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A report on

ELECTROCHEMICAL DISCHARGE MACHINING (ECDM) OF CONDUCTING AND NON-CONDUCTING CERAMICS

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Advanced Machining Process (ME 688)

1. Introduction

ECDM

ECDM is a hybrid process, combining features of EDM and ECM process. The hybrid ECDM process is five to fifty times faster than its parent processes. EDM and ECM process can machine only electrically conductive material, but ECDM can machine both conductive and non-conductive materials. ECDM is a newly developed machining technique where both thermal action and chemical reaction contribute to the material removal from workpiece. ECDM process is an alternative solution to the earlier existing expensive process. The process requires lesser components and is easier to handle compared to the other sophisticated process such as laser beam machining, abrasive water jet machining, etc. As the process is hybrid in nature and it is recently developed therefore the process is in developing stage. The exact mechanism and other aspects are under research.

Therefore, the process is not being fully commercialized and lot of research scope is available. In machining process, there are few issues such as poor surface roughness, environmental and health issues. The fumes produced during machining cause suffocations, and if chemical solution not handled properly, it causes skin problems. The electrochemical discharge machining (ECDM) process is widely investigated in last few decades for machining of variety of materials like glass (Singh and Dvivedi, 2018a, 2018b), ceramics (Bhattacharyya et al., 1999), DZ125L alloy (Zhang et al., 2015), steel (Chavoshi and Behagh, 2014) etc.

This process has emerged as a promising technique for machining micro features such as blind and through holes (Singh and Dvivedi, 2018a, 2018b), grooves (Han et al., 2017), channels (Singh and Dvivedi, 2018a, 2018b), slits (Yang et al., 2006) and complex shapes on electrically non-conductive materials (Zheng et al., 2007a, 2007b) and (Cao et al., 2009).

Ceramics

A ceramic is any of the various hard, brittle, heat-resistant and corrosion-resistant materials made by shaping and then firing an inorganic, non-metallic material, such as clay, at a high temperature. They have incredible strength-to-weight ratio.

There are two types of ceramics:

a. Traditional ceramics: Eg. Earthen pots, Bone-China etc.
b. Advanced ceramics: Eg. Alumina, Silicon carbide, Ruthenium oxide etc.

Advanced ceramic material have superior properties such as high hardness and strength at elevated temperatures, chemical inertness, high wear resistance, low thermal conductivity, high corrosion resistance, oxidation resistance, lower thermal expansion coefficient, low density, high-temperature stability, light weight, high compressive strength, a stronger electromagnetic response than that of metals and good creep resistance due to this it is used as wide application.

2. Machine Set-up

ECDM set-up consists of two electrodes namely, tool electrode (cathode) and auxiliary electrode (anode). Both electrodes are partially immersed in an electrolytic solution.

The work piece is placed below the tool electrode as shown in Fig. 1.

The size of both the electrodes are different, usually size of the auxiliary electrode much larger than the tool electrode which helps to generate potential difference in between two electrodes. When DC power is supplied to both the electrodes it causes the electrolysis process.

When a voltage higher than a critical voltage is supplied, the electric discharge occurs in between the tool electrode and the workpiece.

For conducting materials, the workpiece acts as anode and there is no need of an auxiliary electrode.

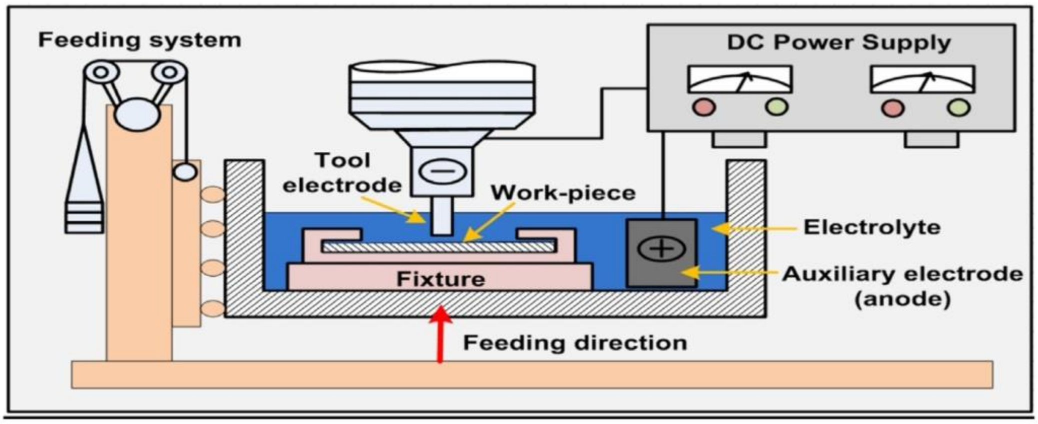


Fig. 1. Schematic diagram of ECDM setup

3. Working Principle

In the ECDM process, the material removal is a combined effect of ECM and EDM processes. The material is removal from workpiece during the process is due to melting, vaporization, high temperature chemical etching, thermal stress and mechanical shocks due to expanding gases.

