A Literature Review on Dry Wire Electrical Discharge Machining

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Abstract— EDM in gaseous media is one of the fastest growing branches among institutions involved in the research and development of EDM as green manufacturing process Dry EDM is an environmental friendly machining process were liquid dielectric fluid is replaced by gaseous dielectric fluids. Present & past performance of dry EDM process using various types of gases & their mixtures as dielectric medium. Development of Dry EDM Technology enhance the performance parameters such as material removal rate (MRR), Low tool wear rate (TWR), thin recast layer.

Key words: EDM, MRR, TWR

I. INTRODUCTION

In spite of the advantages, conventional EDM process has certain limitations in Production application, including low material removal rate, long lead time for reshaped tool preparation, large tool wear, environmental concern caused by toxic dielectric disposal, etc. One of the main sources of environmental pollution during the machining processes is the huge amount of supplied cutting fluids. The lubricants are widely considered to be a benefit to cutting operations, but despite the recognition of their advantages, it has also been stated the negative impact and environmental issues associated with their use. To avoid the problems caused by the use of cutting fluids, considerable progress has been made in the last years in the field of near-dry machining. The conversion from conventional processes to minimal quantity lubrication methods demands new tasks classification in the tribology system in order to guarantee the process. Dry wire EDM is one such method to reduce dielectric disposal and to obtain a better finish machining at low pulse discharge energy.

II. BASIC PRINCIPLE OF WEDM PROCESS

WEDM is a thermo- electrical process in which material is removed by a series of sparks between work piece and wire electrode (tool). The part and wire are immersed in a dielectric (electrically non conducting) fluid, usually deionized water, which also acts as a coolant and flushes the debris away. The material which is to be cut must be electrically conductive. In WEDM, there is no direct contact between work piece and tool (wire) as in conventional machining process, therefore materials of any hardness can be machined [1] and minimum clamping pressure is required to hold the work piece. In this process, the material is eroded by a series of discrete electrical discharges between the work piece and tool. These discharges cause sparks and result in high temperatures instantaneously, up to about 10000º C. These temperatures are huge enough to melt and vaporize the work piece metal and the eroded debris cools down swiftly in working liquid and flushed away, the working principle is shown in the figure 1.

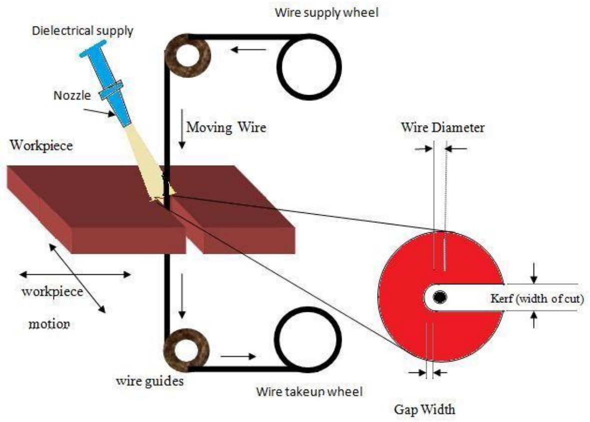


Fig .1: Working principle of WEDM

III. DRY WIRE EDM

Dry EDM, in which application of high flow rate gaseous dielectric fluid, tends to eliminate the environmental problem resulted from the liquid and powder mixed dielectrics and also improves the machining performance. Using inert gas to drill small holes (NASA, 1985) is the first dry EDM attempt. Gas at high pressure is used as the dielectric medium. In dry EDM, tool electrode is formed to be thin walled pipe. The flow of high velocity gas into the gap facilitates removal of debris and prevents excessive heating of the tool and work piece at the discharge spots. Tool rotation during machining not only facilitates flushing but also improves the process stability by reducing arcing between the electrodes The technique was developed to decrease the pollution caused by the use of liquid dielectric which leads to production of vapor during machining and the cost to manage the waste. Dry EDM method with the shortest machining time compare to oil die sinking EDM, & lowest electrode wear ratio. Work removal rate also get enhanced by dry EDM.

