



Review Paper

Hybrid Electric Discharge Machining Processes: A Review

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Abstract

The hybrid EDM process is a very important method which is used to add value to traditional EDM process. It has been effectively used for the machining of the complex shape work piece which is not easy to machine under simple EDM process. The basic principle of working hybrid-machining processes is to combine the advantages of different advanced machining processes to avoid or reduce the adverse effects of the constituent processes. Advanced Machining processes have been divided according to the energy used for the machining of the work materials i.e. Mechanical, Thermal and Chemical. The Ultrasonic machining(USM), Water jet machining(WJM), and Abrasive jet machining (AJM) come under mechanical, Electrical discharge machining(EDM), Electron beam machining(EBM), Laser beam machining(LBM) under thermal, and Chemical machining(CHM), Photo chemical machining(PCM) under chemical energy. In EDM process electric energy is converted into thermal energy for material removal action by melting and evaporation.

Keywords: Electrochemical Discharge Machining (ECDM), Powder Mixed Electric Discharge Machining (PMEDM), Abrasive Jet Electric Discharge Machining (AJEDM), Ultrasonic Vibration Assisted Electric Discharge Machining (USEDM), Magnetic Field Assisted Electric Discharge Machining (MFEDM).

Introduction

A Hybrid EDM Process can be categorized on the basis of utility of others advance process as discussed following: i. The Process which facilitates control of necessary EDM condition such as flushing, normal electric discharge and gap etc. ii. The process which improve machining characteristics for EDM process such as MRR, Surface finish, dimensional accuracy and tool wear etc.

Hybrid EDM process is most effective method to set up normal necessary machining condition and improving performance index, the major problems faced in tradition EDM system. The purpose of combining the ultrasonic vibration, magnetic field and powder mixed in tradition EDM facilitate to meet these necessary conditions to enhance the accuracy. Some researchers have explained EDM a thermo-chemical process as metal melted due high temperature of discharge in the presence of ionized dielectric fluid, but ionization of dielectric medium is physical phenomenon not a chemical, it is rather a thermo-electrical metal removing process. The function of dielectric fluid is to provide channel for transferring ions to ignite the discharge. The mobility of ions, gap and fresh channel between tool electrode and workpiece are necessary conditions for EDM process.

Hybrid EDM process for increasing the performance index comprise some of the combined simple shearing and erosion action of high kinetic energy posed by particles (mechanical),

melting and evaporation (thermal) and oxidation and precipitation (chemical), on workpiece surface for cutting. The involvement of these erosive actions changes both physical and chemical conditions of parent processes by considering other controllable parameters. The combined erosive action of powder addition, laser beam localized heat and ion beam give better results with spark erosion. The performance of Hybrid technology may be relatively different from those that are characteristic of the component processes. For Example the performance of ECDM is 5 to 50 times better as compared to the ordinary ECM or EDM. The advanced manufacturing processes combined with EDM experimentally investigated and development by researchers in Hybrid EDM are shown in Figure-1, this figure also shows interactions of thermal, chemical, and mechanical type machining processes toward performance and efficiency enhancement of traditional EDM, cross-process or hybrid technology can possible be a viable and feasible approach as discussed below.

Electrochemical Discharge Machining (ECDM)

Electrochemical discharge machining (ECDM) process is an electrically controlled thermo-chemical hybrid machining process. In this process, the metal is removed as a resultant of combined effects, heating by electric spark and chemical decomposition of metal schematic. In other word a simultaneous action of electrical spark discharges (ESD) and electrochemical (EC) reaction. A substantial experimental works has been investigated by Kulkarni for micro machining of holes with high

aspect ratio. Synchronized and transient measurements shows the discrete nature of the process; it also helped in making the basic mechanism for the discharge formation and the material removal¹. Kulkarni et al. took advantage of the similarity of ECM and EDM processes simple replaced dielectric fluid to mixture of HCl with distilled Water to induce chemical machining mechanism². Pyrometer and two varieties of K-type thermocouples were used to measure the temperature profile on workpiece and in electrochemical discharge machining cell. Experiment results have claimed improvement in surface topography of the workpiece surface. This combination of processes can machine of wide range of materials.

