Current Research in Powder Mixed Electric Discharge Machining: A Review

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Abstract. Electric Discharge Machining (EDM) is a recognized and commonly used non-conventional machining method for the manufacture of complicated shapes and the processing of particularly hard materials, which are very difficult to machine by any standard machining processes. In this process, there is no direct contact between the electrode and the work-piece, this non-contact machining technique is constantly rising from the press tool and dies the process creation Process for apps for micro-level machining. In the latest decades, several researchers have focused on enhancing machining process capability such as enhanced rates of material removal with improved surface topography. Powder mixed electrical discharge machining (PMEDM) may be a newly developed technique for improving the EDM process capabilities of the EDM process in this trend. In this paper, a broad history, mechanism of PWEDM method, and literature review are presented.

1. Introduction

Electrical discharge machining (EDM) is one of the oldest and preferred non-traditional machining procedures involving the removal of material through the operation of short-length electrical discharges and highly current density between the tool electrode and the work-piece. Complex shape machining is made relatively simple also in difficult-to-machine materials. EDM technique is mostly and widely used in the press tools and dies, aerospace, automotive and surgical parts manufacturing industries. EDM has effectively applied to electrically conductive materials such as hot work dies steel, carbides, stainless steel (SS), different types of alloys, etc. Despite their physical and metallurgical characteristics. The rate of removal of materials and the quality of surface generated in machining are directly associated to the quantity of energy used to erosion material from the surface of the work-piece [1].

EDM is not a conventional technique of machining that has been commonly used. It makes molds and dies. EDM also used for machining components of the automotive, dies and press tool industries [2]. The history of electrical discharge machining (EDM) methods was found in the 1770s by an English scientist after the creation of the relaxation circuit (RC-resistance-capacity) by B.R and N.I. Lazarenko [3], keeping the distance across of the gap between the tool and the work-piece maintained by easy servo control using this method, they discovered a decrease in tonnage and made EDM more lucrative. EDM has been the ideal reducer of orbital and planetary motion methods, pulse generator,
computerized numerical control (CNC) and adaptive control scheme since 1940. However, the EDM was not fully utilized until scientists of Russia studied how the erosive impact of the method could be used and be regulated machining purposes [4].

Die Sinking EDM utilizes spark ignition erosion to metal removal. The power supply produces electrical impulses between the work-piece and the tool. A inter electrode gap between the electrode and the work-piece enables flow of dielectric oil. When adequate voltage is reached to pre-set value, the dielectric oil start ionizes and regulated sparks melts and vaporizes the work-piece. Pressurized dielectric oil cools the vaporized metal and removes the material from the gap.

The filter mechanism cleans the suspended particles out of the dielectric oil. The oil passes through the chilling unit to remove the heat produced by the method of chisel erosion. With the used of chilling unit, a steady temperature of oil can be maintain that helps with the precision of the machine. See in figure Die Sinking EDM, like wire-cut EDM, is a method of spark erosion. Die Sinking EDM, on the other hand, generates sparks along the surface of the electrode created. The gap between the electrode and worke-piece is maintained by a servo control unit. The servo control unit stops the electrode from touching the piece of work. a short circuit would be created and no cutting would happen, when the electrode were to touch the work-piece, [5].

1.1 Powder mixed electrical discharge machining (PMEDM):

In order to overcome constraints associated with conventional EDM, the highly conductive powder particles are get mixed in the dielectric fluid as shown in fig.2, which decreases its insulating capacity and raises an inter-electrode gap. So this PMEDM is also called as a hybrid material removal method. From the point of view of industrial applications, die steel is a very important material and therefore, for the purpose of experimentation, D3 die steel with copper electrode and EDM oil as dielectric has been used. The PMEDM is very complicated in nature and is regulated by a big amount of parameters that have an effect on different reactions. The current research is an effort to explore the ability of PMEDM to increase the material extraction frequency, reduce the tool wear rate (TWR) with enhanced surface roughness (SR) of Die Steels [6].

