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Current Research Issue, Trend & Applications of Powder Mixed Dielectric Electric Discharge Machining (PM-EDM): A Review

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Abstract

In this paper new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. Erosion pulse discharge occurs in a small gap between the work piece and the electrode. This removes the unwanted material from the parent metal through melting and vaporizing in presence of dielectric fluid. In recent years, EDM researchers have explored a number of ways to improve EDM Process parameters such as Electrical parameters, Non-Electrical Parameters, tool Electrode based parameters & Powder based parameters. This new research shares the same objectives of achieving more efficient metal removal rate reduction in tool wear and improved surface quality. This paper reviews the research work carried out from the inception to the development of Powder Mixed Dielectric electric Discharge Machining within the past decade. & also briefly describing the Current Research technique Trend in EDM & optimization Technique used in the Powder mix Electric Discharge Machining research field.

Keyword: EDM, PMEDM, MRR, TWR, SR, SQ, HAZ, RLT

Introduction

EDM as a process was introduced over fifty years ago; improvements in technology have led to increases in both cutting speeds and component precision. Developing from initially tool making industry sectors of press tool and mould tools, the EDM process is now mainly found within production engineering, aerospace, motor sport, medical and scientific industries. Electrical Discharge Machining (EDM) is non traditional, no physical cutting forces between the tool and the workpiece, high precision metal removal process using thermal energy by generating a spark to erode the workpiece. The workpiece 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 whole and various intricate holes and other precision part.

The history of EDM Machining Techniques goes as far back as 1770, when English chemist Joseph Priestly discovered the erosive effect of electrical discharges or sparks. The EDM process was invented by two Russian scientists, Dr. B.R. Lazarenko and Dr. N.I. Lazarenko in 1943. The spark generator used in 1943, known as the Lazarenko circuit, has been employed over many years in power supplies for EDM machines and proved to be used in many current applications . The Lazarenko EDM system uses resistance-capacitance type of power supply, which was widely used at the EDM machine in the 1950's and later served as the model for successive development in EDM . Further developments in the 1960's of pulse and solid state generators reduced previous problems with weak electrode as well as the inventions of orbiting systems. In the 1970's the number of electrodes is reduced to create cavities. Finally, in the 1980's a computer numerical controlled (CNC) EDM was

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introduced in USA. Electric Discharge Machining (EDM) Process shown in the fig.1

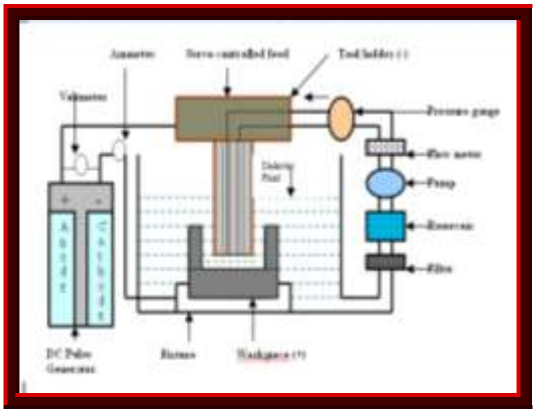

Fig-1: Schematic of EDM Process
[Choudhary& Jadoun (2014)]

1.1Technology of powder mixed EDM

In this process suitable material in the powder form & mixed into the dielectric fluid in tank. For better circulation of the dielectric fluid by stirring system. For constant reuse of powder in the dielectric fluid by the special circulation system. Various powders of particle that can be added into the dielectric fluid include Aluminum (Al) , graphite, copper (Cu) , chromium (Cr), Silicon carbide etc. spark gap provided by the additives particles. When the voltage applied between the tool electrode and workpiece are 80-320V with the gap of 25-50µm & electric field range 10^5 - 10^7 V/m was created. The powder particles of the material get energized & behave like a zigzag way manner. under the sparking zone, the particles of the material powder comes close to each other & arrange themselves in the form of chain like structure between the workpiece surface & tool electrode. The interlocking between the different powder particles occurs in the direction of flow current. The chain formation helps in bridging the discharge gap between the electrodes. Because of bridging effect, the insulating strength of the dielectric fluid decreases resulting in easy short circuit. This causes early explosion in the gap and series discharge' starts under the electrode area. The faster sparking within a discharge causes faster erosion from the work piece surface and hence the material removal rate increases.

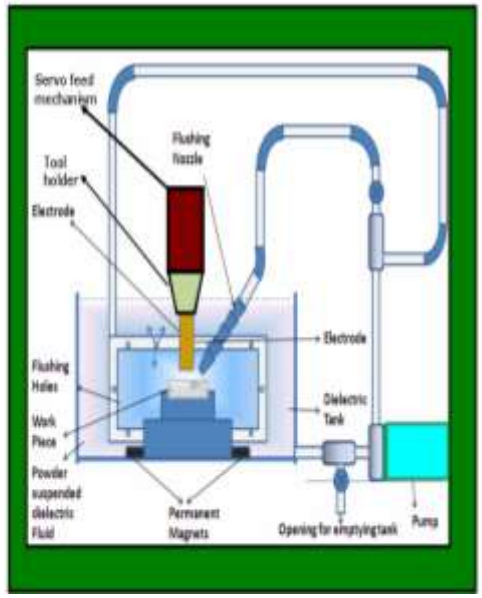

Fig.-2: Line Diagram of PMEDM Setup

1.2 Major Component of Powder mixed Electrical discharge Machining

1. **Power supply:** The power supply is an important part of any EDM system. It transform the alternating current from the main utility supply into the pulse direct current (DC) required to produce the spark discharge at the machining gap.
2. **Pulse Generator & Control Unit:** is responsible for supplying pulses at a certain voltage and current for specific amount of time. The power supply control the amount of energy consumed. First, it has a time control function which controls the length of time that current flows during each pulse; this is called "on time." Then it is control the amount of current allowed to flow during each pulse. The control unit is control the all function of the machining for example of Ton, Ip, duty cycle, putting the values and maintain the workpiece the tool gap**.**
3. **The servo system to feed the tool**: The servo control unit is provided to maintain the pre determined gap. It senses the gap voltage and compares it with the present value and the different in voltage is then used to control the movement of servo motor to adjust the gap.
4. **Tool holder:** The tool holder holds the tool with the process of machining.
5. **Circulating Pump:** Circulation of powder mixed dielectric.

