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Restructured review on Electrical Discharge Machining - A state of the art

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Abstract. In this literature survey, an attempt made to review the Electrical Discharge machining and its related machineoperating parameters and machining parameters were studied the various research works. This work is unique and innovatively constructed which helps to be aware of each parameter in machining collectively and individually. This review furnishes both indispensable and restructured information EDM, PMEDM, WEDM, MEDM, NDEDM etc. The choice of electrodes, optimization methods and influencing parameters and their influences are precisely presented and concluded with research gaps.

1. Introduction

The modern materials possess superior properties and attract for produce highly precise components. Machining of such extremely hard and brittle materials by the conventional manufacturing processes is economically difficult. These high strength materials can be processed by using higher strength tools like polycrystalline diamond (PCD) and carbide cutting tools. On the other hand, it offers increasing of the cost of thetool and high tool wear rates and thus the manufacturing process of arduous materials like MMCs by standard means it increases the manufacturing cost. Therefore the unconventional manufacturing processes can be adapted for economic manufacturing of the arduous materials.

2. Electrical Discharge Machining(EDM)

In the EDM process the heat or thermal force is used as a driving force formachining the conductive materials and non-conductive materials. The basic construction and working of EDM is shown in figure 1. In EDM high-frequency of electric discharge supplied to theworkpiece which conducts electricity in controlled manner. This resultsin the removal of small amount of particles from the workpiece. The melting and evaporation of the material is processed.Complex shapes and geometry can be shaped with fine and high precision work can be carried out. It has some advantage in the manufacture of mould cavities, die casting, automobile, spaceresearchand surgical equipments.Generally, the EDM involves the incident of spark of initialization, dielectric breakdown and thermo-mechanical erosion of metals [1]. There are several non-conventional machining process are availableamong them the Powder mixed Electric Discharge machining (PMEDM) has found to be effective processing of hard materials like composites materials [1,2].

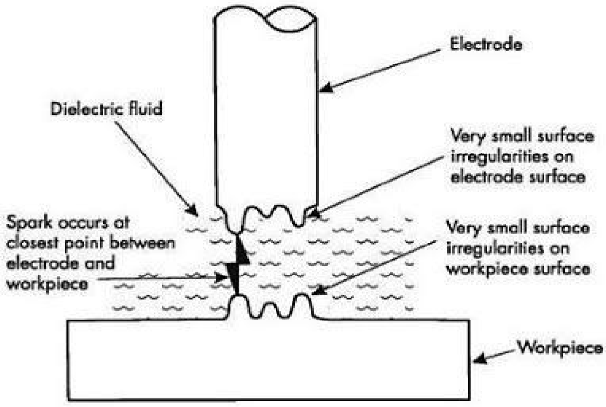

Figure 1. Basic workingprinciple of EDM

3. Powder Mix Electrical Discharge Machining (PMEDM)

The principle of PMEDM is shown in Figure 2. It is used to improve the surface finishing of the manufacturing surfaces by improve the MRR and reduced TWR by increasing the gap between the electrodeand workpiece [36]. In PMEDM the suspended particles are presence in the dielectric fluid and significantly which increases the surface finish and machining efficiency.The recent review of DivyaRana et al[8] reported that PMEDM is excellent research shows the potential area.

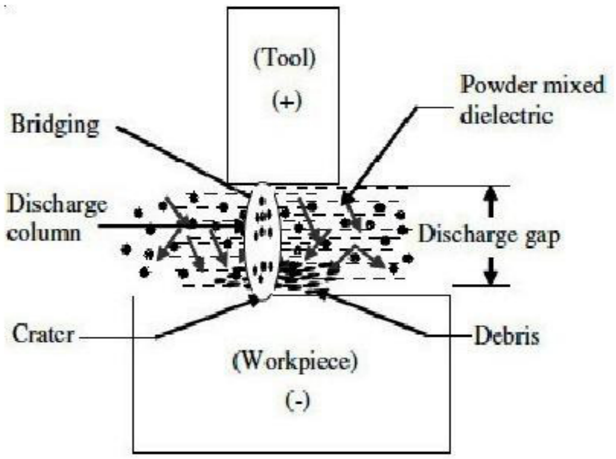

Figure 2. Principle of PMEDM.