In the ECDM process, the constant DC supply voltage (continuous or pulse) is applied to the tool and auxiliary electrode, dipped in the electrolyte solution. An electrochemical reaction happens between the anode and the cathode dipped in the electrolyte medium during the process. The potential difference is created between the tool and auxiliary electrode as a result and there is a generation of hydrogen (H_2) and oxygen (O_2) gases on their surfaces respectively.

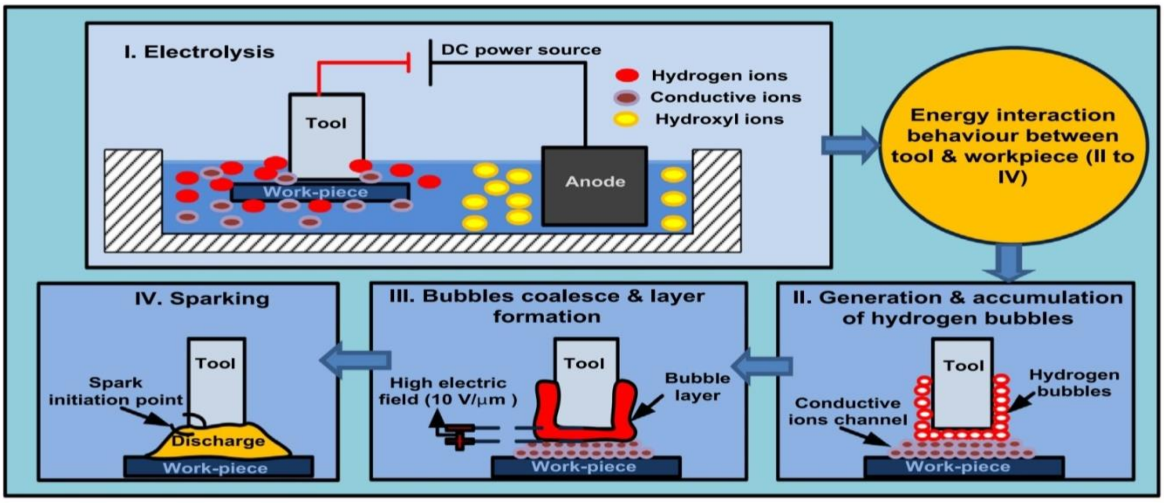


Fig. 2. Process mechanism of ECDM

Fig. 2 represents the schematic view of the discharge mechanism that includes the following steps (i) electrolysis, (ii) generation and accumulation of hydrogen gas bubbles, (iii) bubble coalesce and gas film formation, (iv) sparking.

Electro-Chemical reaction takes place as:

- Reactions at anode & electrolyte interface are

  $M \rightarrow M^{z+} + Z^{e-}$

  $M^{z+} + Z(OH)^{-} \rightarrow M(OH)_z$

  $2H_2O \rightarrow O_2 + 4H^{+} + 4e^{-}$ (In acidic solution)

  $4(OH)^{-} \rightarrow O_2 + 2H_2O + 4e^{-}$ (in alkaline solution)

- Reactions at cathode and electrolyte interface are

  $2H^{+} + 2e^{-} \rightarrow H_2$ (In acidic solution)

  $2H_2O + 2e^{-} \rightarrow 2(OH) + H_2$ (in alkaline solution)

The generation of the H_2 gas bubble in between the tool electrode and workpiece is an important aspect in the ECDM process.

Beyond the critical voltage, the physical contact of hydrogen gas bubbles with each other formed big sized single gas bubble and gets converted into hydrogen gas film around the tool electrode.

The hydrogen gas film behaves like a dielectric medium between the cathode tool and the electrolyte and acts as an insulator around the tool electrode. This insulation of tool electrode, almost ceases the flow of current. When DC voltage reaches to the critical voltage, it develops high electric field across the dielectric film and that results in arc discharge.

Critical voltage depends on many factors like tool material, tool geometry, electrolyte concentration and conductivity of the electrolyte which directly effects the spark formation during the process.

4. Effect of Process parameters

4.1 Voltage

In ECDM process, the gas film on the electrode surface is used as the dielectric medium required for discharge generation. Quality of gas film is the dominant factor that determines the machining qualities such as geometric accuracy, surface roughness and repeatability. Nevertheless, it is difficult to assess the gas film quality of ECDM.