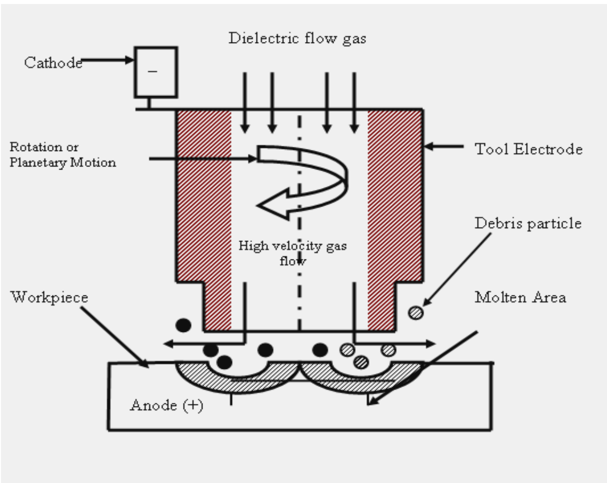


Fig. 2: principle of dry wire EDM

IV. PROCESS PARAMETERS AND PERFORMANCE MEASURES

The process parameters can be divided into two categories i.e. electrical and nonelectrical parameters. Major electrical parameters are discharge voltage, peak,current, pulse duration and pulse interval, electrode gap, polarity and pulse wave form. Main nonelectrical parameters are flushing of dielectric, work piece rotation and electrode rotation. Researches on flushing pressure reveal that it affects the surface roughness, tool wear rate, acts as coolant and also plays a vital role in flushing away the debris from the machining gap. Major performance measures in EDM are MRR, TWR and SR. For MRR, research work has been focused on material removal mechanism and methods of improving MRR. Similarly for TWR, research work on tool wear process and methods of improvement in TWR has been reported. Though EDM is essentially a material removal process, efforts have been made to use it as a surface treatment method and/or an additive process also. Many surface Changes have been reported ever since the process established itself in the tool rooms of manufacturing industry.

V. DISCUSSION ON REVIEWED PAPER

C.C. Kao et,al. (2006) conducted dry EDM experiments on thin work piece using air as dielectric fluid. They studied the effects of spark cycle (T), spark on time (Ton), air flow rate, work piece thickness, and type of material under wet and dry EDM condition. The material removal rate (MRR) was found to be low in dry EDM and could be slightly improved by the use of air flow. Their results show that the increase in work piece thickness and work piece melting temperature had an adverse effect on the MRR. Which is further related to the percentage of spark, arc, and short pulses. They also observed that the deposition of debris in the groove cut by dry EDM and found that for thick work piece, the groove was totally blocked.

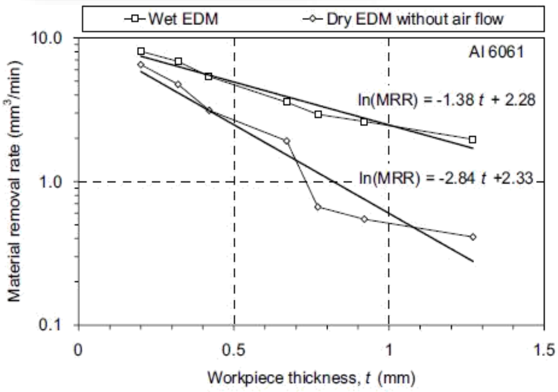


Fig. 3: Effect of thickness on MRR of AL 6061 for wet and dry EDM.

K. Kanlayasiri, S. Boonmung(2007) studied the effects of machining variables on the surface roughness of wire-EDMed DC53 die steel. In this study, the machining variables investigated were pulse-peak current, pulse-on time, pulse-off time, and wire tension. They used Analysis of variance (ANOVA) technique to find out the variables affecting the surface roughness. Quantitative testing methods on residual analysis were used in place of the typical qualitative testing techniques. Results from the analysis show that pulse-on time and pulse-peak current are significant variables to the surface roughness of wire-EDMed DC53 die steel. The surface roughness of the test specimen increases when these two parameters increase. They developed a mathematical model using multiple regression method to formulate the pulse-on time and pulse-peak current to the surface roughness. Eberhard Bamberg, Dinesh Rakwalb (2007) investigated the electrical discharge machining of gallium-doped p-type germanium with a relaxation type pulse generator. They performed series of experiments to establish the slicing rate for different types and sizes of electrode wires. They also analyzed cut samples using a 3D optical profiler and a scanning electron microscope (SEM) for surface roughness and subsurface damage. The samples were etched and analyzed for any contamination using an X-ray energy dispersive spectrometer (EDS). They also investigated the use of small wire diameters (50–200_m) to enhance slicing rate and surface characteristics.