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6. **Electrode:** The EDM electrode is the tool that determines the shape of the cavity to be produce
7. **Permanent magnet:** Magnetic forces are used to separate the debris from the dielectric fluid. For this purpose, two permanent magnets are placed at the bottom of machining tank
8. **Machining Tank:** The system consists of a transparent bath-like container, called the machining tank. It is placed in the work tank of the EDM, and the machining is performed in this container.
9. **Working tank with work holding device:** All the EDM oil kept in the working tank working tank is used to the supply the fluid during the process of machining.
10. **X-y table accommodating the working table:** They are used to the moment of the workpiece form X and Y directio

1.3 - PM-EDM Application, Advantages & Limitations

Table-1

A.	**Applications**
	1. Enhancement of machined surface functional properties, such as wear resistance, corrosion resistance and reduced friction coefficient, through surface modification. **2.** Improvements in performance parameters such as MRR, WR and SQ **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.** The production of these microelements with traditional methods is restricted due to various Complications. **5.** Machining of insulating materials Such as Si_3N_4 ceramics **6.** Improve surface characteristics like mirror finish by graphite & silicon powder mixed into the dielectric fluid of EDM
B.	**Advantages**
	1. Any material that is electrical conductive can be machined, regardless of its hardness, strength, toughness and microstructure etc. **2.** Work piece can be machined in hardness Conditions that is, the deformation caused by the hardened process does not affect the final dimensions. **3.** Complicated die contours in hard materials can be produced to a high degree of accuracy and surface finish. **4.** No stresses are produced in the work, as there is no physical contact between the work piece and the tool electrode. **5.** PMEDM process is totally burring free. **6.** Secondary finishing operations like grinding are generally eliminated. **7.** The surface produced by EDM consists if a number of small craters that help in oil retention and better lubrication, especially for the components such as tools and dies, where proper lubrication is very important for the life of the component. **8.** A die punch can be used as electrode to reproduce its shape in the machining die block, completely with the necessary clearances. As a result better dies and moulds can be produced at reasonable costs.
C.	**Limitations**

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	1. MRR is low making the process economical only for very hard and difficult to machine materials. **2.** The materials to be machined must be electrically conductive. **3.** Fast electrode wear can prove costly. **4.** The process cannot be monitored during machining. Hence any errors on malfunctions are detected only after the entire cut. **5.** Only highly skilled persons can operate the machine.

1.4 Principle of PMEDM

When voltage is applied the powder particles become energized and behave in a zigzag fashion. These charged particles are accelerated due to the electric field and act as conductors promoting breakdown in the gap. This increases the spark gap between tool and the work piece. Under the sparking area, these particles come close to each other and arrange themselves in the form of chain like structures. The interlocking between the powder particles occurs in the direction of flow of current. The chain formation helps in bridging the discharge gap between the electrodes. Because of bridging effect, the insulating strength of the dielectric fluid decreases resulting in easy short circuit. This causes early explosion in the gap and series discharge' starts under the electrode area. The faster sparking within a discharge causes faster erosion from the work piece surface and hence the material removal rate increases.

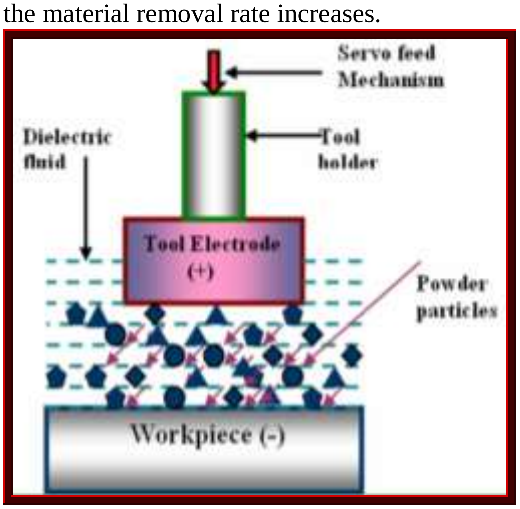

Fig-3: working principle of PMEDM

2. Parameters of PM-EDM.

EDM Parameters mainly classified into two categories.
1. Process Parameters 2. Performance Parameters

2.1. Process Parameters: The process parameters in EDM are used to control the performance measures of the machining process. Process parameters are generally controllable machining input factors that determine the conditions in which machining is carried out. These machining conditions will affect the process performance result, which are gauged using various performance measures.

2.1.1 Electrical Parameters

1. *Polarity:* Polarity of the electrode can be either positive or negative
   - **i.** Straight polarity: Electrode (-) & workpiece (+)
   - **ii.** Reverse polarity: Electrode (+) & workpiece (-)
2. *Supply voltage:* The input voltage applied across the tool electrode and workpiece is called the supply or open circuit voltage.
3. *Discharge voltage:* This is the electrical energy that is available for material removal. The magnitude of Em is calculated from measured pulse on time, discharge voltage and discharge current values.
4. *Discharge Current:* The discharge current (Id) is a measure of the amount of electrical charges flowing between the tool and workpiece electrode. As the flow of electrical charges is the heating mechanism in electro-thermal erosion,
5. *Gap Voltage:* The preset gap-voltage determines the width of the spark gap between the leading edge of the electrode and the workpiece. High voltage settings increase the gap and hence the flushing and machining. However when using graphite electrodes, high open gap voltage drastically increases the electrode wear.
6. *Peak Current:* This is the amount of power used in discharge machining, measured in units of amperage, and is the most important machining parameter in EDM .During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current. In both die-sinking and wire-EDM applications, the maximum

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amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but at the cost of surface finish and tool wear. This is all more important in EDM because the machined cavity is a replica of tool electrode and excessive wear will hamper the accuracy of machining.

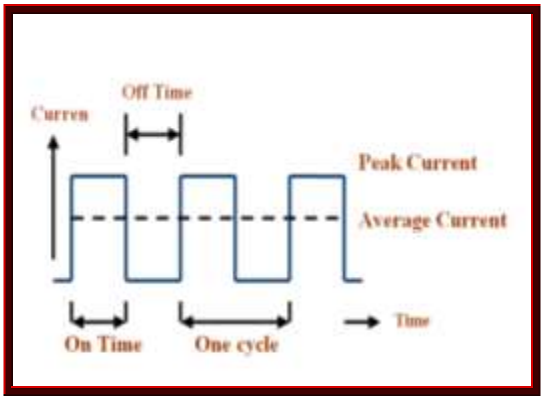

Fig-4

7. *Average Current:* Peak current is the maximum current available for each pulse from the power supply/generator. Average current is the average of the amperage in the spark gap measured over a complete cycle. It is calculated by multiplying peak current by duty factor.