A minimum electrical conductivity of tool and workpiece is a necessary condition for EDM, a major limitation of this process. But this hybrid process has ability to conceived, as phenomenon of electrochemical spark has used for material removal of electrically non-conducting materials.

Lack of electrolyte at the bottom of the hole caused due to the tool penetration towards work piece. Low voltage produces less thermal energy to remove material form surface. Although high voltage creates holes quickly but surface cracks appears as shown in Figure-2(a-d). Cheng et al. were successfully drilled hole of diameter 470-492 μm on glass (Pyrex) with KOH electrolyte in their experiments³.

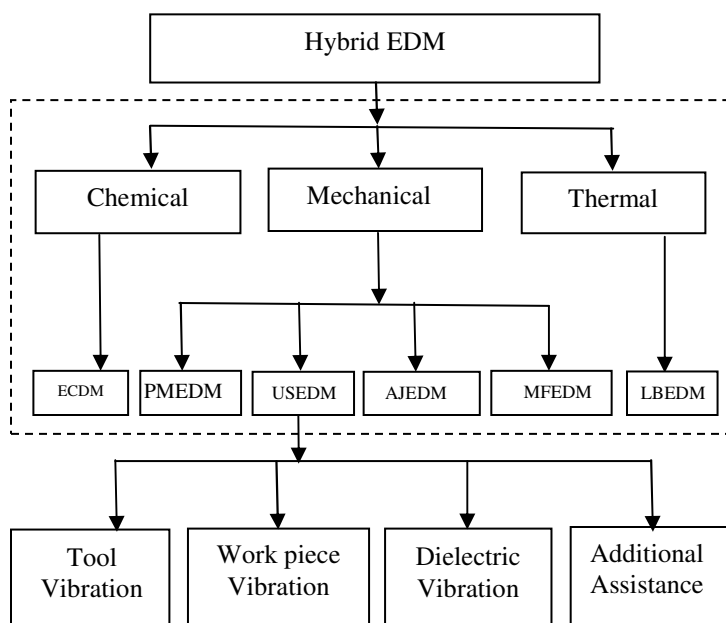


Figure-1
Research and development areas in Hybrid EDM

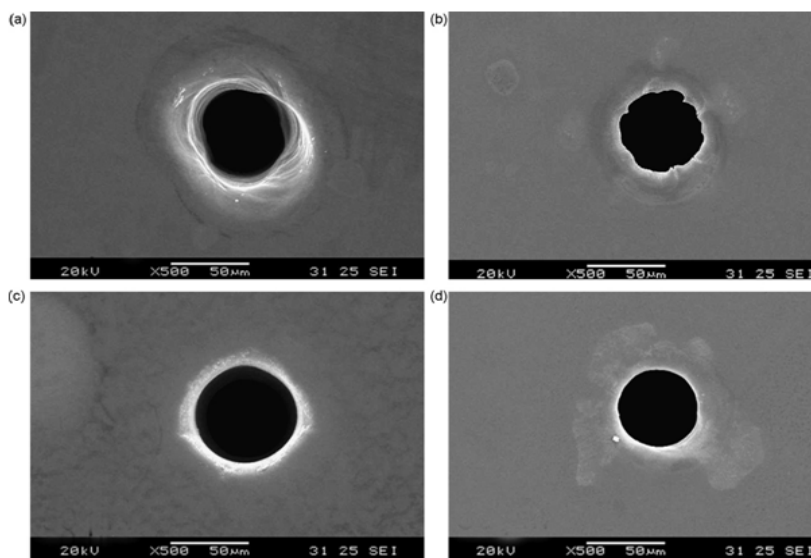


Figure-2
(a) and (b) Hole entrance and exit drilled at 35V³, (c) and (d) Hole entrance and exit drilled at 30V³

A schematic arrangement of the work-piece, tool and auxiliary electrode was proposed by Yang et al. as shown in Figure-3 for wire electrochemical discharge hybrid machining process⁴.

