

BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 72 (76), Numărul 2, 2026
Secția
CONSTRUCȚII DE MAȘINI
DOI: 10.2478/bipcm-2026-0011

DEVELOPMENT OF AN EXPERIMENTAL MODEL FOR CONVENTIONAL ELECTROCHEMICAL MACHINING

BY

TITI DANCIU* and LIVIU-DANIEL GHICULESCU

National University of Science and Technology POLITEHNICA Bucharest,
Faculty of Industrial Engineering and Robotics,
313 Splaiul Independentei, sector 6, 060042, Bucharest, Romania

Received: May 21, 2026

Accepted for publication: June 10, 2026

Abstract. For machining surfaces with high hardness, a good method with high processing efficiency is conventional electrochemical machining (C-ECM). In this article, we present the design and testing of an experimental model under laboratory conditions, using equipment and electrolyte solutions in accordance with the process requirements. After the experiments are completed, the next stage involves validating the model by evaluating its performance in relation to various technological parameters, such as the type and concentration of the electrolyte and the applied voltage, as well as by analyzing the quality of the resulting surfaces. The ultimate goal of this work is to verify the proper functioning of the conventional electrochemical machining system and to identify the most efficient ways to use this technology for machining complex materials. In conclusion, the developed experimental model represents an efficient and versatile tool for advanced material machining, supporting both scientific research and future industrial optimization and implementation.

Keywords: electrochemical machining, electrolyte, linear actuator, nozzle, tool electrode.

*Corresponding author; *e-mail*: titi.danciu@stud.fils.upb.ro

© 2026 Titi Danciu and Liviu-Daniel Ghiculescu

This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

1. Introduction

This paper presents an in-depth study of the conventional electrochemical machining (C-ECM) process applied to advanced cobalt–chromium (Co–Cr) alloys, materials extensively used in biomedical, aerospace, and industrial applications (Ciobanu *et al.*, 2023) due to their superior resistance to corrosion, wear, and elevated temperatures (Bunea *et al.*, 2025; Varol *et al.*, 2024; Wongpromrat *et al.*, 2022).

Cobalt–chromium alloys are recognized for their outstanding mechanical and chemical properties, which make them suitable for orthopedic and dental implants, wear-resistant components, and equipment operating in highly corrosive environments. However, their high hardness, wear resistance, and chemical stability significantly reduce their machinability when conventional manufacturing methods are employed.

In this context, conventional electrochemical machining represents an efficient alternative manufacturing technology, since material removal occurs through controlled anodic dissolution without direct mechanical contact between the tool and the workpiece, without the generation of significant thermal stresses, and without tool wear (Sahu *et al.*, 2022; Wu *et al.*, 2024). These characteristics provide C-ECM with considerable advantages in the machining of difficult-to-cut materials, enabling the production of components with high surface integrity and superior dimensional accuracy. However, the liquid electrolytes in C-ECM flow freely, making it hard to confine them precisely to the intended machining zone. This lack of control may lead to stray-current corrosion in unintended areas (Wang *et al.*, 2022).

Despite extensive research on conventional electrochemical machining of Co–Cr alloys, there is still limited understanding of the combined influence of key process parameters and electrolyte composition on machining stability, material removal rate, and surface integrity, particularly when comparing chloride-based and mixed carbonate–organic electrolyte systems. In addition, electrolyte confinement issues leading to stray corrosion remain insufficiently controlled.

The study examines two categories of electrolytes: a 5% sodium chloride (NaCl) solution and electrolyte systems based on 5% sodium carbonate combined with 4.7% citric acid. Therefore, the main objective of this study is to investigate and compare the conventional electrochemical machining performance of Co–Cr alloys using two electrolyte systems (5% NaCl and 5% sodium carbonate + 4.7% citric acid solution), focusing on process stability, anodic dissolution rate, and surface quality. The specific objectives of this research are to analyze the influence of key C-ECM parameters (applied voltage, current density, electrolyte temperature, pressure, flow rate, and interelectrode gap) on machining performance, to evaluate the effect of electrolyte composition on surface integrity and process stability, and to identify

optimal parameter ranges for improving machining efficiency and minimizing stray current effects.

Conventional electrochemical machining is a non-traditional manufacturing process based on the controlled anodic dissolution of a metallic workpiece immersed in an electrolyte, where the material removal occurs through electrochemical reactions governed by Faraday's laws, without direct mechanical contact between tool and workpiece (Arshad *et al.*, 2024). A critical aspect of C-ECM performance is the continuous removal or prevention of the passivating oxide layer that naturally forms on the workpiece surface during anodic dissolution, which can otherwise hinder the electrochemical reaction and reduce process efficiency. Depending on the mechanism employed to control or eliminate this passive layer, C-ECM processes can be classified into three main categories: natural passivation-based C-ECM, where material removal relies on the intrinsic instability of the passive film under optimized electrochemical conditions; mechanically assisted C-ECM, in which the passive layer is disrupted through controlled abrasive or tool-induced mechanical action; and forced hydrodynamic C-ECM, like in our study, where high-velocity electrolyte flow is used to continuously remove reaction products and prevent the formation of a stable passivation layer on the machined surface (Arshad *et al.*, 2024).