![Figure 1. Die Sinking EDM](image-url)
The appropriate amount of fine abrasive powder is blended with the dielectric fluid. The process of removing the hybrid material is called Powder Mixed EDM (PMEDM) in which the minimum pulse energy is constantly working and the efficiency of the EDM method is considerably affected. The insulation resistance of the dielectric fluid gets decreases due to electrically conductive powders and increases the gap between the tool and the work-piece. The EDM method becomes much more stable and facilitates the machining process. Productivity, MRR, SR. However, most of the research was conducted to estimate the surface finish of the process. It would provide a mirror-like surface finish that becomes a challenge in the EDM. The parameters of the powder, such as size, type, and concentration, affect the dielectric performance [7].

2. Process Parameters:

Process parameters are as follows:

2.1 Electrical Parameters:

2.1.1. Peak Current:

It is essentially the most significant machining input parameter in the EDM. Peak current is the quantity of energy used in the EDM and the measure in the amperage unit. At every pulse-on-time, the current goes increases till it attain the predefined level that is expressed as the peak current. The maximum amount of amperage is to be determined according to the surface of the cut during both die sinking and wire-EDM processes. In rough operations, cavities or details with large surface zones, higher amperages are applied. Higher currents increase MRR, although surface ruggedness and tool wear are sacrificed. [8].

2.1.2. Discharge Voltage:

There is built-up of open circuit voltage between two electrodes before any current starts flowing between them. Once the current flows through the plasma channel, the open circuit voltage falls and is a crucial variable that affects the energy of the spark responsible for greater MRR, greater tool wear rate and rough surfaces.

2.1.3. Pulse-On-Time or Pulse Duration:

It is available in units of microseconds. Because every cut is made in pulses on time, the duration and cycles per second (frequency) of such pulses play a crucial role. The current can flow on a cycle basis. During this phase, dielectric ionizes and sparks occurs. It is the productive spark cycle system in which current flows and machining take place. In this on-time operation, the quantity of material extracted is directly proportional to the amount of power consumed [9].

2.1.4 Pulse-Off-Time or Pulse Interval:
It's the interval of time between two successive pulses. The supply voltage is disrupted during the switch-off period. During this period, dielectric deionizes and recovers its strength. This interval, the molten material can be solidified and separated by flushing the arc. The time to switch off must be held to a minimum. The sequence is finished when the appropriate pulse interval earlier than the start of the next cycle is allowed. The interval of the pulse affects the rate and durability of the cut. In concept, the shorter and smaller the interval, the faster the operation is performed. If the interval is too short then the excluded workpiece material will not flush off with the dielectric fluid and also not deionize the dielectric fluid. This will result in the next spark being unstable and slowed down by cutting downtimes as long and stable [10].

2.1.5. Polarity:

The electrode polarity may be positive or negative. However, the surplus material is separated from the positive side. Polarity is usually measured by experiments and involves tool materials, job materials, current densities and combinations of the pulse length. To avoid arcing, modern energy supplies insert the "swing pulse" of reverse polarity at set intervals. The normal proportion for every 15 normal pulses is 1 Swing Pulse.

2.1.6. Inter-electrode Gap:

The gap between the electrodes is essential for the stabilization of the spark and accurate flushing. The stability of the system separation and responding speed are the most significant preconditions for excellent operation; the existence of the knock-back is especially unwanted. To react to short circuits or open space circumstances, the response rate must be high. The width of the gap may not be immediately estimated but the average gap voltage can be deducted. The servo tool system maintains a fixed value of the working gap. The main purpose is to use electromechanical systems (direct current or step-by-step motors) and electro-hydraulic systems keep medium voltage gap [9].

2.2. Powder Parameters:

2.2.1 Powder types:

The added powder into the dielectric fluid can enhance MRR and reduce the wear rate of the tool and significantly enhance the surface quality of the work-piece. However, the various powders could influence the performance features of the EDM method differently. The following characteristics must exist in the powder which can be suspended in EDM dielectric fluid; It should be electrical conductive, non-magnetic, must have good suspension capabilities, good thermal conductivity, non toxic and odorless. Many investigators have used various kinds of powders such as; Aluminum (Al), Chromium (Cr), Graphite (C), Copper (Cu), Silicon (Si), Nickel (Ni), Silicon Carbide (SiC), Titanium (Ti), Tungsten (W), Bron Carbide (B₄C), Alumina (Al₂O₃), Carbon Nano-tubes (CNT), Diatomite [9].

