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A REVIEW ON ELECTROCHEMICAL MACHINING AND MICRO-MACHINING

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Abstract: *The current review paper deals with the state of the art of electrochemical machining and micro-machining. There are many researchers who made experimental investigations on the machining parameters that fits the best and who are correlated with the surface roughness and material removal rate. The electrochemical process parameters such as material for workpiece and tool, its shape and dimensions, electrical parameters and electrolytes were taken into consideration for the analysis. The input and output parameters, methodology of the research, the trends in the state of art, and the difference between micro and macro machining (hybrid processes included) were the main criteria for the current review.*

Key words: *electrochemical machining, ECM micromachining, capability, parts, industries, ECM*

1. INTRODUCTION

Machining processes (conventional or nonconventional) create final parts, precise and with better surface quality. Conventional machining (see figure 1, classification of machining according to the material removal mechanism) uses tools that must have a higher hardness than the material of the workpiece. The emergence of new materials that are difficult to be machined by mechanical techniques has guided to the introduction of nonconventional ones, which is entrenched in today's industry of manufacturing.

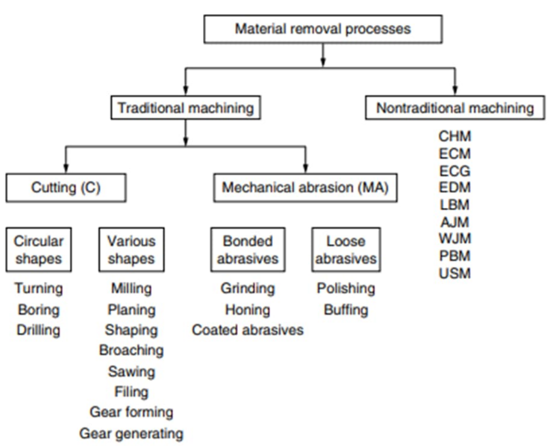


Fig. 1. Classification of machining, according to the material removal mechanism [1]

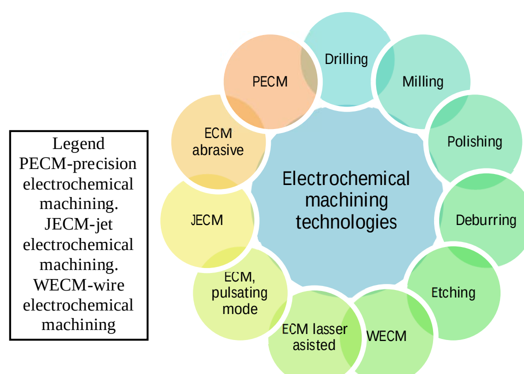


Fig. 2. Electrochemical machining technologies [1], [2], [3], [4], [5], [6], [7], [8]

In modern manufacturing industry, harder, complex materials that implies difficulties in the process of cutting are habitually used. Therefore, more attention is paid to the machining processes as long as the mechanical properties of the workpiece material narrowed the removal mechanism effects. In this respect, nonconventional machining techniques have entered practice as a possible alternative in terms of machinability, surface complexity and quality, as well as ultra-miniaturization. Machining techniques with different degrees of innovation were applied, including combining distinct machining processes. Hybrid machining has used to combine or improve benefits of each other and avoid the drawbacks of constitutive processes when applied separately (figure 2).

Electrochemical machining (ECM) is a process of anodic dissolution of the metal material of the part, ion by ion. It is widely used as a hands-on method of metalworking due to its numerous advantages, for example the lack of tool wear, no tension/burrs, high productivity. According to the small size of the ions [1], the ECM process has an extraordinary potential for micro-meso-scale micromachining (Figure 3).

However, the ECM hangs back other processes, such as electrical discharge machining (EDM) in the domain of micro-machining, due to the struggling of keeping under control the working gap and the machined shape in the course of the ECM.