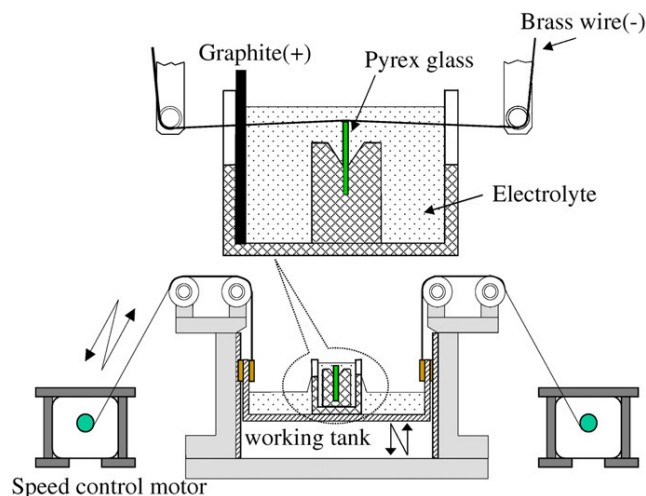


Figure-3

Schematic diagram of experimental set for ECDM⁴

The analysis obtained from the electrochemistry of ECM by Bhattacharyya et al. it has been found that the gas realized during chemical reaction, electroplating of tool electrode occurred and oxidation and decomposition of electrode⁵. These chemical reactions were grouped as electrochemical reaction as these occur at electrode in the system. And chemical combination and precipitation occurred in electrolyte were grouped as chemical reaction in the bulk of electrolyte. The machining of non-conducting ceramic work-piece is due to gas bubbles layer deposited on the work surface in the ECDM process and electric discharge action. Small and macro level size hole can be machined successfully on ceramic components with this hybrid process.

Basak and Ghosh observed 50-80% of the heat energy released by EDM spark is transferred to the work piece, when tool directly strikes the work piece⁶. However, in ECDM, discharging takes close to tool electrode and the electrolyte, lesser quantity of heat dissipate to the work surface. Basak and Ghosh developed a simple model for spark generation and MRR in their work⁷.

Peng et al. experimentally investigate the ECDM set up for slicing Aluminum ceramics, Quartz and optical glass under voltage range 45-90V and frequency range 100-1000Hz and got MRR of 0.06 mm³/min for Aluminum ceramics and Ra of 3.5μm⁸.

Jawalkar et al. highlighted processing condition and materials being investigated by the researchers with this hybrid process⁹. Most worked on glass as work material under different machining parameters subsequently varying results. According to them a generalized metal remove mechanism theory for ECDM process is yet to be reveal.

Powder mixed Electrical Discharge Machining (PMEDM)

The process instability of traditional EDM in pure kerosene results the arcing and short-circuit effect. The working principle and schematic experimental arrangement are shown in Figure-4 (a and b). The applied hypothesis for this hybrid process is addition of metallic powder and abrasives in EDM dielectric medium improve the machining efficiency.

Erden et al. analyzed the effect of metallic powder particles mixed with dielectric on the machining of mild steel¹⁰. They observed that adding powder such as aluminum copper etc. enhance the breakdown characteristics of the dielectric fluid, and MRR increases as the concentration of the added metallic powder increases. Some also observed that excessive powder concentration cause unstable machining process due to the short-circuiting because of decrease in dielectric resistivity.