Average Current (A) = Duty Factor (%) × Peak Current (1)

8. *Pulse On-time (pulse time or Ton)***:** The duration of time (μs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time. To observe the effect of pulse -on time on MRR and SR Value of peak current is varied while keeping the other parameter like pulse- off time, servo voltage, wire feed rate fixed.
9. *Pulse on Time:* The pulse on time represents the duration of discharge and is the time during which the electrode material is heated by the high temperature plasma channel. Material removal is directly proportional to the amount of energy applied during this on-time .A longer pulse on time will increase the discharge energy.
10. *Pulse off time:* The pulse off time represents the duration when no discharge exists and the dielectric is allowed to deionise and recover its insulating properties. A longer pulse off time improves machining stability as arcing is eliminated.
11. *Pulse Frequency:* Pulse frequency is the number of cycles produced across the gap in one second. The higher the frequency, finer is the surface finish that can be obtained. Pulse frequency is calculated by dividing 1000 by the total cycle time (on-time + off-time) in microseconds.

$$\text{Pulse Frequency (kHz)} = \frac{1000}{\text{Total cycle time } (\mu s)} \quad (2)$$

12. *Pulse waveform:* The pulse shape is normally rectangular, but generators with other pulse shapes have also been developed. Using a generator which can produce trapezoidal pulses, Bruyn (1968)
13. *Electrode Gap:* It is the distance between the electrode and the part during the process of EDM. An electro-mechanical and hydraulic systems are used to respond to average gap voltage. To obtain good performance and gap stability a suitable gap should be maintained. For the reaction speed, it must obtain a high speed so that it can respond to short circuits or even open gap circuits. Gap width is not measured directly, but can be inferred from the average gap voltage.
14. *Duty Factor:* Duty factor is a percentage of the pulse duration relative to the total cycle time. Generally, a higher duty factor means increased cutting efficiency.

$$\text{Duty Factor (\%)} = \frac{\text{Pulse duration } (\mu s)}{\text{Total cycle time } (\mu s)} \times 100 \quad \textbf{(3)}$$

2.1.2. Non-Electrical Parameters

1. *Nozzle flushing:* Flushing is defined as the correct circulation of dielectric solution between the electrodes and workpiece. Suitable flushing conditions are essential to obtain the highest machining efficiency. The sinker EDM process has primarily used oil for the dielectric fluid. Flushing system mainly two type:

1. Normal flow 2. Reverse flow

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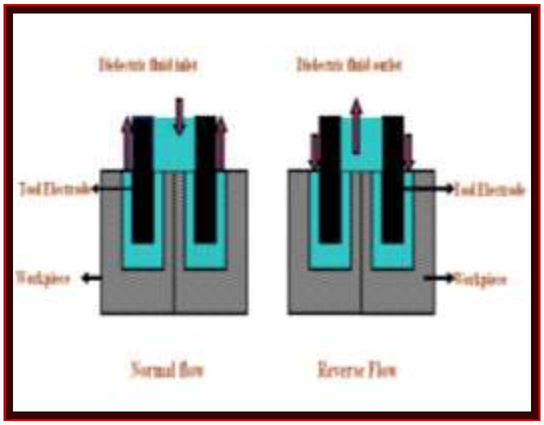

Fig-5: Flushing system

2. Functions of a Dielectric Fluid: The dielectric fluid id in a EDM serves a number of functions:

- The dielectric oil acts as a medium through which controlled electrical discharges occur.
- Cool the section that was heated by the discharging effect
- Flush the eroded particles from the machining gap
- Provide insulation between the electrode and the workpiece
- The dielectric oil acts as a medium used to carry away the solidified EDM debris from the discharge gap to the filter system.
- The dielectric oil acts as a heat transfer medium to absorb and carry away the heat generated by the discharges from both the electrode and the workpiece

3. Types of dielectric fluid

- *Mineral Oils* liquid petroleum is a by-product in the distillation of petroleum.
- *Kerosene* was one of the first popular dielectric oils. Its primary benefit is that it has very low viscosity and flushes very well.
- *Transformer Oil* is another mineral oil based product that was adapted for use in EDMs due to its dielectric properties. Earlier generations of transformer oil were compounded with PCBs. Transformer oil has no current application in EDM.
- *EDM Oils:* There are currently numerous choices of mineral oils formulated specifically for EDM
- *Synthetic oil:* Synthetic oil is oil consisting of chemical compounds which were not originally present in crude oil (petroleum), but were artificially made (synthesized) from other compounds. Synthetic oil is used as a substitute for oil refined from petroleum, stated, to provide superior mechanical and chemical properties than those found in traditional mineral oils.

4. *Properties & Characteristics of Dielectric Fluid*

- *Viscosity* is the property that describes a fluids resistance to flow.
- *Flash Point* "The flash point of a flammable liquid is the lowest temperature at which it can form an ignitable mixture in air." The flash point for commonly used EDM dielectric oils ranges from 160º F to 255º F. Obviously for reasons of safety, the higher the flash point the better." The oil temperature at which ignition of the resulting vapor occurs is the Flash Point. Flash points for common liquids are listed below:
  a. Gasoline -40º F
  b. Ethanol 55º F
  c. Kerosene 120º F
  d. Diesel 143º F
  e. Vegetable Oil 620º F
- *Oxidation Stability* is a measure of the dielectric fluids tendency to react with oxygen.
- *Volatility* is a measure of the tendency of a dielectric fluid to vaporize
- *Acid Number* is used to quantify the amount of acid present in a sample of dielectric oil. Excessive levels of acid in dielectric oil could lead to corrosion in the dielectric system. The acid number is expressed in units of mg KOH/g, or the amount of Sodium Hydroxide necessary to neutralize the acid present in an oil sample.
- *Color* of dielectric oil can be classified by an ASTM test. Ideally, a dielectric fluid should be water white for maximum visibility of the workpiece.
- *Odor.* Quite frankly, no one wants to work in a smelly environment, and no one wants to go home smelling like an EDM machine. Thus, odor is an important consideration in maintaining a decent work environment for the employees.
- *Pour Point* of oil is the temperature below which the oil no longer pours freely.

5. *Electrode lifts time*
6. *Working Time*
7. *Gain*

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2.1.3 Powder Based Parameters

1. Powder type

The powder added into the dielectric fluid could increase the MRR and decrease the tool wear rate (TWR) and improve the surface quality of the work quite clearly. But the different powders would have different impact on the output characteristics of the EDM process. Some kinds of inorganic oxide powders cannot disperse uniformly and persistently in kerosene, concentrate and precipitate quickly, so they do not play a good role in improving the MRR, decreasing the SR and TWR.

A powder which can be suspended into dielectric fluid of EDM must have following properties:-

- It should be electrical conductive in nature.
- It must be non-magnetic in nature.
- It must have good suspension capabilities.
- It should have good thermal conductivities.
- It should be in toxic and odorless.

2. *Concentration of added powder*

Addition of appropriate amount of powder into dielectric fluid plays a very important role on MRR, TWR and SR. The material removal depth reached the maximum value at appropriate concentration. Further increase or decrease in the concentration of the added powder would decrease the MRR.

3. Mesh size of powders

The size of the powder particles affects the PMEDM performance. A large diameter of the powder particle increases the gap but simultaneously decreases the MRR and then increases the SR.

4. Electrical properties of powders

The electrical conductivity of the added Powder directly affects EDM performance. This is because the added powder increases the Conductivity of the dielectric fluid and results in the extension of the gap distance.

