Chapter 18
Performance Enhancement of Electro-chemical Discharge Machining by Process Variants: A Review

Pankaj Kumar Gupta, Tapas Bajpai, Nikhil Jain, and Dharmendra Singh

Abstract Electro-Chemical Discharge Machining (ECDM) process has shown its potential over the other thermal and chemical energy based non-conventional methods due to its better capability in micro-feature generation on nonconductive, hard and brittle materials such as glass and ceramics. In this article, a comprehensive review had been carried out on different process variants which were used to enhance the process capability of ECDM. The process variants were classified into two groups based on level of hybridization or modification in the conventional ECDM. These variants were termed as primary and secondary variants. The article consists review of various process variants such as Electro-Chemical Discharge Trepanning (ECDTr), Electro-Chemical Discharge Dressing (ECDDr), Electro-Chemical Discharge Turning (ECDT), Die Sinking Electro-Chemical Discharge Machining (DS-ECDM), Wire Electro-Chemical Discharge Machining (W-ECDM), Electro-Chemical Discharge Milling (ECDMi), Powder Mixed Electro-Chemical Discharge Machining (PM-ECDM), Rotary Electro-Chemical Discharge Machining (R-ECDM), Electro Chemical Discharge Grinding (ECDG), Magnetic Field assisted Electro-Chemical Discharge Machining (MF-ECDM) Ultrasonic assisted Electro-Chemical Discharge Machining (US-ECDM), etc. These variants were used to enhance performance of ECDM in various aspects such as material removal rate, machining depth, surface quality, aspect ratio etc. In the end a possible multi-hybridization process variant has been proposed by combining of magnetic field and ultrasonic vibration assistances in ECDM.

Keywords ECDM · Process variant · Hybridization · Performance enhancement

P. K. Gupta (✉) · T. Bajpai · N. Jain
Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur, Jaipur, Rajasthan, India
e-mail: pankaj.mech@mnit.ac.in

D. Singh
Department of Mechanical Engineering, Government Engineering College Bikaner, Bikaner, Rajasthan, India

R. Pratap Singh et al. (eds.), *Proceedings of the International Conference on Industrial and Manufacturing Systems (CIMS-2020)*, Lecture Notes on Multidisciplinary Industrial Engineering, https://doi.org/10.1007/978-3-030-73495-4_18

18.1 Introduction

In recent years, a lot of research had focused on advance materials due to their enhanced physical and chemical properties. These advance materials had shown their utility in the field of aerospace [1], medical [2] and in many other industrial applications [3]. The fabrications of micro-features on such materials are difficult with the use of unconventional machining methods. Electrical Discharge Machining (EDM), Laser Beam Machining (LBM) and Plasma Arc Machining (PAM). Electro-Chemical Discharge Machining (ECDM) had been emerged out as a possible solution to create micro features on advance materials such as glass and ceramics regardless of their properties. ECDM process has good capability to create micro-feature on glass [4], ceramics [5] and composite materials [6]. ECDM process is a hybrid machining process and uses the principles of ECM and EDM process [7]. ECDM process removes the material by chemical dissolution and melting [8, 9]. In ECDM process, tool electrode is partially immersed up to few millimetres in the electrolyte solution while the auxiliary anode is fully submerged in the electrolyte solution and situated at some distance away from the tool electrode [10]. The work-piece is suitably placed in the electrolyte chamber with the proper fixture on the worktable arrangement. The potential difference of about 50–60 V is used between electrodes through a suitable DC power supply [11] as shown in Fig. 18.1. The electrolysis process is occurred between two electrodes. Hydrogen and oxygen bubbles are formed at the surface of cathode and anode surface respectively [12]. However, after a certain time the generation rate of the hydrogen gas bubble near the tool electrode increases more rapidly and hydrogen gas film formed in the vicinity of the tool electrode [13]. The gas film behaves as an insulator. It ceases the flow of current and intensified the electric field around the tool electrode which results in arc discharge [12]. The bombardment of electrons from the tool electrode results in the melting of the work-piece [14, 15] and followed by subsequent high-temperature etching that removes the material. Basak and Ghosh [16] proposed a new mechanism of spark generation in the ECDM