2. Experimental model development for C-ECM

The main objectives of this study are to investigate the conventional electrochemical machining process applied to cobalt–chromium (Co–Cr) alloys, to evaluate the influence of process parameters on machining performance, to compare the electrochemical behavior of the material in two distinct electrolyte systems, and to identify potential optimization strategies and future research directions aimed at improving process efficiency, stability, and surface quality.

The laboratory-scale conventional electrochemical machining setup presented in this study is designed based on the schematic representation of the ECM process shown in Fig. 1 (Xu *et al.*, 2021). The schematic representation was used as a conceptual reference for identifying the essential components of the machining system, including the power supply, tool electrode, workpiece, electrolyte circulation system, and interelectrode machining zone. Starting from this established ECM configuration, an experimental installation was designed and assembled to reproduce the fundamental operating principles of conventional electrochemical machining under controlled laboratory conditions. The adopted configuration facilitated the integration of all process-related subsystems and provided a practical framework for investigating the influence of machining parameters on process performance and material removal behavior.

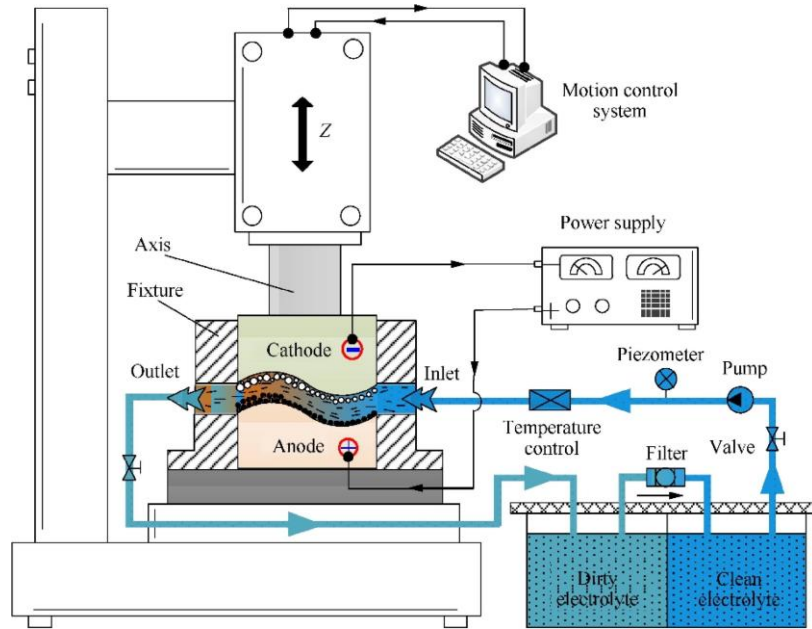


Fig. 1 – Schematic representation of the conventional electrochemical machining process (Xu *et al.*, 2021).

The main components of our system include: a linear actuator driven by a 1.8° stepper motor (Fig. 2), a DC power supply unit, a filtration system, a recirculation pump, clamping fixtures, an electrolyte reservoir, and the machining chamber.

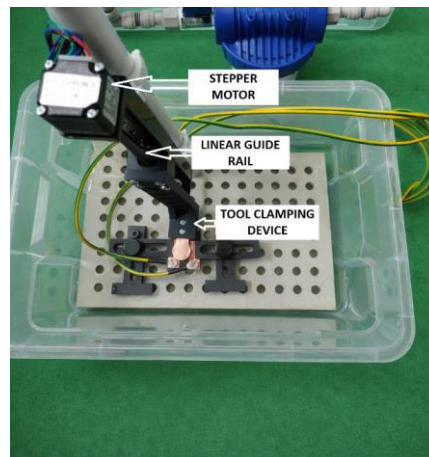


Fig. 2 – Main components of the stepper motor-driven linear actuator.

The linear actuator equipped with the stepper motor is responsible for maintaining a constant interelectrode gap between the workpiece and the machining tool during processing. Its functional role is to compensate continuously for the increase in the interelectrode gap generated by the anodic dissolution of the workpiece material. As material removal progresses, the tool electrode advances toward the workpiece under the controlled motion of the actuator, ensuring a stable and constant working gap throughout the C-ECM process.

The power supply unit provides the electrical current required for each machining operation, enabling the establishment of the desired current density “J”, necessary for conventional electrochemical machining or electrochemical polishing/finishing of advanced materials. In addition, the system allows precise adjustment of the applied voltage during processing. Parameter control is performed using a fine-tuning adjustment mechanism, ensuring stable current delivery with minimal fluctuations throughout the operation. Maintaining a constant current intensity becomes particularly critical at high current values, where increased process sensitivity requires enhanced control accuracy and operational stability.

2.1. Model setup

Following multiple optimization stages of the experimental configuration and the evaluation of various technical solutions, the final version of the C-ECM experimental equipment was developed, as presented in Fig. 3.