5. Powder conductivity

6. Powder density

2.1.4 Electrode Based Parameters

1. Electrode material: EDM electrode materials need to have properties that easily allow charge and yet resist the erosion that the EDM process encourages and stimulates in the metals it machines. Alloys have properties which provide different advantages based on the needs of the application.

- *Brass* is an alloy of copper and zinc. Brass materials are used to form EDM wire and small tubular electrodes. Brass does not resist wear as well as copper or tungsten, but is much easier to machine and can be die-cast or extruded for specialized applications. EDM wire does not need to provide wear or arc erosion resistance since new wire is fed continuously during the EDM wiring cutting process.

- *Copper* and copper alloys have better EDM wear resistance than brass, but are more difficult to machine than either brass or graphite. It is also more expensive than graphite. Copper is, however, a common base material because it is highly conductive and strong. It is useful in the EDM machining of tungsten carbide, or in applications requiring a fine finish.

- *Copper tungsten* materials are composites of tungsten and copper. They are produced using powder metallurgy processes. Copper tungsten is very expensive compared to other electrode materials, but is useful for making deep slots under poor flushing conditions and in the EDM machining of tungsten carbide. Copper tungsten materials are also used in resistance welding electrodes and some circuit breaker applications.

- *Graphite* provides a cleaning action at low speeds. Carbon graphite was one of the first brush material grades developed and is found in many older motors and generators. It has an amorphous structure.

- *Molybdenum* is used for making EDM wire. It is the wire of choice for small slot work and for applications requiring exceptionally small corner radii. Molybdenum exhibits high tensile strength and good conductivity, making it ideal where small diameter wire is needed for demanding applications.

- *Silver tungsten* material is tungsten carbide particles dispersed in a matrix of silver. Silver offers high electrical conductivity and tungsten provides excellent erosion resistance and good anti-welding characteristics in high-power applications. This composite is thus the perfect choice for EDM electrode applications where maximizing conductivity is crucial.

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- *Tellurium copper* is useful in EDM machining applications requiring a fine finish. Tellurium copper has a machinability that is similar to brass and better than pure copper.

2. *Electrode Shape& size:* The performance of die sinking EDM due to the shape configuration of the electrode. The effect of electrode shape on material removal rate (*MRR*), electrode wear rate (*EWR*), wear ratio (*WR*), and average surface roughness (R_a) has been investigated for mild steel work material and copper electrode. The shapes of the electrodes were round, square, triangular, and diamond of constant cross-sectional area of 64 mm^2. Khan A., et al, (2009) study the effect of electrode shape on material removal rate (*MRR*), electrode wear rate (*EWR*), wear ratio (*WR*), and average surface roughness (R_a) has been investigated for mild steel work material and copper electrode. The shapes of the electrodes were round, square, triangular, and diamond of constant cross-sectional area of 64 mm^2.

Fig-6: Electrode shape

3. Electrode Properties:

- High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating.
- High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear.
- Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy.
- High melting point – high melting point leads to fewer tools wear due to less tool material melting for the same heat load.
- Easy manufacturability.
- Cost – cheap.

2.2 Performance Parameters

These parameters measure the various process performances of EDM results. Performance parameters classified into following Categories.

i. *Material removal Rate:* The Material removal rate is expressed as the weight of material removed from workpiece over a period of machining time in minutes

$$MRR\ (mm^3/min) = \frac{\text{Workpiece weight loss (g)} \times 1000}{\text{density (g/cm}^3) \times \text{machining time (min)}} \quad (4)$$

ii. *Tool wear Rate:* The TWR is calculated by using the weight loss from the tool divided by the time of machining.

$$TWR\ (mm^3/min) = \frac{\text{Tool weight loss (g)} \times 1000}{\text{density (g/cm}^3) \times \text{machining time (min)}} \quad (5)$$

iii. *Relative Wear Ratio:* WR is the ratio of TWR/MRR and is used as a performance measure for quantifying tool-workpiece material combination pairs since different material combinations gives rise to different TWR and MRR values. A material combination pair with the lowest WR indicates that the tool-workpiece material combination gives the optimal TWR and MRR condition. The relative wear ratio of the workpiece and tool is expressed.

$$\%WR = \frac{\text{Tool wear rate}}{\text{Material removal rate}} \times 100 \quad (6)$$

iv. *Surface Roughness:* SR is a classification of surface parameter used to describe an amplitude feature, which translates to roughness of the surface finish. Of the many parameters available to quantify SR, the most commonly used in EDM are arithmetical mean surface roughness (*Ra*), maximum peak-to-valley surface roughness (*Rmax*) and root mean square surface roughness (*Rq*). The Surface Roughness of the workpiece can be expressed in different ways like,

a. Arithmetic average (*R*a)
b. Average peak to valley height (*RZ*)
c. Peak roughness (*R*P), etc.

Defined as the arithmetic average roughness of the deviations of the roughness profile from the central line along the measurement.

$$R_a = \frac{1}{L}\int_0^L |h(x)\ dx| \quad (7)$$

Where $h(x)$ is the value of the roughness profile and 'L' is the evaluation length.

v. *Surface quality (SQ):* Surface quality is a broad performance measure used to describe the condition of the machined surface. It

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comprises components such as surface roughness (SR), extent of heat affected zone (HAZ), recast layer thickness and micro-crack density.

vi. *Heat affected Zone (HAZ):* HAZ refers to the region of a workpiece that did not melt during electrical discharge but has experienced a phase transformation, similar to that of heat treatment processes, after being subjected to the high temperatures of electrical discharge.

vii. *Recast layer Thickness (RLT):* The recast layer refers to the region of resolidified molten material occurring as the top most layer of the machined surface. The recast layer is usually located above the heat affected zone.

