Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 10, Issue 04, December 2019: 726 - 740
DOI: 10.53555/tojqi.v10i4.10331

Research Article

A Research Review On The Machining Of Metal Metrix Composite (Mmc) Materials Using Ultrasonic Assisted Electric Discharge Machining (Uaedm)

Prof N J Prajapati[1*], Prof P.R. Parekh[2], Prof K.P. Hirpara[3], Prof S.N.Patel[4]

[1*]Lecturer Mechanical Engineering Department, K D Polytechnic, Patan, Gujarat
[2]Asst. Professor, Mechanical Engineering Department, Government Engg College Modasa
[3]Asst. Professor, Mechanical Engineering Department, LDCE, Ahmedabad
[4]Asst. Professor, Automobile Engineering Department, LDCE, Ahmedabad

***Corresponding Author:** Prof N J Prajapati
*Lecturer Mechanical Engineering Department, K D Polytechnic, Patan, Gujarat

Abstract

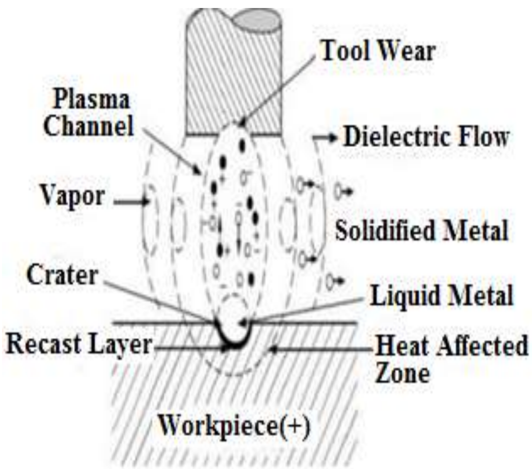
Advanced materials known as metal matrix composites (MMCs) have excellent wear resistance, low thermal expansion coefficient, high specific strength, and increased hardness. They are also lightweight. Reinforcement is hard to manufacture with conventional methods, which has slowed down MMC progress. Since the reinforcement is abrasive, using conventional technology to process MMCs results in significant tool wear. The most dependable nonconventional machining method for MMCs is hybrid electric discharge machining, which has great potential. It demonstrates increased proficiency in precisely machining intricate forms. An improved EDM method that reduces the limitations of the EDM process is Ultrasonic Assisted Electric Discharge Machining (UAEDM), a hybrid EDM process combining EDM and ultrasonic machining techniques. A lot of materials, including ceramic, titanium alloy, and aluminium alloy, are machined using UAEDM for Metal Matrix Composites (MMC). The machining characteristics of the UAEDM process for MMC materials are represented in this review study. A review has been conducted on the effects of various MMC, such as Nickel base alloy, Titanium base alloy, Ceramics, Alumina base alloy, etc., and Tool Material, such as Alumina, Copper, Brass, etc., on Output Parameters, such as Material Removal Rate, Tool/Electrode Wear Rate, Surface Roughness, Aspect Ratio, Crack Propagation, etc. Future research has been identified to enhance productivity and machinability by strengthening the UAEDM process, based on a survey of several literature sources.

Keywords: Metal matrix composites (MMCs), Electric Discharge machining (EDM), Ultrasonic Assisted Electric Discharge Machining (UAEDM), Material Removal Rate (MRR), Tool Wear Rate (TWR), Relative Wear Rate (RWR)

1. INTRODUCTION:

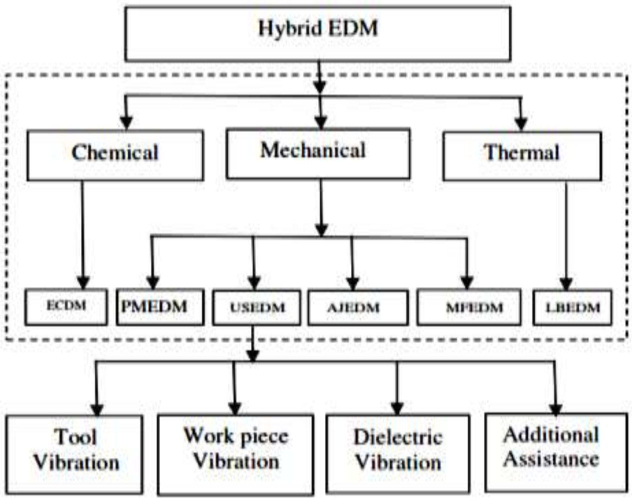
Today's manufacturing companies face hurdles in meeting client expectations and expanding their worldwide market within specified time frames. Customers in the worldwide market face competition and an ever-increasing level of satisfaction for the development of new developing materials that are extremely complicated and tough to produce using classic machining processes. Non-traditional machining procedures can give a solution in which there is no contact between material and tool and the machining process uses thermal, mechanical, or chemical energy to achieve the necessary level of customer satisfaction.[01] EDM is a thermoelectric-based non-traditional machining method that produces complicated, geometrically and dimensionally correct profiles, among other things. EDM is recommended for machining parts in the aerospace, automotive, and medical sectors, as well as tool and die manufacturing. [02,03,04,05]

Fig.1 EDM Spark Description[06]



Source: Singh, A et all 2018, IJETSR

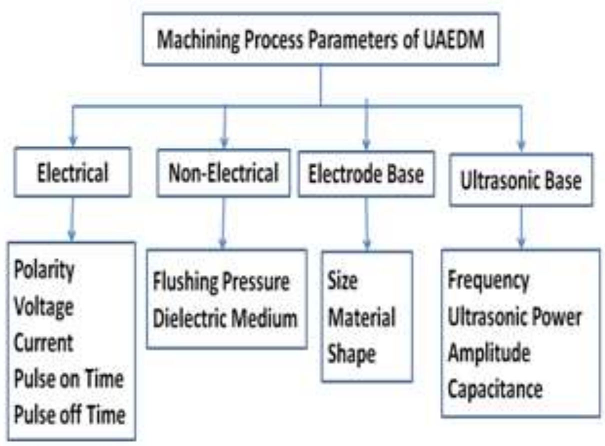
Fig.2 Classification of Hybrid EDM Process[07]



Source: Sandeep Kumar etall 2016, RJES

In EDM, material or metal is removed from the workpiece due to erosion induced by constant immediate sparking between the workpiece and the tool electrode or wire. Material removal occurs as a result of plasma formation, and metal is rapidly converted into vapours and melt as shown in Figure 1[05,06]. The material is removed from both the side work piece and the tool. The limitation of the EDM machining technique is the poor material removal rate, and the tool wears out throughout the operation. Improving the restriction of EDM machining by Hybrid EDM machining process, in which other unconventional machining methods are coupled with EDM process, as shown in Figure 2 [07]. In Ultrasonic Assisted Electric Discharge Machining (UAEDM), ultrasonic vibration is applied to the tool, workpiece, or dielectric fluid in addition to the EDM machining process.