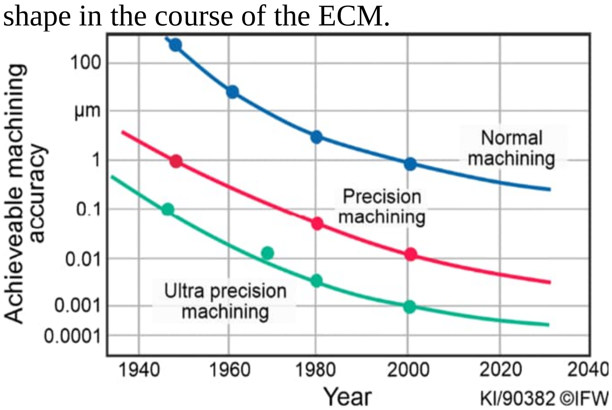


Fig. 3. Evolution of achievable machining accuracy [9]

2. MICROMACHINING MARKET FORECAST

Data Bridge Market Research surveys that the branch of micromachining market will present a rise of 7.18% for the compound annual growth rate – CAGR, during the forecast period 2021-2028 (figure 4). The growth and development of the semiconductor industry, the growing preference of micromachining with laser techniques in detriment of the traditional approach and the growing application of miniaturized parts by different end-users, such as automobiles, semiconductors and electronics, aerospace and defense, medical and aesthetic, telecommunications, energy plastics and polymers, precious stones and jewelry and others are some of the major factors attributable to the growth of the micromachining market. All things considered, the value of the micromachining market would increase by 5.39 billion $ by 2028.

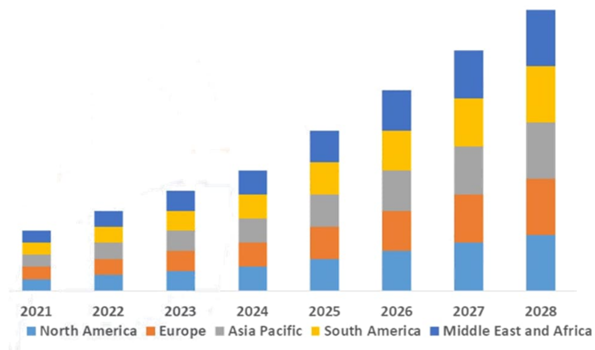


Fig. 4. Global Micromachining Market Forecast [10]

The main competitors covered in the Micromachining Market Report are presented below (figure 5) [10].

Fig. 5. Main micromachining companies

However, the high costs associated with micro-machining [15] will be a major challenge for the market growth rate. The high costs of research and development for micro-machining will continue to create barriers to market growth. The lack of expertise professionals or the lack of technological skill, mainly economies that are developing, will contribute to minimize the market growth rate. The increase in manufacturing costs, along with various government regulations on different manufacturing standards, will also act as restrictions on market growth.

There is an increasing trend in using diverse and multipurpose tools for searching key words, such as Google Trends-for long tail keywords, depending on the subject of interest.

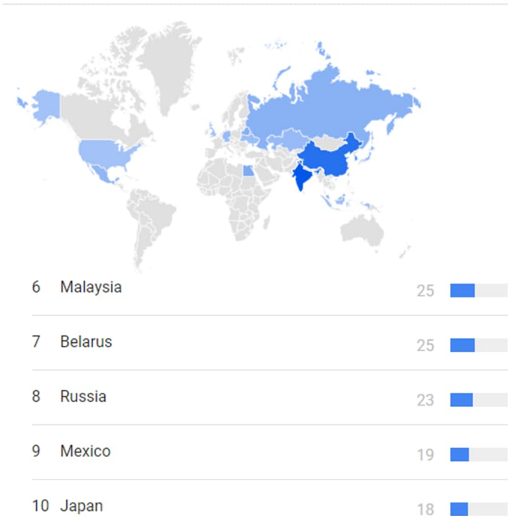


Fig. 6. Interest in electrochemical machining by region [11]

To identify a growing trend, this tool allows to view multiple developments in a synthesis image and to identify the relevant product categories in "Related Topics" [16]. Figure 6 shows the regions interested in the subject of electrochemical machining, and Figure 7 shows the evolution of interest quantified by specialized articles from 2004-present and 2015-present.