Experimental results showed by Chih-Ping Cheng et.al., suggests that a stable and dense gas film could be obtained when the applied voltage exceeded the critical voltage and reached a specific level, which is called the ''transition voltage'' in this study.

At the transition voltage, a stable electrochemical discharge activity could be generated, thus producing the smallest deviation of contour dimensions. Moreover, when the drilling process reached a certain critical depth, bubbles inside the hole could not easily escape.

In order to reduce the interface energy between bubbles, a thicker gas film is formed at the hole entrance, resulting in unstable discharge performance that undermined machining results.

In summary, information provided by current signals can shed light on the changes in gas film structure, which serve as useful reference for varying process parameters to achieve better efficiency and accuracy.

Effects of applied voltage on gas film quality and machining characteristics:

Chih-Ping Cheng et.al., observed the effect of Applied Voltage on material removal rate. Fig. 3 shows morphologies of gas film obtained at different applied voltages. As it can be seen, at lower applied voltage of 30–35 V, the generation of electrolysis bubbles was less intense. There was sufficient time for the electrolysis bubbles to join together or become bigger so as to reduce the interface energy between bubbles. The gas film was either in the state of single- bubble formation as seen in Fig. 3 (a), or of bubbles coalescing loosely, as seen in Fig. 3 (b).

Since large bubbles could easily detach from the electrode surface under buoyancy effect, the electrolyte would come in contact with the electrode, thus producing electrolysis current but not discharge current (the gas film is not yet completely formed).

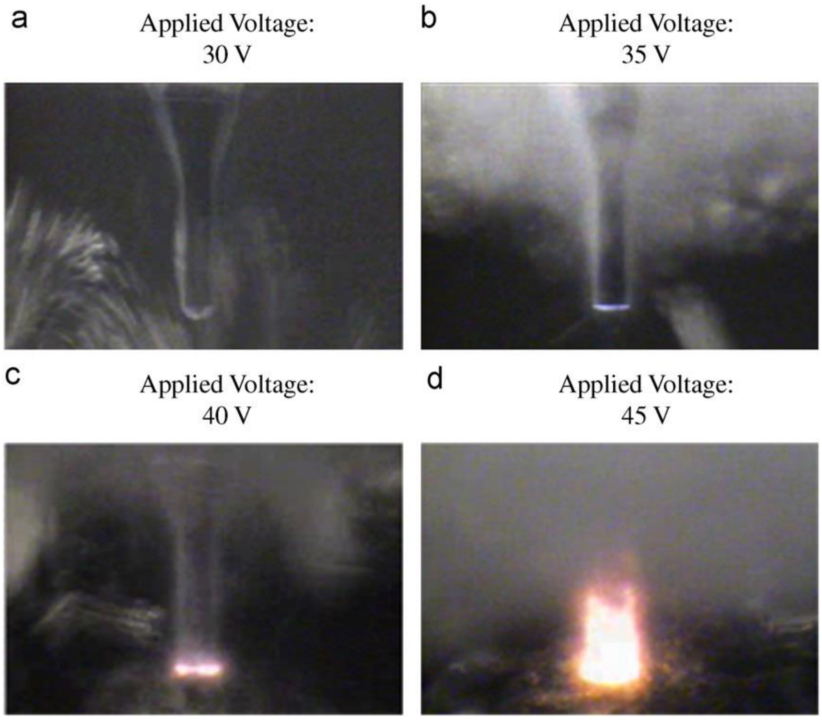


Fig 3. Images of gas film morphology obtained at different applied voltages

As applied voltage reached 40V, the generation of electrolysis bubbles became more intense. Before the bubbles combined in to larger ones, tiny and dense bubbles had completely blanketed the electrode with a thin gas film being formed, as seen in Fig. 3(c).

Hence, stable gas film could be easily produced and stable discharge could be maintained throughout. With further increase in applied voltage (40 V), drastic light emission was presented around the tool, as shown in Fig. 3(d).

Fig. 4 shows the corresponding current signals obtained at different applied voltages. It should be noted that the current peaks are in the range of 0.2–0.4A, as indicated by Wuthrich to be effective discharge form a chinning.

Owing to instability of gas film quality, the electrolyte would come in contact with the electrode, and the peak of electrolysis current would then rise above 0.4A, even up to several Amperes.

However, the electrolysis current could not perform material removal. As mentioned above, it is easy to identify the current signal performance in Fig. 4. Within the range of 30–35V, the current signals show interlocking of electrolysis and discharge currents due to unstable gas film quality, as seen in Figs. 4(a) and(b).

Moreover, it was also indicated by A.Allagui in his research paper that the gas film is more stable at high applied voltages. At applied voltage of 40 V, a stable gas film structure can be sustained on the tool surface all the time (without re-construction problem). The current signals show a full discharge current flow and the current peaks are within the range (0.2–0.4A) for effective machining, as seen in Fig. 4(c).