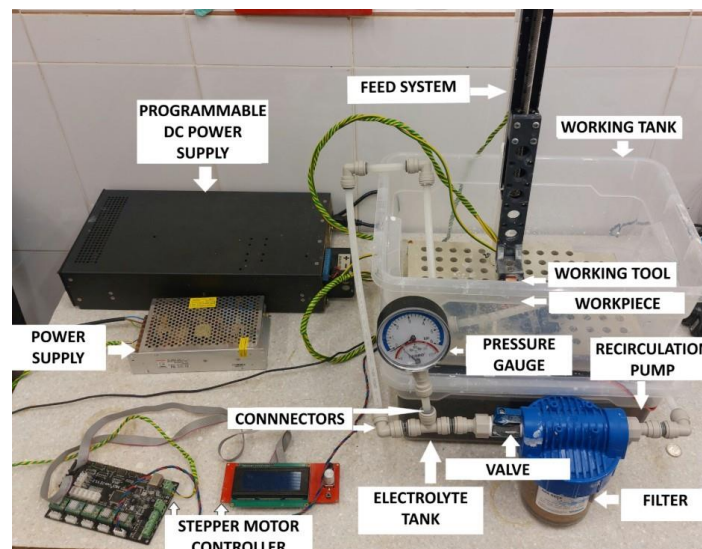


Fig. 3 – Experimental setup for conventional electrochemical machining.

After the integration of all system components, a comprehensive operational verification procedure was conducted to ensure proper sealing and leak-tightness of the installation. Particular attention was paid to the joint interfaces, filter valve connections, elbow fittings, hose coupling areas, and the electrolyte recirculation pump assembly.

Fig. 4 presents representative images of the main component elements composing the proposed technological system for the conventional electrochemical machining of advanced materials.

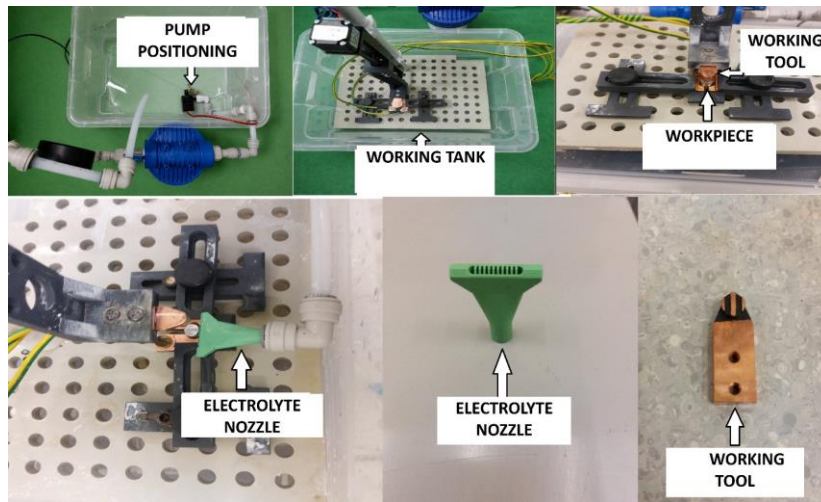


Fig. 4 – Main components of the C-ECM experimental setup.

The workpiece was positioned and secured inside the machining chamber using custom clamping fixtures manufactured through 3D printing technology (Fig. 5).

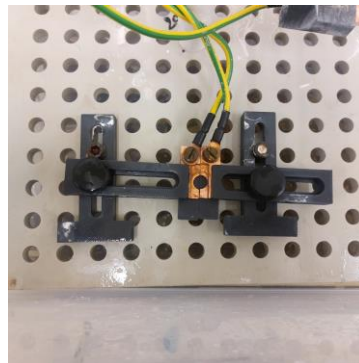


Fig. 5 – Workpiece clamping system.

To ensure proper alignment and parallelism between the workpiece and the tool electrode, the clamping supports were designed with adjustable positioning capability. The electrical connection between the workpiece and the positive terminal of the DC power supply was achieved using two stranded copper conductors with a cross-sectional area of 2.5 mm². The conductors were attached to the clamping supports by means of insulated cable lugs equipped with ring terminals.

2.2. Experimental results

The characteristics of the machined workpiece are shown below in Table 1 (www.dentstore.ro).

Table 1
Technical data of workpiece (www.dentstore.ro)

Property	Value
yield strength (0.2% offset)	575 MPa
elongation	6%
Young's modulus of elasticity	210 GPa
tensile strength	700 MPa
density	8.4 g/cm ³
corrosion resistance	< 200 µg/cm ²
melting point	1340–1400 °C
CTE (25–500 °C) (10 ⁻⁶ K ⁻¹)	approx. 14.1
casting temperature	1485 °C
hardness HV 10/30 (Vickers)	350
maximum firing temperature	approx. 980 °C
dimensions (d, L)	9.5 × 11 mm

The formation of gas bubbles during C-ECM is a normal phenomenon associated with the secondary electrochemical reactions accompanying anodic dissolution. Most of these bubbles originate from gas evolution processes occurring at the electrode surfaces (Babich *et al.*, 2025; Sundén, 2019; Şahin, 2024).

At the cathode, the dominant reaction is the electrochemical reduction of water, resulting in hydrogen evolution according to the following reaction (Eq. (1)) (Zhang *et al.*, 2022):



The main chemical equations governing the conventional electrochemical machining are much more complex than Eq. (1), which illustrates only one aspect of the chemical reactions that occur in the machining process.

Hydrogen generation is generally responsible for the visible effervescence observed during machining (Fig. 6).

