

Review Article

ELECTROCHEMICAL MICROMACHINING– REVIEW OF ADVANCED TECHNIQUES

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Abstract

A promising non-traditional manufacturing technique for creating high-precision microfeatures in electrically conductive materials without causing heat damage, residual strains, or tool wear is electrochemical micromachining (ECMM). Research efforts to enhance the performance and dependability of ECMM have quickened due to the increasing demand for miniaturized components in aerospace, biomedical, micro-electromechanical systems (MEMS), electronics, and microfluidic applications. Dimensional accuracy, surface integrity, material removal rate (MRR), and process stability are all influenced by a number of parameters, including tool electrode design and hybrid machining techniques. With a focus on cutting-edge tool electrode designs, such as insulated, rotating, tapered, hollow, multi-axis, and vibration-assisted electrodes, this article provides a thorough examination of current advancements in ECMM. The integration of ECMM with complementary technologies like ultrasonic vibration, laser assistance, magnetic field aid, electro-discharge machining (EDM), and jet-based electrolyte systems is also included in the review. While reducing problems like stray corrosion and overcut, these hybrid techniques have shown notable gains in electrolyte regeneration, material removal localization, machining precision, and surface quality.

Keywords: Electrochemical, Micromachining, Hybrid machining, Tool electrode, Electrolyte

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1. INTRODUCTION

Electrochemical machining (ECM) research, specifically in micro-ECM (μ ECM), is driven by the increasing need for microproducts with improved surface integrity and accuracy on various applications, such as micro-fluidics systems and non-defective stress-free drilled holes in aerospace and automotive manufacturing systems. Anodic dissolution in the electrolyte under the influence of an electric field causes material removal in ECM, an unusual machining process. Several advanced ECM techniques are presented in this chapter with the goal of enhancing accuracy, surface quality (SQ), and material removal rate (MRR). This chapter's goal is to discuss the most recent cutting-edge methods for enhancing output performance.

2. ADVANCEMENT IN ECM STRATEGIES

Researchers and scientists are always motivated to think about novel ECM solutions by the need for high machining

efficiency and quality. Tool electrode (cathode), electrolyte, electrical parameters, and extra energy (hybrid process) are the three key variables that researchers can manipulate. Figure 1's fish bone diagram illustrates the several factors influencing the ECM process. Therefore, effective control of ECM factors contributes to a greater degree of machining efficiency and quality optimization.

2.1. DESIGN OF TOOL ELECTRODE AND MECHANISM

For effective machining, high surface quality, and accuracy in ECM, electrolyte renewal and scavenging of machined products (debris) from the machining zone are crucial. Therefore, using an ultrasonic assisted vibrating electrode and a properly designed cathode ensures that the machining region is properly flushed (Ghosal and Bhattacharyya 2013, Paczkowski & Zdrojewski, 2017). Pan and Xu (2014) etch a steel plate using a vibrating tool electrode. The machining

localization is enhanced by the use of vibrating tool electrodes. The vibration mechanism and an optical microscope image of a microhole created by a vibrating and static electrode are displayed in Figures 2 and 3. It is clear from the optical microscope that the vibrating electrode creates microholes with a smaller diameter than the static electrode.

The ability to machine intricate geometries on super alloys, including compressor blades and essential gas turbine

components, is one of ECM's primary benefits. The design of the cathode tool is crucial for cutting various workpiece shapes. For instance, Wang et al. (2017) created a tool attachment with rotating cylindrical electrodes with varying speeds and dimensions of 10 mm diameter × 5 mm length in order to manufacture cylindrical workpieces. The cylindrical electrodes of the anode and cathode were maintained on two shafts that rotated at the same speed.