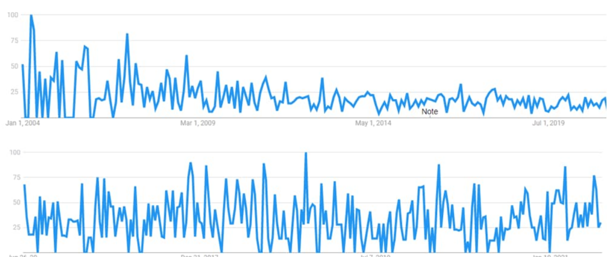


Fig. 7. Interest about ECM: a) from 2004-present, b) 2015-present [11]

Table 1 set side by side four micromachining technologies, available on the market. It is principal to observe that µECM offers an encouraging ability to manufacture characteristics with a high aspect ratio, in the absence of thermal defects and with a high polished surface. All through the process of µECM, the localized removal of the material is due to the anodic dissolution of the conductive substance. Because the removal of the material occurs in the domain of atoms, good surface roughness is obtained. Micro-ECM has been intended as a technique with high potential. Its capacities and the list of materials able to be machined are expected to be rise by combining the energy of the electrochemical process with the process's energies of different technologies. To validate the growth of µECM process and its hybrid variants, an extensive range of know-how is necessary.

Table 1

Evaluation of four distinctive micromachining technologies [12], [13]

	Micro-EDM	**Micro-ECM**	**Laser micro-jet**	**Laser ablation**
Features with high aspect ratio	✓	✓	✓	×
Micro-machining on non-conductive materials	×	×	✓	✓
Design and manu-facture of micro-tools	✓	✓	×	×
Regardless of hardness	✓	✓	✓	✓
Heat affected zone (HAZ, spatter)	✓	×	×	✓
Residual micro-stress on the workpiece	✓	×	×	✓
High polished surface (nm level)	×	✓	×	×
High removal rate	✓	✓	×	×
High volume of production	×	×	×	×

An important aspect is the comparison between µECM and ECM, presented in Table 2 [14]. The ECM is grounded on Faraday's laws of electrolysis, where the tool-electrode and workpiece-electrode are immersed in an aqueous electrolyte, into a tank. At an enough difference of potential between the electrodes, the anode material (workpiece) is removed through successive electrochemical reactions. In the ECM, the technological outputs is determined by well-defined parameters, for example the current density, electrolyte types, concentration, flow, the machining gap and chemical reactions that took place at the anode [14] , [15]. Machining precision, surface finishing and MRR can be increased by intensifying the electrochemical comportment in the machining gap, which involves different strategies [16].

Table 2

Comparison between electrochemical machining and micromachining [17], [18], [19], [20]

Basic machining characteristics/ parameters	µECM	ECM
The size of the active region of the tool-electrode	micro	medium/high
Current intensity	<1 A	150-10000 A
Tension	<10 V	10-30 V
Current density	75-100 A/cm^2	20-200 A/cm^2
Frequency	kHz-MHz	Hz-kHz
Current source (DC)	Pulsatory	Pulsatory and continuous
Speed rate of electrolyte	<3 m/s	10-60 m/s
Concentration of electrolyte	<20 g/L	>20 g/L
Type of electrolyte used	Natural salts or dilute acids, alkaline solutions	Saline Solution
Electrolyte temperature	37-50 º C	24-65 ℃
Machining precision	±0.1-0.02 mm	±0.1 mm
The roughness obtained	0.4-0.005 µm	1.5-0.1 µm
Frontal machining gap	5-50 µm	100-600 µm
Lateral machining gap	<10 µm	>20 µm
Machining speed	5 µm/min	0.2-10 mm/min
Type of operation	Mask/Maskless	Maskless
Problems because of the toxicity and waste disposal	Low to moderate	Low

3. FIELDS OF APPLICATION OF ECM MACHINING AND MICROMACHINING

Until a few hundred years ago, the components of the wristwatch were the only industrial micro components that were manufactured [21], [22], [14]. As time went on, the company move forward and the industry evolved, the demand for micro-components and miniaturized parts increased.

Nowadays, the ECM process has advanced to machine an extensive domain of materials [13], hard to process, conductive and manufacturing, beginning with metals, semiconductors, [23] and composites [24]. Micromachining ECM has become popular in the of micro components and micro-parts for different products (Table 3).