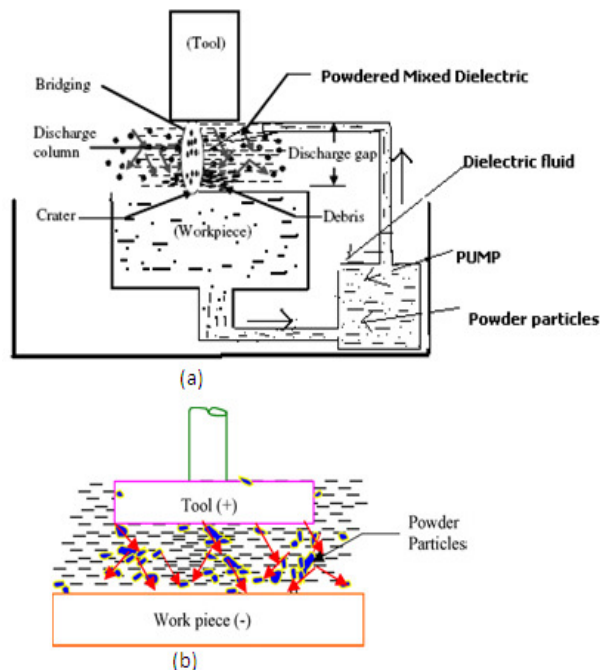


Figure-4

(a) Schematic diagram¹⁰ and (b) The Principle of PMEDM¹⁰

Jeswani et al. added fine graphite powder into kerosene oil and evaluate the results on machining of tool steels as work material¹¹. Some observed that the addition of 4 g/l of graphite powder increases the interspaced for electric discharge initiation and lowered the breakdown voltage. Mohri et al. studied the effect of silicon powder addition into dielectric fluid¹².

Kobayashi et al. has investigated the effects of suspended powder in dielectric fluid¹³. Abrasive powder mixed electric discharge machining (APEDM) provides comparatively much better MRR and reduced the surface roughness than the traditional process. Okada et al. showed the effect of graphite, silicon and aluminum powder in Figure-8(a-d)¹⁴.

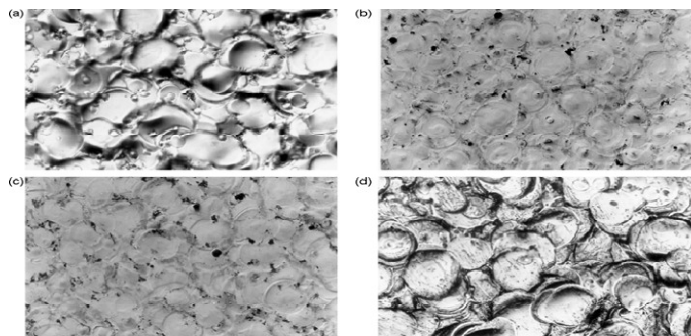


Figure-5

SEM micrographs of SKH-54 steel after machining with copper electrode¹⁴ (a) with no powder, (b) with graphite powder, (c) with silicon powder (d) with aluminum powder (at $I_p = 1A$, $P_{on} = 7.5\mu s$ and $P_{off} = 11\mu s$, magnification = 50 \times , polarity negative)

Klocke et al. performed experiments on Inconel 718 superalloy using Tungsten as tool electrodes and found that Al and Si powder increase the plasma channel and thermal metal removing mechanism affect the morphology and recast layer of the work surface¹⁵. Powder granularity and concentration significantly affect the MRR. According to Ming et al. has reduced the crack inception and extent of crack propagation on the machined surface and the recast layer was thinner and denser¹⁶. The material erosion rate has been affected by the concentration of added silicon powder, pulse duration, and peak current significantly. But Sharma et al. added that with the increase in the concentration of additive powder in the dielectric fluid, the tools wear increases¹⁷. Singh et al. worked on Hastelloy with copper tool electrode and conclude improvement in MRR and reduction in TWR¹⁸. The powder particles arrange themselves in a well defined manor under the sparking area gap in PMEDM process that improve the material removal mechanism and affected the machining surface, reduce the recast layer. According to Tzeng et al. Al powder produce large discharge gap where as Silicon carbide powder smaller. High MRR and better surface roughness were achieved by changing the polarity, powder granularity and concentration significantly¹⁹. Goyal et al. conclude that the Al powder mixed with dielectric enhance MRR and surface finish²⁰.

Singh and Bhardwaj presented a review on the tends in water and powder mixed dielectric in EDM and found that the applied hypothesis of addition of powder in EDM dielectric increase MRR, surface finish and reduced tool wear rate (TWR) found true²¹. Most researchers focused on optimization of the process parameters, but still areas such as effect of pulse interval, polarity and powders of some alloys such as vanadium chromium and magnesium are to be explored referring to work surface characteristic.