3. Literature review

Table-2 PMEDM Research Contribution Year wise national & International standard

Researcher Contribution year wise
Erden A., et al., (1980) Reported during the machining of mild steel that the machining rate increases by the addition of powder particles (aluminium, copper, iron) in the dielectric fluid of dielectric machining. Here improvement in the Break Down characteristics of the dielectric fluid is observed with the addition of powder particles, but after a certain critical concentration of powder short circuiting take place which causes poor machining.
Jeswani M.L., et al., (1981) Study the effect of addition of graphite powder to kerosene used as dielectric fluid in the EDM. He concluded that addition of about 4gm/litre of fine powder having average size of particle as 10Hm increases the MRR (Material Removal Rate) by 60% and TWR (tool wear rate) by 15% in electrical discharge machine. Wear ratio is also reduced by 30%. He concluded that there is 30% reduction in the breakdown voltage of kerosene at spark gap of 50Hm was observed.
Narumiya H., et al., (1989) Used silicon, aluminium and graphite as powder materials. The concentration range of the powder was between 2gm/l to 40gm/l. Their conclusion showed that the gap distance increases with the powder concentration and is larger for the aluminium powder but there is no direct relation between the surface roughness and the gap distance. The best results concerning the surface finish were achieved for low powder concentrations levels and that also for silicon and graphite powders.
Mohri, et al. (1992)Found that an EDM finishing process using dielectric mixed with silicon powder provides a mirror surface of up to 500 cm2, area. Recently this machining method has been introduced in commercial machine tools and practically applied in industry.
Kobayashi K., et al., (1992) Have concluded that silicon powder mixed in the dielectric improves the surface finish of SKD-61 tool steel. It has also been observed, however, that at specific machining conditions in the EDM of steel the aluminium and graphite powders generate better surface roughness than silicon powder.
Yan and Chen (1994) That the powder particles contribute to the reduction of surface cracks and to the smoothness and homogenization of the white layer. The lowest surface roughness levels and a correct balance between the discharge energy density and the discharge rate were observed for a powder concentration within the range of 2 to 5 g/l
Ming and He (1995) Indicates that some conductive powder can lower the surface roughness and the tendency of cracks in middle finish and finish machining but the inorganic oxide additive does not have such effect.
Uno et al. (1998) Observed that nickel powder mixed working fluid modifies the surface of aluminum bronze components. Nickel powder was purposely used to deposit a layer on an EDM surface to make the surface abrasion-resistant.
Wong Y.S., et al., (1998) Study the powder mixed dielectric electric discharge machining (PMD-EDM) by employing a current of 1A and pulse on time as 0.75Hs to produce a near mirror finish on SKH-54 tool steel. The conclusion was that the resulting machining surface was composed of well defined, uniformly

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sized, smoothly overlapped and shallow craters. The analysis was carried out by varying the silicon powder concentration and the flushing flow rate.

Chow et al. (2000) Studied the EDM process by adding SiC and aluminum powders nto kerosene for the micro- slit machining of titanium alloy. The addition of both SiC and aluminum powder to the kerosene enhanced the gap distance, resulting in higher debris removal rate and material removal depth.

Furutani K., et al., (2001) Used titanium powder in dielectric fluid (Kerosene) and found that the layer of titanium carbide of hardness 1600HV (Vickers hardness number) on a carbon steel with negative polarized copper electrode, peak current 3A and 2 Hs pulse duration. Titanium and titanium Carbide are found in X-Ray diffraction (XRD) analysis of machine surface. It was concluded that the breakdown of dielectric takes place and carbon came from it.

Tzeng Y.F., et al., (2001) Examines the effect of powder characteristics on machining efficiency of electrical discharge machining. They reach to a conclusion that 70- 80nm powder suspended in dielectric produces the greatest material removal rate and least increase in the spark gap.

Yan BH., et al., (2001) Studied the electric discharge machining with powder suspended working media and reported that the gap length become shorter regardless of a mixed powder with a decrease of the pulse duration at a duty factor of 0.5.

Kozak J., et al., (2003) Reported that the material removal rate and tool wear rate were decreased by addition of powder. Consequently the machined surface becomes smooth.

Peças P, et al., (2003) Investigated the influence of silicon powder mixed dielectric on conventional EDM. The relationship between the roughness and pulse energy was roughly investigated under a few sets of the conditions in the removal process. However, the effect of the energy was not systematically analyzed.

Klocke F., et al., (2004) Used HSFC high speed forming camera technique to find out that in comparison to standard electrode, the aluminium mixed dielectric forms larger plasma channel. It was concluded that discharge energy distribution is on the larger part on the work piece surface. The type and concentration of the powder mixed in the dielectric fluid also found to have direct effect on the machining performance output.

Wu KL., et al., (2005) Study the problem of powder settling by adding a surfactant with aluminium powder in dielectric fluid and observed that a surface roughness (Ra value) of less than 0.2μm. This is because of more apparent discharge distribution. It was also reported that negative polarity of the tool resulted in better hardness of the surface.

Biing Hwa Yan et al. (2005) Investigates the influence of the machining characteristics on pure titanium metals using an electrical discharge machining (EDM) with the addition of urea into distilled water. Experimental results indicate that the nitrogen element decomposed from the dielectric that contained urea, migrated to the work piece, forming a TiN hard layer, resulting in good wear resistance of the machined surface after EDM. They have concluded that Adding urea into the dielectric, MRR and EWR increased with an increase in peak current. Moreover MRR and EWR declined as the pulse duration increased. The surface roughness deteriorated with an increase in peak current.

H.K. Kansal et al. (2005) Optimized the process parameters of powder mixed electrical discharge machining (PMEDM) on tool steel using Response surface methodology. Pulse on time, duty cycle, peak current and concentration of the silicon powder added into the dielectric fluid of EDM were chosen as variables to study the process performance in terms of material removal rate and surface roughness. The silicon powder suspended in the dielectric fluid of EDM affects both MRR and SR. They concluded that more improvement in MRR and SR are expected at still higher concentration level of silicon powder.

Bai and Koo (2006) Investigated the effects of kerosene and distilled water as dielectric during electrical discharge surface alloying of super alloys.

Kansal H.K., et al. (2006) Establishes optimum process conditions for PMEDM of Al– 10%SiCP Metal Matrix Composites by an experimental investigation using Response Surface Methodology. Aluminium

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powder was suspended into the dielectric fluid of EDM.

Yeo S H., et al., (2007) The experiments were conducted using dielectric with and without additive and at low discharge energies of 2.5μJ, 5μJ and 25μJ, and was observed that a considerable difference in crater morphology is seen between craters in dielectric with and without the powder at low discharge energy of 2.5μJ, 5μJ and 25μJ. More circular shapes with smaller diameters are produced with powder additive as compared to without powder additive. Craters with the additives are smaller and have more consistent depth than in dielectric without additive. They reported that dielectric with additive in it lower the amount of discharge flowing between the work piece and the tool electrode and slows down the rate at which these charges flow.

H.K. Kansal et al. (2007) Have also identified number of issues that need to be addressed in future for implementation of PSD-EDM of this modified process of machining. Few of them are discussed here. Many researchers have shown that powder suspended EDM machining can distinctly improve the SR and surface quality in the finish machining phase and obtain nearly mirror surface effects. Despite the promising results, PMEDM process is used in industry at very slow pace. One of the key reasons is that many fundamental issues of this new development, including the machining mechanism are still not well understood. The complexity of this process, particularly in context with thermo physical properties of the suspended particles deserves a thorough investigation. Secondly, the difficulty in operation of dielectric interchange, the high amounts of powder consumption, the environmental requirements of fluid disposal and its higher initial cost (two to three times higher than the one required for a conventional EDM system) have restricted its frequent use

Norliana Mohd Abbas et al. (2007) Have reported a review on current research trends in electrical discharge machining (EDM). They have observed that Fine abrasive powder is mixed into the dielectric fluid.The hybrid material removal process is called powder mixed EDM (PMEDM) where it works steadily at low pulse energy and it significantly affects the performance of EDM process.

