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REVIEW POWDER MIXED ELECTRO DISCHARGE MACHINING OF EN19 STEEL

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Abstract
The paper systematically categories the literature on EDM and presents a systematic review of literature methodically. The literature on classification of EDM has so far been very limited. The paper presents an overview of EDM and also highlights the contributions of EDM initiatives towards improving manufacturing performance. The paper reveals the important issues in EDM ranging from maintenance techniques.

Keywords: EDM , PMEDM

INTRODUCTION

With the advancement of technology in the industrial field and also with the growth in the field of material science, the hard materials which are difficult to machine by conventional methods of machining, which find different applications in the field of aerospace, nuclear, power and other industries, can be easily machined by the modern machining methods which are popularly known as unconventional machining methods. Also the latest trends in this field provide a concern to the industry and it becomes first choice rather than an alternative to conventional methods from the technical point of view. These machining methods show wide range of applications and they are very successful for machining materials which have high strength, heat resistance and wear resistance. In conventional machining method, it uses the cutting tool ability to stress the material beyond the yield point to start the machining, for this purpose, material of cutting tool should be harder than the work piece material. In conventional machining method, the tool get eroded after the successive machining operations while in unconventional machining, there is no direct contact between tool and work-piece so it notices very little erosion of tool. With the increase in the need of hard materials which are nowadays mostly used in various industries. This machining method is time consuming as it is difficult to machine hard materials since the material removal rate reduces with the increase in hardness of work piece material. These machining processes are not introduced to industrial field to replace the conventional machining processes but to supplement them.

Classification of unconventional machining processes is based upon the fundamental machining energy employed.

- Mechanical processes
- Electrochemical processes
- Chemical processes
- Thermo electric processes
- Some of the important unconventional machining processes are the following:-
- Ultrasonic Machining
- Abrasive Jet Machining
- Electro chemical machining
- Electro chemical grinding
- Electric discharge machining
- Laser beam machining
- Electro chemical discharge machining

From all of the above machining processes, EDM is most popularly used for machining of various hard metals and alloys which are not easily machined by the conventional machining processes.

Mechanism of EDM process

Electric Discharge Machining is a thermo-electric unconventional machining process. In this process, material is removed from the workpiece by localized melting and vaporization of material by electrical spark produced by electrical energy between the tool and the workpiece which are separated by a small gap between each other. This machining operation is carried out in a dielectric medium and a high potential difference is applied across tool and workpiece. The gap between the tool electrode and workpiece increases with the removal of material. The EDM power supply voltage depends upon the spark gap , which is to maintained constantly. For the purpose of machining a automatic servo controlled electrode feeding setup which helps in

maintaining the spark gap, is used. In this process, erosion of the material which is caused by the rapid and repetitive spark discharges between the tool and the workpiece. The tool and the workpiece are separated by a thin gap of about 0.01 to 0.5mm. When the machining is started, the gap between the tool and the work piece, which consists of the dielectric fluid, is not conductive . Commonly used dielectric fluid is either kerosene or EDM oil; however gaseous dielectrics are also used in many cases. When the voltage across the gap reaches to high level, it discharges through the gap in the form of spark in a very short interval of 10 micro-seconds. Electric breakdown of dielectric fluid causes positive ions and electrons to generate and accelerate in the discharge gap which produces a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and thus creating a channel of plasma. A sudden decrease in the electric resistance of the previous channel allows the current density to reach at a very high value thereby producing an increase of ionization and the creation of a high powered magnetic field. When the spark occurs, sufficient amount of pressure is developed between workpiece and tool due to which, a very high temperature is reached and at such high temperature, the phenomenon of melting and erosion of metal occurred.

Powder mixed EDM (PMEDM)

The mechanism of PMEDM is quite different from the conventional EDM process. In this process, abrasive powder is mixed in the dielectric fluid and it is circulated in the fluid with the help of pump at a certain velocity. When a voltage of ranges between 80-320 is applied between the tool electrode and workpiece, the spark gap is filled up with additive particles. The distance setup between the tool and workpiece is increased from 25-50 to 50-150mm. These charged particles are accelerated by the electric field and they act as conductors. The powder particles arrange themselves under the sparking area and gather in clusters. The chain formation helps in bridging the gap between the tool and the work piece.