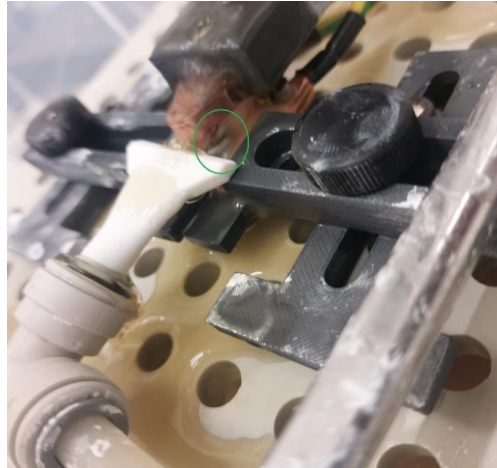


Fig. 6 – Gas bubble formation during C-ECM processing.

Gas evolution at the electrode–electrolyte interface represents an intrinsic aspect of the C-ECM process. Bubble formation is primarily associated with hydrogen evolution at the cathode and, depending on the applied potential and local pH conditions, oxygen evolution at the anode. These phenomena significantly influence the stability of the local electric field and the mass transport mechanisms within the interelectrode gap.

The presence of gas bubbles may partially shield the active surface, leading to non-uniform current density distribution and consequently to localized variations in the anodic dissolution rate of the Co–Cr alloy. Furthermore, the electrolyte composition, particularly the presence of citric acid acting as a complexing agent, contributes to the control of chromium passivation and modifies the kinetics of the electrochemical reactions. These effects influence bubble size, detachment frequency, and transport dynamics, directly affecting surface quality and process efficiency.

Gas bubbles represent not only a visual by-product of the process but also a critical factor influencing machining performance. Insufficient evacuation of gaseous products may lead to disturbances in current distribution, local conductivity variations, electrolyte flow non-uniformities, and the formation of surface defects. Consequently, precise control of electrolyte flow rate and electrical operating conditions is essential to minimize gas accumulation within the interelectrode gap.

The accumulation of gas bubbles can produce several detrimental effects on the C-ECM process. Since gas exhibits low electrical conductivity,

regions covered by bubbles receive reduced current density, resulting in non-uniform material dissolution. In addition, restricted electrolyte renewal near the workpiece surface increases the risk of local passivation of the Co–Cr alloy. These effects may lead to increased surface roughness, localized defects, and micro-pitting phenomena, as illustrated in Fig. 7.

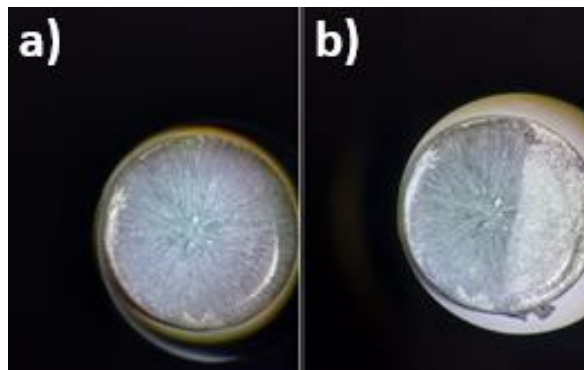


Fig. 7 – Morphology of the passivation layer formed on the Co–Cr alloy surface after conventional electrochemical machining for 420 s: (a) 5% NaCl electrolyte; (b) 5% Na_2CO_3 + 4.7% citric acid electrolyte.

Under extreme operating conditions, gas accumulation may also induce jet instability and feed-rate fluctuations. For this reason, process parameter selection requires a balance between achieving sufficiently high current densities for enhanced productivity and preventing excessive gas volume fractions within the interelectrode gap. In many C-ECM applications, the limiting factor is no longer the anodic dissolution rate itself, but rather the accumulation of gaseous products, which ultimately determines the maximum usable current density.

Several optimization strategies can be adopted in practice to reduce gas accumulation effects, including increasing the electrolyte flow velocity to improve bubble evacuation, optimizing nozzle and channel geometries to promote controlled turbulence, applying pulsed current regimes that facilitate intermittent gas release, and maintaining electrolyte temperatures that do not excessively promote secondary electrochemical reactions.

In the present study, three nozzle geometries with different electrolyte jet configurations were investigated (Fig. 8).

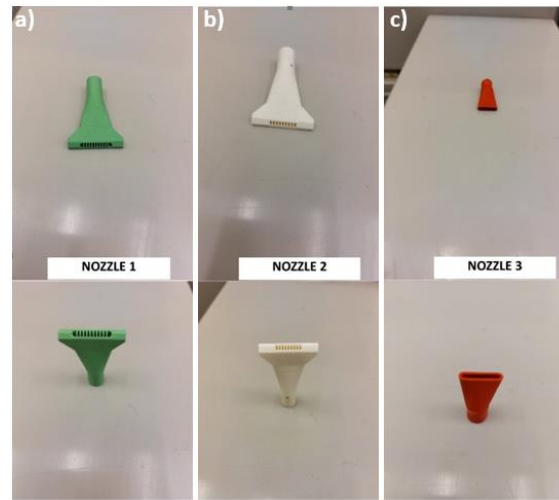


Fig. 8 – Nozzle geometries used in conventional electrochemical machining experiments: (a) slit-based comb structure, (b) compact slit configuration, and (3) geometry generating an oval-shaped (elliptical) focused electrolyte jet.