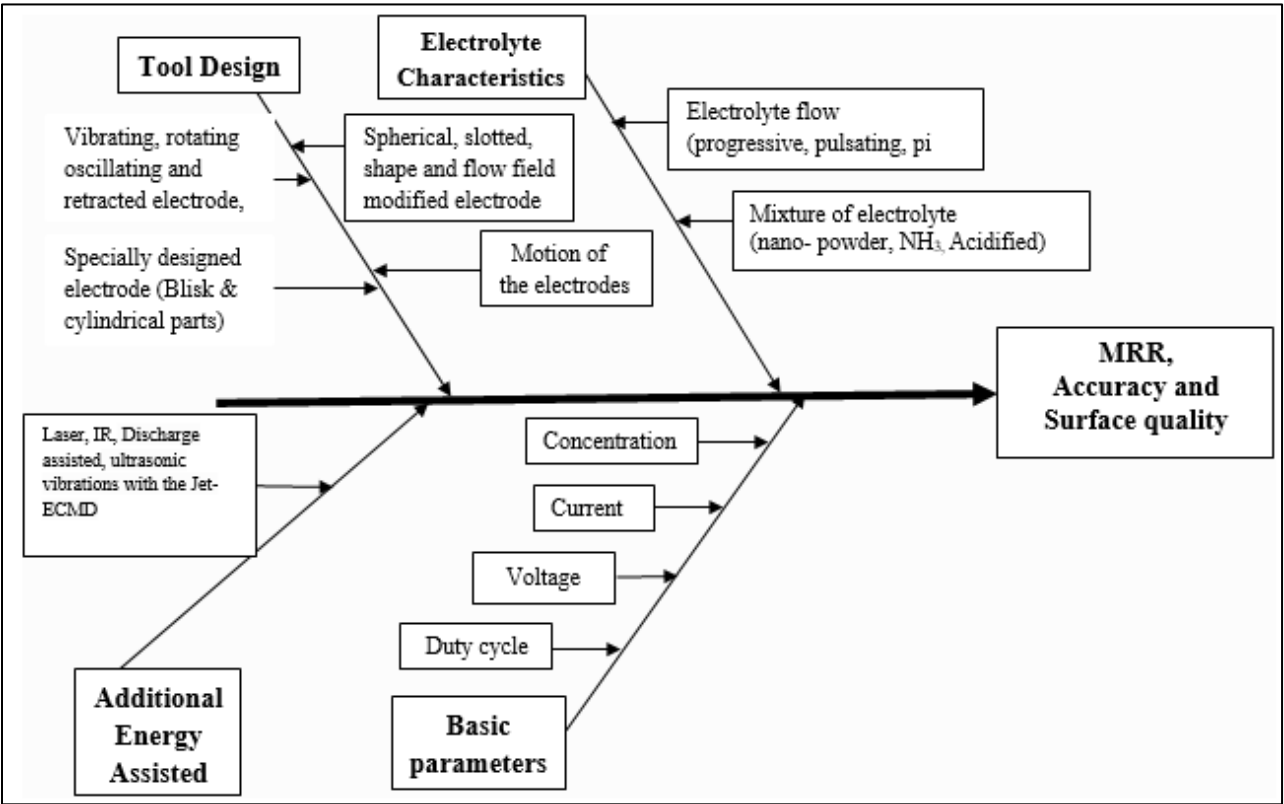


Figure 1: Fish bone diagram of ECM process parameters

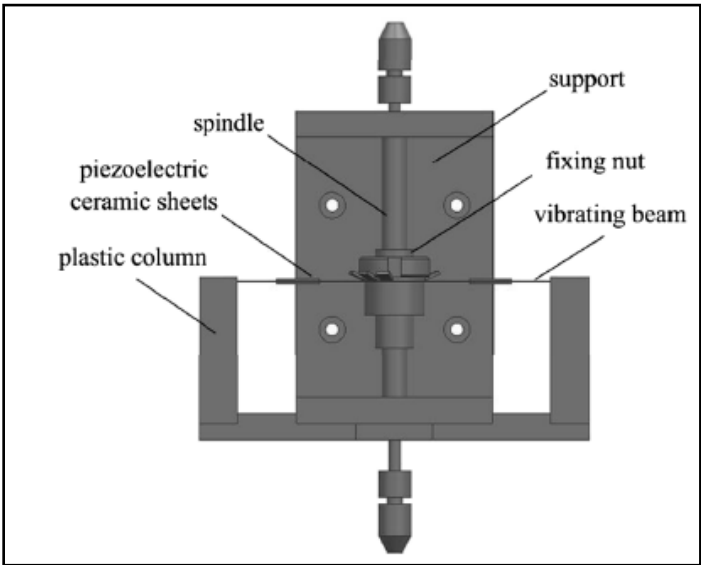


Figure 2: ECM vibration mechanism (Xu and pan., 2014)

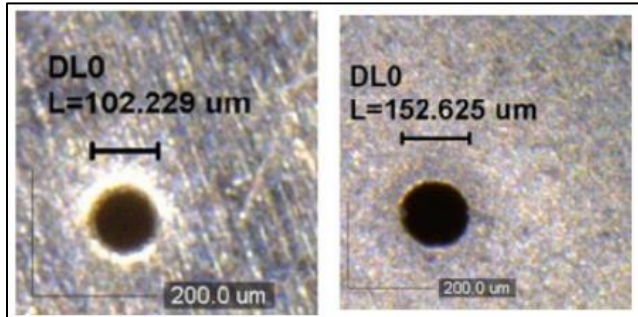


Figure 3: Optical microscope picture of micro hole machined by vibrating and static electrode. (Pan and Xu., 2014)

The insulator is made of circular epoxy resin plates, as seen in Figure 4. By monitoring the current value, the IEG between the two cylindrical electrodes is kept stable. According to the study, MRR is significantly impacted by the rotational speed of cylindrical electrodes in NaNO_3 solution.