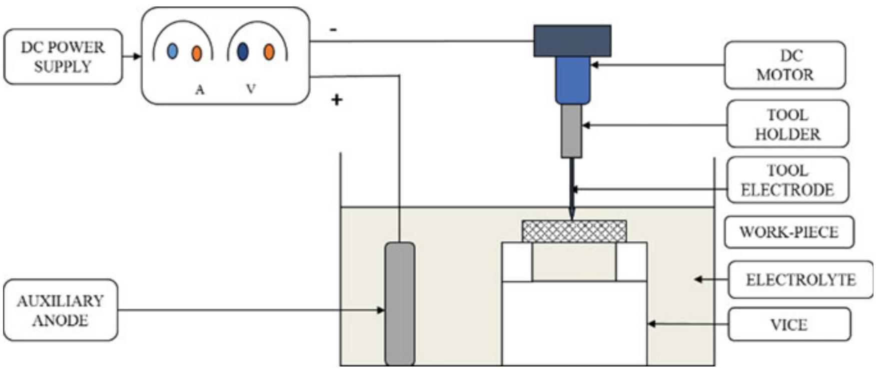

Fig. 18.1 Schematic diagram of ECDM set-up

process. It was found that the discharge location at the tool changes continuously with the period.

18.2 ECDM Variants

ECDM process has gained immense attention of several researchers due to its better capability in fabrication of micro-channel [17], micro-grooves [18], channel engraving and cylindrical hole [19]. ECDM process possess several limitations like overcut, hole taper, circulation of electrolyte in machining zone after certain depth [20] and poor MRR. In order to overcome above draw backs some change in process and experimental set-up are created. These modification or hybridizations are known as variants. The variants can be classified into two groups. The variants which include minor or major modification in existing system component of ECDM are classified as primary variants. On the other hand, the variants which include addition of other process mechanism while keeping existing system components intact are classified as secondary variants. Different types of variants are shown in Fig 18.2 according to their category.

18.2.1 Electro-chemical Discharge Trepanning (ECDTr)

In the ECDM process the drilling depth was difficult to control. Most of the heat evolved during increase in drilling depth is transferred to the electrolyte and only a small portion of heat conducted in the material. To overcome this limitation, ECDTr had been used as an alternative to achieve large drilling depth. In ECDTr process, the tool is offset by a small amount from the spindle rotation axis [21]. The orbital motion of the tool assists in the formation of a deep hole. However, crack propagation

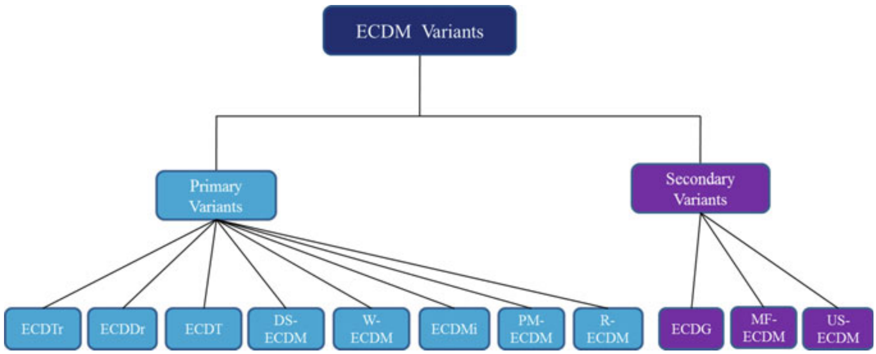

Fig. 18.2 Types of ECDM variants

in the material after achieving a certain depth diminishes the efficiency of the process [22]. To overcome the above drawbacks, [23] explored the effect of the abrasive tool electrode and pulsed power supply during ECDTr process. The abrading action of the abrasive particle helped in material removal with an increase in drilling depth. The pulsed power supply provides sufficient cooling around the work-piece during the pulse off period. Thus, it helped in improving the drilling depth and surface quality.