In the case of electrochemical micromachining, the Ishikawa diagram showing the impact of input factors on the process performance is presented in Figure 8, for example the parameters regarding the machined parts (workpiece-material, conductivity).

Table 3

Industries using electrochemically manufactured miniaturized products [12] [31]

Field of use/ Industries	Products/Characteristics
Aerospace	High ratio, inclined, straight and turbulent cooling holes required for turbine blades, working openings within the aerospace landmarks, manufacture of aerodynamic seals, gears, turbine rotors with integrated blade (blisks), texturing for superhydropower generation (Indec®, PEMTech®);
Automotive	Micro-holes / slots in injection nozzles and lubrication openings in bearings, gears and gears, components of turbochargers (Indec®, PEMTech®);
Medical and biomedical	Micro-needles for cochlear implants, sharp and straight edge instruments, finished for surgical operations, high quality finished molds, optical, for surgical instruments, tablet pushers;
Consumer industry	Shaving heads (finished and grooved, Philips®), hydrophobic surfaces, surfaces that require a very good roughness;
Chemical	Micro heat exchangers and reactors (ECM technologies®)
Tools	Inserts for cutting tools, dies and punches, stamping tools, coin punches;
Specific surfaces	Complex internal and external shapes, micro-surface like holes, channels, slots, cavities on difficult-to-machine materials, superalloys, heavy metals, corrosion resistant materials etc.

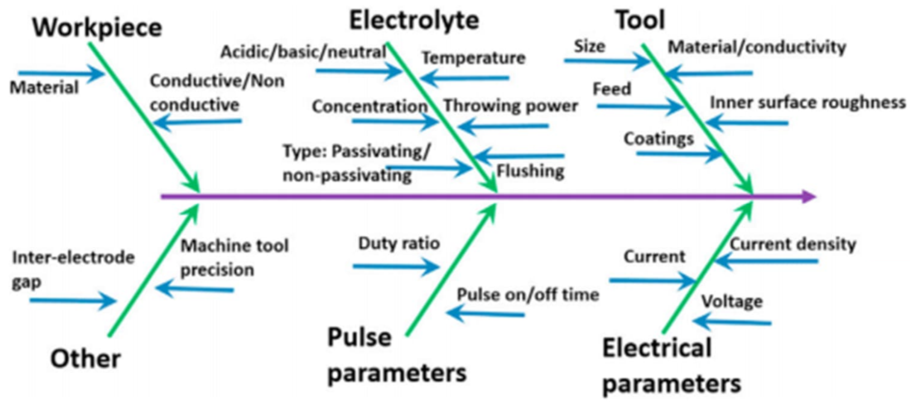


Fig. 8. Ishikawa diagram for Micro-ECM process performance [19]

Table 3 is an overview of the main parameters of the ECM and the trend of influencing, increasing or decreasing, the performance.

Table 4

Summary on the outcome of main parameters of the process on micro-ECM performance, without the behavioral nonlinearities [25]

Parameters	MRR	Surface Finishing	Shape accuracy	Machining gap
↑ Tension	↑	↓	↓	↑
↑ Impulse duration	↑	↓	↓	↑
↑ Concentration of electrolyte	↑	↓	↓	↑
↑ Duty cycle	↑	↓	↓	↑

↑- growing trend, ↓ - decreasing trend.

The versatility of the process is found in the field of use and the main competitors, presented in Table 4. Among the industries, it can be specified the aerospace, automotive, consumer, tools, and the others.

Micro-ECM technology has multiple advantages comparing to other alternative machining processes like:

(1) Material removal occurs regardless of the hardness of the workpiece.

(2) Complex shapes can be processed.

(3) The tool has no wear.

(4) Very good quality of the processed surfaces (comparable to the superfinishing processes, Ra at the level of nm - dissolution takes place at the atomic level);

(5) It has very high productivity (comparable to roughing milling - 10,000 mm^3 / min, compared to EDM - 600 mm^3 / min);

(6) It can be precisely controlled in the field of micromachining by using ultra-short, pulsed power.