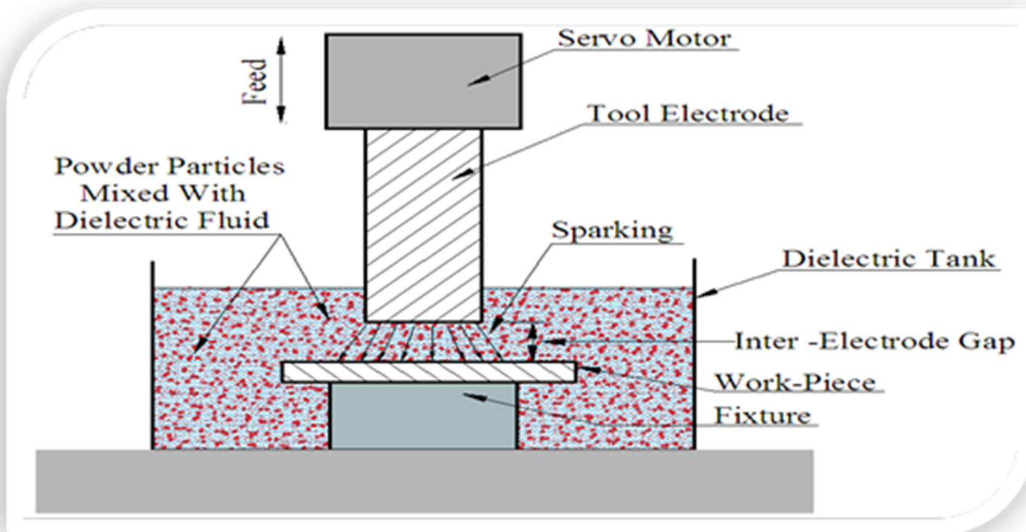

Figure 1.1 PMEDM Mechanism

The floating particles impede the ignition process by providing a higher discharge probability and also lowering the breakdown strength of the dielectric fluid. As a result of which material removal rate (MRR) is increased, tool wear rate is lowered and sparking efficiency is improved. Some of the commonly used abrasive powders are chromium, titanium, copper, aluminium, nickel, cobalt, iron, graphite, molybdenum, silicon and silicon carbide with quoted grain sizes between 1 µm and 100 µm.

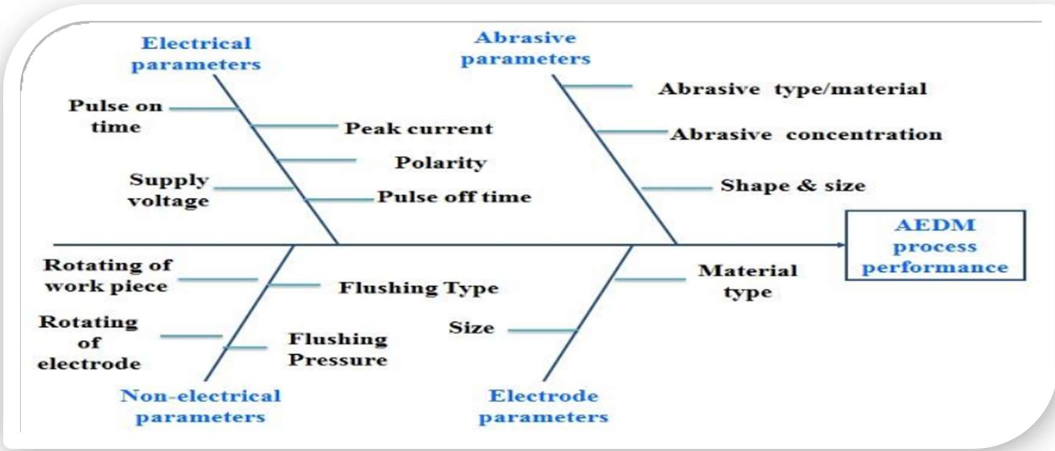

Figure 1.2 Factors affecting PMEDM process

Components of EDM

The main components of EDM process are:-

1. Electric power supply
2. Dielectric medium
3. Work piece and tool electrode
4. Servo control unit

EDM process parameters

Peak Current: - Peak current is the value of maximum current to be measured in a complete cycle. Its unit of measurement is ampere. Also, it is the most important parameter of EDM.

Arc gap: - Arc gap is the distance between the tool electrode and the work piece. It is also known as spark gap, which is controlled by Servo – mechanism.

Discharge voltage: - It is the voltage which discharges across the gap and also it is related to electric break down of dielectric fluid. It is help full in providing flow of current through the dielectric medium and the voltage drop which helps in stabilizing the gap.

Engineering applications of EDM process

It has the capability to machine small components which are highly demanded usually more complicated, multi-functional parts used in the field of micro-electronics.

It is used to machine delicate parts such as sharp edges and corners that are not accurately machined by other machining processes.

It is used to machine very hard materials which are not easy to machine by conventional machining methods like alloys, tool steels, tungsten carbides etc.

Ceramic materials which are not easy to machine by conventional machining methods can be efficiently machined by the EDM process.

EDM is used for the manufacturing of different tools which have complicated profiles as well as for other complex shaped parts. The decision to use the spark erosion for broadly applicable process is usually due to the basic inherent characteristics.