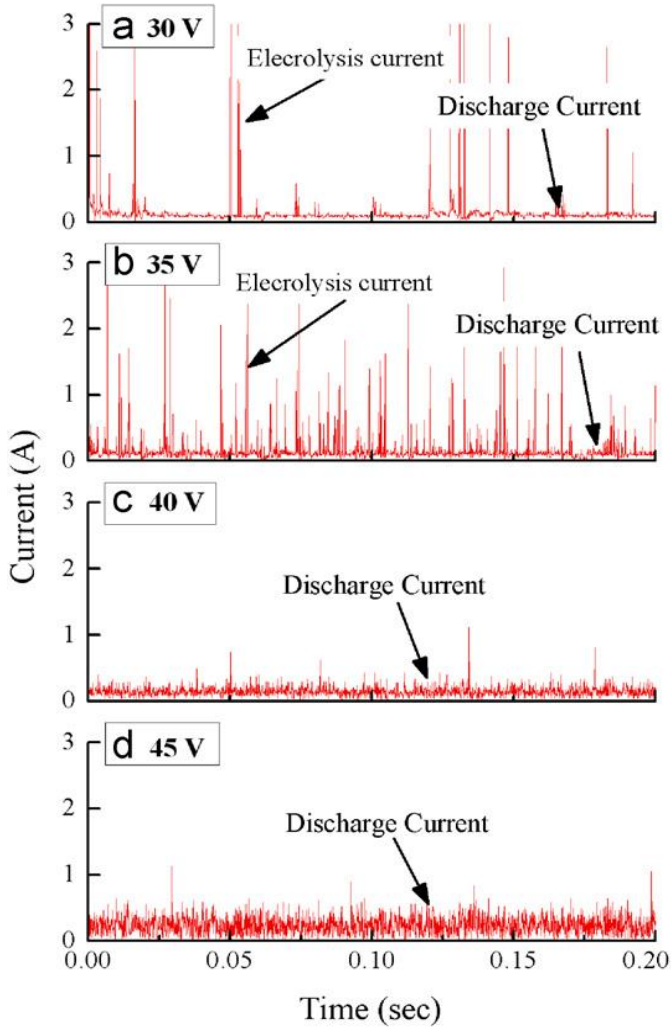


Fig. 4. ECDM current signals at different applied voltages.

Current signals in such status are taken in this study as indicative of stable discharge activity. With further increase in applied voltage, the discharge energy density began to show a linear relationship with applied voltage, as shown in Fig. 4(d) (according to a field-emission law).

Fig.5 displays SEM images of micro-hole entrance drilled under gravity- feed for 3s at different applied voltages. It is interesting to note that the diameter of the machined contour decreased with increase in applied voltage and reached the smallest value at 40V.

Once the voltage exceeded 40V, the diameter began to increase gradually. At the same time, there was some distortion in the circular contour.

Even though the electrochemical discharge and material removal may continue when the applied voltage exceeds the critical voltage (Vc, typically about 30V), the quality and structure of gas film will vary, which in turn affect the machining quality.

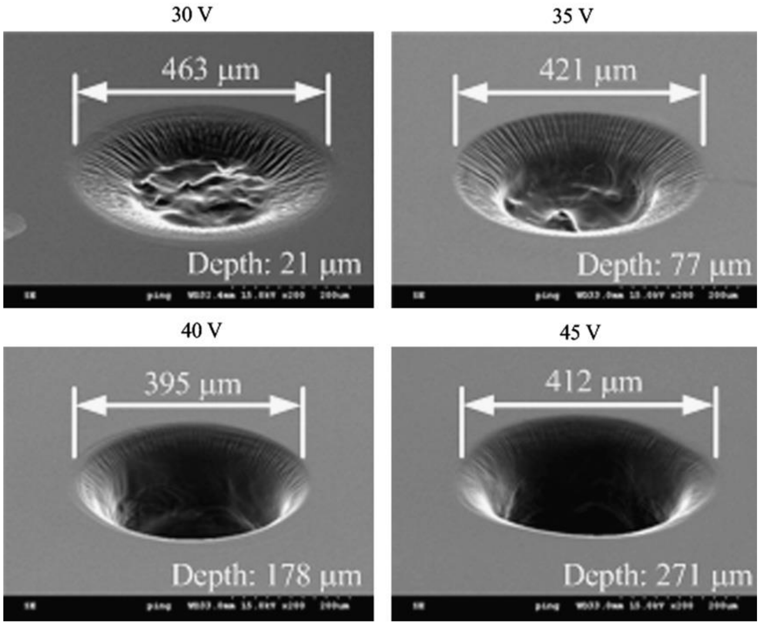


Fig. 5. SEM images of micro hole entrance obtained at different applied voltages

If the applied voltage (30–35V in this study) is just slightly higher than the Vc. The generation of electrolysis bubble was not intense enough. The bubbles still had sufficient time to coalesce and grow in size.