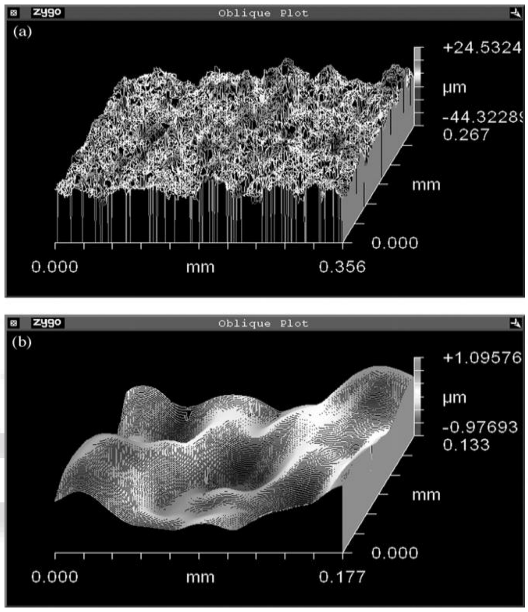


Fig. 4: (a) Optical profile of a surface machined using WEDM with surface roughness 3.06µm *R*a.

(b) Optical profile of a WEDM machined surface after etching with surface roughness 0.38µm *R*a.

Jia Tao et,al.(2008) presented the experimental studies by using oxygen gas and copper electrode for high MRR in dry EDM and the nitrogen-water mixture and graphite electrode for fine surface finish near-dry EDM. Near dry EDM exhibits the advantage of good machining stability and surface finish under low discharge energy input. A 25−1 fractional factorial design is applied to investigate the effect of discharge current, pulse duration, and pulse interval on the MRR and surface finish in dry and near-dry EDMs. Lower pulse duration and lower discharge current are identified as key factors for improving the surface finish in near-dry EDM. Oxygen demonstrated the capability to promote MRR and exothermal oxidation in both the dry and the near-dry EDM. Liquid phase dispersed in the gas medium is hypothesized to enhance the electric field and thus results in a large discharge gap distance and a stable discharge at low energy input. Nitrogen and helium gases could prevent the electrolysis and yield better surface finish in near-dry EDM.

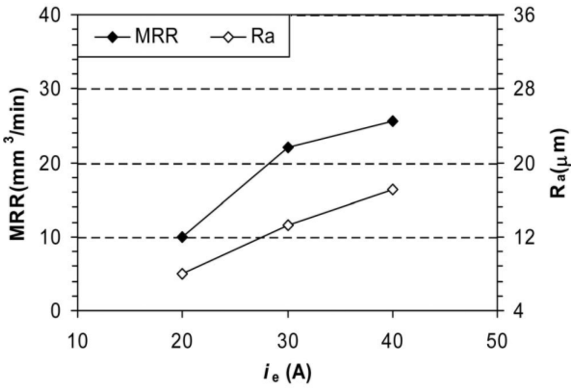
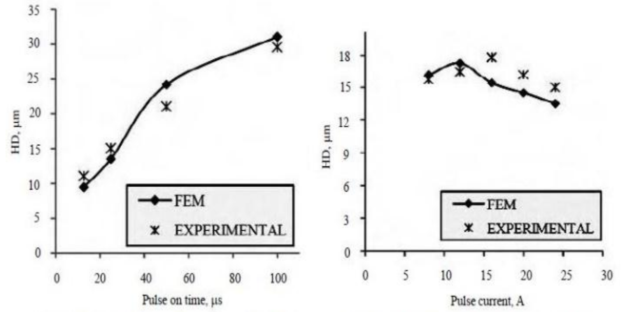


Fig. 4: Effect of the discharge current on high energy input dry EDM with oxygen , ti=4 _s, t0=8 _s, ue=60 V, and ui=200 V…