2.2.2. Powder Concentration:

Process effectiveness and stabilization are achieved due to the proper particle concentration. The optimum concentration is determined by powder properties for increasing performance. More concentration than ideal value leads to short circuits, arcing, or unstable processes because of excessive particles like residual particles, which are generally considered by too many debris as the dominant reason for spark concentration. Excessive particles in the discharge gap also cause settling and bridging issues, which lead to surface deterioration [11].

2.2.3 Powder Size:
Powder particle size is identified as a significant powder parameter to achieve the desired PMEDM performance. The effect is more abbreviated for higher pulse-on-time values due to higher contamination and lesser deionization between work-piece and tool [12] and bigger particles resulting in greater gap growth. The additive particles’ size is a crucial factor for the quality of the working surface, Yih-Fong and Fu-chen [13] indicated. The highest surface finish is achieved by smaller particles (70-80 nm), but recast layer thickness get increased. These small particles (70-80 nm) produced, according to Tzeng and Lee [12], the lowest discharge gap, the maximum MRR, and also least tool wear rate.

3. Literature review:

On the basis of the literature review, the researchers’ contribution to PMEDM studies is discussed below:

The impact of aluminum powder on the AISI D3 steel machining has been found by Jamadar et al. [14]. The process performance variables are investigated such as material removal rate (MRR), the tool wear rate (TWR) and surface roughness (SR). The machining efficiency was considerably affected by aluminum mixed with dielectric liquid. Razak et al. [15] explored that concentration of SiC micro powder in PMEDM in Hot Die steel and its particle size. A number of trials conducted by orthogonal Taguchi array with three levels and two variables.

The impact of Aluminum powder on the errosion of metal matrix composites (Al / SiC) was researched by Hussain et. al. [16]. Different parameters have been selected and test findings show that the removal rate of materials improves with a small peak 2A current. With the trending technologies addition of micro particles like MoS$_2$ was held in the dielectrical fluid in a microform by Prihandana, Mahardika [17] and additional ultrasonic vibration. Results indicate that ultrasonic vibration and micro-particle addition considerably boost the surface quality of the MRR.

Many scientists have come to realize about implementing nanoparticles for many applications in nano-technology with increasing speed. The list of nanoparticles used in EDM, although few, have shown that the best surface finish obtained by introducing nanoparticles in machining process as a powder mixed in EDM. Jahan, Rahman [18] studied the effect of nano particles and micro particles in WC-Co EDM and reported that the smoother and clean surface was achieved as compared to the sinking micro EDM. The highest and lowest SR values were 37 nm and 17μm, respectively.

Tan et al. [19] explored the effect of nanopowder particles on surface roughness and discharge gap ranges during the micro EDM of stainless steel mould of AISI 420 grade. SiC and Al$_2$O$_3$ nanopowders have been recorded to decrease surface roughness during the micro EDM of stainless steel. Jahan and team studied impact of graphite nanopowder on material SKH-51 grade tool steel micro-EDM [20]. Subsequently, the effects of graphite, aluminium and Al$_2$O$_3$ nanopowders on surface topography were studied [21]. The conclusion was that, smoother and mirror-like surfaces were found with semi conductive graphite nanopowder among the three types of powders.

Table 1. Current Research Literature carried out for PMEDM with different powders and the impact of varying input parameters with distinct optimization techniques is shown in the following table.

| Sr No | Name of Authors | Year | Material: Work-piece and Electrode | Dielectric media | Parameters | Performance Measures | Findings |
|-------|----------------|------|-----------------------------------|------------------|------------|----------------------|---------|

5
01  Pushpendra S. Bharti et.al. [22]  
2011  
Inconel 718  
Copper  
EDM oil  
Kerosene  
Pulse On Time, Pulse Off Time, Shape Factor, Current, duty cycle, gap voltage, flushing pressure and lift time of tool electrode.  
Surface Roughness (SR) & Material Removal Rate (MRR)  
The orthogonal L27 array has used for conduct experiments The EDM process ANN model was then created through the training of the ANN with experimental data. Experimentally confirmed the prediction capacity of a trained ANN model. The trained network was finally used by regulating elitist NSGA-II to achieve the Pareto-optimal solution set. Matlab conducted a simulation. So they obtained 103 Pareto-optimal solutions and due to conflicts in response variables, they found that range between 26-55 is best to run to get an optimized solution.