As a result, a thicker gas film of looser structure is formed, resulting in greater deviation in diameter of the machined contour. When the applied voltage reaches a certain voltage (40V in this study) relative to Vc, the generation of electrolysis bubbles gradually becomes more intense. Tiny and dense bubbles are generated and coated completely on the electrode before they have time to coalesce and grow in size.

Consequently, a thinner gas film of denser structure and greater stability is formed at higher voltages, which is in accordance with previous findings. Deviation in diameter of the machined contour will also become smaller. With further increase in the applied voltage, the discharge energy density began to show a relationship with it.

This can account for the drastic increase in diameter of machined contour at applied voltage above 40V. To describe the current signal and machined contour at different applied voltage, there exists a specific level for generating successive and uniform discharge activity while keeping the smallest deviation in machined contour.

Below the specific level, the generation of electrolysis bubbles is less intense, resulting in unstable gas film structure. Consequently, current signals become unstable (interlocking of electrolysis and discharge currents) and large deviations in machined contour occur. On the contrary, a stable gas film can be sustained at applied voltage above the specific level.

However, a larger deviation in contour will occur due to excessive discharge energy. In this study, the specific level is called transition voltage Vt, which denotes the voltage level applied for achieving good gas film quality, thus attaining continuous and stable discharge activity and smallest deviation in machined contour.

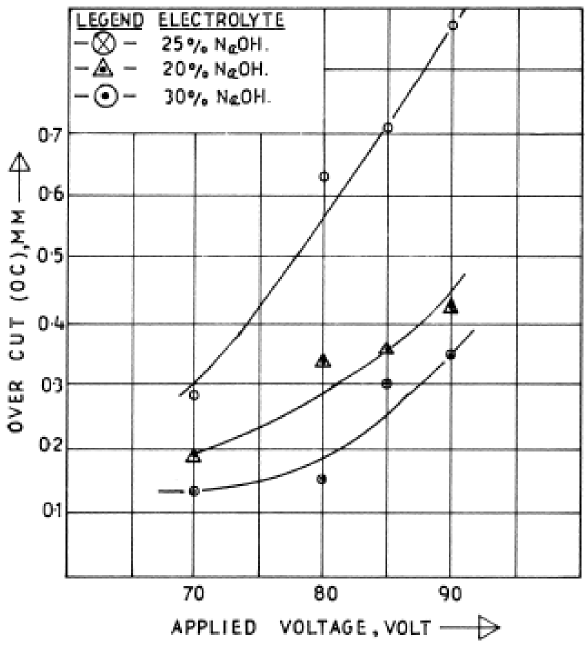


Fig. 6. Effect of applied voltage on over-cut for various electrolyte concentrations.

4.2 Electrolyte concentration

B.Bhattacharyya et.al. have concluded a comprehensive experiment which gave the relationship between different working parameters and material removal rate.

The test workpiece specimen was made of Aluminium oxide ceramic material. An aqueous solution of NaNO3 was used as the electrolyte, but due to electrochemical reaction the electrolytic dissolution of copper was taking place, resulting in a large amount of sludge, which contaminated the electrolyte solution.

Hence, the MRR achieved when using an aqueous solution of NaNO3 as electrolyte was very low.

The owing electrolyte test was also conducted but did not yield the desired MRR because the gas bubbles were carried away by the owing electrolyte, thereby lowering the frequency of sparking and hence reducing the material removal rate. It was also observed that using an aqueous solution of NaCl as the electrolyte, the resulting MRR was also very low.

NaOH electrolyte solution was also used for experimentation, and yielded a high machining rate. Since NaOH has a higher specific conductance, chemical reactions take place at a higher rate and gas bubble generation takes place at a faster rate. Hence, an aqueous NaOH solution under stagnant conditions has been used as the electrolyte for the experimentation.

The experiments are carried out with electrolyte concentrations of 20%, 25% and 30% (i.e., 30 g NaOH per 100 cm^3 of water).