Ultrasonic vibration Assisted EDM (USEDM)

Ultrasonic vibration assisted Electrical Discharge Machining (USEDM) process is a innovative hybrid process and an area of

research. Researchers have investigated this hybrid process for normalizing the EDM's necessary process conditions and performance characteristics enhancement for advanced materials. EDM can be consider as a system itself as shown in Figure-6 consists of four main elements which are Tool electrode, Workpiece, Dielectric medium with Control system.

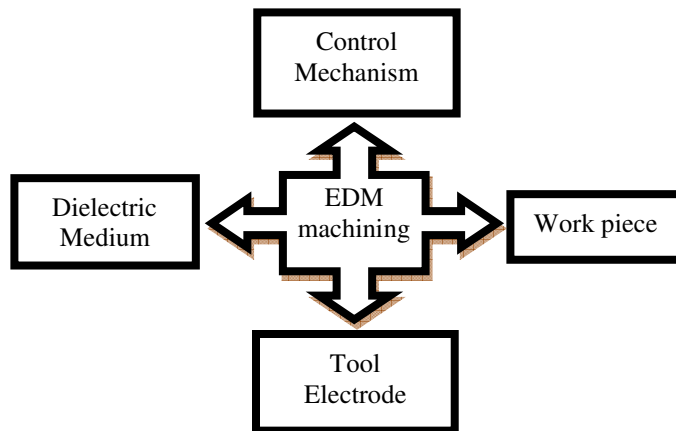


Figure-6
EDM System²²

UV action is accomplished by traversing vibration to any of the sub-system except control sub-system as mentioned above in a traditional EDM system with the help of UV generating devices. An Integrated UV generating device comprises generator, transducer, booster and horn/sonotrode is easily available in market in Figure-7. Simply by redesigning the horn and/or sonotrode longitudinal ultrasonic vibration can transferred to any of sub-system of traditional EDM system.

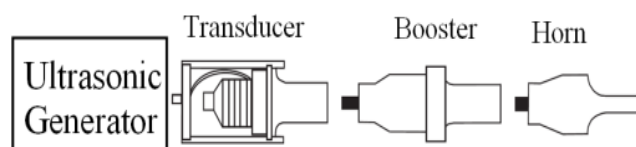


Figure-7
Piezoelectric ultrasonic vibration generating device²²

USEDM hybrid process has been proposed to machine high strength materials i.e. composites and super alloys with complex geometries successfully. In USEDMD, Relative reciprocating motion of sub-system (Tool, Workpiece and Dielectric) replaced the relative stationary machining gap with intention to test various working hypothesis as mentioned in this paper with better circulation of dielectric fluid to attain normal necessary discharge conditions and improved performance index.

This review paper emphasizes the recent development in USEDMD process and its future scope in next section of retrospective review in USEDMD.

Abrasive Jet Electrical Discharge Machining (AJEDM)

The hybrid process comprises Abrasive Jet Machining and electrical sparks that can increase the machining drastically. The stream of fine grains mixed with dielectric in Figure-8 affecting with high kinetic energy cause erosive action not only increase MRR but also helps to generate fine surface integrities. Machining is accomplished by directing mixture in the machining gap at high speed possessed by abrasives and thermal energy of electrical discharge.

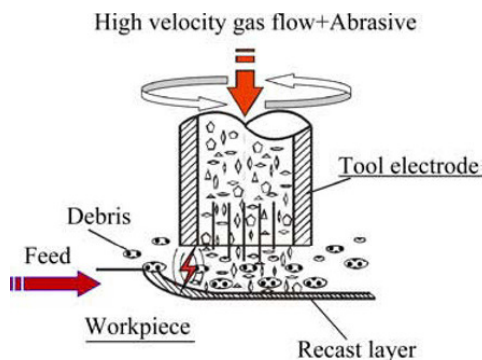


Figure-8
Hybrid process of AJM and EDM²²

The jet action also improves the flushing of contaminated dielectric medium. Lin et al incorporated the AJM with EDM process to permute the machining performance²². They used Al_2O_3 and SiC abrasive grains directed on to the machining surface. The experimental results show this combined process is better to the dry EDM both in MRR and Surface Roughness. The author claimed increase in MRR between 32-46% at peak current 9-6 A individually. They observed a relationship between SR and peak currents only up to a certain limit, which increases with peak current. Beside, the SR increased with the pulse duration first, and then it reduce with the further extended the pulse duration.

