ABSTRACT

Electrochemical Discharge Milling (ECD milling) is an advanced hybrid machining process capable of fabricating intricate features on electrically non-conductive materials. However, its wider application is limited by unstable gas-film formation, inadequate fresh electrolyte supply, and uncontrolled spark discharge, particularly during deep-channel machining. To address these limitations, this research developed an indigenous Electrochemical Discharge Milling setup and proposed a novel vertically upward tool feeding technique to improve gas-bubble evacuation, electrolyte circulation, and spark localization. Numerical simulations were performed to investigate gas-film formation and temperature distribution under different tool-feeding techniques. The proposed upward tool feeding method concentrated higher temperatures at the tool tip, resulting in more stable spark discharges, an approximately 11% reduction in channel width, and the lowest tool wear (4.95%) compared with conventional feeding techniques. The effects of applied voltage, electrolyte concentration, and tool feed rate on material removal rate (MRR), channel width, surface roughness, and taper angle during ECD milling of silica glass were investigated. Maximum MRR of 6.097 μg/min was achieved at 45 V and 25 wt% NaOH, whereas the best surface finish (R_a = 0.222 μm) was obtained at 40 V, 20 wt% NaOH, and 40 μm/s tool feed rate. The proposed technique also enabled successful fabrication of high-quality channels, zigzag channels, rectangular cavities, E-shaped channels, and micro-pillars on silica glass. Process optimization was carried out considering electrolyte concentration, applied voltage, and tool feed rate. The applicability of the proposed technique was extended to polymers (PMMA and polycarbonate). The results demonstrated that electrolyte selection significantly influences machining quality and the spark-affected zone, enabling the fabrication of better channels suitable for lab-on-chip and microfluidic applications. This research has established the vertically upward tool-feeding technique as a simple, effective, and reliable approach for enhancing ECD milling performance.

Keywords: ECD milling, Simulation, Upward tool-feeding technique, Process optimization, Non-Conducting Materials

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13/07/2026

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