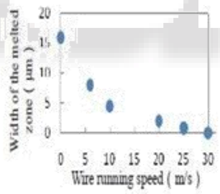
Sourabh K. Saha, S.K. Choudhury(2009) experimentally obtained polynomial models for *MR*R and *R*a and they used it for optimizing the dry EDM process. They performed Process optimisation using Non–dominated Sorting Genetic Algorithm (NSGA II) to obtain the Prato–optimal front. Based on the optimization results and the subsequent focused experiments, they concluded that high air pressure and high spindle speed combination is favourable for obtaining both a high MRR and a low Ra. Such a combination of these input parameters leads to a higher flushing efficiency. Finish machining region (low Ra) was obtained for low current, high pulse–on time and low duty factor values. Rough machining region (high MRR) was obtained for high current, low pulse–on time and high duty factor values. Y. Perez Delgado et,al. (2010) performed linearly reciprocating sliding wear experiments on WC-Co and WC-Ni cemented carbides and ZrO2-WC,ZrO2–TiCN and ZrO2–TiN composites with different surface finishes corresponding to sequential wire-EDM using an ASTM G133 system with WC-6 wt.% Co cemented carbide as counter body. 3D topography mapping and volumetric quantification of the wear tracks was obtained by surface profilometry. Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) spectroscopy were employed to observe morphological and chemical features of worn surfaces and wear debris. The identified wear mechanisms are discussed. Monica Balas et,al.(2011) evaluated the heat affected zone in sub-surface layers of the samples made by technology of wire electrical discharge machining. The samples produced on EDM-WC machine SP 640-P from two different materials, steel and tungsten carbide. The cutting tool was wire brass electrode of 0.25 mm diameter. They determine experimentally and with FEA the influence of the heat affected zone and micro-hardness. They found that HAZ depth increasing with the current intensity and high temperature during the process affects material micro hardness of manufactured surfaces. M R Shabgard et,al.(2011) presented a finite element model (FEM) to model temperature distribution for AISI H13 tool steel work piece in electrical discharge machining (EDM) at different machining parameters (pulse current, pulse on-time, temperature-sensitive material properties, size of heat source, and material flushing efficiency). Scanning electron microscopy (SEM) with energy dispersive x-ray (EDX) and micro-hardness tests being used by them to validate accuracy of FEM predictions. Increasing pulse on-time leads to a higher depth of heat affected zone and increasing pulse current results in a slight decrease of depth of heat affected zone.



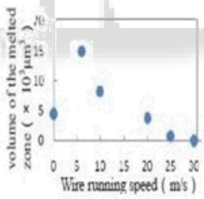
Heat affected zone (*HD*) depth vs pulse on time (*TI*) at different pulse current (*I*): a) *I* = 12A; b) *I* = 24A

Heat affected zone (*HD*) depth vs pulse current (*I*) at different pulse on time (*TI*): a) *TI* = 12.8 µs; b) *TI* = 25 µs

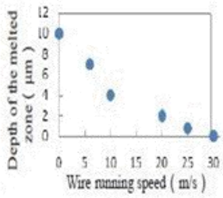
Xiaodong Yang et,al.(2012) presented their investigation considering the relative motion between the wire electrode and the work piece, they established heat transfer model of wire electrode under moving heat source, and they simulated temperature field of wire electrode in single pulse discharge by FEM. Their results indicated that the size of the melted zone along the wire electrode axial direction increased remarkably while the depth size, the width size and the volume of the melted zone reduced apparently when the wire running speed increased. They concluded that the high relative speed between the wire electrode and the work piece is beneficial to reduce the wire electrode wear in radial direction. Furthermore, when the wire running speed is higher than a certain value, the discharge column will slide over the wire electrode surface before the wire material reaches its melting point, thus the melting and ablation of the wire electrode material does not happen, which can almost realize no wire electrode wear.



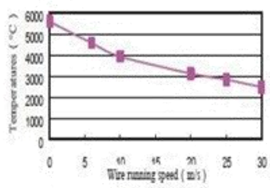
Relationship between melted zone width and wire running speed



Relationship between melted zone volume and wire running speed



Relationship between melted zone depth and wire running speed



Relationship between the highest temperature of heated region on wire electrode wire and wire running speed