The geometric differences between these nozzles are not merely constructive variations, but were selected to investigate the influence of electrolyte flow characteristics on machining stability and material removal behavior.

A comparative analysis of the three nozzle configurations is presented in Table 2.

Table 2
Comparative characteristics of nozzle geometries

Feature	Nozzle 1	Nozzle 2	Nozzle 3
jet type	flat, uniform	flat, high-energy	oval, focused
lateral resolution	medium	good	very good
depth uniformity	high	medium–high	low
risk of gas accumulation	low	medium	high
typical applications	texturing, deburring	micro channels	micro holes

In addition to the nozzle configurations, three cathodic tool electrode geometries were also investigated, as illustrated in Fig. 9.

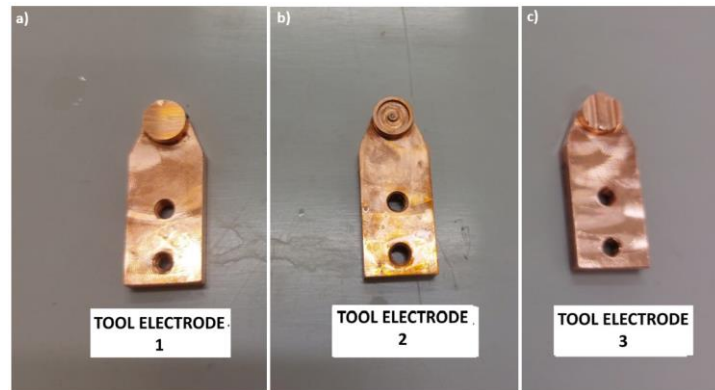


Fig. 9 – Tool electrode geometries used in experiments: (a) quasi-planar geometry, (b) dual-circular geometry, and (c) grooved geometry.

Within the C-ECM process, the tool electrode should not be considered solely as the negative replica of the desired geometry, but rather as an active element responsible for controlling the electric potential distribution, electrolyte flow velocity, and local gas fraction within the interelectrode gap.

Tool electrode 1

The first tool geometry consists of an almost flat active surface positioned perpendicular to the feed direction. This configuration generates relatively parallel electric field lines, producing an initially uniform current density distribution and predominantly axial electrolyte flow.

The main advantages of this geometry include high geometrical predictability and simplified numerical modeling.

However, as the electrolyte progresses through the interelectrode gap, several changes occur simultaneously: electrolyte heating, increased ionic concentration, and gas bubble accumulation. These phenomena alter local conductivity and cause current density intensification toward the outlet region, leading to reduced dissolution uniformity.

Tool electrode 2

The second tool geometry incorporates two circular active regions aligned along the feed direction. This configuration concentrates the electric field in the central area, increases local electrolyte velocity, and promotes passive film breakdown.

Since chromium rapidly forms stable oxide layers, insufficient shear stressor inadequate current density may result in localized passivation. The inner circular feature acts as a controlled activation zone capable of enhancing localized dissolution.

The main limitations associated with this geometry include an increased risk of crater formation (Fig. 10), higher depth gradients, and the requirement for more precise feed-rate control.

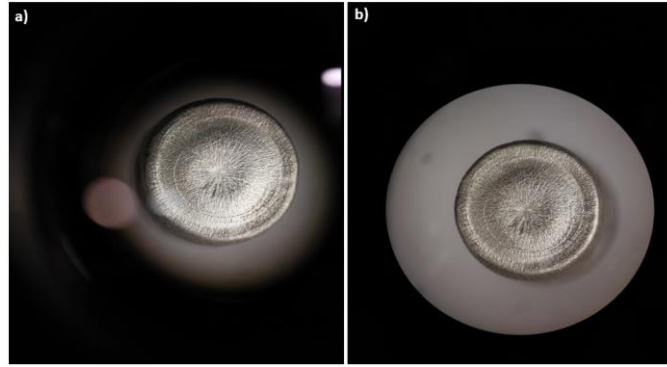


Fig. 10 – Conventional electrochemical machining using tool electrode 2: (a) machining process at 180 s (10 V, 20 A/cm²), (b) machining process at 640 s (10 V, 20 A/cm²).

Tool electrode 3

The third tool geometry incorporates grooved active surfaces specifically designed to compensate naturally for non-uniformities developing along the interelectrode gap. Usually, for distinct reasons (presence of gases, electrolyte impurity, etc.), the current density tends to decrease towards the electrolyte exit zone from the machining gap (Fig. 11).

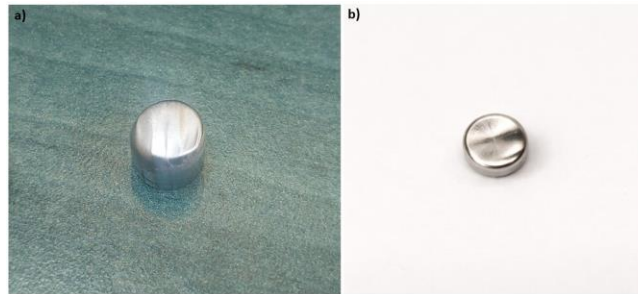


Fig. 11 – Conventional electrochemical machining using tool electrode 3: (a) machining process at 120 s (10 V, 20 A/cm²), (b) machining process at 600 s (10 V, 20 A/cm²).