(7) The machining process is a non-contact one, so there aren't internal stresses to be introduced into workpiece material;

(8) It can be effortlessly combined with other processes to expand its technological performances and the material machining rate;

(9) The mechanism of removing the particles is controlled by the modification of electrical and pulse parameters (voltage and current, frequency, duration, duty cycle).

(10) Cleanses bacteriologically and radioactively the processed surface.

Regarding the disadvantages, it can be specified the difficulty of keeping under control the precision of the machined surface; many of the electrolytic liquids have high toxicity and are difficult to handle.

ECM technology is applied by Philips Consumer Lifestyle for the mass production of the key functional part of the Philips shaving head, as in Figure 9 g). The production process of this part consists of cold forming, heat treatment and finishing. The last step is the ECM process that allows you to achieve the desired accuracy and therefore the required shaving performance.

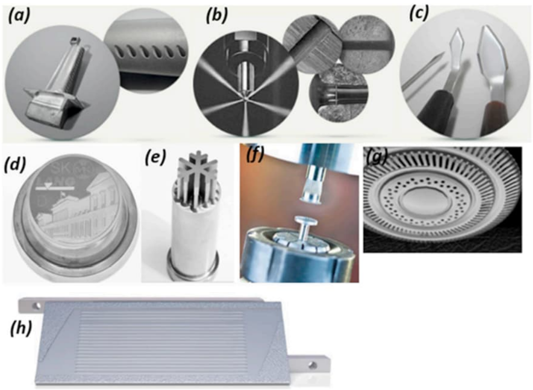


Fig. 9. Significant applications of electro chemical micromachining [19]

(a) Cooling and other working openings in aerospace (turbine blades) (b) Orifices and micro-holes through fuel injection jets (c) Profiling of cutting edges of micro-surgery instruments with edge transversal dimensions <1 µm. (Picture courtesy: INDEC ™). (d) Stamps for metal money industry. (e) Micro pressing dies (Picture courtesy: PEMTec® (f) Micro-gear containing inner teeth features, used in medicine appliances (Picture courtesy: Bosch GmbH) (g) Micro-slots and high polished surface shaver head (Picture courtesy: Philips DAP) (h) A micro heat-exchanger with grooves dimensions (width x depth 800 µm x 400 µm, Picture courtesy: ECM Technologies®.).

ECM is a complicated process that incorporates several phenomena that interact with each other. For example, any disturbance of the electrolyte flow regime can lead to a drop in pressure and insufficient washing (suffocation) which can in turn lead to local boiling of the electrolyte (dead zone) and disturbance of dissolution adversely affecting the accuracy of machining.

4. EVOLUTION OF CAPABILITIES OF ECM

Over the decades, technological innovations have increased the demand for complex micro-miniature products in various fields, made of advanced materials [26] and unique, both conductive and non-conductive, with greater technical precision [27]. Deloitte [28] announces that the companies are beginning to understand the massive impact of Fourth Industrial Revolution and role of technology in transforming the business model and processes.

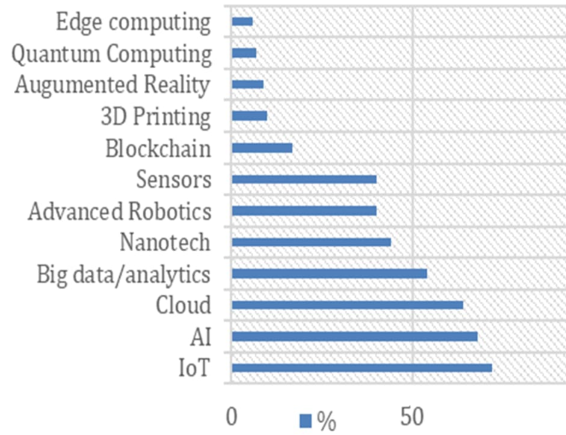
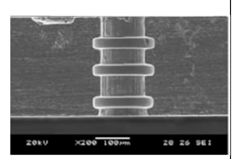