By using EDM process, higher tolerance limits can be achieved. Hence machining areas which require higher accurate surface use the application of EDM process.
EDM has also applicable in the fields of sports, medical and surgical instruments, optical and also include automotive R&D areas.

Advantages of EDM process

Complex shaped parts which are not easy to produce with conventional cutting tools, can be easily made with EDM process.
Extremely hard materials which require very close tolerances can be machined with EDM machine tools.
In very small work pieces where there is a possibility of damaging the part by conventional cutting tools due to excessive cutting tool pressure can be easily machined with EDM process.
As there is no direct contact between tool and work piece so the delicate sections and weak materials can be machined without any obstruction.
It is helpful in maintaining a good surface finish.

Any material which is electrically conductive can be easily cut irrespective of its hardness, strength, toughness and microstructure etc. This process is extensively used for the cemented carbides and also new super tough space-age alloys which are not easy to cut by the conventional methods.
Work-pieces can be effectively machined in the hardened state so that the final dimensions does not be affected.
Different complicated die contours of hard materials can be produced with high accuracy and good surface finish.

Limitations of EDM technology

Slow rate of material removal of EDM process is a big problem to use it in the manufacturing of different components.
The extra time and cost is quite higher for ram/sinker EDM for the creation of various electrodes.
Reproduction of sharp edges on the work-piece is not easy due to electrode wear.

Materials which are electrically non-conductive can be machined only with specific set- up of process.
The use of kerosene and other hydrocarbon oils as dielectric fluids makes the process hazardous and adequate safety precautions need to be taken.

Research potentials in EDM technology

The optimization of the process often involves relating the various process variables with the performance measures maximizing the MRR, while minimizing the TWR and yielding the desired SR. In several cases, S/N ratio together with the analysis of variance (ANOVA) techniques is used to measure the amount of deviation from the desired performance measures and identify the crucial process variables affecting the process responses. In addition, the feasibility of manufacturing the electrode using the RP technique has been extensively studied

to improve the performance of tools and sparking. Therefore, with the continuous research effort made in understanding the initialization and development of sparking process, the different
means of optimizing the various process variables will continue to be a major research area as (shown in figure 1.3).

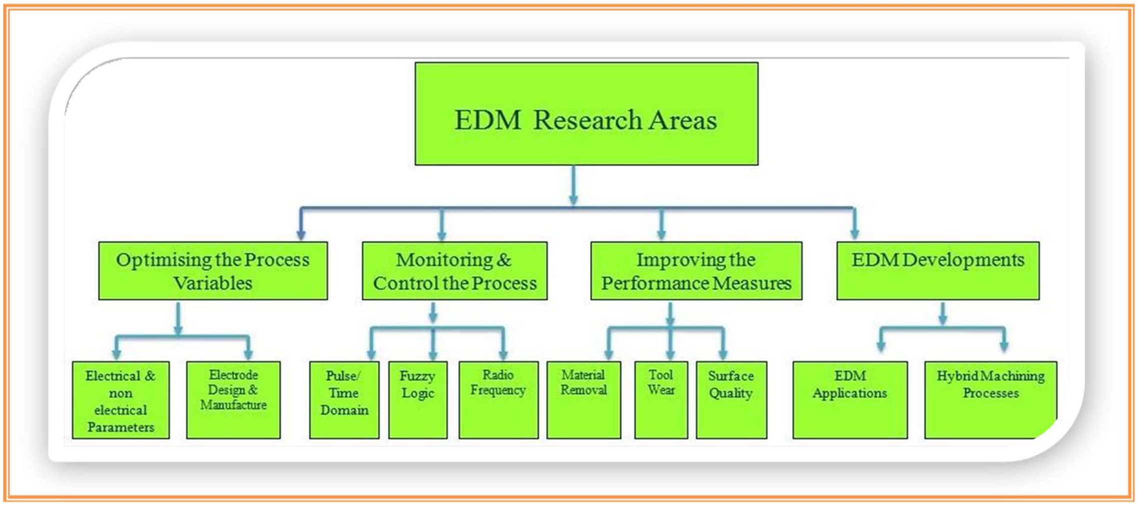

Figure 1.3 Schematic diagram of various research areas of EDM process.

LITERATURE REVIEW

In this chapter, extensive review of literature from published work by various researchers on EDM process and its effects on Material Removal Rate, Tool Wear Rate, wear ratio, hardness, roughness of machined surface and other machining parameters is presented. Many researchers have worked on the different materials in EDM process to see the effect of additives in dielectric fluid, changes in the re-solidified layer of material etc. Given below is the work of some of the researchers.

N. Mohri, et. al. (1995) investigated electrode wear phenomena in EDM process. Time dependence of an electrode shape was observed during machining process. It was found that while the electrode wears at the edge portion in the beginning of machining, it grows at the flat portion in the longitudinal direction. In the stationary state of machining, the wear rate of an electrode was affected by the materials of work piece. The mechanism of electrode wear was investigated through the consideration of the effect of carbon on the electrode surface. Low wear of electrode was realized due to the precipitated carbon on the electrode surface. The carbon on the surface of electrode prevents the electrode from spark erosion in EDM.