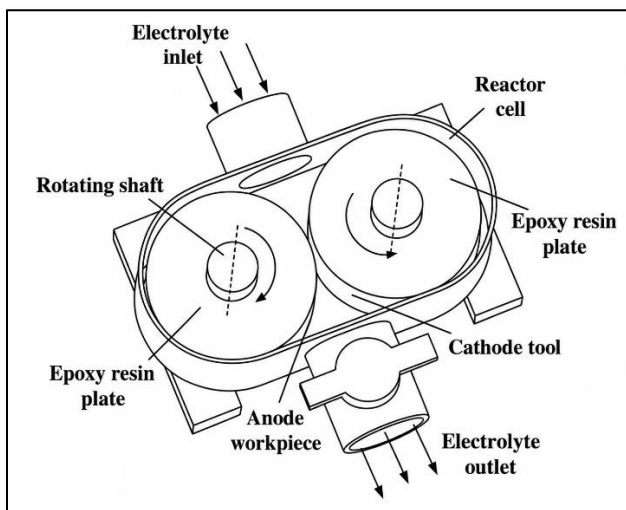


Figure 4: Rotating electrode setup (Wang et al.2017)

Qu et al. (2014) used an equal-thickness cathode to mill a nickel-based superalloy, which has several disadvantages, such as trailing edge distortion that causes the workpiece shape to deform. As seen in Figure 5, Zhang et al. (2016) employed an extended cathode, a specially made cathode, to increase the trailing edge's precision. By using the expanded cathode, a workpiece that resembles the intended blisk can be manufactured. When comparing the two cathodes, the equal-thickness cathode reduces the surface roughness R_a by 29.6% and the allowance difference at the trailing edge by 31.6%.

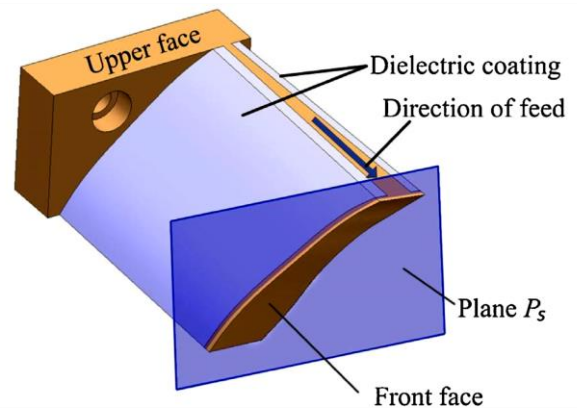


Figure 5: Extended cathode (Zhang et al.2016)

The ideal mix of cathode feed and anode position is crucial for machining accuracy when it comes to ECM blade machining, and the cathode and anode feed rate plays a significant impact. The three-cathode feeding approach, which is seen in Figure 6 and involves two cathodes oriented coaxially with the anode axis positioned vertically to the cathodes, was introduced by Qu and Xu in 2013. The findings demonstrate that the machining precision can be increased by optimizing the cathode feeding directions and anode position. Convex and concave parts had maximum errors of just 0.054 and 0.047 mm, respectively.

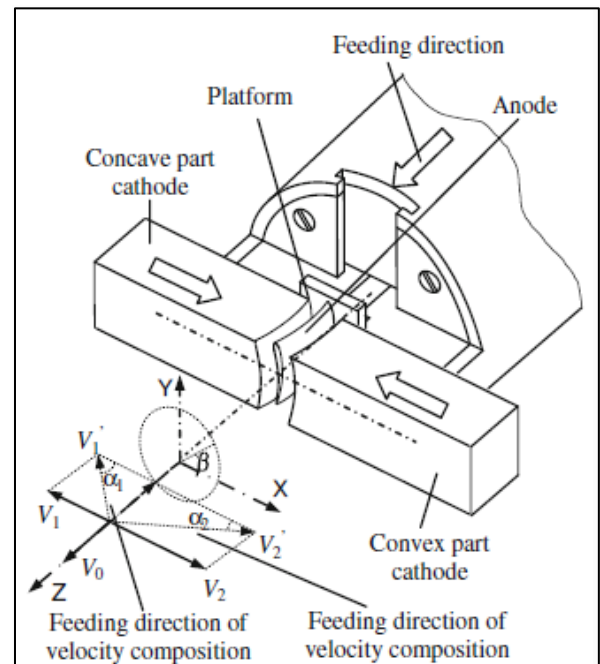


Figure 6: Three cathode feeding method (Qu and Xu 2013)