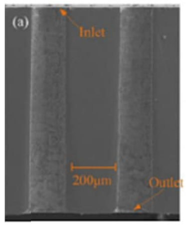
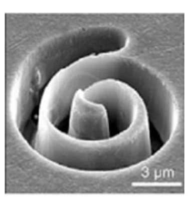
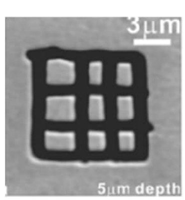
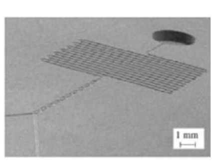
Fig. 10. Technology expected effect [28]

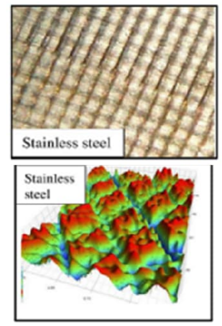
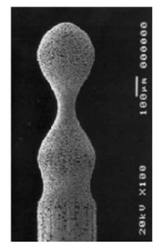
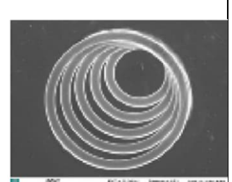
Regarding technology's forecast outcome, business headmen anticipate IoT, AI, and cloud solutions will have the most intense impact on their companies. Figure 10 shows the distribution of percent regarding the technology, and the electrochemical machining and micromachining play an important role into achieving parts with small dimensions.

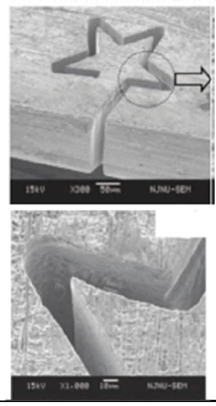
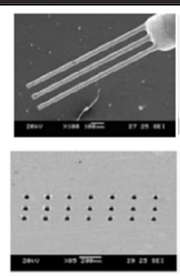
Table 5

Capabilities of advanced electrochemical micromachining processes in the current literature [26]

Process capability	**Figure and Bibliographic references**	**Details**
The cooling passage of the spiral pipe	 [29]	Controlled parameters of µECM: 8 V, 150 g / l, NaNO3, electrolyte pressure 0.2 MPa, electrolyte speed 15 m / s, machining time 10 min
Clearance matrix in micro-holes	 [30]	Manufactured using a single electrode disc in µECM, hole D= 130 µm, channel depth 30 µm and height and 33 µm.

Process capability	Figure and Bibliographic references	Details
Inverted conical holes		Holes at micrometric scale, with an inlet D= 178 µm and α= 1.05º on a 18CrNi8 thickness of 1 mm, machined by voltage variation, variable load ratio and feed rate machining.
Bamboo hole		Manufactured using a variable feed rate machining mode on a h=1.0 mm, workpiece material 18CrNi8, Ra, inner=674 nm.
Pocket machining		µECM milling mode, made of cylindrical electrodes, the short passage distance generates smooth surfaces.
Spiral channel		Depth=5 mm, WP - Ni, T- Tungsten, electrolyte - HCl 0.2 M, Electric parameters: 3 ns, pulses of 2 V, repetition rate of 33 MHz.
Micro-structuring		WP - Au, electrolyte - 1 M LiCl / DMSO solution, working parameters used: 4.2 V, pulses of 20 ns.
Manufacture of micro-reactors		1.4541 stainless steel workpiece, manufactured by milling with JECM, use of free electrolytic jet for local machining.

Process capability	Figure and Bibliographic references	Details
Texturing		Machining parameters: U= 5 V, ti=10 µs, t0=10 µs, electrolyte $NaNO_3$ with 5% concentration, IEG: 100 µm.
Turning at micro scale [31]		ECM turning is made using a rotation of the cylindrical workpiece and manipulating the jet axially. The geometry is achieved within the modification of the sinusoidal current (0 -50 mA).
Polishing of previously processed surfaces	 After rough milling  After ECM finishing	Using the electrode-tool with spherical tip, electrolyte 15% aqueous solution of $NaNO_3$, U= 16 V.
Banana channels, finished	 Philips® DAP	In the manufacturing of shaving heads, the ECM process was the last phase. Generating banana-shaped channels and the necessary surface finishing, achieved by ECM.
Manufacture of sharp edges		Applying electrochemical jet micro-machining, WP: steel 1.4541, the geometry is composed by several coaxial surfaces with different radii (1-2.2 mm) and the number of passes (10 -50 passes), with a R minimum of the edge= 1 µm.