Fig.3 Process Parameters of UAEDM



1.1 Process Parameters:

In UAEDM process has electrical parameters like polarity, voltage, current, pulse on time, pulse off time etc., non electrical parameters like flushing pressure and dielectric medium, electrode base parameters like electrode size, electrode shape and electrode material etc. and ultrasonic base parameters like frequency, ultrasonic power, amplitude, capacitance etc. are affect directly to machining process and surface of machining. Machining process parameters of UAEDM as per fig.3.

1.2 Objective of present review article:

The present article explicitly emphasizes the influence of process parameters like polarity, pulse on time, pulse off time, current, voltages, power, etc. on the material removal rate, tool wear rate, surface roughness, crack, white layer, etc. More over parameters pertinent to ultrasonic such as ultrasonic power, vibration amplitude, capacitance, etc have direct effect on machining process. So review become imperative that author has try to sum up in this piece of writing.

2. LITERATURE REVIEW:

Researcher have experimented with various workpiece and tool material with various modes to employ ultrasonic vibrations in UAEDM system to study material removal rate, tool wear rate, surface roughness, crack, taper, recast layer etc.

2.1 Material Removal Rate (MRR):

T. C. Lee, J. H. Zhang, W. S. Lau[08] conducted experiments on workpiece material as 65%Al2O3 + 35% (WC+TiC), Q.H. Zhang, J.H. Zhang, S.F. Ren, J.X. Deng, X. Ai[09] conducted experiments on workpiece material as 45#steel and copper as tool material, M. R. Shabgard, H. Alenabi[10] conducted experiments on workpiece material as Ti6Al4V and tool material as copper and found that the Material removal rate of UAEDM process is higher than the conventional EDM process.

Aminollah Mohammadi, Alireza Fadaei Tehrani & Amir Abdullah[11] proposed work on face-centred central composite design scheme and found that The MRR increase with increase power and voltage both because of its increase elevated discharge energy which is used for melting and vaporizing the work piece. Also MRR increase with increase rotational speed of tool. Increasing Ultrasonic amplitude up to 12.5 µm, MRR is increase max. In high ultrasonic vibration amplitude Wire break down and short circuit occurs, due to that MRR is decrease.

Kuang-Yuan Kung & Jenn-Tsong Horng & Ko-Ta Chiang[12] investigated cobalt-bonded tungsten carbide (WC-Co) with copper electrode and concluded that MRR increase with increasing aluminum powder concentration up to some extend afterward increasing powder concentration MRR is decreased. MRR also increase with increasing grain size. MRR Increase with increasing discharge current and pulse on time because of higher spark energy produce larger craters.

Guang Zhu, Min Zhang, Qinhe Zhang, ZhenChao Song, Kan Wang[13] an orthogonal experiment was designed and conducted to explore the effects of processing parameters on the machining behaviors and conclude that At high peak current, more energy is generated at work piece and work piece metal is melt and removed, so MRR increase with increase peak current. Vibration Assisted EDM (VAEDM) is increase average discharge gap, which result in improve discharge condition and better stable machining process. MRR is 8595 mm3/min achieved and increased by 33%.

S H Yeo and L K Tan[14] the impact of expanding the amplitude and frequency of the instrument vibration on the rate of material expulsion during the time spent ultrasonic-helped EDM is numerically explored. The exhibited outcomes demonstrate that by expanding the amplitude of the device vibration, the development rate of the electrical-release created vapor bubble increments. A higher development rate of the air pocket prompts a higher rate of weight drop inside the air pocket which, thus, causes a higher rate of weight drop on the outside of the workpiece. Subsequently, a higher weight drop on the outside of the workpiece encourages the launch of liquid material from the cavity and builds the rate of material evacuation.

Table 1. Summery on progress of research work on Material Removal Rate (MRR) for different tool material and workpiece material.

Author Name & Year	Tool Material	Work piece Material	Remarks (Material Removal Rate)
V. S. R. MURTI, et al 1987[15]	Copper	High C, high Cr steel	Improving sparking efficiency and improve material removal rate in planning operation greater than drilling or cavity sinking.

Author Name & Year	**Tool Material**	**Work piece Material**	**Remarks (Material Removal Rate)**
D. Kremer, et al 1989[16]	Graphite ELLOR 9	steel 35 NCD 16	In air, electric discharge occurs more greater than liquid dielectric. MRR is increased.
Q.H. Zhang, et al 2006[17]	copper	AISI 1045 steel	In UEDM in gas MRR is nearly twice than EDM in gas. In the process of UEDM in gas, the increase of MRR is at the expense of surface roughness.
Jatinder Kumar, et al 2008[18]	High Carbon Stee, titanium alloy	Titanium (ASTM grade I)	Tool Material, Power Rating, great size of slurry are affect MRR of Titanium alloy. At 200 grit size of alumina slurry and 400W power rating with high carbon steel tool material higher material removal rate found.
Chaiya Praneet pongrung, et al 2010[19]	copper tungsten (Cu-W)	sintered Si3N4 insulating ceramic	The MRR of USEDM was two time higher than EDM. higher Ultrasonic amplitude does not affect every time to MRR.
Mohammadreza Shabgard, et al 2011[20]	graphite	FW4 Welding Metal	MRR is increase four times in USEDM process than EDM process at short pulse on-times and MRR is reduced at long pulse on time.
M.R. Shabgard, et al 2013[21]	Copper	WC-Co Composite Material	With increasing discharge current and pulse duration, MRR rate is increased as work piece material is tungsten carbide.
E. Uhlmann, et al 2013[22]	graphite	MAR-247	MRR is Improved by 11 %.
Eckart Uhlmann, et al 2016[23]	graphite	nickel base alloy MAR-M247	The vibration amplitude is highly affect on MRR And lower amplitude leads better result in process.
Zhen Zhang et al 2016[24]	Copper	Titanium Alloys (Ti6Al4V)	By use of Experimental work and theoretical work, Flushing of debris more effectively by use of Ultrasonic effect to WEDM process. Its improve pulse discharge, due to that improves the MRR.
JiangtaoChe, et al 2016[25]	Copper	45#steel	The MRR of HU-EDM has increased from 0.49 mm^3/s to 1.71 mm^3/s, nearly by 3 times.
Yan-Cherng Lin, et al 2016[26]	Copper	SKD 61 Tool Steel	MRR is increase with increase peak current. In Hybrid EDM Process, MRR is higher than EDM in gas. Highest MRR achieve in dielectric media as oxygen and lowest in dielectric media as argon in hybrid EDM process.
Behnam Khosrozadeh, et al 2017[27]	Brass, Zink Coated Brass	Ti-6Al-4V	Low frequency of ultrasonic vibration will improve result of MRR
Behnam Khosrozadeh, et al 2017[28]	Copper	Ti-6Al-4V	The MRR of Hybrid machining process is more than the traditional EDM. The MRR of UAEDM is higher than Powder Mixed EDM (PMEDM) process and Powder Mixed UAEDM (PMEDM) has higher MRR than UAEDM.
an-Cherng Lin, et al 2017[29]	Copper	SKD 61 tool steel	The environment friendly feature can be found by use of gas as dielectric medium. By increase of peak current MRR is increased.