4. Micro – Electrical Discharge Machining (M-EDM)

The M-EDM is another modified form of the EDM process;it has the ability to machine the complex3D- shapes on any electric power conductible materialsin spite of its hardness, toughness, and strength.

5. Wire Electrical Discharge Machining (WEDM)

The WEDM is especially used in aerospace, nuclear and automotive industrial components manufacturing industries, in the figure 3 the basic principles operation of Wire EDM is shown in Figure 3. It is more popular to machining various hardest materials like molybdenum, titanium,

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nimonics, zirconium, etc,withthehighaccurate surface finish and intricate shapes. It is an economical process to cut hardest materials with complex shapes withexact contours in low volume and larger variety. Discharge current, discharge capacitance, pulse duration, pulse frequency, wire speed, wire tension, average working voltage and dielectric flushing condition are the most important control parameters of the WEDM.

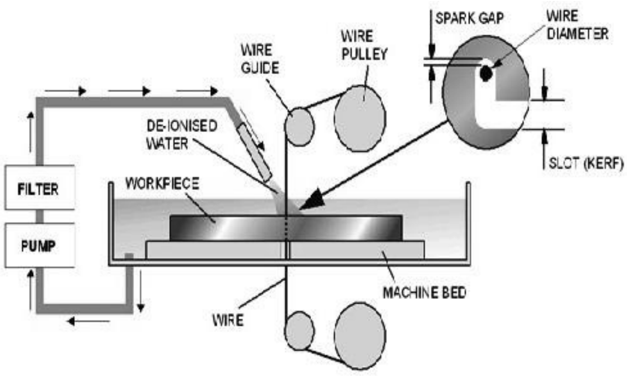

Figure 3 Principles of Wire EDM

6. Parameters and their Influences

The parameters commonly involved in EDM, PMDEM WEDM were shown as Fish Bone Diagram in Figure 4.