M. P. Samuels, et. al. (1997) gives a theory that in EDM, tool performance was one of the important factors that determine the quality of the machined component. Due to ease of manufacturing and control over the properties of electrodes, the powder metallurgy technique had an edge over the other methods of fabrication. Powder metallurgy electrodes can be controlled over a wide range by adjusting the compacting and sintering conditions. They also had an effect on micro (breakdown process ignition delay, etc) and macro (MRR, EWR, etc) variables of EDM. These electrodes were found to be more sensitive to pulse current and pulse duration than conventional solid electrodes.

Y. S. Wong, et. al. (1998) tries to obtain near mirror finish surface in EDM by using fine powder particles in dielectric fluid. The study was done on different types of steels with different powders. Surfaces produced from these techniques were much smoother than usually EDM surfaces which were typically covered with deep craters, pock marks and globules. For appropriate settings of electrode polarity and pulse parameters with correct combination of workpiece material and powder characteristics had significant influences to achieve near mirror finish. The use of negative electrode polarity was necessary to achieve the mirror-finish condition. Other features of the powder-mixed dielectric EDM were shorter machining time, more uniform dispersion of the electrical discharges and stable machining. From the study, it can be seen that when mixed with dielectric in EDM, some types of powders, notably graphite and silicon powders, had been found to distribute the discharges in the spark gap to generate fine to glossy finish surfaces even at relatively high pulse currents. The presence of the powder had the effect of lowering the breakdown voltage so that discharges can occur at a wider electrode gap, the wider gap makes machining more stable. Aluminium powder had been reported to give mirror finish workpiece in Powder mixed dielectric EDM for many materials.
S. L. Chen, et. al. (1999) explained that the working fluid plays an important role affecting the material removal rate and the properties of the machined surface. The machining characteristics of Ti–6A1–4V were investigated with kerosene and distilled water as the dielectrics in their experiments. The result showed that the material removal rate was greater and the relative electrode wear ratio was lower, when machining was done in distilled water rather than in kerosene. They also found that carbide (TiC) and oxide (TiO) were formed on the surface of workpiece using kerosene and distilled water respectively. It was also found that micro cracks and debris was formed using distilled water as dielectric. It was seen that material removal in kerosene was done by melting and vaporizing but with distilled water it was by melting and vaporizing accompanied with crack propagation.
J. Marafona, et. al. (2000) investigated and analyzed the effect of carbon which had migrated from the dielectric to tungsten–copper electrodes. This work had led to the development of a two-stage EDM machining process where different EDM settings were used for the two stages of the process giving a significantly improved material removal rate for a given tool wear ratio. With the new methodology, it was possible to achieve an improvement of the material removal rate for a given tool wear ratio.
S. H. Lee, et. al. (2001) studied the influence of operating parameters of EDM of tungsten carbide on the machining characteristics. The effectiveness was measured in terms of MRR, TWR, and Surface finish of workpiece material. The machining parameters were the electrode material, electrode polarity, open-circuit voltage, peak current, pulse duration, pulse interval, flushing. It was found that for all the electrode materials MRR increases with peak current. Graphite electrodes had given best results than come copper, tungsten electrodes. Also wear ratio decreased with peak current for graphite but increased for copper tungsten. The negative tool polarity gives higher MRR, low wear ratio and better surface roughness. The MRR generally decreased with open circuit voltage but wear ratio and surface roughness increased.
W. S. Zhao, et. al. (2002) performed experiments which were revolve around machining efficiency and surface roughness of PMEDM in rough machining work. From their experiment results, it was clearly found that PMEDM can clearly improve machining efficiency and surface roughness only when proper discharging parameters are selected. It was also deduced

that PMEDM makes discharge breakdown easier, so widens the gap and also helped in forming evenly distributed etched cavities. The loss of discharge energy in the gap leads to reduction in ejecting force on the melting material so machining efficiency becomes lower and so the surface roughness becomes smaller. They also found out that increasing peak current and reducing pulse width gives better surface roughness.

I. Puertas, et. al. (2003) found out that the optimum selection of manufacturing conditions are very important to determine surface quality and dimensional precision of work parts.

H. T. Lee, et. al. (2004) explore the influence of electrode size, EDM parameters and material thermal conductivity on surface cracking of the workpeice. The current results revealed that the surface crack distribution was influenced by the machining parameters, the electrode diameter and the material conductivity. It was noted that cracks tend not to appear when the machining is performed with a decreased pulse current and increased pulse-on duration. It was also found that when using the EDM process to machine high thermal conductivity materials, a large diameter electrode should be used in order to suppress surface cracking. However, when machining a low thermal conductivity material, surface cracking was best avoided by selecting a small electrode and then machining with a large pulse current and short pulse-on duration.