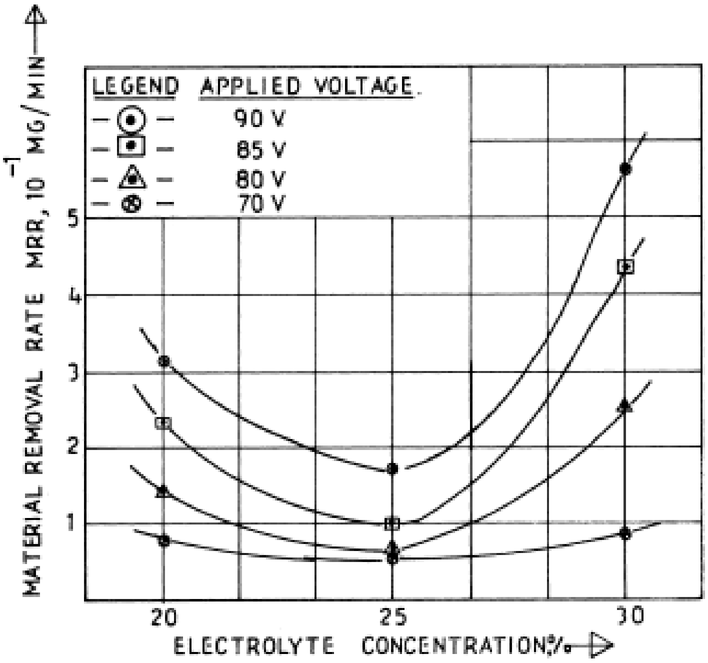


Fig 7. Effect of electrolyte concentration on the MRR at different applied voltages

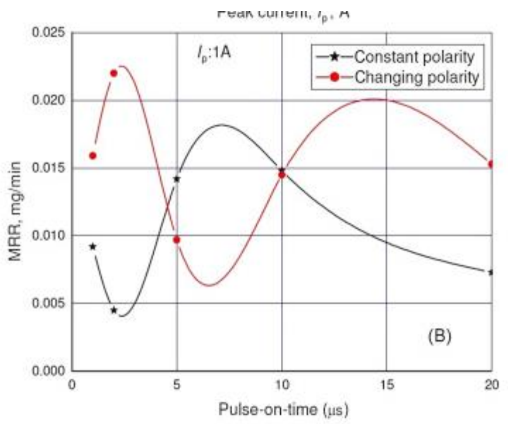
4.3 Pulse on time

Material removal rate with pulse on time increases. The variations of MRR with peak current and pulse-on-time with constant and changing polarity while keeping all other process parameters constant, i.e., pulse-on-time at 10 μs in case of a varying peak current, and peak current at 1 A in case of a varying pulse-on-time, duty factor at 95%, and flushing pressure at 0.5 kgf/cm^2

MRR increases monotonically in both cases, with the increase in peak current from 0.5 to 1.5 A, but for changing polarity, it decreases as peak current increases from 1.5 to 2 A.

The magnitude of MRR in both cases is almost equal in the considered peak current range. The low MRR at a smaller peak current could be due to lower discharge energy when machining in both constant and changing polarity (Fig.8).

However, MRR at a changing polarity is low compared with that at a constant polarity, because of the change in the position of maximum liberation of heat energy due to sparking. The increase in MRR with increasing peak current is attributed to a larger discharge energy.



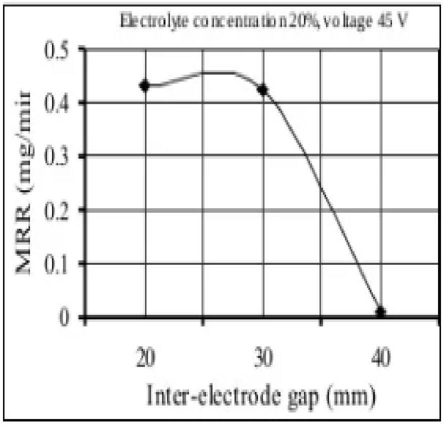


Fig. 8 MRR vs Pulse-on-time with constant and changing polarity

Fig.9: MRR vs inter electrode gap

4.4 Standoff distance or inter electrode gap

Standoff distance or inter electrode gap plays an important role in accurate shape generation in EMM. The small interelectrode gap localizes the electric current at the anode surface, thereby reducing the stray removal.

A small interelectrode gap produces a high electric field inside it, resulting in high current and therefore, high material removal (Fig 9).

The other advantage of a small interelectrode gap is that it lowers the required machining voltage and electrolyte concentration by a considerable amount.

However, a very small interelectrode gap is also disadvantageous for several reasons.

First, it makes flushing away the reaction products increasingly difficult, and second, there is a very high possibility of the thin layer of electrolyte in the interelectrode gap reaching high temperatures that may even lead to boiling, which severely affects the accuracy of the process.

4.5 Tool shape

For investigating the influence of tool tip geometrical shape on the ECDM process criteria, three different tool tip shapes were designed and utilised. The designed tool tips are exhibited in Fig. 4 and are as follows: (i) straight side wall and flat front; (ii) taper side wall and at front; and (iii) taper side wall and curvature front.

These test results clearly indicate that the MRR increases considerably for taper side wall – curvature front tool tip compared to the straight side wall - flat front and, the taper side wall - flat front tool tip.