18.2.2 Electro-chemical Discharge Dressing (ECDDr)

ECDDr was used as an alternative for the efficient dressing of worn micro-grinding tool. The conventional method for dressing is grinding and rolling with the use of ultra-hard dresser. These methods are not very effective. In ECDDr, the electrolyte behaves as a dresser. The electrolysis process occurred between the micro-grinding tool and auxiliary anode. The grains protruded during the dressing do not damage the grinding face of the tool. Therefore, significant improvement in surface quality was observed [24].

18.2.3 Electro-chemical Discharge Turning (ECDT)

ECDT is a unique process variant to achieve deep grooves on cylindrical parts with the rotation of the work-piece. The remnants attached at the bottom of the tool electrode diminish the machining efficiency and restrict the electrolyte circulation in a deeper zone of machining. The rotation of the work-piece ensures the supply of fresh electrolyte in the narrower gap between tool and work-piece. Therefore, significant improvement in the debris removal was achieved, which leads to an increase in the machining depth. However, at a very high rotational speed, the stability of gas film was destroyed and a subsequent drop in the MRR was observed [25].

18.2.4 Die Sinking Electro-chemical Discharge Machining (DS-ECDM)

DS-ECDM process was used for the fabrication of a small shallow cavity with the use of a non-rotating tool. In DS-ECDM operation, the melted work-piece material re-solidified on the work-piece surface [26]. Therefore, efficient flushing of electrolyte was the major concern in the DS-ECDM process. The electrolyte concentration and duty factor were the most influencing parameters to get higher MRR during the DS-ECDM process [26]. An increase in the electrolyte concentration accelerates the electrolysis process, which leads to an increase in the MRR. However, beyond a certain limit further increase in electrolyte concentration caused a decrease in the specific conductance of electrolyte, which leads to decrease in MRR. An increase in the duty factor ensures more amount of spark energy available for a longer period, which leads to an increase in the MRR.

18.2.5 Wire Electro-Chemical Discharge Machining (W-ECDM)

W-ECDM process was used for slicing large volumes of material during the fabrication of micro-grooves and other complicated surface profiles on non-conductive materials. The wire electrode behaves as a cutting tool and feeds toward the workpiece with the help of feed spool, takes up spool, pulley and stepper motor. Bhuyan and Yadva [27] explored the effect of pulse on-time and applied voltage on MRR and kerf width during the Travelling Wire ECDM (TW-ECDM) process. It was found that an increase in pulse on time and applied voltage increased the MRR and Kerf width due to more spark energy available for discharge. Yang et al. [28] explored the effect of mixing of SiC abrasive particles into the electrolyte on overcut and surface quality during the TW-ECDM process. It was observed that abrasive particles caused a significant increase in the critical voltage of the process and decrease in discharge energy. Thus, a significant reduction in the overcut was observed. The abrasive particles induced a lapping action in the process due to their relative motion. Thus, it helped in refining the micro-crack. Therefore, surface quality was improved.

18.2.6 Electro-chemical Discharge Milling (ECDMi)

ECDMi process was used to create 3D shaped profile structures, micro-grooves [29], micro-pyramid and micro-channel [30]. The rotating cylindrical shape wheel was used as a cutting tool. The tool travel rate and tool rotation rate played a major role in achieving a good quality surface profile. It was observed that higher tool rotation helped in electrolyte circulation which leads to the formation of a sharp edge micro-groove profile. An increase in the tool travel rate leads to increased depth of cut during formation of shallow micro-groves. In order to achieve a good surface profile of micro-grooves, the material was removed layer by layer with very low depth of cut. This mechanism of material removal caused electrolyte flushing at deeper and narrower grooves. Thus, the surface quality of the micro-grooves was improved.

18.2.7 Powder Mixed Electro-chemical Discharge Machining (PM-ECDM)

In the PM-ECDM process the distribution of discharge energy around the machining zone plays a vital role to affect surface integrity and process repeatability. The addition of conductive powder particles assists in reducing the critical voltage and reduces the impact of discharge energy around the surface of the work-piece. Han et al. [31] used graphite powder mixed electrolyte. It was found that the addition of abrasive particles caused the intensification of the electric field around the tool electrode. The dynamic behaviour of particles helped in reducing the current density. Thus, surface quality was improved.