To counteract this effect, the local electric field intensity is intentionally reduced through modifications of the interelectrode gap, partial shielding effects, or changes in the active surface area.

These design adaptations contribute to achieving a more uniform material removal rate (MRR), improved surface roughness consistency, and enhanced dimensional tolerances.

The three investigated tool geometries, therefore, reflect distinct design philosophies: theoretical field uniformity (Tool electrode 1), localized

electrochemical activation (tool electrode 2), and predictive compensation of field non-uniformities (Tool electrode 3).

Before C-ECM, the Co–Cr alloy specimens were degreased in isopropyl alcohol and subsequently rinsed with demineralized water.

Electrolyte 1: sodium chloride (NaCl)

During experiments, a 5–20% NaCl solution was used. This electrolyte is a neutral electrolyte characterized by high electrical conductivity and low cost. Chloride ions (Cl^-) promote the breakdown of the passive Cr_2O_3 oxide layer, thereby facilitating anodic dissolution of the alloy.

The main process parameters for electrolyte 1 are presented in Table 3.

Table 3
Process parameters for electrolyte 1

Parameter	Value
concentration	5–20 wt.% NaCl
voltage	10–20 V
current density	10–20 A/cm ²
temperature	20–30 °C;
machining time	1–10 min
electrolyte flow rate	800 l/h
operating pressure	0.6 bar

Experimental observations

For the 5% NaCl electrolyte, the ECM process demonstrated a high material removal rate, attributed to the high electrical conductivity of the solution and the ability of chloride ions to disrupt the passive Cr_2O_3 film on the surface of the Co–Cr alloy. However, the use of this electrolyte resulted in an increased susceptibility to localized corrosion (pitting) and produced a relatively high surface roughness, as illustrated in Fig. 12. The reaction products generated during electrochemical dissolution remained predominantly dissolved in the electrolyte, with no significant formation of adherent deposits on either the workpiece or the tool electrode. During processing, the electrolyte composition gradually changed due to the accumulation of dissolved metallic ions originating from anodic dissolution of the alloy. Nevertheless, the electrolyte exhibited relatively good operational stability, as certain chemical species were partially regenerated through secondary electrochemical reactions. To maintain consistent machining performance, periodic filtration and replenishment of the electrolyte were required to control the concentration of dissolved metallic ions. The principal limitations of this electrolyte system include limited dimensional accuracy and process controllability, as well as the adverse environmental impact associated with the use and disposal of chloride-containing solutions.



Fig. 12 – C-ECM processing using a 5% NaCl electrolyte at 10 V and a current density of 10–20 A/cm².

Electrolyte 2: 5% sodium carbonate (Na₂CO₃) and 4.7% citric acid (C₆H₈O₇)

This electrolyte system combines a mildly alkaline medium with an organic acid, offering a more environmentally benign alternative to conventional chloride-based electrolytes. The main process parameters for Electrolyte 2 are presented in Table 4.

Table 4
Process parameters for electrolyte 2

Parameter	Value
concentration	5–10 wt.% Na ₂ CO ₃ ; 4.7 wt.% citric acid
voltage	10–20 V
current density	10–20 A/cm ²
temperature	20–30 °C;
machining time	1–10 min
electrolyte flow rate	800 l/h
operating pressure	0.6 bar

Experimental observations

The Na₂CO₃–citric acid electrolyte system produces a smooth and homogeneous surface finish and exhibits good chemical stability; however, it promotes the formation of metal hydroxides and carbonates due to the presence of sodium carbonate, while citric acid enhances metal-ion complexation without fully inhibiting precipitation processes, leading to an increased tendency for sludge and solid by-product formation. Consequently, the electrolyte shows limited self-regeneration capability, and stable processing conditions can only

be maintained through continuous replenishment with fresh solution and the implementation of an efficient filtration system. Overall, the process is characterized by a moderate material removal rate and requires strict control of pH and electrolyte concentration, while also imposing a significant environmental burden associated with electrolyte handling, regeneration, and waste treatment.

2.3. Comparative evaluation of electrolyte systems

The presence of chromium in the alloy promotes passivation through the formation of protective oxide films. In sodium chloride solutions, the passive layer can be more easily disrupted due to the aggressive nature of chloride ions, which sustains a high current efficiency but may also promote secondary electrochemical reactions.

In the sodium carbonate–citric acid electrolyte system, complexation processes contribute to maintaining metal dissolution; however, under certain conditions, localized passivation phenomena may occur, requiring careful control of the operating parameters.

The use of a 5% NaCl solution results in intense anodic dissolution, characterized by high current densities and elevated material removal rates. The process is less selective, and local micro-heterogeneities may lead to slightly increased surface roughness. Moreover, the risk of post-process parasitic corrosion is more pronounced.

In contrast, the sodium carbonate–citric acid electrolyte promotes the formation of soluble complexes of metal ions and a more uniform dissolution at the microscopic scale, resulting in generally smoother surfaces with lower roughness values.

In the case of the NaCl-based electrolyte, the high conductivity may lead to a less controlled distribution of the electric field, particularly in regions with variable interelectrode gaps, thereby affecting dimensional accuracy.