Danial Ghodsiyeh,et al.(2013) studied the research trends in WEDM and found that the research trends in WEDM on relation between different process parameters, include pulse on time, pulse off time, servo voltage, peak current, dielectric flow rate, wire speed, wire tension on different process responses include material removal rate (MRR), surface roughness (Ra), sparking gap (Kerf width), wire lag (LAG) and wire wear ration (WWR) and surface integrity factors, different types of WEDM methods introduced and discussed. In addition the paper highlights different modeling and optimization methods and discussed their advantage and disadvantage. There are also some recommendations about the trends for future WEDM research.C.D. Shah, J.R.Mevada, B.C.Khatri(2013) conducted experiment on Inconel-600 material in Wire Cut EDM and they developed RSM models, the interesting conclusions were drawn from their studies. The effects of Pulse On time, Pulse Off time, Peak Current, Wire Feed rate setting are experimentally investigated in machining of Inconel-600 using CNC Wire-cut EDM process. The level of importance of the machining parameters on the material removal rate is determined by using ANOVA and it is shown that Pulse on, Pulse Off, Peak current are most significant. An optimum parametric combination for the maximum material removal rate was obtained by using Signal-to-Noise (S/N) ratio. Improved S/N ratio and conformation test indicated that it is possible to increase material removal rate by using the proposed statistical technique. They developed mathematical model, i.e. Response surface Model for the performance characteristic such as Material removal rate (MRR) in the CNC Wire-cut EDM process is successfully proposed for the proper selection of the machining parameter. G. Skrabalak, J. Kozaka, M. Zyburaa(2013) concluded that the EDM milling process conducted in air and sulphur hexafluoride is very effective method of machining. It is especially suitable for micromachining of complex cavities and shapes. Due to the negligible tool wear ratio it is more precise than EDM milling in kerosene. Comparative tests of machining in gaseous dielectrics (gas flow rate 13 l/min) and kerosene (work piece submerged + forced side flow, no through electrode flow) were performed for the parameters such as Free run voltage 160V, reference voltage (used for process controller) 50V, Pulse ON/OFF time Peak current 1A, Electrode rotation 5000rpm.Preparing tool paths is much easier in this kind of EDM machining.

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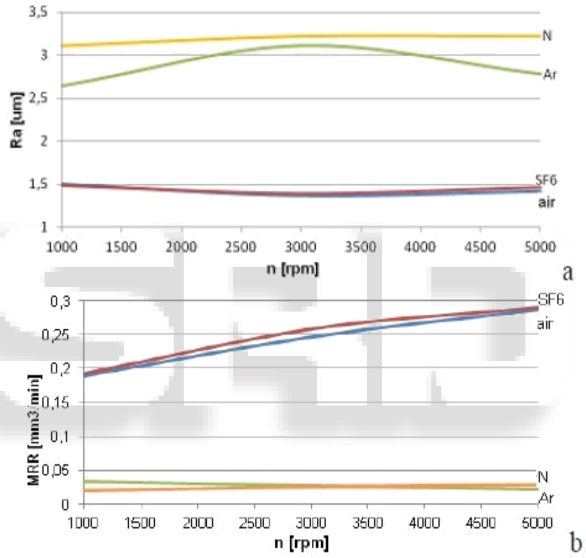


Fig. Surface roughness (a) and Material Removal Rate (b) vs electrode tool rotation – hardened tool steel, constant gas flow rate 13 l/min

R. Rotha et,al.(2013) analysed MRR and discharge behaviour of DEDM for different more or less oxidizing gases. Current specific and power specific MRR are presented and hypothesis of the ruling mechanisms regarding the influence of oxygen in DEDM are elucidated. The influence is given by two different mechanisms. The first one occurs only at high oxidation capability of the flushing gas acting on the stability of the process. The second effect of the oxidation results in different specific MRR values and saturates already with little oxidation capability of the flushing gas