18.2.8 Rotary Electro-chemical Discharge Machining (R-ECDM)

In R-ECDM process rotary motion was provided to the tool with the help of DC motor. In R-ECDM process a gap was maintained between rotary tool electrode and work-piece. The rotary tool was positioned at the depth of cut while the work-piece is feed with constant velocity. The machining area was divided between Electro-chemical dissolution zone and electro-chemical discharge zone. The surface irregularity and cracks formed during the electric discharge process were removed by the electro-chemical dissolution. Therefore, this method was used to obtain crack-free smooth surface [32]. Harugade et al. [33] explored the effect of high speed tool rotation on overcut and hole taper during ECDM process. The high speed tool rotation assisted in reducing the contact area between the tool and work-piece. Moreover, better electrolyte circulation improved the heat conduction throughout the work-piece. Thus, considerable reduction in the overcut and hole taper were observed.

18.2.9 Electro-chemical Discharge Grinding (ECDG)

ECDG process was used to remove material by mechanical abrasion along with the assistance of ECDM principle. The abrasive particle embedded on rotary tool behaves as a grinding wheel [34]. The metallic bond is situated in between the abrasive particle layers. The metallic bond created spark while the abrasive particle induced cutting action during the ECDG process. In ECDG, the contact area between the tool and work-piece surface was kept very low so that the maximum abrasion was achieved by abrasive particles attached on tool. The abrasive particle provided maximum cutting action during the process which leads to increase in MRR. ECDG process was used to obtain micro-holes on alumina and borosilicate glass materials [35].

18.2.10 Magnetic Field Assisted Electro-chemical Discharge Machining (MF-ECDM)

In the MF-ECDM process, a permanent magnet was fixed at the tool holder. It caused upward and downward magnetic field action on the tool during the ECDM process. The magneto-hydrodynamic convection was induced in the process due to the magnetic field. The magneto-hydrodynamic convection helped in improving the electrolyte circulation. Thus, the machining efficiency of the process was improved [36]. Rattan and Mulik [37] studied the effect of the magnetic field on overcut and hole taper during the TW-ECDM process. It was found that magnetic field assistance helped in the removal of debris in the vicinity of the tool and work-piece. Moreover, the stable discharge during MF-ECDM increased the process efficiency. Therefore, the hole taper and overcut were significantly reduced in the case of the MF-ECDM process.

18.2.11 Ultra-sonic Assisted Electro-chemical Discharge Machining (US-ECDM)

The US-ECDM process consists of an ultrasonic generator and transducer to impart vibration to the tool. The ultrasonic assistance in the ECDM process provides the drag force on the bubbles. The drag force helps in thinner gas film formation. Thin gas film imparts small discharge and small micro-holes with good dimensional accuracy [38]. Rusli and Furtani [39] explored the effect of ultrasonic vibration and electrolyte level on MRR during ECDM process. At low electrolyte level the ultrasonic vibration improves the electrolyte circulation. Thus, the MRR was increased.

A summary of researchers who have worked on different ECDM process variant to improve the surface quality, MRR and dimensional accuracy for micro feature generation on non-conductive materials like glass, composite and ceramics is given in Table 18.1.

18.3 Proposed ECDM Variant

Characteristics of different process variants are studied to improve the performance of the ECDM process. A different type of process variants can be proposed based on the characteristics in preceding section. In this article, a variant is proposed by combining the ultrasonic assistance with magnetic field assistance which is shown in Fig 18.3 and named as Magnetic Field and Ultra Sonic assisted ECDM (MF-US-ECDM). The magnetic unit is attached to the tool holder and the tool is vibrated with the help of the transducer. The ultrasonic assistance increases the drag force on the bubbles and helps in the formation of the thinner gas film. The magnetic