Figure 7 shows how Lee et al. (2015) replicated the ECM process using various tool electrode designs. A and D have been determined to be appropriate for the ECM process among these tools. When compared to the other four cathode tools, these two forms generate a lower temperature. During the ECM process, steady anodic dissolution could result from low temperatures on electrodes or in the electrolyte.

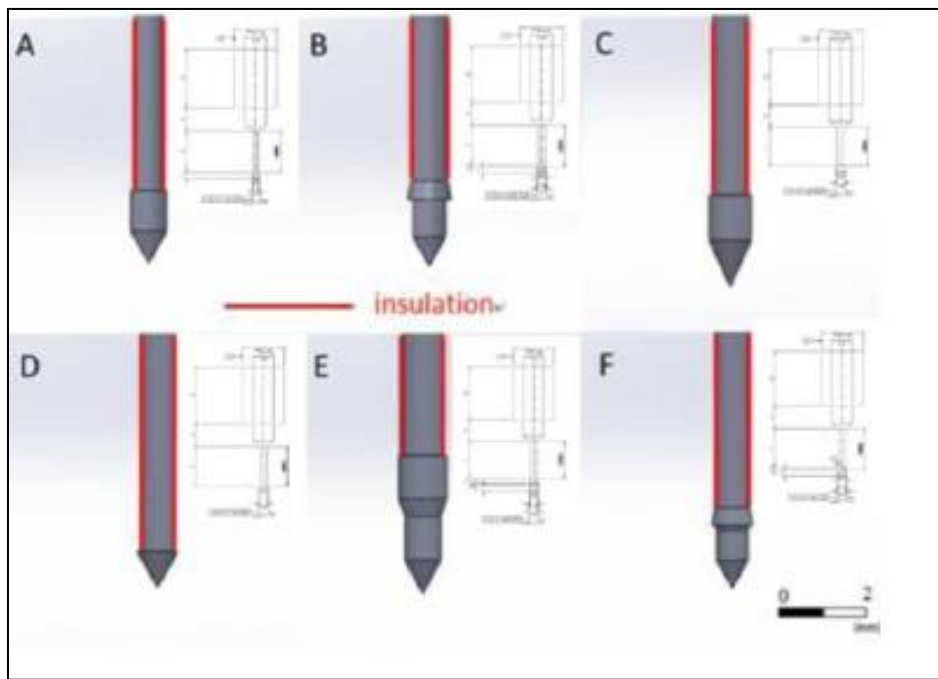


Figure 7: Shapes of tool electrode (Lee et al 2015)

In a similar vein, Liu et al. (2015) created four spherical cathodes with various drain passageways, including slant jet, numerous holes, side gap, and drain from the bottom half. The option depicted in Fig. 7d has been selected as the process's final solution among these designs, as seen in Fig. 8. Better flow stabilization results from the slant jet's direct orientation toward the machining area and its ability to supply sufficient electrolyte to the machining gap.

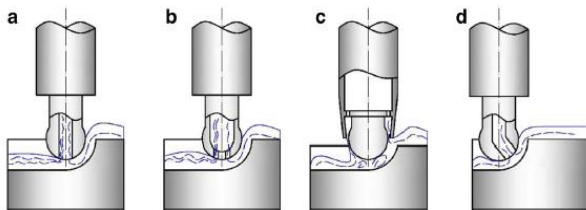


Figure 8: Spherical cathodes design (Liu et al.2015)

2.2. HYBRID ECM

The integration of various manufacturing techniques into a single machine tool is one of the current manufacturing technology research and development trends. Laser aided machining (LAM) makes it easier to manufacture challenging materials by using an external heat source, such as a laser beam, to heat and soften the workpiece locally in front of the tool. Laser-induced electrochemical machining (LIECM), a compound process that combines an electrolyte process with a laser beam, was created by Long et al. in 2015. Figure 9 shows the LIECM mechanism. Large sediments, impact damage, thermal stress, and heat-affected zones are all eliminated by this compound etching method. Furthermore, it inhibits passive film assists to increase the aspect ratio and avoids lateral etching.