I. Puertas, et. al. (2005) studied surface roughness of silicon carbide based on its large industrial applications and found that the design factors having most influence on SR turned out to be intensity, pulse time and duty cycle, whereas the dielectric flushing pressure was not an influential factor.

H. K. Kansal, et. al. (2007) performed experiments on silicon powder mixed in dielectric fluid of electric discharge machining of AISI D2. Six process parameters, namely peak current, pulse on time, pulse-off time, concentration of powder, gain, and nozzle flushing had been considered. The process performance was measured in terms of machining rate (MR). The study indicated that all the selected parameters except nozzle flushing had a significant effect on the mean and variation in MR. it was also found that the percentage contribution of peak current and powder concentration on MR was highest among all the other parameters. The confirmation runs showed that the setting of peak current at a high level (16 A), pulse-on time at a medium level (100 µs), pulse-off time at a low level (15 µs), powder concentration at a high level (4 g/l), and gain at a low level (0.83 mm/s) produced optimum MR from AISI D2 surfaces when machined by silicon powder mixed EDM. The suspension of silicon powder into the dielectric fluid of EDM appreciably enhanced material removal rate.

H. K. Kansal, et. al. (2007) presents a tutorial introduction, comprehensive history and review of research work carried out in the area of PMEDM. They also explained the machining mechanism and applications of PMEDM.

P. Kuppan, et. al. (2008) did experimental investigation of small deep hole drilling of Inconel 718 using the EDM process. The parameters such as peak current, pulse on-time, duty factor and electrode speed were chosen to study the machining characteristics. The output responses measured were MRR and depth averaged surface roughness (DASR). It was observed that MRR increased with the increase in peak current, duty factor and electrode rotational speed. An increase in electrode speed leads to increase in MRR whereas DASR decreased to minimum value (between 200 to 300 rpm) and then increased. For Inconel 718, the effect of pulse on-time was insignificant on MRR but strongly influenced the DASR.

A. A. Khan (2008) evaluate the electrode wear during EDM of aluminum and mild steel using copper and brass electrodes. During analysis it was found that electrode wear increased with an increase in both current and voltage, but wear along the cross-section of the electrode was more compared to the same along its length. This was due to easier heat transfer along the length. It was also found that the wear ratio increased with an increase in current. That means, though a higher current caused more removal of work material and the electrode, comparatively more material was removed from the electrode. Wear of copper electrodes were less than that of brass electrodes. That was due to the higher thermal conductivity and melting point of copper compared to those of brass. It was concluded that copper electrodes gives best

N. Beri, et. al. (2008) attempted to correlate the usefulness of electrodes made through powder metallurgy (PM) in comparison with conventional copper electrode during electric discharge machining. Experimental results were presented on electric discharge machining of AISI D2 steel in kerosene with copper tungsten (30% Cu and 70% W) tool electrode made through PM technique and Cu electrode. The effect of process input factors (viz. current, duty cycle and flushing pressure) on the output factors {viz. MRR and SR) had been checked. At the end of the study it was found that CuW electrode (made through PM) gives high surface finish where as the Cu electrode is better for higher material removal rate. During EDM of AISID2 steel they found out that electrode material, current and duty cycle had significant effects on both the performance parameters. From there study they found that Cu electrode is better for higher MRR and CuW electrode gives minimum surface roughness.

H. M. Chowa, et. al. (2008) added SiC powder to pure water as a working fluid to verify the micro EDM process performance. Results indicated that the addition of SiC powder would increased working fluid electrical conductivity, enlarge the electrode and workpiece gap and also extrude debris easily and helped in increasing the material removal rate. Also the use of SiC powder helped bridge the electrode and workpiece gap and disperse discharge energy, thus creating two discrete discharging pulses from a single discharging period. The discharging results could then generate a minor crater and debris since minor debris would ease gap exhaust and accelerate material removal rate. The minor crater could simultaneously refine the surface roughness. Also using pure water as dielectric increase MRR and low electrode wear by giving negative polarity to tool. Mixture of SiC and water caused high conductivity therefore the gap between tool and workpiece increases.

P. Pecas, et. al. (2008) compared the performance of EDM technology with powder mixed dielectric to the conventional EDM, when dealing with the generation of high-quality surfaces. The surface quality was assessed through the roughness measurement and the analysis of the craters (diameter and depth) and white-layer dimensions. The results achieved show a linear relationship between the electrode area and the surface quality. Also a significant performance improvement was achieved when the powder mixed dielectric was used. As it was confirmed that the electrode area had influence on the surface quality, so the sensitivity of the surface quality measured to the electrode area was smaller when mixed-power dielectric was used. Powder-mixed dielectric significantly increased process robustness. So PMEDM was must when large electrode areas were involved and when a high-quality surface is a requirement.