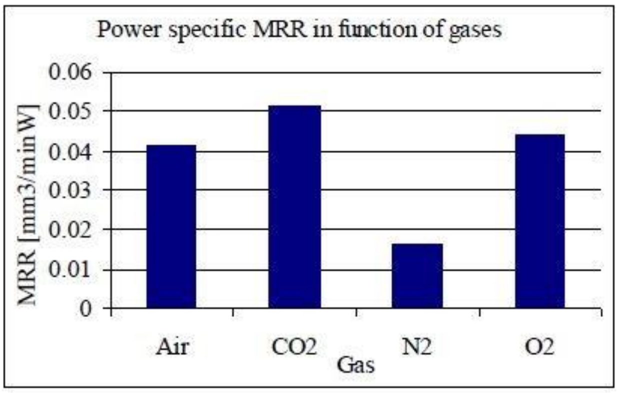


Fig. 5: current specific material removal rate for different flushing gases

Prof. Chirag P. Patel et.al, (2013) suggested that fewer tool electrodes are required in dry EDM due to lower tool wear. The total machining time for dry EDM may then be lower than die-sinking EDM. In the process of UEDM in gas, the increase of MRR is at the expense of surface roughness. It was found that discharge current, duty factor, air pressure and spindle speed are the significant factors which affect MRR and MRR increases with an increase in any of these factors. Genetic Algorithm (GA) based multi-objective optimization for maximization of MRR and minimization of Ra has been done by using the developed empirical models Sushil Kumar Choudhary, R. S Jadoun(2014)find the following characteristics: Dry EDM is eco-friendly machining. Pollution is reduced by use of gas instead of oil based dielectric. Harmful & toxic fumes are not generated during machining. Material removal rate (MRR) &electrode wear ratio (EWR) also get enhanced by dry EDM. Hollow tube and eccentric drilled hole type electrode are reported to have positive impact on MRR due to improved flushing condition.. Shaaz Abulais (2014) in his study of current research trends in WEDM he found the characteristics of dry EDM and concluded as tool electrode wear is negligible for any pulse duration. The processing reaction force is much smaller than in conventional EDM. It is possible to change supplying gas according to different applications. The residual stress is small since the melting solidification layer is thin. Working gap is narrower than in conventional EDM. The process is possible in vacuum condition as long as there is a gas flow. The machine structure can be made compact since no working basin, fluid tank and fluid circulation system needed. G.M.Pradeep, M.S.Heaven Dani (2015) presented a literature survey on the use of water based gaseous dielectric medium that provide an alternative to dielectric fluids. Gaseous dielectrics such as oxygen, Helium, Argon may also be the alternative. From the literature review, with a help of gaseous dielectric mediums like oxygen, air, argon, helium, we can reduce the environmental pollution and also the machining time is reduced, surface roughness of the work piece material is increased.Ibrahem Maher et, al. (2015) presents an experimental investigation of wire electric discharge machining (WEDM) for improving the process performance. The effects of the machining parameters were investigated on the machining performance. ANFIS was used to predict the cutting speed, surface roughness and heat affected zone in WEDM. The predicted cutting speed, surface roughness, and heat affected zone were compared with measured data, and the average prediction error for cutting speed, surface roughness, and heat affected zone were 3.41, 3.89, and 4.1 respectively

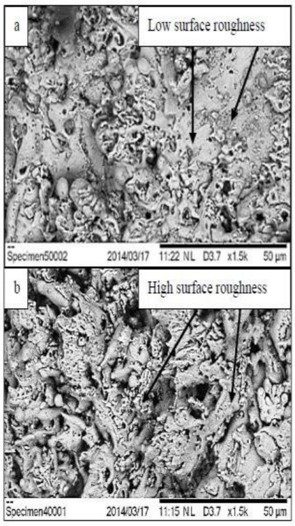
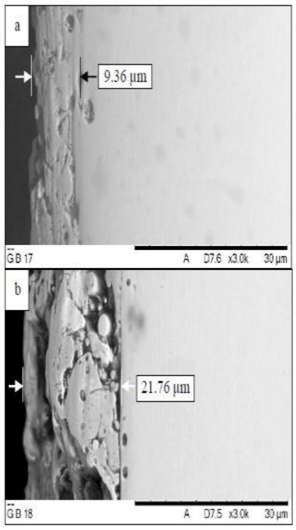


Fig. SEM micrograph at different levels of spark energy. a) SEM micrograph at the lowest levels of peak current (IP=16A) and pulse on time (Ton=0.15μs). b) SEM micrograph at the highest levels of peak current (IP=17A) and pulse on time (Ton=0.25μs)



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VI. CONCLUSION

Dry EDM is eco-friendly machining. Pollution is reduced by use of gas instead of oil based dielectric because harmful & toxic fumes are not generated during machining.In dry WEDM material removal rate &electrode wear ratio improves. This machining process should be supported and more research should be carried out since it helps to save the environment. Recent enhancement in various parts of EDM that reflect the state of the art in these processes are presented in this review paper. Researcher works on increasing of material removal rate (MRR),lowering of tool wear rate (TWR),enhance Surface Quality (SQ) by study and experimentaion. Numerous methods like Vibration, rotary and Vibro-rotary mechanism based EDM, water based EDM has been incorporated for increase of EDM efficiency, Dry EDM use of gas instead of oil electrolyte, PM-dielectric Electric Discharge Machining. It also plays a significant role in medical, optical, Jewellery, automotive and aeronautic industry & making a various mechanical component in manufacturing industries.

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