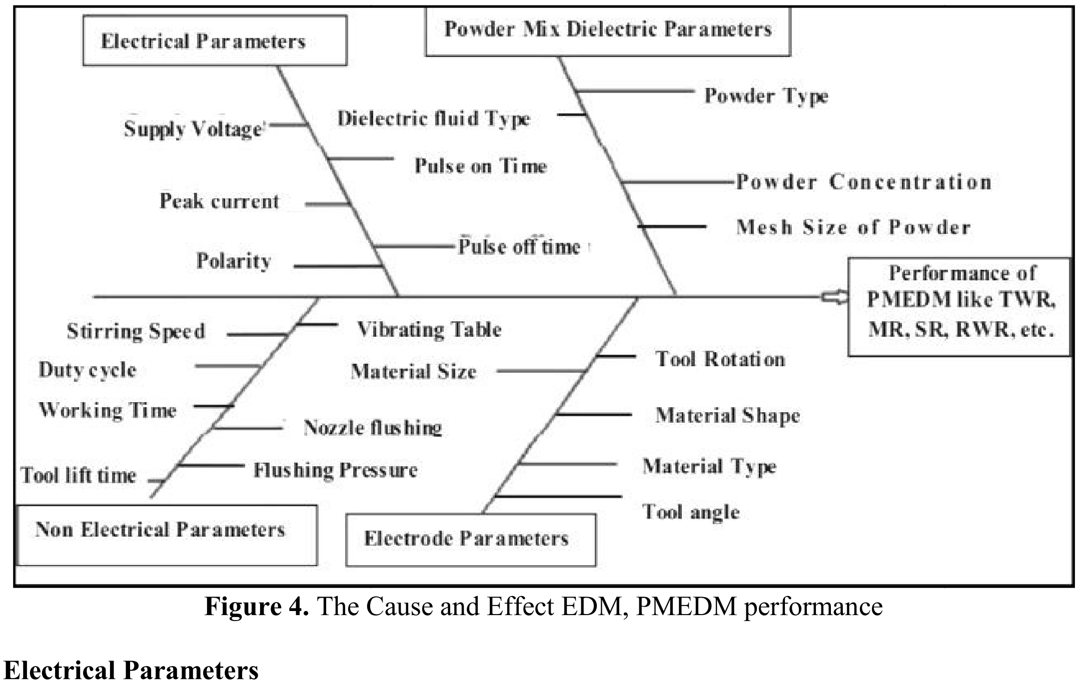

Figure 4. The Cause and Effect EDM, PMEDM performance

7. Electrical Parameters

7.1. Polarity

- Straight or reverse depending on the application [1].
- In reverse polarity, tool/ electrode and workpiece connect to the positive and negative terminal of the D.C. source respectively [1].

- Positive polarity improves MRR and negative polarity improves surface finish [1].
- Material removal rate with reversed polarity was considerably lower than that of straight polarity [2].
- The machining time was about eight times longer than straight polarity [2].
- The surface obtained by reversing polarity was found to be smoother than that using straight polarity [2].

7.2. Peak Current
- MRR will be improved by applying high current, but it results in tool wear and some surface roughness [3].

7.3. Pulse duration
- Increase in pulse durationup to 750µs has improved MRR for Inconel 718 [8].
- Higher peak current and pulse duration capable of increasing the performance and productivity of EDM Inconel 718.

7.4. Discharge Voltage
- The flushing condition is improved by increasing the gap and cut operation is stabilized by setting it to higher voltage [3].
- By increasing the open circuit voltage the electric field strength is increased which results in increase in surface roughness, TWR and MRR [3].

7.5. Pulse ON Time and Pulse OFF Time
- Metal removal is directly proportional to the amount of energy applied during the pulse on time [1].
- When longer pulse is given to the work piece material, a substantial amount of metal will be melted extra than the short pulse duration, results the crater to be broader and deeper. This develops surface roughness, heat affected zone will be deeper and has a larger recast layer. [4].
- There will be counter productiveness when the pulse duration is on the extreme side [3].
- If the interval and duration are not set properly many pulses will have failure by which the machining efficiency will be lost [1].
- The material removal rate starts decreasing when the optimum pulse duration for each tool and the workpiece combination is exceeded [4].
- The output of electrode can be restricted by applying long pulse for the machining process[2].
- More is pulse off time greater will be the machining time [5].
- Pulse off time also governs the stability of the process[4].

7.6. Spark frequency
- An increase in spark frequency results in an improved SR[5].
- The material removalperiod of time is shared by a large number of sparks,the size of the crater is reduced to increase in frequency, and thus SR decreases [5].

7.7. Duty factor
- The flushing time is very less when the high duty factor and this might lead to the short circuit condition [6].
- The high pulse off time arrases for small duty factor of the low machining rate [6].

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8. Powder Parameters

In EDM the suitable powdermaterial is to be mixedinto the dielectric fluid of EDM for enhancing the machining performance called PMEDM [29]. PMEDM is a different machining of mechanism as compared to the conventional EDM. Hence a detailed review of recent literature is presented here below to illustrate the effects of powder type, powder size (mesh size) and powder mixing ratio with adielectric (powder concentration).

8.1. Type of Powder

- The powder added into the dielectric fluid could increase the material removal rate and it decrease the (TWR) and which improves the surface quality of the work quite clearly [5].
- The different powders have a different impact on the manufacturing process output of the PMEDM process [8].
- Some of the inorganic oxide powders notdissolve uniformly and persistently in kerosene, concentrate and precipitate quickly, so they do not works a good role in improving the MRR, decreasing the SR and TWR [14].

The requirements of properties of Powder which can be suspended into thedielectric fluid of EDM must have thefollowing [14].