Author Name & Year	Tool Material	Work piece Material	Remarks (Material Removal Rate)
Param Singh, et al 2018[30]	Tungsten Carbide	Ti-6Al-4V	At 3Amp gap current and ultrasonic power increases from 0 to 120 W, Flushing efficiency is increased and also increase MRR up to 42.23%.
Atsutoshi Hirao, et al 2018[31]	Copper	High-tension steel (NAK 55)	Material removal rate found seven times At 6µm Amplitude of tool vibration. Further increase amplitude can increase material removal rate.
Albert Wen-Jeng Hsue, et al 2018[13]	---	SKD 61 High Speed Steel	Without rotation of tool, UAEDM contributes higher MRR. at 1500 rpm tool rotational UAEDM (RUEDM) decreasing MRR up to 51% and increasing rotational speed of tool further decreasing MRR.
M. Y. Tsai, et al 2018[33]	copper, copper-tungsten, graphite	titanium alloy (Ti-6A-4V)	Due to unstable flow of debris, The discharge time increases with increase depth of machining. Copper and Copper tungsten electrode have higher MRR with UAEDM than traditional EDM.
Param Singh, et al 2018[34]	tungsten carbide (WC)	Inconel 718 Superalloy	The Hole Sinking Ultrasonic Assisted Micro EDM (HSUAMEDM) has 2.85 times higher MRR than HSMEDM.

Source: Prepared by author through extensive review of articles and papers from renowned journals/conferences:

2.2 Tool Wear Rate (TWR):

V. S. R. Murti, P. K. Philip[15] comprehensively evaluates High C, high Cr steel with copper tool the influence of ultrasonic irradiation of spark gap on EDM characteristics for both planning and drilling operations. In Planning operation influence of Ultrasonic on tool wear rate is not cleared., as difference fluctuate on both side of zero, through the positive average value obtained from regression analysis suggests an increase in tool wear rate with ultrasonic.

Jatinder Kumar, J.S. Khamba, S.K. Mohapatra,[18] Experiments have been conducted to assess the effect of three factors-tool material, grit size of the abrasive slurry and power rating of ultrasonic machine on machining characteristics of titanium (ASTM Grade I) using full factorial approach for design and analysis of experiments and concluded that Tool Wear of High Carbon Steel is higher than titanium alloy as tool material. At Grit Size as 500 and power rating as 200W, Optimum tool wear rate is achieved for titanium alloy as tool material.

Albert Wen-Jeng Hsue, Tian-June Hab, Tsing-Ming Lin,[13] this examination proposed to UAEDM and RUEDM spindle with ultrasonic transducer for die sinking EDM and EDM Milling, the analyst incorporates examination of ultrasonic impact, shaft speed, peak current and feed rate on instrument ear rate of SKD 61 steel and found that There was induced as higher release recurrence was made by the garbage cell dividers with higher EDM heartbeat effectiveness. Be that as it may, it was went with an expense of higher apparatus wear rate.

E. Uhlmann, D. C. Domingos[22] author addresses the design and utilization of a unit composed of piezoelectric actuators for machining seal slots in turbine components with MAR-247 workpiece material and graphite as tool material and found that In EDM machining of deep cavities, the longitudinal vibration influences positively on tool wear. The relative tool electrode wear was reduced up to 21% by this experiments.

Param Singh, Vinod Yadava, Audhesh Narayan[30] examined Ti-6Al-4V workpiece material with Tungsten Carbide electrode and reported that At 3 to 2 A gap current with increase in ultrasonic power from 0 to 120 W decrease TWR significantly by 25.67% because of reducing in arc phenomenon by ultrasonic vibration. At 1A Lower value of gap current, it was observed that gradual increment with increase in ultrasonic power.

Table 2. Summery on progress of research work on Tool Wear Rate (TWR) for different tool material and work piece material.

Author Name	Tool Material	Work piece Material	Remarks (Tool Wear Rate)
Amir Abdullah et al 2008[35]	Copper	cemented tungsten carbide	The tool wear ratio of the UAEDM was higher than the tool wear ratio of traditional EDM..
M. R. Shabgard, et al 2009[36]	graphite	AISIH13 Tool Steel	Work piece ultrasonic vibration slightly reduces the tool wear ratio (TWR) on finishing regime.
Kuang-Yuan Kung et al 2009[12]	Copper	cobalt-bonded tungsten carbide	Increasing pulse on time increases EWR and Increasing discharge current also increases EWR.
Mohammadreza Shabgard, et al 2011[20]	graphite	FW4 Welding Metal	The TWR in USEDM process is higher than traditional EDM process in case larger pulse on time. This condition reverses with decreases in pulse on time.
M.R. Shabgard, et al 2013[21]	Copper	WC-Co Composite Materia	Tool Wear Ratio increases with decreasing of pulse on time and discharge current.
M. R. Shabgard, et al 2015[10]	Copper	Ti6Al4V	In shorter pulse duration Tool Wear Ratio in USEDM process is lower than traditional EDM process and it occurs inversely when increases duration of pulses.
Yan-Cherng Lin, et al 2016[26]	Copper	SKD 61 Tool Steel	Highest EWR was found when oxygen uses as dielectric medium and Lower EWR was found when argon uses as dielectric medium. As increasing of peak current ,EWR was increased.
Yan-Cherng Lin, et al 2017[29]	Copper	SKD 61 tool steel	The environment friendly feature can be found by use of gas as dielectric medium. By increase of peak current TWR is increased.
Param Singh, et al 2018[34]	tungsten carbide	Inconel 718 Superalloy	At high value of gap current, ultrasonic power give very good positive result which decrease in TWR. It give negative effect on TWR at lower value of gap current as 1A.

Source: Prepared by author through extensive review of articles and papers from renowned journals/conferences:

2.3 Surface Roughness:

Q.H. Zhang, J.H. Zhang, S.F. Ren, J.X. Deng, X. Ai[09], author conduct experiment on 45# steel and copper as tool material and it was observed that Surface Roughness was increased from 0.028 to 0.046mm with increasing pulse duration over range of amplitude examine.