Process capability	Figure and Bibliographic references	Details
WECM		Modification of the working gap and feed rate (De= 10 µm, electrolyte: HCl 0.1 M, ti= 1 µs,) Geometry obtained by micro wire electrochemical machining. [32]
Micro hole array generated using multiple electrodes	 [31]	The principal concern during ECM drilling is the taper induced on the workpiece. Some technical solutions for this issue is to design for manufacturing the tool, using double poles tools, tool insulations, and tools with profiles ends.

All the current research points out the multitude of shapes and the accuracy of obtaining small and very small parts, made of new and difficult to machine materials.

5. ACKNOWLEDGEMENTS

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6. CONCLUSION

Unlike conventional machining technologies (turning, milling, mortising, etc.) that have passed the maturity phase, nonconventional technologies (LBM EBM, IBM, EDM, ECM etc.) are on the rise, appearing relatively recently. The arguments are also based on the increasing trend on the subject, using key words in online tools-Google trends, in specialized journals and literature. The emergence of new fields has led to the appearance of new materials (super alloys, titanium alloys, carbides, etc.), with special properties, difficult to process classically. Thus, electrochemistry responds to these needs on the market. Currently, the electrochemical machining process is used to make simple and profiled holes in hard and extra-hard materials, complex mold cavities, revolution bodies, etc.

The Fourth Industrial Revolution and the role of technology in the manufacturing sector reveals the increasing trend in using nonconventional technologies, like electrochemical machining and micromachining.

At present times, micro-ECM technology is successfully used in manufacturing micro parts in the electronics industry. Compared to EDM and WEDM, ECM develops in a slow and sinuous way, which is closely related to its characteristics, industrial demand, disciplinary development and understanding. There are still many unknowns about the sophisticated ECM process that require further study. However, micro-ECM is one of the most important microfabrication technologies.

7. REFERENCES

[1] B. Huaiqian, X. Jiawen and L. Ying, "Aviation-oriented Micromachining Technology-Micro ECM in Pure Water," vol. Chinese Journal of Aeronautics, no. pg. 455-461, 2008.

[2] Y. Yang, W. Natsu and W. Zhao, "Realization of eco-friendly electrochemical micromachining using mineral water as an electrolyte," Precision Engineering, vol. 2, no. 35, pp. 204-213, 2011.

[3] K. Bo Hyun, P. Byung Jin și C. Chong Nam, „Fabrication of multiple electrodes by reverse EDM and their application in microECM," Journal of Micromechanics and Microengineering, vol. 16, nr. 4, p. 843, 2006.

[4] M. Hackert-Oschatzchen și et al., „Micro machining with continous electrolyte free jet," Precision Engineering, vol. 36, nr. 4, pp. 612-619, 2012.

[5] S. Hong Shik and K. C. N. C. Bo Hyun, "Analysis of the side gap resulting from micro electrochemical machining with a tungsten wire and ultrashort voltage pulses," Journal of Micromechanics and Microengineering, vol. 18, no. 7, p. 075009, 2008.

[6] E. Brinksmeier and W. Preuss, "Micro-machining, ultra precision engineering-from physics to manufacturing," Royal Society, 2012.

[7] S. Kunar and B. Bhattacharyya, "Investigation into fabrication of microslots arrays by electrochemical micromachining," Machinig Science and Technology, vol. 23, no. 4, pp. 629-649, 2019.

[8] Z. Liu, C. .Gao and J. Zhao, "Microelectrochemical machining: Principle and capabilities," Woodhead Publishing Reviews: Mechanical Engineering Series, pp. 143-162, 2017.

[9] B. Denkena, B. Bergmann and H. Klemme, "Cooling of motor spindles—a review," The International Journal of Advanced Manufacturing Technology, vol. 110, pp. 3273-3294, 2020.