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

8.2. Concentration of added powder

- In addition to that the appropriationquantity of powder into dielectric fluid plays a very important role on MRR, SR, and TWR. The finding of various powder concentrations is presented in the article for better understanding [15].
- The MR depth reached the maximum value of appropriate concentration. Sometimes increases the TWR and SR. So it is to be optimized based on machining requirements [16-19].
- Increase or decrease in the concentration with the powder would decrease the MRR [20].

8.3. Mesh size of powder

The size of the powder particles affects the PMEDM performance. A large diameter of the powder particle (mesh size) increases the gap, but simultaneously decreases the MRR and then increases the SR [10].

8.4. Electrical properties of powders

The electrical conductivity of the added Powder directly affects EDM performance [8].
The added powder increases the conductivity of the dielectric fluid and results in the extension of the gap distance

9. Non- Electrical Parameters

The electrical conductivity of the added Powder directly affects EDM performance [8].
The added powder increases the conductivity of the dielectric fluid and results in the extension of the gap distance.

9.1. Dielectric Flushing

- Lonardo and Bruzzone[13]exposed that the MRR and TWR are in fluencies the flushing roughing operation, while in the finishing operation; it influenced the SR.

- The influence of flushing rate also plays a vital role in the crack density and recast layer; it is also minimize the optimal flushing rate [12].
- Poor flushing ends up with the stagnation of dielectric fluid and builds up of machining residues, which apart from low MRR also leads to short circuits and arcing [8,21, 22].

9.2. Electrode Gap

The presence of backlash is particularly undesirable.

- Gap width is not measured directly, but can be inferred from the average gap voltage [9, 11].

9.3. Rotating the electrode

- As the tool rotation serves as an effective gap flushing technique, the MRR and SR can be significantly improved by introducing the rotary motion to the electrode [24 - 27].

9.4. Electrode Parameters

The electrodes don't only differ by materials, but also its shape, size, and coating over it. The electrode material for specific applications is shown in table 1. The certain clearance usually provided in the electrode design based on the materials of theelectrode and the workpiece, and MRR. The details are furnished in Table 2 are side clearance inatool with respect to finish [29].

Table 1. Electrode Material and Applications

Sl. No	Material	Wear Ratio	MRR	Fabrication	Cost	Application
1	Copper	Low	Rough range is high	Easy	High	Metals
2	Brass	High	High at finishing	Easy	Low	Metals
3	Tungsten	Lowest	Low	Difficult	High	Drilling the small holes
4	Tungsten copper alloy	Low	Low	Difficult	High	Accuracy is high
5	Cast iron	Low	Low	Easy	Low	Only on few materials
6	Steel	High	Low	Easy	Low	Finishing work
7	Zinc based alloy	High	High on rough range	Easily die-casted	High	Metals
8	Copper graphite	Low	High	Difficult	High	Metals

Table 2. The operating Condition vs side clearance

Sl. No.	Rate of Cutting	Finish	Side Clearance (mm)
1	Rapid	Coarse	0.6 – 0.7
2	Medium	Medium	0.3 – 0.4
3	Very Low	Fine	0.04 – 0.07

9.5. Conventional and Non-Conventional Optimization Methods

The conventional and non- conventional methods of optimization were consolidated and presented in the chart in Figure 5.