Table 18.1 Summary of different type of process variants

S.No.	Author name	Process variant	Performance enhancement in term of
1	Pawariya et al. [21], Chak and Rao [23]	ECDTr	Drilling depth and surface quality
2	Wei et al. [24]	ECDDr	Surface quality
3	Furutani and Maeda [25]	ECDT	Machining depth
4	Khairy and Mc-Geough [26]	DS-ECDM	MRR
5	Bhuyan and Yadava [27], Yang et al. [28]	W-ECDM/TW-ECDM	Surface quality and MRR
6	Kuo et al. [29], Didar et al. [30]	ECDMi	Surface quality
7	Han et al. [31]	PM-ECDM	Surface quality
8	Kozak and Zybura [32], Harugade et al. [33]	R-ECDM	Surface quality, dimensional accuracy
9	Chak and Rao [34], Jain et al. [35]	ECDG	MRR
10	Cheng et al. [36], Rattan and Mulik [37]	MF-ECDM	Machining efficiency and dimensional accuracy
11	Elhami and Razfar [38], Rusli and Furtani [39]	US-ECDM	MRR and dimensional accuracy

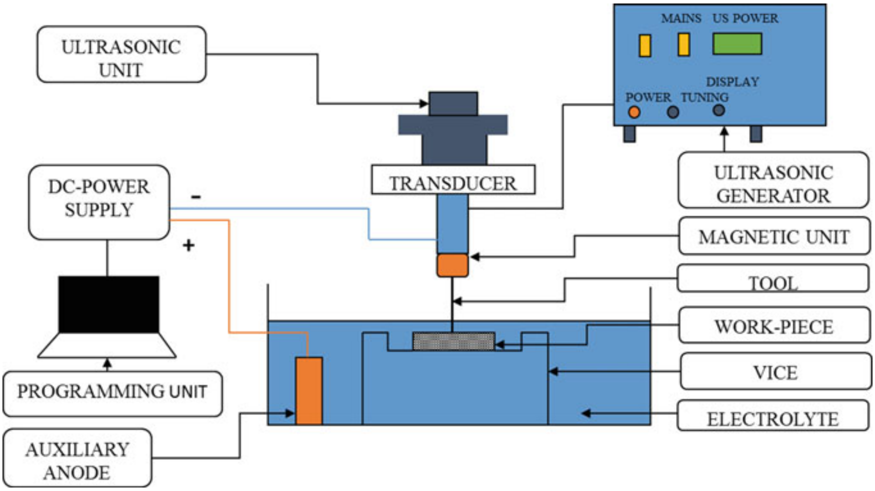

Fig. 18.3 Schematic diagram of MF-US-ECDM set-up

field assistance caused magneto-hydrodynamic convection in the process. Thus, it helps in concentrating the spark around the machining zone. Therefore, MRR and dimensional accuracy may be improved.

18.4 Conclusion

A comprehensive literature review on different process variants results in following conclusions:

ECDTr is an emerging method for deep hole formation on alumina and quartz. ECDDr was used for dressing of worn micro-grinding tools. Thus, ECDDr was used to improve the surface quality. ECDT involves the rotation of the work-piece. Therefore, fresh electrolyte removes the debris and deeper depth of cut was achieved. DS-ECDM was proved as an efficient process variant for the small cavity formation and higher MRR was attained. W-ECDM was used for slicing while TW-ECDM achieved higher MRR. ECDMi was very useful variant for fabrication of 3 D shaped structures. PM-ECDM was an effective approach to attain good surface quality during micro-feature generation. MF-ECDM improved the electrolyte circulation which results in lesser overcut and hole taper. US-ECDM develops thinner gas film formation which leads to better dimensional accuracy and higher MRR. A proposed variant MF-US-ECDM can be used to obtain advantages of individual process variant.