02  Uttam Kumar Mohanty [23]  
2017  
High carbon steel  
Copper  
Standard dielectric  
Kerosene  
Pulse On Time, Current and Volatage.  
MRR, TWR, SR and Radial Overcut (ROC).  
Experiments were conducted by L9 orthogonal array, then the simpler regression model has developed the establishment of correlations between input and output parameters also ANOVA used to see most influencing process parameter. And finally, VIKOR Index method was used for multi-objective optimization used to optimize simultaneously performance variables. They found that among process parameters under study current is the most influence on the performance of EDM.

03  B. Singaravel et.al [24]  
2019  
AISI D2 Steel  
Cryo-treated Copper  
Kerosene, Jatropha and cottonseed oils.  
Types of dielectric, Current and Pulse On Time.  
MMR, TWR, and SR  
In order to decide the optimum parameters, a new Hybrid TAGUCHI and VIKOR method is introduced, and VIKOR index value is used for optimum parameters. They observed that MMR is increased by higher spark energy density and less tool wear is recorded due to Cryo treated electrode.

04  Muhammad Han et.al [25]  
2019  
AISI D2 Steel copper  
Graphene nanoplatelets mixed in kerosene  
Pulse On Time, Pulse Off Time, Discharge Current, Powder concentration.  
MMR, SR and White Layer Thickness (WLT)  
For the design of experiments, they used a Box-Behnken design based on Response Surface Methodology (RSM). The most important factors have been identified by ANOVA. In terms of desirability, multi-objective optimization is carried out. They discovered that pulse-off time has a significant effect on WLT among input parameters. For larger discharge current and conch, greater MMR was obtained. Low discharge current and high concentrations of nanoparticles and minimum SR were obtained. Multi-objective optimization and optimal process performance with desirability function.
| No. | Author(s)                  | Year  | Description                                                                 | Process Parameters                                    | Taguchi L16 array used for DOE. A new approach Principal component analysis (PCA) - the technique for order preference by similarity to ideal solution (TOPSIS) used to the optimized process. Results indicate that the peak current is the most significant process parameter. The proposed technique is very suitable for getting an optimum set of input parameters. |
|-----|---------------------------|-------|------------------------------------------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| 05  | Deepak Kumar Naik et al.  | 2018  | Nickel free Austenite stainless steel Copper                                 | Nickel Powder Mixed with Kerosene, Pulse On Time, Peak Current and Powder concentration, MMR, SR and ROC | For the design of experiments, they used a Box-Behnken design based on Response Surface Methodology (RSM). Particle Swarm Optimization (PSO) and Desirability Function these two methods multi-objective optimization techniques are used and they got results as the powders improve the material removal rate and surface finish. With the use of nanopowders, it has seen that MMR increased and SR decreased. |
| 06  | Shalini Mohanty et al.    | 2017  | AlSiCp Metal matrix composite Copper                                         | Alumina Oxide(Al2O3) powder, Low and High Voltage current, Pulse On Time, Pulse Off Time, Flushing Pressure, MMR, TWR, and SR | For the design of experiments, they used a Box-Behnken design based on Response Surface Methodology (RSM). Particle Swarm Optimization (PSO) and Desirability Function these two methods multi-objective optimization techniques are used and they got results as the powders improve the material removal rate and surface finish. With the use of nanopowders, it has seen that MMR increased and SR decreased. |
| 07  | Soumyakant Padhee         | 2011  | EN31 steel                                                                  | Silicon Powder, Pulse On Time, Peak current, duty cycle and Powder concentration, MMR and SR | A Face Centred Central Design (FCCD) is used to conduct the experiments. RSM is applied to do study the effect of process parameters on responses and developed predictive model. It is required to obtained optimum process parameters selection that result in higher material removal with lower surface roughness, due to conflicting nature of responses so it was necessary to explore the optimization area to obtain the set of the dominant solution with help of Non-sorted genetic algorithm (NSGA). |
