The MRR tends to increase steadily with both current and pulse-on time increasing it is because of the fact that increasing both current and pulse-on time result in higher and more prolonged electro-thermal energy released in the machining gap which is capable of removing more material from the work surface within a certain time interval leading to a greater removal rate.

Wong et al [10] studied the near-mirror-finish phenomenon in electrical discharge machining (EDM) by fine powder introduced into the dielectric fluid. Al powder at concentration of 2 g/l has been reported to give mirror finish in PMEDM for SKH-51 work pieces.

Chow et al. [11] carried out a study on micro-slit machining of titanium alloy with aluminium and SiC powder added in kerosene. It was proposed that SiC powder can produce a better material removal depth than Al powder added to the kerosene.

K. Ojha, R. K. Garg, K. K. Singh et al. [12] investigated the significant factors affecting TWR when chromium powder was dispersed into the dielectric of EDM. He observed that Peak current, powder concentration and electrode diameter were significant factors contributing to TWR. They also observed that TWR decreases with an increase in tool diameter.

Ndaliman et al. [13,14] investigated Micro hardness of Ti–6Al–4V through the surface modification of EDM process parameters. He found that urea solution produces rougher surface than distilled water. This was mainly happened due to much higher cooling rate of urea solution as compared to distilled water. Moreover, the intensive thermal forces subjected to workpiece surface increases due to the combined reaction of electrode and urea solution with workpiece. This leads to larger cracks and deeper craters. Moreover, nitrides and carbides of the titanium were formed due to the reaction between urea solution and workpiece during machining.

K. M. Patel et al [15] investigated the influence of parametric setting on machining performance during EDM of Al2O3/SiCw/TiC ceramic composite. He observed that pulse on time influences the SR more predominantly than other factors due the fact that any increase in the pulse-on time increases the plasma channel diameter that reduces both energy density and impulsive force. The melted debris cannot be removed completely due to reduction in impulsive force and forms an apparent globule like recasted layer to degrade SR. Furthermore, the SR increases first and then decreases with the increase in the duty cycle due to the fact that the gap voltage does not affect the quality of the surface.

V. Senthilkumar., et al [16] investigated the effect of current, pulse on time and flushing pressure on aluminium composite with the addition of titanium Carbide particle. He observed that increase in discharge current has a moderate effect on TWR up to an optimum value and thereafter a significant rise in the wear rate is associated with higher thermal loading. The negligible tool wear in the initial period is due to the deposition of workpiece material on the tool electrode which inhibits the wear of electrode. However, as the current is further increased the tool electrode exhibits substantial wear. Increasing the duration of pulse increases the tool wear during the initial period. However, as the pulse on time reaches an optimum value a gradual reduction in the tool wear is noticed.

Chen, Lin, et al [17] studied the surface modification by combining EDM with ultrasonic machining (USM) and addition of Ti particles to the dielectric fluid. Wear resistance and hardness of workpiece (Al–Zn–Mg) alloy was improved due to presence of an alloyed layer.

Table 1:
Literature review on optimization of process parameters

Work material	Powder	Input Parameter	Response variables	Optimization technique	Results	References
En-31	Silicon	Peak current Pulse on Duty cycle Powder Concentration	MRR, SR	RSM	Peak current and powder concentration were the most influential Parameters.	[18]
Inconel 718	Aluminium	Voltage Discharge current Duty cycle Powder Con.	MRR,SR, WR	One variable at a time	Particle concentration and size significantly affect machining efficiency	[19]
AISI-D2 Die Steel	Silicon	Peak current Pulse-on time Pulse-off time Powder concentration Gain,Nozzle flushing	MR	Taguchi Method	The machining rate was mostly influenced by peak current and concentration of silicon Powder.	[20]
EN-8	Chromium	Current Tool angle Powder con. Duty cycle	MRR, TWR	RSM	Powder concentration and current were the most significant parameters affecting MRR. Whereas, TWR is greatly influenced by current and electrode angle.	[21]
EN-19	Nickel micro powder	Peak current Duty cycle Electrode angle Powder concentration	MRR TWR	RSM	ANOVA results revealed that the current was the most dominant factor affecting both MRR and TWR. Both MRR and TWR increase with an increase in current and powder concentration.	[22]

Table 2:
Physical properties of various powders

Powder	Density (gcm^{-3})	Specific heat ($Calg^{-1}$ / °C)	Electrical resistivity(μΩcm)	Melting point (°C)	Thermal conductivity (Wcm−1 °C−1)
Si	2.33	0.17	$1x10^5$	1410	1.48
Al	2.70	0.215	2.45	660	2.38
Sic	3.21	0.18	$1x10^9$	2987	1.0-5.0
Cr	7.16	0.11	2.60	1875	0.67
Cu	8.96	0.092	1.59	1083	4.16

V. APPLICATIONS OF PMEDM

1) PMEDM has promising application for achieving near mirror like surface finish.
2) Advanced materials such as MMC'S, insulating ceramics like Tio_2 etc. have been successfully machined by dispersing various powders in to the EDM dielectric.
3) Making and machining of micro product & sophisticated micro mechanical Element. It is the use of light, thin, compact, special purposes work such as micro-engines, micro pumps, micro-robots etc.
4) Enhancement of machined surface functional properties, such as wear resistance, corrosion resistance and reduced friction coefficient, through surface modification.

VI. CONCLUSIONS AND FUTURE DIRECTIONS

Since the invention of EDM many advancements in the machining process has been made. EDM has the capability of machining intricate profiles and materials which are difficult to cut. EDM has been broadly applicable for manufacturing of complex cavities in molds and dies, aerospace, automotive and surgical components. Several advancements have been made in the past to enhance the machining performance. PMEDM is a well-established machining option for improving the MRR, TWR, SR. After a detailed study of the published work, the following main results can be drawn:

- The material removal rate increased by mixing powder in the dielectric fluid as compared with conventional EDM process. Tool wear rate in PMEDM is smaller as compared with the conventional EDM Process. Material removal rate is increased by the increase of peak current. Material Removal Rate has been decreased by increasing the pulse off time. The optimum powder concentration and size of powder particles to achieve the highest efficiency of EDM process. Higher peak currents produce more rough surfaces in EDM process. The applicability of PMEDM process for industrial purposes is constrained by several key technical issues that need to be further investigated.
- More studies on the effect of process parameters like tool rotation, workpiece rotation need to be addressed to gain a better understanding of the process.
- Role of powder on study of various properties such as micro hardness, microstructure, corrosion resistance, fatigue resistance and wear resistance has been taken up by very few researchers. There is an urgent need to work out on this area.

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