Additionally, Zhang et al. (2015) investigated the impact of LIECM on MRR and surface roughness. At a laser frequency of 5 Hz, there was very little surface roughness. The current range of 7mA to 12mA produced the best machining. Additionally, the micro-hole taper dropped from 1.505 to 0.769 as the pulse number increased.

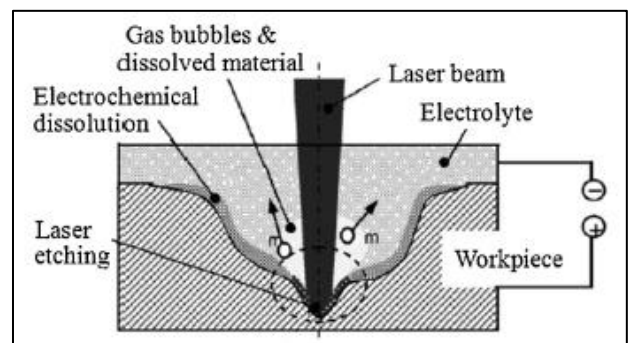


Figure 9: LIECM mechanism Long et al.2015

Thanigaivelan et al. 2017 studied the effect of Infra-red (IR) assisted ECM on machining of copper. Figure 10 show the schematic of the IR assisted ECM. The use of IR light heats the electrolyte and changes the conductivity of the electrolyte. The result showed that the machining rate for heated electrolyte is 4.2 times better than the electrolyte at room temperature. Moreover, the change in electrolyte conductivity of heated electrolyte solution shows considerable effect on overcut and the study reveals that use of IR.

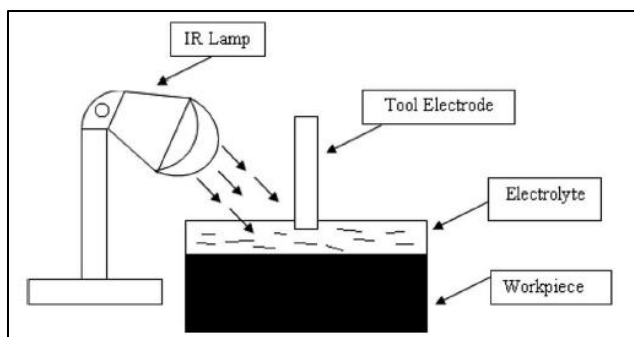


Figure 10: Infra-red (IR) assisted ECM (Thanigaivelan et al. 2017)

Goel and Pandey 2017 combining ultrasonic vibrations with the Jet-ECMD resulted in an enhancement of the process capabilities in terms of improvement of MRR and reduction in the hole taper. Ma et al. 2015 studied the influence of the electro discharge machining–pulse electrochemical machining method as shown in Figure 11, on surface quality and accuracy of the hole. By combining these two methods the surface quality improved from 4.277 to 0.299mm and the hole taper was reduced from 1.04° to 0.17° after pulse electrochemical machining.

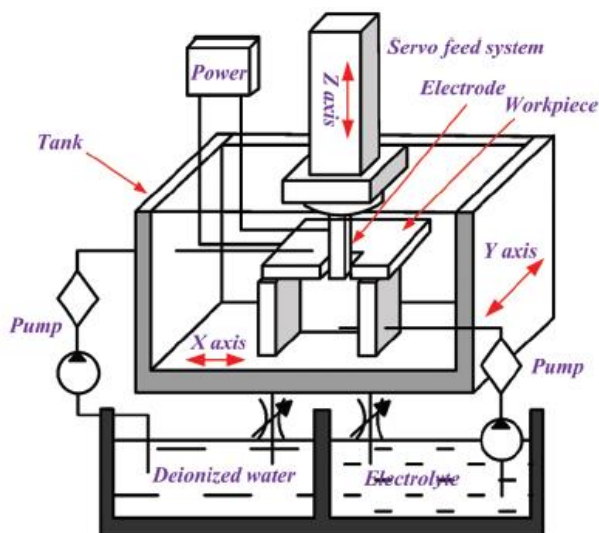


Figure 11: Electro discharge machining–pulse electrochemical machining (Goel and Pandey 2017)

3. CONCLUSIONS

It is evident that based on the continuous research researchers are finding the efficient ways such as vibrating the electrode, modifying the cathode design and feed movement, varying the concentration and flow of electrolyte and through hybrid process to improve the MRR, accuracy and surface quality. In industry viewpoints any method which is low cost, more accurate, environment friendly and high productivity are preferred.

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CONFLICT OF INTEREST

There is no conflict of interest among the authors.

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