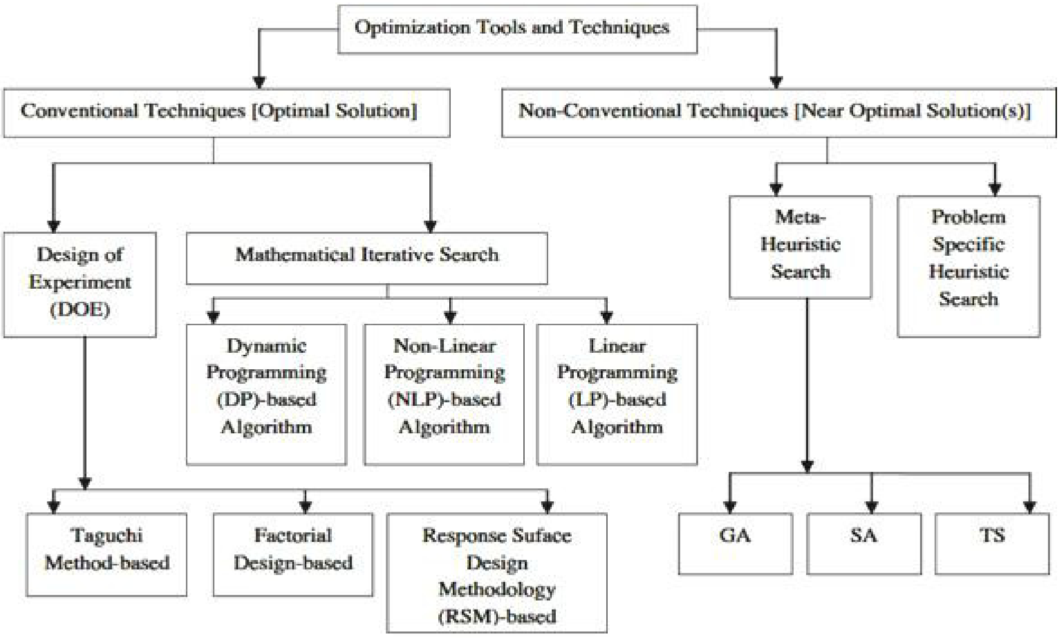

Figure 5. Optimization Method

9.6. Recent Investigations on Parameters Influence

Amandeep Singh and Ranjot Singh[48] comprehensively reviewed the time of past works, the mechanism ofthePMEDMprocedure, and study the research literature in this area. But this review is unique to consolidate the recent research upto date to reveal the innovative methods of research like theuse of new materials, methods, powders, concentration ratios etc. Razak et al.[10] investigation was on the EDM of premium stainless mold steel (Stavax) material. SiC powder mixed with various concentrations (5, 10 and 15 g/l) kerosene dielectric fluid, the mesh size also varied at three levels (10, 20 and 30 μm) and concluded that PMEDM improves MRR and reduces the SR, TWR, Machining Time and Machining Cost. Muniuet.al.[15]investigated the effects of suspending diatomite powder in distilled water dielectric fluid in the machining of mild steel workpiece withagraphite electrode. The increase of powder concentration in the distilled water dielectric fluid improves the MRR. XueBai et al.[16]studied a unique case of the influence of various combinations of workpiece and tool electrodes powder mixed near dry electric discharge machining (PMND-EDM) process with the parameter variations in pulse off time, peak current, and pulseON time, air pressure, tool rotation and powder concentration on the MRR. They reported that brass is the best tool for machining W18Cr4V on the basis of maximum MRR. While work with same brass tools for machining C45 carbon steel workpiece exhibited superior MRR when there was improper heat dissipation.

Nimo Singh Khundrakpam et al.[17] reported that powder concentration and peak current were significant parameters to maximizing the MRR after they studied the effect of mixing Zinc powder in kerosene dielectric fluid forthe EDM of EN-8 steel. They investigated the effects of process parameters like tool electrode diameter, peak current, flushing pressure, pulse off time and powder concentration. Taguchi’s L 27 orthogonal array was employed in research design. Satpal Singh and Kalra[18] investigated the influence of mixing of tungsten powder in the dielectric fluid for the EDM of EN 24 steel alloy. The authors used Taguchi’s L 27 orthogonal array to analyze the effects of process parameters like peak current, tungsten powder concentration, duty cycle, and pulse on time on TWR as well as in MRR. They used powder concentration in the range of 0 to 4g/l. Khalid et al.[20]studied kerosene dielectric with aluminium PMEDM of Al-SiC metal matrix composite by using copper electrodes. Their variable process parameters were Peak current and aluminium powder concentration.

They found that the powder concentration is indirectly proportional to surface roughness. At higher powder concentration, the lowest peak current value of 2A setting gives least surface roughness values.