A. S. Todkar, M. S. Sohani, G. S. Kamble, Rajan B. Nikam[37], the impacts of amplitude, vibration frequency, and electrical parameters on the machining execution, just as surface quality and precision of the small scale gaps have been explored. It has been found that The optimum vibration amplitude as 15 µm and frequency as 750 Hz produces improvement in machining process and surface quality. High vibration amplitude and frequency produces unstable machining process of surface quality and accuracy. Zhen Zhang Hao Huang Wuyi Ming Zhong Xu Yu Huang Guojun Zhang[24], author creator contemplated, a half and half strategy of WEDM utilizing helped ultrasonic vibration (USV)and attractive field (MF) is right off the bat proposed to improve the machine attributes, and afterward to examine the impacts of the principle procedure parameters on the MRR and surface quality including surface harshness (R) in machining Ti6Al4V by copper electrode and observed that the use of ultrasonic vibration to the work piece amid WEDM can all the more proficiently flush away the debris, building up the pulse discharge states with the goal that surface quality is progressed.

Yan-Cherng Lin, Jung-Chou Hung, Han-Ming Chow, A-Cheng Wang, Jyun-Ting Chen[26], consider explored the machining qualities of a created crossover procedure of electrical discharge machining (EDM) in gas joined with abrasive jet machining (AJM) and ultrasonic vibration (USV). The created cross breed EDM process was received to inspect the surface harshness (SR) for SKD 61 steel through the exploratory works. In this examination, the compacted dielectric media, for example, air, oxygen, and argon were utilized in the analyses to research the impacts on material evacuation productivity and surface respectability The exploratory outcomes demonstrate that SR picked up by the crossover EDM process was lower than that by EDM in gas. SR expanded with an expansion of peak current. the SR picked up by oxygen exhibited the most elevated esteem, and the SR showed the least as the ensuring argon was provided into the machining region.
Guang Zhu, Min Zhang, Qinhe Zhang, ZhenChao Song, Kan Wang[13] To enhance the preparing effectiveness, the present investigation executed electrical arc machining into VEDM and created a novel technique named vibration-helped electrical arc machining(VEAM). The impacts of vibration on the exhibitions of VEAM are considered, and a symmetrical analysis was planned and led to investigate the impacts of handling parameters on the machining practices. The outcomes show that The vibration of workpiece can expand the normal release hole, which results in a superior release condition and a progressively steady machining procedure. therefor the Rz was decreased by 39% contrasted with EDM without vibration when the full-wave vibration of 200 Hz was received. High flushing weight and high axle speed are advantageous for evacuating the release garbage, diminishing the length of electro-circular segment, and scattering release vitality; in this manner, with the expansion of shaft speed and flushing weight Rz decline.
Amir Abdullah & Mohammad R. Shabgard[35] conduct experiment on cemented tungsten carbide (WC-Co) and tool material as copper , M. R. Shabgard, B. Sadizadeh, H. Kakoulvand[36] conduct experiment on Titanium and tool material as High carbon steel and titanium alloy, Amir Abdullah & Mohammad R. Shabgard & A. Ivanov & Mohammad T. Shervanyi-Tabar[38] conduct experiment on cemented tungsten carbide (WC-Co) and tool mateial as copper, Mohammadreza Shabgard, Hamed Kakolvand, Mirsadegh Seyedzavvar, Ramin Mohammadpour Shotorbani[20] are found that Surface roughness achieved by UAEDM process is slightly higher than the roughness achieved by the normal EDM process.

Table 3. Summery on progress of research work on Surface Roughness (SR) for different tool material and workpiece material.

Author Name	**Tool Material**	**Work piece Material**	**Remarks (Tool Wear Rate)**
V. S. R. MURTI, et al 1987[15]	Copper	High C, high Cr steel	Extensively improve Surface finish.
Jatinder Kumar, et al 2008[18]	High Carbon Steel, titanium alloy	Titanium	Surface roughness value was negligible effected by tool material and power rating. Optimum value of surface roughness was found at 500 grit size for alumina for both tool material.
Chaiya Praneet pongrung, et al 2010[19]	copper tungsten (Cu-W)	sintered Si3N4 insulating ceramic	The surface roughness value was increased when applied ultrasonic vibration with EDM.
M.R. Shabgard, et al 2013[21]	Copper	WC-Co Composite Material	Increasing Pulse Duration and Discharge Current increasing the surface roughness in machining with tungsten carbide.

Author Name	Tool Material	Work piece Material	Remarks (Tool Wear Rate)
A. M. Nikalje, et al 2013[39]	Copper	Maraging steel (MDN 300)	Longer pulse on time and higher discharge current produces rougher surface with more crater, micro crack and globules of debris than lower pulse on time and discharge current.
M. Iwai, et al 2013[40]	Copper	PCD	applying ultrasonic vibrations to the terminal acquired little distinction the surface roughness of the workpiece in correlation with the situation when no vibration was given, appearing great condition.
Aminollah Mohammadi, et al 2015[11]	-----	-------	Relatively High time off and high rotational speed can be produce improved surface finish and reduce surface roughness.
M. Goiogana, et al 2016[41]	Copper	1.2344 tempered alloy steel	The roughness value was lowered 14% in centered and 20% in bordered area of machined surface. The surface roughness accomplished without US(UltraSonic) vibration was enhanced presenting beat US vibration in the completing EDM process.
P. Radhakrishnan, et al 2017[27]	Brass, Zink Coated Brass	Ti-6Al-4V	The normal roughness estimation of the machined surface enhances as the recurrence of wire vibration is expanded..
Behnam Khosrozadeh, et al 2017[28]	Copper	Ti-6Al-4V	Applying ultrasonic vibration increased surface roughness of machined specimens; the lowest surface roughness among the mentioned hybrid processes belonged to PMEDM process.
M. Y. Tsai, et al 2018[33]	copper, copper-tungsten, and graphite	titanium alloy (Ti-6A-4V)	The machined by vibration-helped EDM indicated less smaller scale pores and holes per unit territory contrasted with machined without vibration help.

Source: Prepared by author through extensive review of articles and papers from renowned journals/conferences:

2.4 Other Parameters:

M. R. Shabgard, H. Alenabi [10], an endeavor was made to research the impact of copper device vibration with ultrasonic frequency on output parameters in Electrical Discharge Machining of Ti-6Al-4V and The results revealed that In low pulse energies, recast layer thickness in both US-EDM and EDM mode are not all that extraordinary. In high pulse energies, thickness of recast layer, length and thickness of splits in US-EDM are more than regular EDM.

M.G. Xu, J.H. Zhang, Y.L, Q.H. Zhang, S.F. Ren [42], experimental equipment was planned by which a progression of machining tests of solidified carbide material by copper tool electrode were completed. The systems of solidified carbide material expulsion are examined in detail through watching and breaking down the miniaturized scale structures of machined surface and found that The smaller crack depend not just on electrical parameters, for example, release voltage, pulse on time, peak current and so on, yet in addition on properties of solidified carbide that was machined, for example, thermal conductivity, melting point, crack durability, and so on

Zhao Wansheng, Wang Zhenlong, Di Shichun, Chi Guanaxin, Wei Hongyu [43], author conduct experiment on Ti6-Al4-V by carbide YG6X tool material and observed that a rotating single notch micro electrode to EDM a small and deep hole can enlarge the space through which the debris flows, and therefore increase the machining efficiency and minimize the machining taper.