The carbonate–citric acid mixture enables better localization of the oxidation process, reducing the tendency toward over-erosion and improving the geometric fidelity of the workpiece. Consequently, the NaCl electrolyte is advantageous for high productivity and operational simplicity, whereas the sodium carbonate–citric acid system provides superior surface quality and higher precision, at the expense of stricter monitoring of composition and process parameters.

An increase in voltage leads to higher current density but also promotes parasitic reactions. The current density must be sufficiently high to prevent chromium passivation, with typical values for Co–Cr alloys ranging between 10 and 50 A/cm². The operating voltage is generally in the range of 5–25 V, depending on electrolyte conductivity and interelectrode gap size.

The tool–workpiece interelectrode gap is typically maintained between 0.1 and 0.5 mm; lower values improve dimensional accuracy but increase the risk of short-circuiting.

The electrode feed rate is correlated with the anodic dissolution rate, ensuring maintenance of a stable interelectrode gap throughout the process.

Elevated temperature increases reaction kinetics but reduces the stability of organic electrolytes. Therefore, temperature is typically controlled within the range of 20–35°C to maintain stable electrochemical properties.

High electrolyte flow rates and forced circulation through the machining zone are required for efficient removal of reaction products and to prevent passivation phenomena. Increased flow enhances product evacuation and improves process uniformity.

Optimization proposals for future studies

For the NaCl-based electrolyte system, future optimization strategies should focus on reducing the electrolyte concentration and implementing pulsed current regimes to improve process control and minimize undesirable side reactions, as well as on the incorporation of corrosion inhibitors to mitigate localized corrosion phenomena and enhance overall surface integrity.

For the Na₂CO₃–citric acid electrolyte system, future optimization efforts should focus on fine-tuning the alkaline-to-acid ratio in order to improve process stability and control metal-ion complexation equilibria, as well as on the application of pulsed current to enhance dissolution uniformity, reduce passivation tendencies, and improve surface quality.

2.4. Further research

Future research should focus on the optimization of the principal C-ECM process parameters, including applied voltage, current density, electrolyte flow rate, and electrolyte temperature, to evaluate their influence on material removal rate, surface roughness, and interelectrode gap stability.

Another important research direction concerns the electrochemical behavior of Co–Cr alloys, particularly the mechanisms of passivation and depassivation, oxide film formation, and the influence of citrate-based electrolytes on the complexation behavior of cobalt and chromium ions.

In addition, numerical modeling of the coupled physical fields involved in C-ECM processing may contribute significantly to process improvement. Such studies may include computational fluid dynamics (CFD) simulations of electrolyte flow through nozzle geometries, as well as multiphysics simulations of electric potential distribution, current density, temperature evolution, and interelectrode gap development, to predict the final machined geometry and process stability.

Further investigations should also address detailed surface characterization using Scanning Electron Microscopy (SEM) techniques,

together with analyses of surface roughness, microstructural modifications, chemical composition changes, corrosion resistance, and potential effects on biocompatibility, particularly for biomedical applications.

For large-scale industrial implementation, studies concerning energy efficiency and current utilization efficiency are also necessary. Determining the specific energy consumption and identifying operating regimes that maximize useful anodic dissolution while minimizing secondary electrochemical reactions represent important objectives for process optimization.

Additional future research directions may include the investigation of pulsed-current C-ECM regimes, the integration of C-ECM within hybrid manufacturing processes, the evaluation of electrolyte stability and durability through long-term monitoring of electrolyte composition and reaction product accumulation, as well as the development of advanced monitoring and automation strategies based on sensor integration and adaptive feed control algorithms for maintaining a stable interelectrode gap and preventing short-circuit conditions.

3. Conclusions

The C-ECM performance of cobalt–chromium alloys is strongly influenced by both the electrolyte composition and the selected processing parameters. While sodium chloride-based electrolytes provide high material removal rates and increased machining productivity, electrolyte systems based on sodium carbonate and citric acid represent a more sustainable and controllable alternative for advanced and precision applications.

This study presented the development of an experimental setup dedicated to the electrochemical processing of advanced materials. The realization of the system was preceded by an extensive analysis of the C-ECM technology, followed by stages of numerical modeling and simulation of key operating parameters, including electrolyte flow behavior (laminar and turbulent regimes), hydrodynamic conditions within the interelectrode gap, and electrolyte circulation characteristics. These stages were subsequently integrated into the design and construction of the experimental installation, comprising the machining chamber, support structures, recirculation pump, filtration unit, and fluid connection components.

The implementation of the setup also involved several constructive adaptations and innovative modifications of existing components, including machining operations applied to the tool electrode, drilling operations on the polypropylene base plate, and the integration of customized spacer elements. In addition, several components were specifically designed and manufactured using additive manufacturing technologies, including the linear actuator support, workpiece clamping fixtures, and fastening elements.

The paper further presented the preliminary C-ECM experiments performed using the developed installation, focusing on the machining of advanced cobalt – chromium alloys.

Based on these observations, several process improvement strategies were proposed. The critical limitations identified during the operation of the experimental setup constitute important directions for further optimization and future development of the prototype installation.