K. Y. Kung, et. al. (2009) studied material removal rate and electrode wear ratio (EWR) in the powder mixed electrical discharge machining of cobalt-bonded tungsten carbide (WC-Co). From the study it was found that in PMEDM process, the aluminum powder particles suspended in the dielectric fluid dispersed and makes the discharging energy dispersion uniform. The result showed that using dielectric fluid with conductive aluminum powder can effectively disperse the discharging energy dispersion in order to improve the machining efficiency. The MRR generally increased with an increase of aluminum powder concentration. But that trend was valid up to a maximum value and after a certain limit, the increase of aluminum powder concentration leads to the decrease of MRR. The EWR value tends to decrease with the aluminum powder concentration down to a minimum value after which it tends to increase. Both the MRR and EWR increase with an increase of the grain size, discharge current and pulse on time.

Y. F. Chena, et. al. (2009) investigated the machining performance and surface modification on Al–Zn–Mg alloy by integrating electrical discharge machining (EDM) and ultrasonic machining (USM). In their experiment, TiC particles were added into the dielectric to explore the influence of the combined process on the material removal rate (MRR), the relative electrode wear ratio (REWR), surface roughness and the expansion of the machined hole. Micro hardness and wear resistance tests were conducted to evaluate the modifications on the machined surface caused by the combined process. The experimental results showed that the combined process was associated with improved machining performance. The combination of EDM with USM yielded an alloyed layer that improved the hardness and wear resistance of the machined surface. The MRR of the combined process exceeded that of conventional EDM at a high peak current but the REWR of the combined process was lower than that of conventional EDM. The surface roughness of the combined process was lower than that of conventional EDM but it can be increased at a higher peak current. The expansion of the machined hole obtained by the combined process was smaller than that obtained by conventional EDM, indicating that the combined process provided better machining precision.

M. S. Popal, et. al. (2009) during handling national research projects referring to micro machining and special applications presented comparatively the values of the roughness obtained by EDM process on different types of materials and by different process parameters. The operator used the CAM programs to write the CNC program, but the parameters of the machine were set concerning the material and the thickness of the work piece. The final scope was to elaborate a technological data base with the purpose of optimizing the EDM process on different machines. Although the parameters were optimized, the quality of surface was different for each machining because external conditions were different for each machining process.

J. Y. Kao, et. al. (2010) focused on parameter optimization of the electrical discharge machining process to machine Ti–6Al–4V alloy considering multiple performance characteristics. These performance characteristics were electrode wear ratio, material removal rate and surface roughness. The process parameters selected in that study were discharge current, open voltage, pulse duration and duty factor. An application of the Taguchi method and grey relational analysis was used to improve the multiple performance characteristics. The machining performance of the electrode wear ratio decrease, the material removal rate increase and the surface roughness decreased respectively. The improvement in electrode wear ratio is 15%, material removal rate 12% and surface roughness 19% respectively.

K. Ponappa, et. al. (2010) performed experiments to find out quality of drilled-hole taper cut and surface finish for magnesium nano-composites. Experiments were conducted using Taguchi methodology to ascertain the effects of EDM process parameters. The process parameters such as pulse-on time, pulse-off time, voltage gap, and servo speed were optimized to get better surface finish and to reduce taper. From the analysis, it is observed that surface roughness and taper mainly depends on servo speed and pulse-on time. By optimizing the process parameters, the damages on the mechanical surfaces such as recast layer and hairline cracks were also minimized.

G. Kibria, et. al. (2010) tries to know the behavior of different types of dielectrics such as kerosene, deionized water, boron carbide (B4C) powder suspended kerosene, and deionized water to explore the influence of these dielectrics on the performance criteria such as MRR, TWR, overcut, diametric variance at entry and exit hole and surface integrity during machining of titanium alloy (Ti-6Al-4V). The experimental results revealed that MRR and TWR were higher using deionized water than kerosene. When suspended particles, i.e., boron carbide-mixed

dielectrics were used, MRR was found to increase with deionized water but TWR decreased with kerosene dielectric because of the formation of carbide on the surface of workpiece due to kerosene. Also it was found that the thickness of white layer was less on machined surface when deionized water was used as compared to kerosene. There was a great influence of mixing of boron carbide additive in deionized water dielectrics due to the efficient distribution of discharge and results in increased machining efficiency. Tool wear was higher with deionized water compared to kerosene. Also, TWR was more when B4C-mixed deionized water was used compared to pure kerosene. The accuracy of the micro hole was higher at lower peak current and pulse-on-time using deionized water and at higher peak current and pulse-on-time using kerosene. Using B4C additive, the both dielectrics showed larger overcut compared to pure dielectrics. Results showed that white layer formation using B4C additive-mixed dielectrics was relatively low than pure dielectrics. This was due to quick removal of molten workpiece material from the machining zone. The boron carbide-mixed deionized water also resulted in smoother surface than additive mixed kerosene.