Rendi Kurniawan, S. Thirumalai Kumaran, V. Arumuga Prabu, Yu Zhen, Ki Moon park, Ye In Kwak, Md. Mofizul Islam, Tae Jo Ko [44], A ultrasonic helped dry electrical release machining (US-EDM) process in a gaseous fluid medium was proposed to evacuate the burrs framed on the leave area of a penetrated gap. In fundamental analysis, three distinctive cathode instruments (copper, metal, and aluminum) were used. In auxiliary analysis, US-EDM and dry-EDM were looked at and performed utilizing the copper electrode and found that Higher Burr removal Rate (BRR) and Debarring quality achieved by Copper than Brass and Aluminum and also BRR increased non-linearly with voltage and linearly with capacitance. BRR decreased when ultrasonic vibration amplitude increased.

Table 4. Summery on progress of research work on other parameters for different tool material and workpiece material.

Author Name	**Tool Material**	**Work piece Material**	**Parameter**	**Remarks (Tool Wear Rate)**
Amir Abdullah, et al 2009[38]	Copper	cemented tungsten carbide (WC-Co)	Recast Layer	Ultrasonic vibration of the apparatus, connected particularly to completing mode machining, diminishes the thickness of recast layer.
Yan-Cherng Lin, et al 2016[26]	Copper	SKD 61 Tool Steel	Recast Layer	The thickness of the recast layer gotten by the EDM in gas joined with AJM was thicker than that acquired by the created hybrid EDM process.
Mohammad Reza Shabgard, et al 2108[45]	Copper	H13 hot work tool steel	Recast Layer	Applying ultrasonic vibrations to EDM process builds plasma flushing productivity and diminishes the measure of made recast layer thickness on machined surface in all pulse flows and term.
Amir Abdullah et al 2009[38]	Copper	cemented tungsten carbide (WC-Co)	Crack	Ultrasonic vibration of the instrument, connected particularly to completing mode machining, diminishes the thickness of the Heat affected zone (HAZ) and recast layer, and by along these lines decreases the numbers, size and profundity of ordinary and transverse breaks showing up on the machined surface.
P. Radhakrishnan, et al 2017[27]	Brass, Zink Coated Brass	Ti-6Al-4V	Crack	The cracks are generated more while machining with brass wire compared zinc coated brass wire.
Behnam Khosrozadeh, et al 2017[28]	Copper	Ti-6Al-4V	Crack	Reduces crack while machining by ultrasonic assisted EDM process than traditional EDM process.
Param Singh, et al 2018[30]	Tungsten Carbide	Ti-6Al-4V	Taper	Taper angle decline altogether by 33.96% at 3 and 2 A hole current, with increment in ultrasonic power from 0 to 120 W because of decrease in arcing marvels by the ultrasonic vibration, while at low estimation of hole current (1 A), steady addition in Taper angle is seen with increment in ultrasonic power.

Source: Prepared by author through extensive review of articles and papers from renowned journals/conferences:

3. SUMMARY OF LITERATURE REVIEW:

The researchers formulated and tested various applied hypothesis experimentally under various controllable parameters to evaluate the probability rather than the certainty of effects summarized in this paper. A few researchers have tested the working hypothesis such as material removal rate (MRR), Tool Wear Rate (TWR), Surface Roughness (SR), Taper, Crack, Recast Layer, Burr removal Rate (BRR)etc.
Material removal rate is mainly influenced by current, voltage, pulse on and pulse off time, which are electrical parameters and also affected by ultrasonic power, frequency and amplitude. By increasing

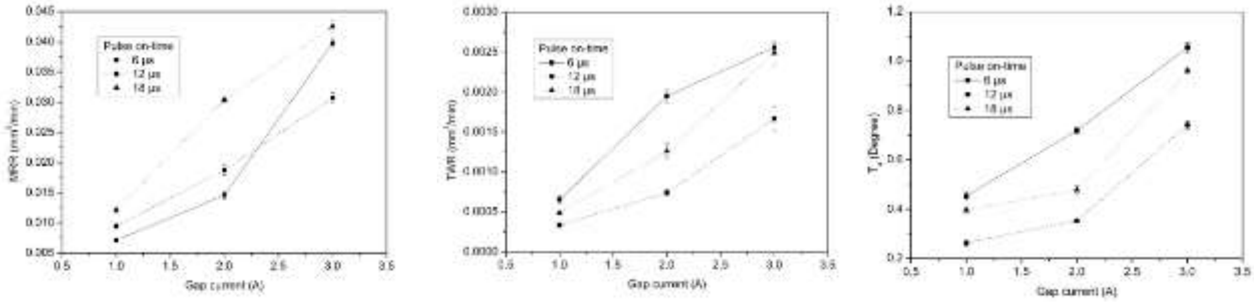
gape current, pulse on time, ultrasonic power material removal rate is increased because of increasing heat at workpiece material and vaporize material very quickly.[13,20,21,26,35,36] Flushing pressure, Electrode or tool Size, and capacitance are those parameters which not influence to material removal rate. As pulse off time increase material removal rate is decrease.[20,21,36] Material removal rate is higher in gaseous medium than liquid medium.[26] As ultrasonic power increases material removal rate is increases.[19,23] Due to adding ultrasonic effect material removal rate is higher than traditional EDM process.[10,13,20,24,25,28,35,36]

Tool Wear Rate is for the most part influenced by current, voltage, pulse on and pulse off time, which are electrical parameters and furthermore influenced by ultrasonic power, recurrence and adequacy same as material expulsion rate. By expanding gape current, pulse on time, ultrasonic power tool wear rate is expanded in view of higher warmth produced to apparatus and workpiece contact zone.[05,13,20,21,29,39,49] Flushing pressure, Electrode or tool Size, and capacitance are those parameters which not impact to Tool Wear Rate. tool wear rate is decline as pulse off time increment.[20,21] Tool wear rate is higher in gas dielectric medium than fluid dielectric medium. [05,26,29] Tool wear rate in USEDM process is lower than customary EDM process. [05, 13, 20, 22, 30, 35, 49] As ultrasonic power expands Tool Wear rate is diminished. [13,30]

Surface Roughness is manly influenced by pulse on time, current, voltage, amplitude and ultrasonic power. Surface roughness is less influenced by frequency, capacitance of ultrasonic, tool material, tool size and polarity. as current increases surface roughness increase because higher hearting create larger vapor bubble and higher burr from surface of workpiece. as pulse on time increases surface roughness decreases up to some extend and further increase pulse on time increase surface roughness.[13,20,21,41] as pulse off time and ultrasonic power increases surface roughness is increase. [27] Surface roughness in USEDM is lower than Traditional EDM. [19,20,24,26,28,35,36,38,41]