Acknowledgements. Special appreciation is addressed to the academic coordinator and supervisor for his continuous guidance, scientific support, and valuable recommendations throughout the development of the experimental setup, the execution of the electrochemical processing experiments, and the interpretation of the obtained results.

The authors also acknowledge the support provided by the research laboratory and technical staff involved in the realization of the experimental installation, including the manufacturing, assembly, and optimization of the mechanical, electrical, and fluid circulation systems used in the study.

REFERENCES

- Arshad M.H., Saxena K.K., Huang S., Reynaerts D., *Macro and micro-scale material removal mechanisms during C-ECM/hybrid laser-C-ECM of a passivating multiphase NbC–Ni cermet*, Int. J. Mach. Tools Manuf., **200**, 104182 (2024).
- Babich A., Bashkatov A., Eftekhari M., Yang X., Strasser P., Mutschke G., Eckert K., *Oxygen versus hydrogen bubble dynamics during water electrolysis at microelectrodes*, PRX Energy, **4**, 013011 (2025).
- Bunea I.A., Păun A.G., Ghiculescu L.D., Enciu C.C., *Study of Electrolyte Flow in Electrochemical Finishing*, Nonconv. Technol. Rev., **29**, 1, (2025).
- Ciobanu D., Nagit Gh., Dodun O., Hrituc A., Craciun E., Slatineanu L., *The Influence of Some Working Conditions on Roughness in Electrochemical Machining of Some Carbon Steel Workpieces*, Nonconv. Technol. Rev., **27**, 4, (2023).
- Sahu A.K., Malhotra J., Jha S., *Laser-based hybrid micromachining processes: A review*, Opt. Laser Technol., **146**, 107554 (2022).
- Şahin M.E., *An overview of different water electrolyzer types for hydrogen production*, Energies, **17**, 4944 (2024).
- Sundén B., *Hydrogen*, in Hydrogen, Batteries and Fuel Cells, Academic Press, 37–55 (2019).
- Varol T., Aksa H.C., Yıldız F., Akçay S.B., Kaya G., Beder M., *Influence of post processing on the mechanical properties and wear behavior of selective laser melted Co-Cr-Mo-W alloys*, Tribol. Int., **192**, 109336 (2024).
- Wang J., Natsu W., *Mechanism and characteristics of conventional electrochemical machining using electrolyte absorbed in solid porous ball*, Precis. Eng., **77**, 307–319 (2022).
- Wongpromrat P., Galerie A., Thublaor T., Chandra-Ambhorn W., Ponpo P., Watasuntornpong P., Yamanaka K., Chiba A., Tunthawiroon P., Siripongsakul

- T., Chandra-Ambhorn S., Ruangtrakoon N., *Evidence for chromium, cobalt and molybdenum volatilizations during high temperature oxidation of Co-27Cr-6Mo alloy*, Corros. Sci., **202**, 110285 (2022).
- Wu F., Tong H., Chen F., Liu Z., Liu X., Zhou J., *Electrochemical surface modification of GH4742 nickel-based superalloy in C6H5Na3O7 solution*, Surf. Interfaces, **45**, 103815 (2024).
- Xu Z., Wang Y., *Electrochemical machining of complex components of aero-engines: Developments, trends, and technological advances*, Chin. J. Aeronaut., **34**(2), 28–53 (2021).
- Zhang Q., Luo H., Liu P., Liu G., Zhang Y., *Bipolar nano-second pulse power supply for electrochemical micromachining of tungsten carbide without tool wear*, Procedia CIRP, **113**, 471–476 (2022).
- https://dentstore.ro/aliaje-si-turnare/212175-aliaj-cr-co-system-d.html?fast_search=fs

DEZVOLTAREA UNUI MODEL EXPERIMENTAL PENTRU PRELUCRAREA ELECTROCHIMICĂ CONVENȚIONALĂ

(Rezumat)

Prelucrarea suprafețelor realizate din materiale cu duritate ridicată reprezintă o provocare majoră pentru tehnologiile convenționale de fabricație. În acest context, prelucrarea electrochimică convențională (C-ECM) constituie o alternativă performantă, caracterizată prin productivitate ridicată, absența uzurii sculei și capacitatea de a genera suprafețe de înaltă calitate. Lucrarea prezintă realizarea și testarea unui model experimental de prelucrare electrochimică convențională, dezvoltat în condiții de laborator, utilizând echipamente și soluții electrolitice selectate în conformitate cu cerințele specifice procesului. Etapa de validare a modelului experimental presupune evaluarea performanțelor acestuia prin analiza efectelor generate de variația parametrilor de proces, precum tipul și concentrația electrolitului, valoarea tensiunii aplicate și condițiile de lucru. De asemenea, sunt investigate caracteristicile de calitate ale suprafețelor prelucrate, în vederea stabilirii corelațiilor dintre parametrii tehnologici și rezultatele obținute. Obiectivul principal al cercetării constă în verificarea funcționării corespunzătoare a sistemului de prelucrare electrochimică convențională și în identificarea condițiilor optime de proces pentru prelucrarea materialelor complexe.

În concluzie, modelul experimental dezvoltat reprezintă un instrument de cercetare eficient și flexibil, capabil să susțină atât investigațiile științifice fundamentale, cât și dezvoltarea unor soluții tehnologice inovatoare destinate prelucrării materialelor avansate.