References

1. Ranganayakulu, J., Srihari, P.V.: Multi-objective optimization using Taguchi's loss function-based principal component analysis in electro-chemical discharge machining of micro-channels on borosilicate glass with direct and hybrid electrolytes. In: *Advances in Manufacturing Processes, Lecture Notes in Mechanical Engineering*, 349–60 (2018)
2. Jawalkar, C.S., Sharma, A.K., Kumar, P.: Investigations on performance of electro-chemical discharge machining process using NaOH and NaNO3 electrolytes while micro machining soda lime glass. Int. J. Manuf. Technol Manage. **28**(1/2/3), 80–93 (2014)
3. Singh, T., Dvivedi, A.: Developments in electro-chemical discharge machining: a review on electro-chemical discharge machining. Int. J. Mach. Tool Manuf. **105**, 1–13 (2016)
4. Arab, J., Kannojia, H.K., Dixit, P.: Effect of tool electrode roughness on the geometric characteristics of through hole formed by ECDM. Precis. Eng. **60**, 437–447 (2019)
5. Dhanvijay, M.R., Ahuja, B.B.: Micro-machining of ceramic by electro-chemical discharge process considering stagnant and electrolyte flow method. Procedia Eng. **14**, 165–172 (2014)
6. Singh, M., Singh, S.: Machining of carbon fibre reinforced polymer composites by electro-chemical discharge machining process. IOP Conf. Ser. Mater. Sci. Eng. **521**, 1–6 (2019)
7. Ghosh, A.: Electro-chemical discharge machining: principle and possibilities. Sadhana-Acad. Proc. Eng. Sci. **22**, 435–447 (1997)
8. Gupta, P.K., Dvivedi, A., Kumar, P.: Developments on electro-chemical discharge machining: a review of experimental investigations on tool electrode process parameters. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. **229**, 920–930 (2014)
9. Gupta, P.K., Dvivedi, A., Kumar, P.: Effect of electrolytes on quality characteristics of glass during electro-chemical discharge machining. Key Eng. Mater. **658**, 141–145 (2014)

10. McGeough, J.A., Khayry, A.B.M., Munro, W., Crookall, J.R.: Theoretical and experimental investigation of the relative effects of spark erosion and electrochemical dissolution in electrochemical arc machining. Ann. ClRP **32**, 1–6 (1983)
11. Jain, V.K., Adhikary, S.: On the mechanism of material removal in electrochemical spark machining of quartz under different polarity conditions. J. Mater. Process. Technol. **200**, 460–470 (2008)
12. Gupta, P.K., Dvivedi, A., Kumar, P.: Effect of pulse duration on quality characteristics of blind hole drilled in glass by electro-chemical discharge machining. Mater. Manuf. Process **31**, 1740–1748 (2015)
13. Singh, M., Singh, S.: Electro-chemical discharge machining: a review on preceding and perspective research. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. **233**, 1425–1449 (2018)
14. Jain, V.K., Dixit, P.M., Pandey, P.M.: On the analysis of the electrochemical spark machining process. Int. J. Mach. Tools Manuf **39**, 165–186 (1999)
15. Kulkarni, A., Sharan, R., Lal, G.K.: An experimental study of discharge mechanism in electro-chemical discharge machining. Int. J. Mach. Tool Manuf. **42**, 1121–1127 (2002)
16. Basak, I., Ghosh, A.: Mechanism of spark generation during electro-chemical discharge machining: a theoretical model and experimental verification. J. Mater. Manuf. Process **62**, 46–53 (1996)
17. Cao, X.D., Kim, B.H., Chu, C.N.: Micro structuring of glass with feature less than 100 μm by electrochemical discharge machining. Precision Eng. **33**, 459–465 (2009)
18. Lu, C.J., Gu, A., Meng, L., Yang, S.Y.: The micro-milling machining of Pyrex glass using the electro-chemical discharge machining process. Adv. Mater. Res. **403**, 738–742 (2012)
19. Maillard, P., Despont, B., Bleuler, H., Wutchrich, R.: Geometric characterization of micro hole drilled in glass by gravity-feed with spark assisted chemical engraving (SACE). J. Micromech. Micro Eng. **17**, 1343–1349 (2007)
20. Jui, S.K., Kamaraj, A.B., Sundaram, M.M.: High aspect ratio micromachining of glass by electrochemical discharge machining (ECDM). J. Manuf. Process. **15**, 460–466 (2013)
21. Pawariya, K., Dvivedi, A., Singh, T.: On performance enhancement of electro-chemical discharge trepanning (ECDT) process by sonication of tool electrode. Precis. Eng. **56**, 8–19 (2018)
22. Jain, V.K., Chak, S.K.: Electro-chemical spark trepanning of alumina and quartz. Mach. Sci. Technol. **4**(2), 277–290 (2000)
23. Chak, S.K., Rao, P.V.: Trepanning ofAl_2O_3 by electro-chemical discharge machining (ECDM) process using abrasive electrode with pulsed DC supply. Int. J. Mach. Tools Manuf. **47**, 2061–2070 (2007)
24. Wei, C., Hu, D., Xu, K., Ni, J.: Electro-chemical discharge dressing of metal bond micro-grinding tools. Int. J. Mach. Tools Manuf. **51**, 165–168 (2011)
25. Furutani, K., Maeda, H.: Machining a glass rod with a lathe-type electro-chemical discharge machine. J. Micromech. Microeng. **18**(6), 1–6 (2007)
26. Khairy, A.B.E., McGeough, J.A.: Die-sinking by electro-erosion-dissolution machining. Ann. ClRP **39**, 1–5 (1989)
27. Bhuyan, B.K., Yadava, V.: Experimental study of travelling wire electrochemical spark machining of borosilicate glass. Mater. Manuf. Process. **29**, 298–304 (2014)
28. Yang, C.T., Song, S.L., Yan, B.H., Huang, F.Y.: Improving machining performance of wire electro-chemical discharge machining by adding SiC abrasive to electrolyte. Int. J. Mach. Tools Manuf. **46**, 2046–2050 (2006)
29. Kuo, K.Y., Wu, K.L., Yang, C.K., Yan, B.H.: Wire electrochemical discharge machining (WECDM) of quartz glass with titrated electrolyte flow. Int. J. Mach. Tool Manuf. **72**, 50–57 (2013)
30. Didar, T.F., Dolatabadi, A., Wuthrich, R.: Characterization and modelling of 2D-glass micro-machining by spark assisted chemical engraving with constant velocity. J. Micromech. Microeng. **18**, 1–9 (2008)
31. Han, M.S., Min, B.K., Lee, S.J.: Improvement of surface integrity of electro-chemical discharge machining process using powder-mixed electrolyte. J. Mater. Process. Technol. **191**, 224–227 (2007)