The investigation of the effect of both electrical and non-electrical machining parameters of WEDM, such as current, pulse on-time, off-time, servo reference voltage, maximum feed speed, wire speed, flushing pressure and wire tension along with workpieces of metal matrix composites (Al/Al2O3) for the responses of cutting speed, surface finish, and kerf width. They reported that Reinforcement percentage, current, and on-time was found to have a noteworthy effect on the responses. Wire breakages were found to pretense limitations on the cutting speed in machining of Al/Al2O3p composite materials. Wire shifting was bringing into being to get worse the machined surfaces [30]. Anuraag and Vijay Kumar Reddy[31] conducted research by introducing material as one of the variable parameters. That isthe various proportions of reinforced aluminium matrix with silicon carbide weight percentages like 3%, 9% & 15% were considered. The other parameters are various concentrations of Aluminium powder in Kerosene dielectric, Pulse on time (discharge time) and peak current. Polarity used to beNegative, The tool was acopper electrode. The reinforcement by weight and pulse on time increases the rate decrement of MRR increases. The Peak current increases the MRR significantly increased. At constant peak current the workpiece variation influence is very less.

Jahan et al. [32]investigated the effects of various operating parameters such as capacitance, resistance, supply voltage, electrode rotational speed and gap control parameters on the micro-EDM of Duralumin by engraving micro-grooves on the surface of it. The responses set wherethe material removal rate (MRR), tool wear ratio (TWR), thesurface roughness (SR) and machining depth of the microgrooves. The authors reported that increase of capacitance and voltage results in anincrease of MRR, TWR, and SR. Lal et al.[33] conducted a study of WEDM of different reinforced AMC (Al7075/7.5 % SiC/7.5 % Al2O3) work material along with the other variable parameters like the wire drum speed on the kerf width, discharge duration, discharge current and pulse interval time and reported that the discharge current influenced more significantly on kerf than discharge duration.

Satishkumar et al.[34]investigated WEDM of Al6063/SiCp composites to observe the effects of parameters such as an experimental study of wire electrical discharge machining characteristics of Al6063/SiCp composites. In this work, the effect of WEDM parameters such as gap voltage, pulse off time, wire feed and pulse on time, on MRR and SR. Prabu et al.[35]investigated the EDM parameter effects on TiB2 reinforced aluminium AMCs (Al-TiB_2) work materials TiB2 with thelow-frequency vibrating tool. And found that when setting of the current increased, the MRR and surface cracks of the workpiece also increased. The increase in reinforcement ratio decreases the MRR and surface cracks.Zain et al.[37, 8]studied the effect of Tantalum Carbide (TaC) powders,the stainless steel workpiece machining in PMEDM thedifferent levels of powder concentration and peak current (5, 10 and 15g/l.)were studied. The result was current proportionate to MRR and surface roughness (Ra). However, the response of powder concentration variation was not uniform.

Similarly,Rizi et al.[38]StudiedSiC PMEDM of Titanium alloy Ti-6Al-4V workpiece with thecopper electrode and included mesh size of particles at different levels. They achieved littleamount of MRR, surface finishare increased and alessamount TWR is reduced. Ali et al.[39] carried out their study on SiC PMEDM of Ti-6Al-4V alloy workpiece with tungsten carbide electrode. They investigated the effect of discharge energy and powder concentration in micro-EDM machining. And reported that powder concentration factor has influenced lesser than the discharge current. Ajay and Anirban[40] used different PMEDM setup with powders of Graphite, aluminium, copper and tungsten materials and used different dielectric fluids such as refined mineral oil, EDM oil and kerosene for machining Die Steel H11 and H13 grade. The results were that even at the lower current setting, the micro-hardness was improved in tungsten powder mixed EDM and with thetungsten-copper electrode.

The relative comparison of micro-hardness between deposited and non-deposited regions exhibited a boost of 56% for H13 and 37% for H11 than EDM.