Peças P. et al., (2008) Study the effect of silicon powder particles suspended in dielectric fluid. The powder concentration and flushing flow rate are two input parameters. They reach to a conclusion that even for small level of powder concentration there is evident amount of reduction in crater depth, crater diameter and the white layer thickness. They reported that for a particular experimental configuration used, we can find the powder concentration that generates better surface morphology. It was observed that there is dielectric flow rate that minimizes the surface roughness for each electrode area and for larger flow rates, no positive effect on the surface morphology.

Han-Ming Chow et al. (2008) Have investigated the the use of SiC powder in water as dielectric for micro-slit EDM machining of titanium (Ti) alloy. They have concluded that SiC powder suspended in pure water causes a larger expanding-slit and electrode wear than those of using pure water alone. Also, pure water and a SiC powder attain a smaller amount of machined burr than that of using pure water alone.

Beri and Anil (2008) Performed experimentation on EDM of AISID2 steel in kerosene with copper tungsten (30% Cu and 70% W) electrode (made through Powder Metallurgy technique) and conventional Cu electrode. An L18 orthogonal array of Taguchi methodology was used to identify the effect of process input factors (viz. current, duty cycle and flushing pressure) on the output factors (viz. material removal rate and surface roughness). It was recommended to use conventional Cu electrode for higher MRR and CuW electrode made through PM for low SR.

Chiang K.T. (2008) Proposes mathematical models for the modeling and analysis of the effects of machining parameters on the performance characteristics in the EDM process of Al2O3+TiC mixed ceramic. It was concluded that discharge current and the duty factor affects significantly the value of MRR. The discharge current and the pulse on time also have statistical significance on both the value of the electrode wear ratio and the surface roughness.

Furutani K., et al., (2009) The conditions for deposition machining by Ti powder suspended EDM was investigated with respect to discharge current and pulse duration in this paper. They concluded that the discharge energy affected the deposit able condition range. TiC could be deposited in the case that both discharge energy and powder density was small. They reported that the hardness of the deposition achieved was 2000Hv. The matrix surface was also hardened.

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Kun Ling Wua et al. (2009) Explored the influence of surfactant on the characteristics of electrical discharge machining (EDM) process on mold steel (SKD61). In this study, particle agglomeration is reduced after surfactant molecules cover the surface of debris and carbon dregs in kerosene solution. The experimental results show that after the addition of Span 20 (30 g/L) to dielectric, the conductivity of dielectric is increased. The machining efficiency is thus increased due to a shorter relay time of electrical discharge. When proper working parameters are chosen, the material removal rate is improved by as high as 40–80%. Although the improvement of surface roughness is not obvious, the surface roughness is not deteriorated since the material removal rate is great.
Kung et al., (2009) Reported that the material removal rate and electrode wear ratio in powder mixed electrical discharge machining of cobalt-bonded tungsten carbide by suspending aluminium powder in dielectric fluid. They observed that the powder particles disperses and makes the discharging energy dispersion uniform.
Prihandana G.S., et al. (2009) Presents a new method that consists of suspending micro-MoS2 powder in dielectric fluid and using ultrasonic vibration during μ-EDM processes. It was observed that the introduction of MoS2 micro-powder in dielectric fluid and using ultrasonic vibration significantly increase the MRR and improves surface quality.
Kibria G., et al. (2009) Compares different dielectrics in micro- EDM machining operation and reported that the machining characteristics are greatly influenced by the nature of dielectric used during micro-EDM machining. From the available literature, it is concluded that the machining characteristics of some hard and difficult to cut material can be studied by suspending powder of some material in the dielectric fluid of EDM.
Kumar S., et al., (2010) Found that significant amount of material transfer takes place from the manganese powder suspended in dielectric fluid to the machined surface under appropriate machining conditions which changes the surface composition and its properties. They reported that percentage of manganese increased to0.95% from 0.52% and that of carbon to 1.03% from 0.82% that result in increase in the micro hardness. For surface alloying favourable machining conditions were found to be low peak current (4 A), shorter pulse on-time (5μs), longer pulse offtime (85μs),
Singh P. et al., (2010) investigate the Concentrations of aluminium powder and grain size of powder mixed in dielectric fluid strongly affects the machining performance of EDM process
Sharma S. et al (2010) Study the effect of aluminium powder on the machining performance of conventional EDM with reverse polarity. The machining performance is evaluated in terms of material removal rate, tool wear rate, percentage wear rate, surface roughness. Concentration and grain size of aluminium powder are taken as the input powder parameters and its effect are presented on machining performance. It is found experimentally that powder characteristics significantly affect machining characteristics.
Sharma S. et al. (2011) Study the effect of graphite powder on the machining performance of conventional EDM. The machining performance is evaluated in terms of tool wear rate. Concentration of graphite powder, polarity, electrode type, peak current, pulse on time, duty cycle gap voltage and retract distance is taken as the input parameters and their effect are presented on machining performance. Conventional copper electrode and cold treated copper electrodes were used during the experimentation. It is found experimentally that with the addition of the powder particles in the dielectric and the use of cold treated electrode Tool Wear Rate decreased.
SYED K. H. et al., (2012) Investigations on addition of aluminium metal powder to dielectric fluid in electric discharge machining (EDM). As more emphasis is given nowadays to the green manufacturing concept, the present investigation uses distilled water mixed with aluminium powder as dielectric fluid instead of conventional hydrocarbon-based oils. The workpiece and electrode materials chosen for the investigation are W300 die-steel and electrolytic copper, respectively. Taguchi design of experiments is used to conduct experiments by varying the parameters peak current, pulse on-time, concentration of the powder, and polarity. The process performance is measured in terms of material removal rate (MRR), electrode wear ratio (EWR), average surface roughness (Ra), and white layer thickness (WLT). The experimental results indicate that the polarity significantly affects the machining performance. Signal-to-

noise (S/N) ratio and the analysis of variance (ANOVA) are employed to find the optimal levels for the process parameters to achieve maximum MRR, low EWR, Ra, and WLT values.