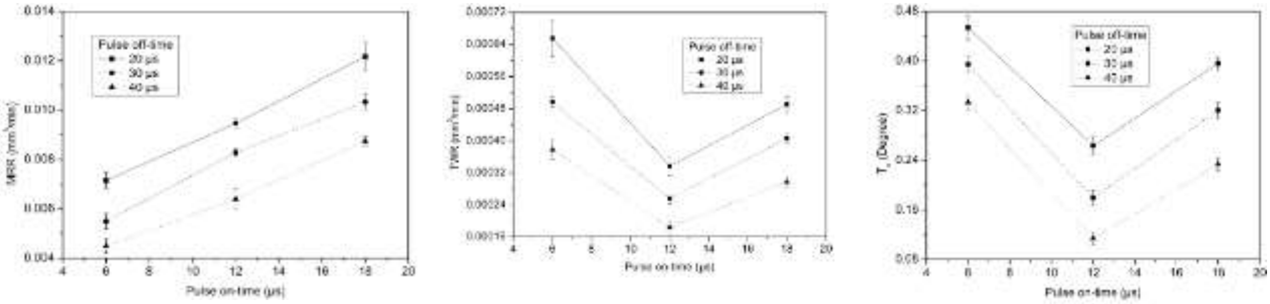
Crack in traditional EDM process is developed larger and bigger on surface of workpiece than Ultrasonic assisted EDM process.[27,28,38] The smaller crack depend not just on electrical discharge parameters, for example, discharge voltage, peak current, pulse on time, and so forth, yet additionally on properties of tool material that was machined, for example, melting point, thermal conductivity, crack durability, and so on.[42]. Taper angle reduced significantly gap current, with raising in ultrasonic power due to diminution in arcing phenomena by the ultrasonic vibration, while at small value of gap current, gradual growth in Taper angle is observed with increase in ultrasonic power.[30] Utilizing a turning single indent small scale anode to EDM a small and profound opening can broaden the space through which the debris streams, and along these lines increment the machining proficiency and limit the machining Taper.[43] In low pulse energies, recast layer thickness in both US-EDM and EDM models are not all that extraordinary. In high pulse energies, thickness of recast layer, length and thickness of splits in US-EDM are more than traditional EDM.[10, 38, 29]

Machining characteristics like material removal rate,[48,49,12] tool wear rate,[48,49,39,12] surface roughness,[48,49,50,39] crack and recast layer of W300 Steel [46], Bright Mild Steel,[47] AISI D3 Steel,[25] EN8 Steel,[48] Al2124Sic25p supplied by Materion Aerospace Metal Composites,[49] Inconel 718,[50] Aerospace Nickel Alloy,[50] titanium grade 6, Maraging steel (MDN 300),[39] materials are examined by use of traditional EDM machining process only by electrode or tool material like copper, brass, copper tungsten etc.



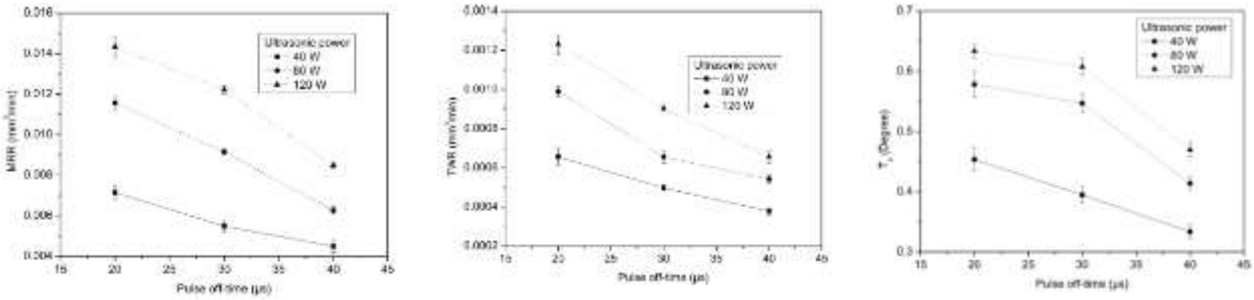
(a) (b) (c)

Fig. 5 Effect of Gap Current on (a) MRR (b) TWR (c) T_a at T_{off} = 20 µs and U_p=40 W for different Pulse on Time [34]



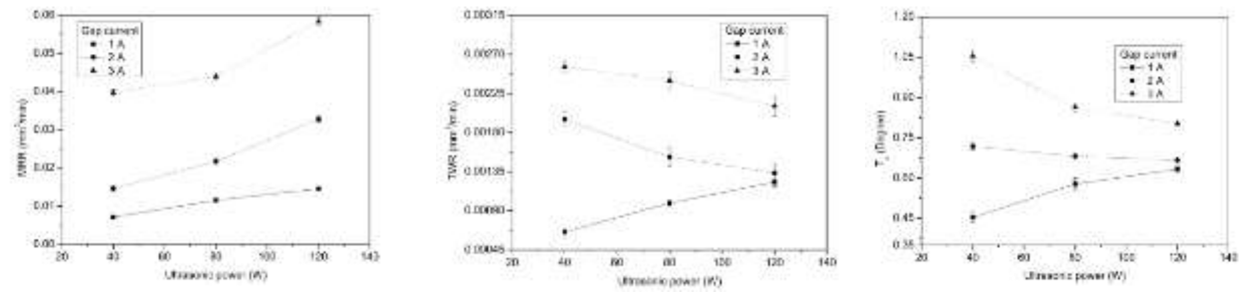
(a) (b) (c)

Fig. 6 Effect of Pulse on Tome on (a) MRR (b) TWR (c) T_a at I_g=1A and Up=40 W for different Pulse off Time [34]



(a) (b) (c)

Fig. 7 Effect of Pulse off Tome on (a) MRR (b) TWR (c) T_a at I_g=1A and T_{on}=6 µs for different values of ultrasonic power [34]



(a) (b) (c)

Fig. Effect of Ultrasonic Power on (a) MRR (b) TWR (c) T_a at T_{off}=20 µs and T_{on}=6 µs for different values of ultrasonic power [34]

Source : Param Singh et all 2018 Journal of Advanced Manufacturing Systems (JAMS)

4. CONCLUSION & FUTURE RESEARCH DIRECTION:

EDM is one of the broadly utilized flighty machining technique that is fit for delivering the unpredictable shapes. The main impediment in the EDM is the work piece ought to be conductive in nature. With the time there is part of enhancements in the EDM and its helped procedures just as streamlining systems, which made some new research scopes in the EDM. A few investigations found that non-electrical parameters additionally assume an imperative job in the execution of the EDM. Advancements in displaying systems have made new research scopes in the EDM and enhances the execution of EDM process. In light of the different research work displayed the accompanying perceptions are made based on this review work.

a) In this review paper, there is accumulation of different research work in the field of helped EDM process improvements which have been created to give the better surface completion and great quality items at the lower cost.

b) It is discovered that both the electrical and nonelectrical parameters assume an essential job in the execution of EDM process yet a few investigations announced that non-electrical parameters are fundamental parameters which influences the surface nature of the item.

c) It is additionally discovered that there are loads of enhancement in the advancement systems yet the goal is same for all the streamlining methods to enhance the EDM execution, to get the ideal yield from the information and to build up some new crossover strategies to machine new materials under the better working conditions.

d) Machining characteristics of W300 Steel, Bright Mild Steel, AISI D3 Steel, EN8 Steel, Al2124SiC25p, Titanium Grade 6, MDN 300 Steel were investigated by traditional EDM process. Machining Characteristic can be improved by use of UAEDM process and also found optimum machining process parameters by use of different optimization techniques.