Menzies and Koshy proposed an abrasive assisted wire electrical discharge (AWEDM) machining by coating the surface of wire in Figure-9 with diamond abrasive particles significant improvement in MRR²³.

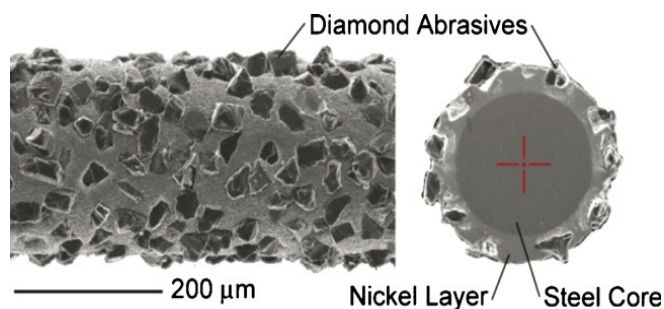


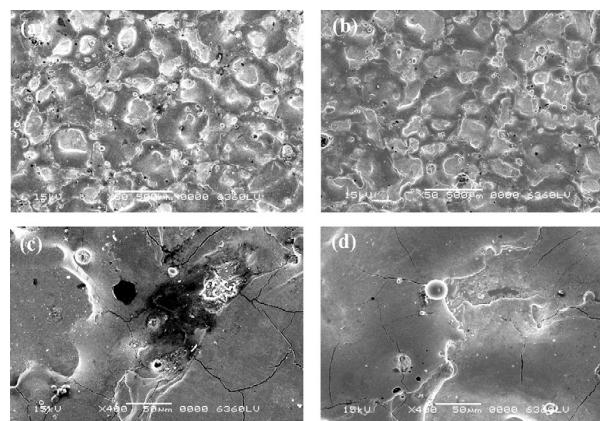
Figure-9
Surface and section of diamond wire²³

Magnetic Field Assisted Electrical discharge Machining (MFAEDM)

In this hybrid process the magnetic forces are combined with the normal EDM process by a specially designed device that expels debris for the machining gap to maintain the normal EDM process condition. As discussed previously the accumulation of debris in machining gap contaminate the dielectric medium due to which abnormal discharging occurred that affect the quality of the surface of work piece and process stability. The hypothesis for combining magnetic force in EDM device is used to reduce the probability of abnormal electrical discharge, so that the machining efficiency could be improved more.

Cao et al. worked on to main disadvantage of EDM that are low MRR and poor surface finish²⁴. They combined the a constant magnetic field on both side of discharge channel the discharge current and pulse duration were chosen as the variable to investigate the effect on MRR and surface roughness.

Lin and Lee investigated experimentally the stability of this hybrid process and analysis discharge waveforms, for machining characteristics (MRR, EWR, and surface integrities) and found significant improvements in Figure-10(a-d)²⁵.



Standard EDM Magnetic force assisted EDM

Figure-10
(a-d) Micrographs of machined surface obtained by magnetic force assisted EDM and standard EDM²⁵

The experimental set up was designed by them as shown in Figure-11; comprise a specific magnetic force assist rotating disc due to which they successfully implemented the discharge wave form distribution in machining gap.

The magnetic force facilitates the remove of debris through the gap and normalized the discharge condition to improve machinability of this assisted process. Apply a centrifugal force and whirl condition of Rotary tool electrode improve flushing result decrease in surface roughness and Magnetic field reduce arcing and short circuit. The magnetic field causes change in the ion path migration by generating Lorentz force around the electric field, and this force increases the lead overcut.