4. Research progress in powder mix dielectric discharge machining (PM-EDM)

Table-3

Author /year	Process parameters	Tool Electrode	Workpiece	Research finding
Ming, Q.Y. et al. (1995)	Current Pulse width, Pulse interval, Additives powder concentration	Copper	high-carbon steel	• The surface roughness decreased with increase in powder concentration, but increased with excessive powder concentration. • The tendency for crack inception and extent of crack propagation on the machined surface was reduced. • The recast layer was thinner and denser
Tzeng, Y.F. et al. (2001)	Aluminium chromium copper & silicon carbide powders concentration	Copper	SKD-11	• The discharge gap distance and material removal rate increased as powder granularity was increased. • Of the powder materials capable of remaining in suspension during machining, aluminium produced the largest discharge gap enlargement and silicon carbide produced the smallest.
Zhao, W.S., et al. (2002)	Pulse on time Peak current Discharge gap Pulse width Concentration of Al powder	Copper	Steel workpiece	• PMD-EDM was applied to improving the efficiency of rough machining. • PMD-EDM enabled a 70 % improvement in machining efficiency over EDM in powder-free dielectric while achieving similar machined surface roughness
Pecas p. et al. (2003)	Peak current Duty Cycle Polarity Flushing Concentration of Silicon powder	Electrolytic Copper	AISI H13	• The positive influence of the Si powder in the reduction of the operating time, achieve a specific SQ, and in the decrease of the SR, allowing the generation of mirror-like surfaces.
Klocke, F., et al. (2004)	Polarity Voltage Pulse duration Duty Cycle Concentration	Tungsten electrodes	Inconel 718 superalloy	• The powder additives caused greater expansion of plasma channel compared to a powder-free dielectric. • The powder additives changed the

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	of Aluminum, & Silicon			thermal material removal mechanism and affected the composition and morphology of the recast layer.
Kansal et al. (2005)	Pulse on time, Duty cycle, Peak current, Concentration of the added silicon powder	Copper	EN 31 tool steel	• MRR increased with the increase in the concentration of silicon powder. • Surface roughness improves with increased concentration of silicon powder.
Tzeng et al. (2005)	Concentration of Al, Cr, Cu & SiC powders	Copper	SKD-11	• Results show that the particle size of additives in the dielectric oil affects the SQ of EDMed work. While the smallest particles (70–80 nm) generates the best surface finish of the machined work, the greater the particle size the less the improvement in the SR • Particle size has opposite effect on the recast layer, as the smallest particles generated the thickest recast layer of the EDMed surface, and the greater the particle size the thinner the recast layer.
Kansal H. K. et. al. (2006)	Peak current, pulse duration, Duty cycle, Concentration of silicon powder	Copper	H-11 Die Steel	• The concentration of Added silicon powder, pulse duration, & peak current significantly affect the material removal rate & Surface roughness in powder mix electrical discharge machining. • Addition Of appropriate quantity of silicon powder into dielectric fluid of EDM enhances the material erosion rate.
Kansal H. K. et. al. (2007)	peak current, pulse on time, pulse-off time, concentration of powder, gain, and nozzle flushing	Copper	AISI D2 Die Steel	• The concentration of Si powder into the dielectric fluid of EDM appreciably enhances material removal rate. • Peak current, concentration of the Si powder, pulse-on time, pulse-off time, & gain significantly affect the MR in PMEDM. • The nozzle flushing when applied at the interface of tool electrode and workpiece does not significantly affect the MR.
Celik S. A. et al. (2007)	peak current, pulse on time, pulse-off time, Gap Voltage,	Copper	AISI D2 tool steel	• The PM Workpiece on lower surface roughness on standard tool steel • For its finer surface finish Quality, PM materials could be used where high Accuracy needed.

Pecas et al. (2008)	Powder concentration & flushing flow rate.	copper	hardened mould steel AISI H13	• Crater diameter, crater depth and the white-layer thickness are reduced by the use of silicon powder particles suspended in the dielectric. • The increase of the silicon content for higher values only slightly reduces the crater dimensions.
Chow, H.M., et al. (2008)	Polarity, Peak current, Pulse duration Concentration of Si. powder	Copper	Ti–6Al–4V,	• PMD-EDM using pure water was applied to the fabrication of micro-slits. • Using SiC increased the electrical conductivity of water which increased discharge gap and dispersed the discharge energy. • PMD-EDM produced a larger slit expansion and electrode wear but a smaller amount of machined burr compared to powder-free dielectric.
Furutani, K., et al. (2009)	Discharge current, Pulse duration, Concentration of Titanium Powder	copper	Titanium carbide	• PMD-EDM was applied to accretion process. • Deposition of TiC was possible at discharge energies below 5 mJ under certain discharge current and pulse on time combinations. • There existed a maximum discharge current for deposition. • The larger the discharge current, the smaller the range of pulse on time durations available for deposition.
Sharma s. et al. (2010)	concentration of Al. powder and the grain size of the Powder particles, Reverse Polarity Current, voltage, pulse on time, duty cycle	Copper	Hastelloy	• The surface roughness of the work material continuously decreases with the increase in the concentration of aluminium powder and with change in the grain size of the powder particles. • With the increase in the concentration of the powder, percentage wear rate decreases sharply. • With change in the grain size of the powder, the percentage wear rate decreases continuously. • With the increase in the concentration of additive powder in the dielectric fluid, the tools wear increases. • With the addition of aluminium powder in the dielectric fluid of EDM, the material removal rate increases.
Singh P. et al. (2010)	Concentration s of aluminum	Copper electrode.	Hastelloy	• The addition of Al powder in dielectric fluid increases MRR,

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	powder and grain size of powder			decreases TWR and improves surface finish of Hastelloy.
Ojha et Al. (2011)	Peak current, Pulse on time, Dia of electrode, Concentration of Cr powder	Copper	EN-8 Steel	Current powder concentration & electrode diameter are significant factor affecting both MRR & TWR. MRR shows increasing trend for increase in powder concentration. TWR increases with lower range of powder concentration but than de-crease. •
Singh G. et al. (2012)	Polarity, peak Current, pulse on time, duty Cycle, gap Voltage, Concentration of abrasive Powder	Copper	H 13 steel	• Negative polarity of tool electrode is desirable lowering of surface roughness. • Increasing pulse on time leads to produce more rough surfaces. • Addition of powder particles in dielectric fluid decreases surface roughness of specimen in EDM process. • Higher peak currents produce more rough surfaces in EDM process.
Syed & Palaniyandi (2012)	peak current, pulse on-time, Polarity, Concentration of Al powder,	electrolytic copper,	W300 die-steel	• Uses distilled water mixed with aluminium powder improve the performance of MRR, SR & WLT. • High MRR, is obtained in positive polarity, whereas better surface quality (surface roughness and white layer thickness) is achieved in negative polarity. Hence for rough machining positive polarity can be selected to achieve higher MRR and during finishing a better surface is achieved by changing the polarity.
Mathapathi U. et al. (2013)	Pulse on time, Pulse off time Peak current Tool electrode lift time, Concentration of graphite & Cr powder	Copper	ASI D3/HCHCR	• TWR in PMEDM is smaller as compared with the conventional EDM. • MRR has increased by adding the powder in dielectric fluid as compared with conventional EDM. • MRR is maximum effected by the increase of peak current. • MRR has been decreased by increasing the pulse off time. • As the tool electrode lift time has increased, the MRR.
Muniu J.M. et al. (2013)	Concentration of Copper, Diatomite, Aluminium	Graphite	Mild steel	• MRR for copper, aluminium and diatomite powder increases to maximum and then decreases with further increase in powder concentration.