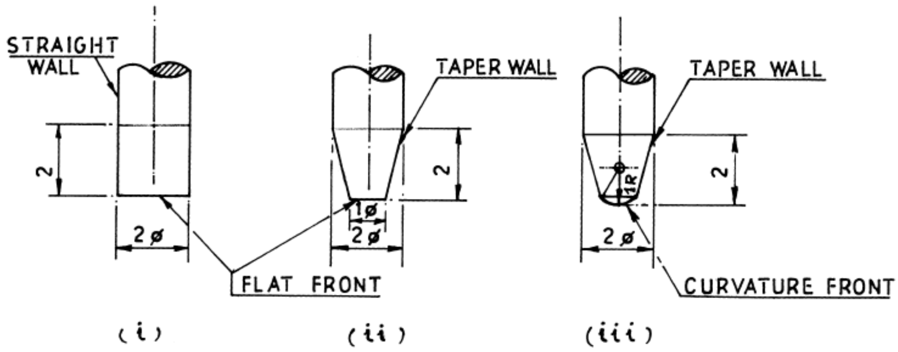


Fig 10. Different geometrical shapes of the tool tip (dimensions: mm)

At the straight side wall - flat front tool tips, the availability of electrolyte in the gap between tool and job is very poor because they are always in contact with each other due to the gravity feed force and thus causing occurrence of lower number of sparks which in-turn decrease the MRR.

But at the taper side wall - flat front tool tip, the availability of electrolyte is more resulting in more sparking which increase MRR. Tapper side wall-curvature front tool tip causes maximum amount of electrolyte availability in sparking zone which creates maximum number of sparks and thus increases MRR.

5. *Influence of machining parameters on the over-cut phenomena*

The over-cut phenomena have been investigated for measuring the machining accuracy. Fig. 11 shows the effects of applied voltage on over-cut for different electrolyte concentrations, i.e., 20%, 25% and 30% NaOH electrolyte solution.

At higher applied voltage for different electrolyte concentrations, the observed over-cut phenomena are more predominant because of the fact that at higher applied voltage, more gas bubbles generate at the sparking zone, which may create more possible stray sparking at the side wall of the tool tip and result in more over-cut.

However, at moderately low concentrations, the over-cut phenomena are much lower compared to that for higher concentration.

Further, it is observed from the graph that at 25% concentration, the over-cut is low compared to that for 20% concentration. This may be due to a lesser amount of side spark generation at 25% concentration which results in a lower MRR and also a lower over-cut: this tends to corroborate the results that have already been observed from the previous investigation, i.e., at 25% concentration the machining rate is lower.

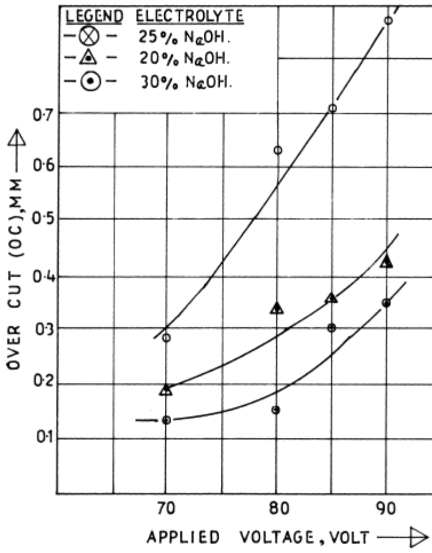


Fig 11. Effect of applied voltage on over-cut for various electrolyte concentrations.

From the experimental results and Fig. 11, it is clear that at 25% NaOH solution, the over-cut is much lower compared to that for 20% and 30% concentration.

Figs. 13 and 14 represent this very point: both are machined at 80 V applied voltage.

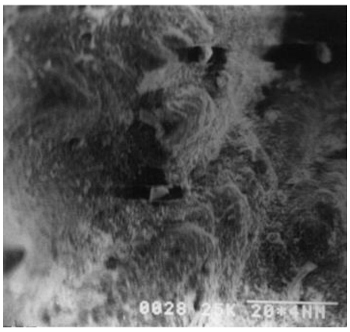


Fig. 12. Micrograph of a ceramic work sample machined at 90 V and 30% NaOH solution

Fig. 13. Micrograph of the machined hole in ceramic work sample machined at 80 V and 25% NaOH solution

The ceramic work sample of Fig. 13, which was machined at 25% of NaOH and the 80V Applied voltage condition, exhibits a lesser amount of the over-cut effect and a lesser amount of heat-affected zone at the periphery of the blind hole.