P. Singh, et. al. (2010) studied the effect of aluminium powder mixed in the dielectric fluid of during EDM of hastelloy using copper electrode tool. Concentrations of aluminium powder and grain size of powder were taken as process input parameters. Material removal rate, tool wear rate, %age Wear Rate, surface roughness were taken as output parameters to measure process performance. The study indicated that both the input parameters strongly affect the machining performance of hastelloy. The addition of aluminium powder in dielectric fluid increases MRR, decreases TWR and improves surface finish of hastelloy.

V. Kumar, et. al. (2010) studied the process performance of electrical discharge machining with powder metallurgy tool electrode during the machining of hastelloy using positive polarity. Where current and voltage were taken as process input parameters and material removal rate, tool wear rate, percentage wear rate, surface roughness were taken as output parameters. The study indicated that, the maximum material removal rate is at the average value of current and above average value of voltage within selected range of process input parameters, the minimum tool wear rate is with the minimum value of current and voltage, the minimum Percentage wear rate for below average value of current and minimum voltage, the minimum average surface roughness for average value of current and voltage.

D. Wang, et. al. (2011) concluded that Polycrystalline diamond (PCD), with its superior wear and corrosion resistance, was an ideal material for micro-hole parts in the field of micro-

fabrication. The study investigated the micro-hole machining performance for PCDs by micro-EDM. A series of experiments were carried out to investigate the proper machining polarity and the impacts of micro-EDM parameters on machining performance. Experimental results indicated that negative polarity machining was suitable for micro-EDM of PCDs because of the protection brought over by the adhesion sticking to the electrode. An appropriate volume of adhesion on the tool electrode can help to increase the MRR and reduce the relative TWR. An excessive volume of adhesion can lead to overlarge diameters. So it can be explained that the electrode in negative polarity machining can be protected by the adhesion composed of heat-
resolved carbon and graphite. It was also seen that with an increase of the electrode rotation speed, the MRR increased first until peaking at a maximum and then decreased afterwards, and meanwhile, the TWR declined to a minimum and then raised slightly.

S. Kumar, et. al. (2012) put light on surface modification by material transfer during EDM as it had emerged as a key research area in the last decade. They investigated the response of three die steel materials to surface modification by EDM method with tungsten powder mixed in the dielectric medium. Peak current, pulse on-time and pulse off time were taken as variable factors and micro-hardness of the machined surface was taken as the response parameter. X-ray diffraction and spectrometric analysis showed substantial transfer of tungsten and carbon to the workpiece surface and an improvement of more than 100% in micro-hardness for all the three die steels. Study also found that under appropriate machining conditions, significant amount of material transfer can take place from the powder suspended in the dielectric medium to the work
material so it can be concluded that surface modification was possible by the EDM method. Favorable machining conditions for material transfer by EDM were found to be low discharge current, shorter pulse on-time, longer pulse off-time and negative polarity of the tool electrode.

B. Singh et. al. (2013) in their work closely examine the machining properties of H11 steel in Electric Discharge Machining (EDM) process utilizing copper electrode. The chosen input parameters of the process are polarity, peak current, pulse on time, duty cycle, gap voltage and concentration of abrasive powder in dielectric fluid. To examine the machining performance of H11 steel, three output process parameters such as material removal rate (MRR), tool wear rate (TWR), wear ratio (WR) are evaluated. By utilizing electronica make smart ZNC electric discharge machine tool, total eighteen experiments were conducted on H11 steel as per $L18$ orthogonal array. The result of the research explores the important input parameters and their influence on the machining performance of the H11 steel.

B. Jabbaripour et. al. (2013) fabricated two series of machining tests. First one is powder mixed electrical discharge machining (PMEDM) of γ-TiAl through various powders such as aluminum, chrome, silicon carbide, graphite and iron is conducted to examine the output characteristics of surface roughness and topography, material removal rate (MRR), electrochemical corrosion resistance of machined samples and also the machined surfaces are examined through EDS and XRD analyses. Secondly after choosing the aluminum powder as the most suitable sort of powder, the current, pulse on time, powder size and powder concentration are changed in different levels for whole comparison between EDM and PMEDM output characteristics. In the first arrangement of input machining parameters, the surface roughness of TiAl sample improves nearly by 32% due to aluminum powder as

compare with EDM case and also the size of 2μm of the aluminum particles, in the second arrangement of input parameters
lead to 54% increase of MRR compared with EDM case. The outcomes of the electrochemical corrosion resistance shows that, the sample that is machined without powder provides less corrosion resistance as compared to the sample machined with graphite and chrome powders respectively. The corrosion resistance of the samples which are machined with graphite and chrome powders respectively are nearly three and two times more as compare to sample which is machined without powder.