32. Kojak, J., Zybura, M.: Mathematical modelling of rotary electro-chemical discharge machining. Proc. World Congr. Eng. Comput. Sci. **2012**, 1–6 (2012)
33. Harugade, M., Waigaonkar, S., Mane, N., Hargude, N.: Experimental investigation of high speed tool rotation on heat affected zone and over-cut in electro-chemical discharge machining. Mater. Today Proc. **18**, 1472–1478 (2019)
34. Chak, S.K., Rao, P.V.: The drilling of Al_2O_3 using a pulsed DC supply with rotary abrasive electrode by the electro chemical discharge process. Int. J. Adv. Manuf. Technol. **39**, 633–641 (2008)
35. Jain, V.K., Choudhury, S.K., Ramesh, K.M.: On the machining of alumina and glass. Int. J. Mach. Tools Manuf. **42**, 1269–1276 (2002)
36. Cheng, C.P., Wu, K.L., Mai, C.C., Hsu, Y.S., Yan, B.H.: Magnetic field-assisted electrochemical discharge machining. J. Micromech. Microeng. **20**, 1–8 (2010)
37. Rattan, N., Mullick, R.S.: Experimental set-up to improve machining performance of silicon dioxide quartz in magnetic field assisted TW-ECSM process. Silicon **10**, 2783–2791 (2018)
38. Elhami, S., Razfar, M.R.: Effect of ultrasonic vibration on the single discharge of electro-chemical discharge machining. Mater. Manuf. Process. **33**(4), 444–451 (2016)
39. Rusli, M., Furutani, K.: Performance of micro-hole drilling by ultrasonic assisted electro-chemical discharge machining. Adv. Mater. Res. **445**, 865–870 (2012)