Acknowledgements:

The authors would like to acknowledge the support and motivation from Commissionerate of Technical Education, Gujarat State, and Gujarat Technological University (GTU), Gujarat State. The authors are also thankful to all those who contributed, supported and motivated directly or indirectly for carrying out research.

Declaration of conflicting interests: The authors declare that there is no conflict of interest.

5. REFERENCES:

1. Kumar, S., Grover, S., & Walia, R. S. (2017). Optimisation strategies in ultrasonic vibration assisted electrical discharge machining: a review. International Journal of Precision Technology, 7(1), 51-84.
2. Khatri, B. C., Rathod, P., & Valaki, J. B. (2016). Ultrasonic vibration–assisted electric discharge machining: A research review. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 230(2), 319-330.
3. Jamwal, A., Aggarwal, A., Gautam, N., & Devarapalli, A. (2018). Electro-Discharge Machining: Recent Developments and Trends.
4. MAITY, K., & CHOUBEY, M. (2018). A REVIEW ON VIBRATION-ASSISTED EDM, MICRO-EDM AND WEDM. Surface Review and Letters, 1830008
5. Selvarajan, L., Manohar, M., Jayachandran, J. A. R., Mouri, P., & Selvakumar, P. (2018). A Review on Less Tool Wear Rate and Improving Surface Quality of Conductive Ceramic Composites by Spark EDM. Materials Today: Proceedings, 5(2), 5774-5782
6. Singh, A., Kumar, A., Kumar, S., Kumar, A., & Vidya, S. (2018). A Review on Research Aspects and Trends in Electrical Discharge Machining (EDM).
7. Sandeep Kumar, Sumit, Tarun Saini and Sumit Sabharwal (2016). Hybrid Electric Discharge Machining Processes: A Review. Research Journal of Engineeerign Science, 5(8), 14-21
8. Lee, T. C., Zhang, J. H., & Lau, W. S. (1998). Machining of engineering ceramics by ultrasonic vibration assisted EDM method. MATERIAL AND MANUFACTURING PROCESS, 13(1), 133-146.

9. NIR-57 Zhang, Q. H., Zhang, J. H., Ren, S. F., Deng, J. X., & Ai, X. (2004). Study on technology of ultrasonic vibration aided electrical discharge machining in gas. Journal of Materials Processing Technology, 149(1-3), 640-644.
10. Shabgard, M. R., & Alenabi, H. (2015). Ultrasonic assisted electrical discharge machining of Ti–6Al–4V alloy. Materials and Manufacturing Processes, 30(8), 991-1000.
11. Mohammadi, A., Fadaei Tehrani, A., & Abdullah, A. (2015). Modelling and optimisation of the process parameters in ultrasonic-assisted wire electrical discharge turning. Advances in Materials and Processing Technologies, 1(3-4), 338-349.
12. NIR-65 Kung, K. Y., Horng, J. T., & Chiang, K. T. (2009). Material removal rate and electrode wear ratio study on the powder mixed electrical discharge machining of cobalt-bonded tungsten carbide. The International Journal of Advanced Manufacturing Technology, 40(1-2), 95-104.
13. Zhu, G., Zhang, M., Zhang, Q., Song, Z., & Wang, K. (2018). Machining behaviors of vibration-assisted electrical arc machining of W9Mo3Cr4V. The International Journal of Advanced Manufacturing Technology, 96(1-4), 1073-1080.
14. Shervani-Tabar, M. T., & Shabgard, M. R. (2011). Numerical study on the effect of the frequency and amplitude of the tool on the material removal rate in ultrasonic-assisted electrical discharge machining. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225(3), 408-413
15. Murti, V. S. R., & Philip, P. K. (1987). A comparative analysis of machining characteristics in ultrasonic assisted EDM by the response surface methodology. International Journal of Production Research, 25(2), 259-272.
16. Kremer, D., Lebrun, J. L., Hosari, B., & Moisan, A. (1989). Effects of ultrasonic vibrations on the performances in EDM. CIRP Annals-Manufacturing Technology, 38(1), 199-202.
17. Zhang, Q. H., Du, R., Zhang, J. H., & Zhang, Q. B. (2006). An investigation of ultrasonic-assisted electrical discharge machining in gas. International Journal of Machine Tools and Manufacture, 46(12-13), 1582-1588.
18. Kumar, J., Khamba, J. S., & Mohapatra, S. K. (2008). An investigation into the machining characteristics of titanium using ultrasonic machining. International Journal of Machining and Machinability of Materials, 3(1-2), 143-161.
19. Praneetpongrung, C., Fukuzawa, Y., Nagasawa, S., & Yamashita, K. (2010). Effects of the EDM combined ultrasonic vibration on the machining properties of Si3N4. Materials transactions, 51(11), 2113-2120.
20. Shabgard, M., Kakolvand, H., Seyedzavvar, M., & Shotorbani, R. M. (2011). Ultrasonic assisted EDM: Effect of the workpiece vibration in the machining characteristics of FW4 Welded Metal. Frontiers of Mechanical Engineering, 6(4), 419-428.
21. Shabgard, M. R., Badamchizadeh, M. A., Ranjbary, G., & Amini, K. (2013). Fuzzy approach to select machining parameters in electrical discharge machining (EDM) and ultrasonic-assisted EDM processes. Journal of Manufacturing Systems, 32(1), 32-39.
22. Uhlmann, E., & Domingos, D. C. (2013). Investigations on vibration-assisted EDM-machining of seal slots in high-temperature resistant materials for turbine components. Procedia CIRP, 6, 71-76.
23. Uhlmann, E., & Domingos, D. C. (2016). Investigations on vibration-assisted EDM-machining of seal slots in high-temperature resistant materials for turbine components–part II. Procedia Cirp, 42, 334-339.
24. Zhang, Z., Huang, H., Ming, W., Xu, Z., Huang, Y., & Zhang, G. (2016). Study on machining characteristics of WEDM with ultrasonic vibration and magnetic field assisted techniques. Journal of Materials Processing Technology, 234, 342-352.
25. Che, J., Zhou, T., Zhu, X., Kong, W., Wang, Z., & Xie, X. (2016). Experimental study on horizontal ultrasonic electrical discharge machining. Journal of Materials Processing Technology, 231, 312-318.