Y. Zhang et. al., (2014) provides an organized and inclusive examination of the properties of material removal of the EDM process with the use of different type of dielectric as the working fluid . Five dielectrics comprising gaseous dielectrics, air and oxygen and liquid dielectrics, de- ionized water kerosene and water-in-oil (W/O) emulsion were employed as the working fluids. The metallographic method exactly defined the entire geometry parameters of the craters, comprising the recast material in the craters. The melted and removed material's volume and removal efficiency in various dielectrics were comparatively examined. By relating the properties of material removal to the development of discharge generated bubbles in various dielectrics which were performed by computer simulation, it appears that the pressure beyond the discharge point is an important factor that can influence the properties of material removal. The outcomes of this work were assumed to be beneficial for further clarifying the intricate material removal mechanism of EDM.

M. Kolli et. al. (2014) provides an experimental approach to make assessment of material removal rate, surface roughness and tool wear rate for electrical discharge machining of Ti-6Al- 4V.In this method B4C powder is mixed into the dielectric fluid in different concentrations and influence of this concentration has been examined. It has been found that the material removal rate, surface roughness and tool wear rate has influenced by the different concentrations of the
B4C powder mixed in the dielectric fluid. The method has been properly explored and outcomes has been debated.

G. Talla et. al. (2014) constructed and machined Aluminum/Alumina metal matrix composite (MMC), which finds numerous applications in automobile and aero- space industry in EDM by adding aluminium powder in kerosene dielectric. The effect process variables such as powder concentration, peak current, pulse on time and duty cycle on two responses namely, material removal rate (MRR) and surface roughness were measured. With the use of Grey relational analysis (GRA), a multi response optimization was conducted in order to obtain most favorable combination of the process parameters for maximum MRR and minimum SR. The outcomes display that the powder concentration of 6 g/L provides most favorable result for multi response.

G. Talla et. al. (2015) made an effort to construct and machine aluminum/alumina MMC with the use of EDM by mixing aluminum powder in kerosene dielectric. Outcomes displayed that MRR grow's up and surface roughness Rc diminish compared to those for conventional EDM. Based on the machining variables and effective thermo physical characteristics, semi empirical models for MRR and Ra were established with the use of hybrid approach of dimensional and regression analysis. By utilizing principal component analysis-based grey technique (Grey-PCA), a multi response optimization was conducted to define most favorable settings of process variables for maximum MRR and minimum Ra inside the experimental range. For the proposed process, the recommended settings of process parameters has found to be powder concentration (Cp) = 4 g/l, peak current (Ip) = 3 A, pulse on time (Ton) =150 ms, and duty cycle (Tau) =85%.

Al-Khazraji A. et. al. (2016) studied the effect of powder mixing electrical discharge machining (PMEDM) parameters using copper and graphite electrodes on the white layer thickness (WLT), the total heat flux generated and the fatigue life. Response surface methodology (RSM) was used

to plan and design the experimental work matrices for two groups of experiments: for the first EDM group, kerosene dielectric was used alone, whereas the second was treated by adding the SiC micro powders mixing to dielectric fluid (PMEDM). The graphite electrodes gave a total heat flux higher than copper electrodes by 82.4%, while using the SiC powder and graphite electrodes gave a higher total heat flux than copper electrodes by 91.5%. The lowest WLT values of 5.0 μm and 5.57 μm are reached at a high current and low current with low pulse on time using the copper and graphite electrodes and the SiC powder, respectively. This means that there is an improvement in WLT by 134% and 110%, respectively, when compared with the use of same electrodes and kerosene dielectric alone. The graphite electrodes with PMEDM and SiC powder improved the experimental fatigue safety factor by 7.30% compared with the use of copper electrodes and by 14.61% and 18.61% compared with results using the kerosene dielectric alone with copper and graphite electrodes, respectively.

Pulse on-time: - Pulse is the time during which the machining operation is performed. With the increase in the value of pulse on time, the operation becomes faster and it is measured in microsecond (μs). Material removal rate is affected by the maximum current and the length of on time. Pulse on time is also known as pulse duration.

Pulse off-time: - Pulse of time is duration of time to be measured between two consecutive sparks. It is the time in which re-ionization of dielectric medium takes place. Insufficient amount of off-time may lead to erratic cycling and retraction of the Servo-mechanism by which operating cycle slow down. This time helps molten metal to solidify and to wash out of debris from the gap. It is non pulse duration.

Pulse waveform: - The shape of the pulse is generally rectangular, but now generators with other shapes of waveform have been developed.

Polarity: - In this process, the electrode polarity to be used is either positive or negative.

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