Goyal S. et al.(2014)	Current, Voltage, Pulse on time, Duty factor Grain size of Al. powder & Concentration of Aluminium powder	Copper	AISI 1045 steel	• Mixing of Aluminium (Al) powder in Di-electric fluid ensures improved Metal removal rate and surface finishing.

5. Current research trend in EDM

EDM basically two kinds of research trends are carried out by the researchers viz modeling technique and noble techniques. Modeling technique includes mathematical modeling, artificial intelligence and optimization techniques such as regression analysis, artificial neural network, genetic algorithm etc. The modeling Techniques are used to validate the efforts of input parameters on output parameter since EDM is a complicated process of more controlled input parameters such as machining depth, tool radius, pulse on time, pulse off time, discharge current, offset depth, output parameters like material removal rate surface and quality. Novel technique deal with hour other machining principles either conventional or unconventional such as ultrasonic can be incorporated into EDM to improve efficiency of machining processes to get better material removal rate and surface quality. Mostly used optimization technique in powder mix electric discharge machining (PM-EDM) is: Taguchi Methodology, Genetic Algorithm. Response surface methodology (RSM), artificial neural Network technique (ANN), Grey relational analysis (GRA), Entropy measurement method etc.

5.1 Summary of Optimization Technique Used In Improving & Optimization Performance Measure of PMEDM

Table-4

S. No.	Author/ year	Process parameters	Performance Measures	Name of Optimization Technique	Remark
1.	Kansal et al. (2005)	Peak current, Pulse duration, Duty Cycle Concentration of silicon powder	MRR, Surface roughness	RSM	The Increasing powder concentration of silicon powder in the dielectric fluid increases MRR & improve SR
2.	Kansal et al. (2006)	Peak current, Pulse duration, Duty Cycle Powder concentration	MRR, TWR, SR	Taguchi Method	Concentration of added silicon powder in dielectric fluid & peak current are the most influential parameters for TWR,MRR, & surface roughness
3.	Kansal et al. (2007)	Peak current, pulse on time, Pulse off time, Gain , nozzle flushing, powder concentration	Material removal Rate	Taguchi Method	Powder mixing into the dielectric fluid in EDM achieved the better MRR at desired surface quality
4.	Tzeng	Open circuit	Precision	Fuzzy logic	Simple & efficient in

	&Chen (2007)	voltage, Pulse duration, peak current, Powder concentration, Electrode Lift, time interval for electrode lift	Accuracy	analysis coupled with Taguchi	developing a high speed Electric discharge machining process capability.
5.	Kolahan et al. (2008)	Discharge current Pulse on time Grain size of Aluminum powder, concentration of powder,	Metal removal rate (MRR) and Electrode wear rate (EWR).	Genetic Algorithm	Optimize the desire output value. such as MRR increase & reduced the electrode wear
6.	Ojha et Al. (2011)	Peak current, Pulse on time, Dia of electrode, Concentration of Cr powder	MRR & TWR	RSM	Current powder concentration & electrode diameter are significant factor affecting both MRR & TWR. MRR shows increasing trend for increase in powder concentration. TWR increases with lower range of powder concentration but than de-crease.
7.	Kumar et al.(2012)	Peak current, pulse on time, polarity, Duty cycle, gap voltage, Retract distance concentration of fine graphite powder	TWR,Wear ratio	Taguchi Method	TWR &WR are minimum with the use of cryogenically treated Cu electrode
8.	Syed & Palaniyandi (2012)	Peak current, pulse on time, polarity, concentration Al. of the powder	MRR, EWR, SR, White layer thickness	Taguchi Method	Addition of Al powder in distill water is result in high MRR , good surface finish,& minimum .white layer thickness
9.	Padhee et al. (2012)	Peak current Pulse on time Duty cycle Concentration of powder in dielectric fluid.	Material removal rate & surface finish	Response surface methodology (RSM)	Mathematical models for prediction of MRR & SR through the knowledge of four process variable are developed using RSM & Statistically validated.
10.	Padhee et al.(2012)	Peak current Pulse on time Duty cycle Concentration of powder in dielectric fluid.	MRR& Surface finish.	Genetic Algorithms (GA)	In order to simultaneously optimize Both MRR & SR, NSGA II is adopted to obtain the Pareto optimal solution.

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11.	Modi & Agarwal (2013)	current, pulse-duration, wheel-speed, duty-cycle and powder-concentration	MRR & Average surface roughness	Response surface methodology (RSM)	The highest MRR is achieved when current, Pulse on-time and wheel speed are at peak levels. Similarly, The highest MRR is achieved when the Duty cycle is at the lowest level. Surface roughness less comparison of dielectric EDM.
12.	Kumar A. et al.(2013)	electrode polarity, electrode type, peak current, pulse on time, duty cycle, gap voltage, flushing pressure & abrasive concentration	effect on dimensional accuracy in terms of overcut	Taguchi Method	By optimizing the machining parameters the overcut is minimized which enhances the quality of machining process.
13.	Syed et al.(2013)	Pulse peak current, pulse on-time and concentration of aluminum powder	White layer thickness (WLT)	Response surface Method (RSM)	Result show Low thickness of white layer 17.14 µm is obtained at high concentration of powder of 4 g/l and low peak current of 6 A.
14.	Ganachari et al, (2013)	pulse on time, duty cycle, gap voltage, peak current, concentration of (Al + Si) powder	Surface Roughness, MRR	Taguchi method with GRA optimization	The proportion of the powder is 1:1. Oil quantity 10 lit. Flow rate 5 lit/min Taguchi method with GRA optimization is adopted to study the effect of independent variables on responses and develop predictive models
15.	Vhatkar et al. (2013)	Peak current, Pulse on time, Pulse off time, gap voltage, and concentration of fine silicon powder added	MRR & SR	Taguchi Method	With the addition of the powders in the dielectric, MRR has been increased to a great extent and the SR has been reduced. Silicon gives better results in terms of MRR & SR.
16.	Agrawal A. et al.(2013)	Peak current Pulse on time Pulse of time Powder concentration	Tool wear rate (TWR)	ANN	Mixing graphite powder in dielectric significantly reduces the TWR during machining of MMC. The peak current has been identified as most significant control factor affecting TWR, followed by powder concentration. The developed ANN model is reliable and adequate to predict the TWR with negligible prediction error.

					The optimization result shows considerable reduction of 94.57 % in TWR.
17.	Goyal et al. (2014)	Current, Voltage, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of Al. powder & Concentration of Al. powder.	MRR & Surface Roughness	Taguchi Method	Grain size of powder and concentration of powder have a great influence on the SR & MRR) in powder mixed EDM.

6. Conclusions

- Use of powder mix in electrolyte provide mirror like surface finish and increase in material removal rate. Proper work piece and powder combination must be used for better results.
- Totally Burr free & no stresses produced in work piece.
- 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 maximum effected by the increase of peak current.
- Material Removal Rate has been decreased by increasing the pulse off time.
- Additive mixed EDM enhance machining rate appreciably.

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