Pichai and Apiwa[41] explored a unique case of surface improvement by a titanium coating layer in the tungsten carbide surface in electrical discharge coating (EDC) in b PMEDM (titanium powder mixed with oil). The oil used was employed as dielectric fluid as well as produce carbide material for coating. The current and duty cycles were varied for observing the titanium coating layer thickness. Kansal et al.[42] conducted the FEA,it was infered that the temperature profiles and material transformations occur in the workplace are resulted by high temperature, large deformations and transient operation.Gopalakannan et al.[43] developed mathematical modeling by using response surface methodology for estimating the optimal process parameters for the EDM of Al 7075-B_4C MMCs. The variable factors were Pulse Gap voltage, current, Pulse off time, Pulse on time for the targeted responses of MRR, TWR, and SR. Kumar et al.[44] developed mathematical modeling to fix optimal Wire speed, Pulse on/off time for WEDM of Al-SiC(20%) AMC to obtain desired MRR and SR.

Gopalakannan et al.[45] statistically optimized EDM process parameters such as current, Pulse on time, Pulse off time and Gap voltage for the EDM of aluminium Hybrid metal matrix composite for the responses of MRR, TWR and SR. Grey. Suresh Kumar et al.[46] investigated machinability of new material of Al (6351)- 5% SiC-10 % B4C Hybrid Composite in EDM. The variable process parameters such as current, Pulse on time, Duty cycle, and Gap voltage were considered and studied the TWR and SR performances. Laxman et al.[47] considered the factors such as peak current, tool lift Time, pulse off time and pulse on time, In EDM of Titanium Super Alloy for investigating MRR and TWR performances. Ndaliman et al.[49] reported an interesting case of influence of tool material that is enhancing microhardness of titanium alloy (Ti-6Al-4V) through modification of electrical discharge machining process parameters. They considered Cu–TaC composite electrode, urea mixed distilled water asadielectric fluid, process variable parameters, peak current, the pulse duration, the duty factor and Urea concentration. The result revealed that micro-hardness of the electrical discharge machined surfaces with Cu–TaC electrode/urea dielectric fluid was generally higher than that of those with Cu electrode/distilled water dielectric fluid. The highest microhardness of 1795 Hv was attained with 10 g/L of urea concentration.

10. Conclusion

The contribution of EDM research to industries formachining the newlyinvented hard materials to machining is makes the EDM technology to remains as indispensable. This review of the research trends in EDM and some of its types like PMEDM, NDEDM, Micro EDM and WEDM from the recent contributions was presented. Some innovative approaches were found in the review All most the available research works on PMEDM have studied for enhancing the cutting speed (MRR), reducing the tool wear, and improving surface quality (low SR). Some common results are listed below

- The MRR improved by mixing powders in the EDM's dielectric Fluid. Which namely PMEDM.
- The MRR increased by the increase of Peak Current.
- Higher Peak Current leads to higher MRR, TWR, and SR.
- The MRR decreased or less responded by the increase of Pulse off time.
- The TWR comparatively lesser in PMEDM than EDM
- The use of optimum use of powder concentration and particle size (mesh size) leads to reach the maximum efficiency of EDM process. Either completely experimental or partly experimental to establish the relationship among parameters to find optimal parameters. The statistical methods like GRA, RSM, ANOVAetc.are used to it.

11. Future Directions

- The simulation and FEA need to be addressed more.
- Most of the research work has been reported with use of Al, Si, and graphite powders and some literature available on the uses of powder like Cr, Ni, Mo, tungsten, SiC etc., but only a few literature was found in using Nanopowders.
- More studies need to address in Role of powder concentration and mesh size of powders in the surface properties like microhardness, corrosion resistance, microstructure, wear resistance and fatigue resistance etc.
- Higher peak currents produce rougher surfaces in EDM process. The applicability of PMEDM process for industrial purposes is constrained by several key technical issues that need to be further investigated.
- The investigation on the influence of process parameters such as tool vibration, tool rotation, and workpiece rotation has been taken up by very few researchers. More investigations need to be addressed to gain a better understanding of the process.

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