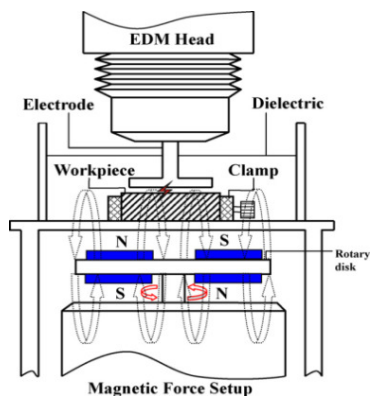


Figure-11
Magnetic Force Setup²⁵

The magnetic force facilitates the debris removal from the machining zone more easily and quickly. Research shows that the magnetic field assisted EDM process has a better machining stability and it also improve MRR and surface roughness with less TWR.

Chu et al. in their analytical study interpreted that the collision probability of free electron increases and the expansion of discharge channel which a reason the magnetic field assisted machining crater morphology is larger and shallower²⁶.

Laser Beam assisted Electrical Discharge Machining (LBAEDM)

Lin et al proposed hybrid machining processes consisting laser beam machining (LBM) and EDM for drilling micro-holes of next generation fuel injection nozzles²⁷. The conditions of LBM and EDM were examined by them to meet the desired alignment of nozzle hole. They reported the significant improvement in dimension accuracy of micro-hole a shown in Figure-12 (a-c). Rasheed M S gave comparison of MRR for micro hole obtained by LMB and EDM in Figure-13 below here²⁸.

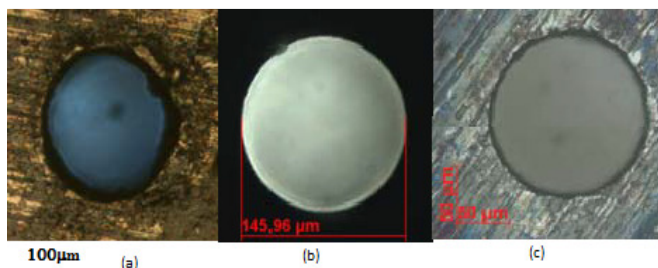


Figure-12
Comparison of (a) laser pilot hole, (b) standard EDM drilled hole, and (c) laser-EDM hole²⁸

Kuo et al. used LBM in EDM to produce micro holes and compared the results with Micro-EDM process for dimensional accuracy regarding over cut and tapered angle²⁹. From experimentation, he concluded that performing micro-EDM and LBM such as MRR and dimensional accuracy is mainly

depends upon the laser power, wavelength, pulse duration, frequency discharge energy, and thermal properties of the material. The heat affected zone around the micro-hole machined by LBM is higher as compared to the micro-hole machined by the micro-EDM. Stute et al. combined Nd-YAG laser radiation to EDM process using low power laser radiation to stabilization of the discharging³⁰.

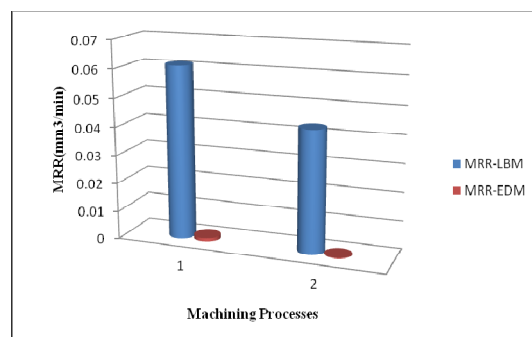


Figure-13
Comparison of MRR of micro-hole obtained by LBM and micro-EDM²⁸

Conclusion

Large numbers of researchers have explored these methods in various fields and find very beneficial as compared to Electric Discharge Machining. Hybrid discharge machining increases the performance of various parameters which affects the performance of EDM. Hybrid EDM has resulted out as an efficient and most effective machining process recently. The capacity to machine hard and brittle material makes it as one of the important machining method. Powder mixed EDM and Ultrasonic assisted EDM has not only reduces tool wear but also increases material removal rate. This approach can further be used to evaluate the performance of various hybrid process used in Advance manufacturing technology to analyze the effects of various hypothesis pre-assumed. Simple EDM cannot give a better performance in complex shape of work piece. So, in complex shape mainly Hybrid discharge machining is being preferred.

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