| 08  | Huu-Phan Nguyen et al.    | 2018  | SKD61, SKD11, SKT4 Graphite Copper                                           | Titanium Powder, Pulse On Time, Pulse Off Time, polarity of electrode and nano powder concentration, MMR, SR and Micro Hardness(HV) | Taguchi L16 array used for DOE. The results showed that MMR and HV increased and SR gets decreased with the addition of titanium powder in the dielectric. The most significant parameter found as Powder concentration. They also consider studying interactions of process parameters with each other. TOPSIS used for further multi-objective optimization to obtain optimum sets of parameters. |
| 09  | Neeraj Agarwal et al.     | 2018  | AISI D2 steel                                                               | EDM oil, Pulse On Time pulse current, Duty cycle, and gap voltage, MMR, and SR | To predict quadratic polynomial models, a multiple regression technique was coupled to a single objective. A modern Jaya algorithm was then applied to optimize process parameters and an optimal combination set was introduced. |
|   | Study Authors                                      | Year | Material                  | Fluids                  | Parameters                                             | Taguchi's orthogonal array | Experimental Methodology                                                                 |
|---|---------------------------------------------------|------|---------------------------|-------------------------|--------------------------------------------------------|---------------------------|------------------------------------------------------------------------------------------|
| 10| Chinmaya P.Mohanty et. al [31]. 2017 Inconel 718 Graphite | Pulse On Time, Open circuit voltage, flushing pressure, duty factor, material of electrode, discharge current. | MRR,ROC,TWR and SR      | Taguchi's orthogonal array L27 was used for experimenting, ANOVA was also conducted and discovered to be significant process parameters as an electrode material, Pulse On Time and discharge current. A hybrid method has been suggested and contrasted for acquiring the highest parameter setting for the EDM method, using the Quantum Particle Swarm Search Optimization (QPSO) and PSO algorithms. |
| 11| G. Venkata et. al [32]. 2019 Inconel 750 Copper wire | Kerosene, Pulse On Time, Pulse Off Time, Wire feed rate, water pressure | Machining speed and SR   | Taguchi's orthogonal array L18 was used for experimenting. The TOPSIS is integrated with the Gray Wolf Optimizer(GWO). Method of multi-objective optimization. Multi-objective is originally converted to a single objective by using TOPSIS, with the help of Wire EDM machining a relative close value has been calculated. TOPSIS was used as an objective function (equation) for the Grey Wolf Optimizer (GWO), and the optimal setting of the parametric was established. |
| 12| Jun Ma et. al [33]. 2017 SiCp/Al Composite Copper wire | Kerosene, Pulse On Time, Pulse Off Time, Wire tension, and Water pressure | MMR and SR               | Taguchi's orthogonal array L18 was employed in experimenting with an Optimization Model for predicting MMR as well as SR. The findings were compared with the linear regression model and the back propagation neural model and the best methodology for improving the process of EDM, using the novel hybrid Gaussian Regression (GPR) and Wolf Pack Algorithm. |
| 13| Shankar Chakraborty et. al [34]. 2018 Alumina ceramic | Water pressure, jet feed speed, abrasive mass flow rate, nozzle speed | MMR and SR               | Two non-linear regression models were developed based upon the experimental data and using RSM methods, which are afterward employed for multi-objective of Abrasive Water Jet Machining process(AWJM) for that purpose Grey Wolf Optimization (GWO) technique were used and they found that optimum set of parameters. |
| 14| Osama Lari et. al [35]. 2015 AISI 1046 steel Copper | Concentration of powder and Grain size of powder | MMR and SR               | Taguchi L9 array has been used for conducting experiments, analysis of single and multi response stage was done with Taguchi method, also multi response stage was done with Utility concept. ANN model used for close proximity with experiment values. |
15. Arvind Kumar et al. [36], 2019. AA7050-10%B4C Composite Copper Kerosene, Pulse-on-time, Pulse-off-time and pulse current. MMR, SR and depth of cut (DC). A new multi criteria decision making model of AHP-The Additive Ratio Assessment (ARAS) has been used for optimization multi response. For experiments Taguchi L9 array has been utilized. ARAS is a MCDM which determines the performance of chosen alternatives also compares the scores of those chosen alternatives with the best alternative.