26. Lin, Y. C., Hung, J. C., Chow, H. M., Wang, A. C., & Chen, J. T. (2016). Machining characteristics of a hybrid process of EDM in gas combined with ultrasonic vibration and AJM. Procedia CIRP, 42, 167-172.
27. Radhakrishnan, P., & Vijayaraghavan, L. (2017). Assessment of material removal capability with vibration-assisted wire electrical discharge machining. Journal of Manufacturing Processes, 26, 323-329.
28. Khosrozadeh, B., & Shabgard, M. (2017). Effects of hybrid electrical discharge machining processes on surface integrity and residual stresses of Ti-6Al-4V titanium alloy. The International Journal of Advanced Manufacturing Technology, 93(5-8), 1999-2011.
29. Lin, Y. C., Hung, J. C., Lee, H. M., Wang, A. C., & Chen, J. T. (2017). Machining characteristics of a hybrid process of EDM in gas combined with ultrasonic vibration. The International Journal of Advanced Manufacturing Technology, 92(5-8), 2801-2808.
30. Singh, P., Yadava, V., & Narayan, A. (2018). Parametric study of ultrasonic-assisted hole sinking micro-EDM of titanium alloy. The International Journal of Advanced Manufacturing Technology, 94(5-8), 2551-2562.
31. Hirao, A., Gotoh, H., & Tani, T. (2018). Some Effects on EDM Characteristics by Assisted Ultrasonic Vibration of the Tool Electrode. Procedia CIRP, 68, 76-80.
32. Hsue, A. W. J., Hab, T. J., & Lin, T. M. (2018). Pulse Efficiency and Gap Status of Rotary Ultrasonic Assisted Electrical Discharge Machining and EDM Milling. Procedia CIRP, 68, 783-788.
33. Tsai, M. Y., Fang, C. S., & Yen, M. H. (2018). Vibration-assisted electrical discharge machining of grooves in a titanium alloy (Ti-6A-4V). The International Journal of Advanced Manufacturing Technology, 1-8.
34. Singh, P., Yadava, V., & Narayan, A. (2018). Machining Performance Characteristics of Inconel 718 Superalloy Due to Hole-Sinking Ultrasonic Assisted Micro-EDM. Journal of Advanced Manufacturing Systems, 17(01), 89-105.
35. Abdullah, A., & Shabgard, M. R. (2008). Effect of ultrasonic vibration of tool on electrical discharge machining of cemented tungsten carbide (WC-Co). The International Journal of Advanced Manufacturing Technology, 38(11-12), 1137-1147.
36. Shabgard, M. R., Sadizadeh, B., & Kakoulvand, H. (2009). The effect of ultrasonic vibration of workpiece in electrical discharge machining of AISIH13 tool steel. World Academy of Science, Engineering and Technology, 3, 332-336.
37. Todkar, A. S.; Sohani, M. S.; Kamble, G.S; Rajan, B (2013). Effects of Vibration on Electro Discharge Machining Processes. International Journal of Engineering and Innovative Technology (IJEIT), 3 (1), 270-275
38. Abdullah, A., Shabgard, M. R., Ivanov, A., & Shervanyi-Tabar, M. T. (2009). Effect of ultrasonic-assisted EDM on the surface integrity of cemented tungsten carbide (WC-Co). The International Journal of Advanced Manufacturing Technology, 41(3-4), 268.
39. Nikalje, A. M., Kumar, A., & Srinadh, K. S. (2013). Influence of parameters and optimization of EDM performance measures on MDN 300 steel using Taguchi method. The International Journal of Advanced Manufacturing Technology, 69(1-4), 41-49.
40. Iwai, M., Ninomiya, S., & Suzuki, K. (2013). Improvement of EDM properties of PCD with electrode vibrated by ultrasonic transducer. Procedia CIRP, 6, 146-150.
41. Goiogana, M., Sarasua, J. A., Ramos, J. M., Echavarri, L., & Cascón, I. (2016). Pulsed ultrasonic assisted electrical discharge machining for finishing operations. International Journal of Machine Tools and Manufacture, 109, 87-93.
42. Xu, M. G., Zhang, J. H., Li, Y., Zhang, Q. H., & Ren, S. F. (2009). Material removal mechanisms of cemented carbides machined by ultrasonic vibration assisted EDM in gas medium. Journal of materials processing technology, 209(4), 1742-1746.

43. Wansheng, Z., Zhenlong, W., Shichun, D., Guanxin, C., & Hongyu, W. (2002). Ultrasonic and electric discharge machining to deep and small hole on titanium alloy. Journal of Materials Processing Technology, 120(1-3), 101-106.
44. Kurniawan, R., Kumaran, S. T., Prabu, V. A., Zhen, Y., Park, K. M., Kwak, Y. I., ... & Ko, T. J. (2017). Measurement of burr removal rate and analysis of machining parameters in ultrasonic assisted dry EDM (US-EDM) for deburring drilled holes in CFRP composite. Measurement, 110, 98-115.
45. Shabgard, M. R., Gholipoor, A., & Mohammadpourfard, M. (2018). Numerical and experimental study of the effects of ultrasonic vibrations of tool on machining characteristics of EDM process. The International Journal of Advanced Manufacturing Technology, 1-13.
46. Büttner, H., Roth, R., & Wegener, K. (2018). Limits of Die-Sinking EDM for micro Structuring in W300 Steel with pure Copper Electrodes. Procedia CIRP, 77, 646-649.
47. Kumaran, S. T., Ko, T. J., & Kurniawan, R. (2018). Grey fuzzy optimization of ultrasonic-assisted EDM process parameters for deburring CFRP composites. Measurement, 123, 203-212
48. Kishan, B., Premkumar, B. S., Gajanana, S., Buchaiah, K., & Gaffar, M. A. (2018). Development of Mathematical Model for Metal Removal Rate on EDM using Copper & Brass Electrodes. Materials Today: Proceedings, 5(2), 4345-4352.
49. Shyha, I., & Rudd, M. (2016). Electro-discharge machining of metal matrix composite materials. Advances in Materials and Processing Technologies, 2(2), 235-244.
50. Tanjilul, M., Ahmed, A., Kumar, A. S., & Rahman, M. (2018). A study on EDM debris particle size and flushing mechanism for efficient debris removal in EDM-drilling of Inconel 718. Journal of Materials Processing Technology, 255, 263-274.
51. Yadav, U. S., & Yadava, V. (2014). Parametric study on electrical discharge drilling of aerospace nickel alloy. Materials and Manufacturing Processes, 29(3), 260-266.