This is due to the fact of concentrated and controlled spark generation from the front face of the tool tip. However, Fig. 14 represents a ceramic work sample that was machined at a comparatively lower concentration, i.e., 20% NaOH solution, and the same applied voltage, i.e., 80 V.

Here, the over-cut effect is clearly visible and a larger peripheral heat-affected zone is produced, possibly due to the generation of a larger amount of stray and uncontrolled sparking from the side wall and the periphery of the tool tip.

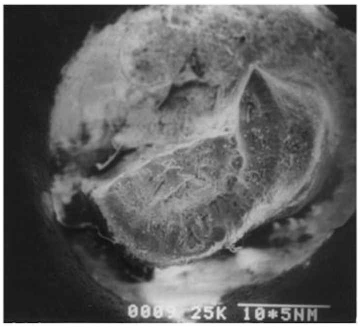


Fig. 14. Micrograph of the machined hole in a ceramic work sample machined at 80 V and 20% NaOH solution.

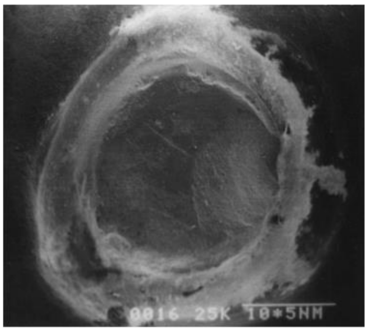


Fig. 15. Micrograph of the machined hole in a ceramic work Sample machined at 20% NaOH and 80 V by the straight side wall and flat front tool tip.

6. <u>Conclusion</u>

The electrochemical discharge machining (ECDM) process can be utilised effectively for the machining of non-conductive materials such as ceramics and advanced composites. The material removal during the machining of non-conducting ceramic workpiece in the ECDM process, mainly takes place due to spark discharge action across the gas bubble layers formed on the workpiece surface.

The ECDM process has the potential for small- and macro-hole drilling operations on ceramic components. At low applied voltage, the MRR is very low, but at higher voltage and higher electrolyte concentration, a higher MRR can be achieved. However, at higher electrolyte concentration the over-cut is greater. Hence for improving machining accuracy, a lower concentration is preferred.

With a higher voltage, the MRR is greater, but micro-cracks and other defects are generated on the machined surface. It is evident from the test results that the machining rate of ceramic materials is low in the ECDM process but the method is more effective for cutting those non-conductive materials considering the capability of machining a complex profile. The machining rate and accuracy can be enhanced through effective and precise control of the spark generation.

The tool tip shape is also a prominent factor for controlling spark generation in ECDM. The taper side wall and flat front tool tip shape is the most effective for controlled machining.

References

1. *Amitabha Ghosh et al., "ECDM: Principle and possibilities", Saadhana, Vol. 22, Part 3, June 1997, pp 435-447*
2. *Ankit D. Oza, Ashish Goyal, Vyomesh Buch and Manoj Kumar, "Electrochemical discharge machining process: A review on process parameters and future scope", 2021, pp 1-5.*
3. *B. Bhattacharyya, B.N. Doloi and S.K. Sorkhel et al., "Experimental investigation into electrochemical discharge machining (ECDM) of non-conductive ceramics materials", November 1998, pp 146-153.*
4. *C.T.Yang et al ."Improving machining performance of wire-ECDM by adding SiC abrasive to electrolyte" , January, 2006 pp 2-6*
5. *Chih-Ping Cheng et al., "Study of gas film quality in electrochemical discharge machining", April, 2010 pp 1-10*
6. *Manpreet singh, sarbjit singh and Sanjeev et al., "Experimental investigation for generation of micro holes on silicon wafer using electrochemical discharge machining process"", September 2019, pp 1684-1689.*
7. *Pravin Pawar et. al., "An overview of machining process of alumina and alumina ceramic composites", October,2015, pp 11-15*
8. *Rajendra Kumar Arya et al., "Investigation on quantification and replenishment of vapourized electrolyte during deep microholes drilling using pressurised flow-ECDM process", October, 2018, pp 2-12*
9. *Sadashiv bellubbi et al, "Optimization of process parameters in electrochemical discharge machining of silica glass through analysis of means", 2021, IOP Conf. ser. pp 1-5.*
10. *Sanjay k. CHAK et al., "Electro chemical discharge machining: process capabilities", volume- 4, issue-10, October, 2016.*
11. *Tarlochan Singh et al. "Developments in electrochemical discharge machining: A review on electrochemical discharge machining, process variants and their hybrid methods", March, 2016 pp 3-12*
12. *Tianyu Geng et al., "ECDM for fabricating holes in conductive materials: A review", April, 2021, pp 1-12*
13. *Xuan Doan Cao et al., "Micro structuring of glass with features less than 100 micrometers by ECDM", January, 2009 pp 2-6*