16. Rajkamal Santosh Shukla et al. [37]. Tzeng and Chen have created a process EDM configuration, perform experiments with copper electrode JIS SKD 61 steel. Pulse-on-time, Pulse-on-time, Discharge Current and Gap voltage; use a Regression Predictive Model for performance parameters such as MMR, RA, and REWR. Authors used same model developed by Tzeng and Chen and apply Fireflies Algorithm (FA) to get optimum process parameters. The Fireflies Algorithm (FA) have distinctive characteristics compared to the many other optimization algorithms, such as., Particle Swarm Optimization (PSO), Genetic Algorithm, SA, Artificial Bee Colony algorithm (ABC), etc. This FA algorithm possesses multi-modal characteristics, high convergence rate and few control parameters.

17. Zheng-Ming Gao et al. [38], 2019. Research Article: An Improved Grey Wolf Optimization Algorithm with variable Weights. An enhanced Gray Wolf Improvement optimization (GWO) variable-weight algorithm (VW-GWO) program is proposed in this paper. A hypothesis has been established that the social hierarchy of the packs even works in their view positions. And then their search technique is given variable weights. A governing equation of the dominant parameter is implemented to reduce the probability of being caught in local Optima, thus exponentially decreasing from the maximum. Finally, there are 3 types of studies to check the merits of the VW-GWO algorithmic program envisaged. The original GWO and therefore the ALO, PSO and BA algorithms are compared. The selected experiment findings indicate that under entirely distinct circumstances, the predicted VW-GWO algorithmic program operates higher than the others.

18. Tarik A. Rashid et al. [39], 2019. Research Article: A multi hidden recurrent neural network with a modified grey wolf optimize. Identifying the weaknesses of university learners leads to better study and can be an early warning system for improving learners. However, current schemes do not have a successful amount of satisfaction. New and dynamic measurement of hybrid systems needed for this mechanism. A hybrid scheme is used to anticipate the results of learners (a modified recurrent neural network with the tailored gray Wolf Optimizer). This planned scheme would improve faculty training and enhance the learning experiences of the learners. Results indicate that the altered recurred neural web has the most efficient precision compared to various designs with the tailored gray Wolf Optimizer.

4. Gaps in literature:

In the past couple of decades, research on EDM machining performance variables, such as MRR, TWR and SR, has been conducted in the area of PMEDM (Powder Mixed Electric Discharge Machining). However, information about the variation to a known work piece and electrode of process parameter for a particular powder is insufficient. Furthermore, the critical size of the powder is still
not determined and its variation with other process parameters. The conclusive experimental work can achieve this. In research, researchers can find the optimal value of distinct process parameters through the use of multiple types of powders, varying workpiece and electrode material.

In recent years numerous scientists have used powders for the machining of workpiece such as silicon, silicon carbide, aluminum mixed in the dielectric. Powdered materials, such as nickel, chromium, copper, graphite etc, can be blended in a dielectric process. Few trials focused on powder parameters such as powder size and powder concentration. Consequently, further studies are needed regarding the effect of process parameters. Micro and nano-powder surface modification was not much attempted yet.

5. Conclusions:

PMEDM is a very useful type of EDM which provides improved efficiency, including compared to conventional EDM, in terms of MRR, SR and TWR, and others. By blending powders into the dielectric fluid in comparison with the conventional EDM technique, the removal speed of the material enhanced. The wear frequency for tools in PMEDM is below the normal EDM method. The removal rate is highest, depending on the increase in peak current. The use with an electrolyte of a powder mixture offers a surface finish similar to a mirror. To generate better outputs, optimum set of process parameters and powder mix must be used which can be obtained through new and improved multi-objective optimization. Following an in-depth analysis of the paper, the main focus of the research is the PMEDM of conventional materials, such as steels, alloys and so on.

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