[10] D. B. M. Research, "Global micromachining market".

[11] Google, "Google Trends," 2021.

[12] K. Saxena, M. Bellotti, J. Qian, D. Reynaerts, B. Lauwers and X. Luo, "Overview of Hybrid Machining," in Hybrid Machining, Academic Press, 2018, pp. 21-41.

[13] K. Rajurkara, M. Sundaramb and A. Malshe, "Review of Electrochemical and Electrodischarge Machining," Procedia CIRP, vol. 6, pp. 13-26, 2013.

[14] Z. Rahman, A. Kumar and D. Chattopadhyaya, "Microhole drilling through electrochemical processes: A review," Materials and Manufacturing Processes, vol. 33, no. 13, pp. 1379-1405, 2018.

[15] A. Singha, S. Ananditaa and S. Gangopadhyay, " Microstructural Analysis and Multi Response Optimization During ECM of Inconel 825 Using Hybrid Approach," Material Manufacturing Processes, vol. 30, no. 7, pp. 842-851, 2015.

[16] M. Malapati and B. Bhattacharyya, "Investigation into Electrochemical Micromachining Process during Micro-Channel Generation," Material Manufacturing Processes, vol. 26, pp. 1019-1027, 2011.

[17] B. Bhattacharyya and J. Munda, "Experimental investigation on the influence of electrochemical machining parameters on machining rate and accuracy in micromachining domain," International Journal of Machine Tools and Manufacture, vol. 43, no. 13, pp. 1301-1310, 2003.

[18] M. M. Lohrengel, " Pulsed Electrochemical Machining of Iron in NaNO3: Fundamentals and New Aspects. Mater," Fundamentals of Manufacturing, vol. 20, no. 1, pp. 1-8, 2005.

[19] K. Saxena, J. Qian and D. Reynaerts, "A review on process capabilities of electrochemical micromachining and its hybrid variants," International Journal of Machine Tools and Manufacture, vol. 127, pp. 28-56, 2018.

[20] B. Bhattacharyya, J. Munda and M. Malapati, "Advancement in electrochemical micro-machining," International Journal of Machine Tools & Manufacture , vol. 44, pp. 1577-1589, 2004.

[21] T. Masuzawa, " State of the Art of Micromachining," CIRP Annals Manufacturing Technologies , vol. 49, no. 2, p. 473–488, 2000.

[22] E. Momosaki and S. Kogure, "The Application of Piezoelectricity to Watches," Ferroelectrics , vol. 40, no. 1, pp. 203-216, 2011.

[23] M. e. a. Bassu, "Electrochemical micromachining as an enabling technology for advanced silicon microstructuring," Advanced Functional Materials, vol. 22, no. 6, pp. 1222-1228, 2012.

[24] S. e. a. Choi, "Fabrication of WC micro-shaft by using electrochemical etching," The

International Journal of Advanced Manufacturing Technology, vol. 31, no. 7, pp. 682-687, 2007.

[25] T. Kurita, K. Chikamori, S. Kubota and M. Hattori, “A study of three-dimensional shape machining with an ECμM system,” International Journal of Machine Tools and Manufacture, vol. 46, no. 12-13, pp. 1311-1318, 2006.

[26] M. M. Lohrengel, K. P. Rataj, N. Schubert, M. Schneider, S. Höhn, A. Michaelis, M. Hackert-Oschätzchen, A. Martin and A. Schubert, “Electrochemical Machining of Hard Metals—WC/Co as Example,” Powder Metall, vol. 57, no. 1, pp. 21-30, 2013.

[27] H. Gawad El-Hofy, Advaced Machining Processes. Nontraditional and Hybrid Machining Processes, vol. Mechanical Engineering Series, McGraw-Hill, 2005.

[28] Deloitte Insight, “At the intersection of readiness and responsability,” *The Fourth Industrial Revolution,* 2020.

[29] M. W. Wang, W. Peng, C. . Yao and Q. Zhang, “Electrochemical machining of the spiral internal turbulator,” *The International Journal of Advanced Manufacturing Technology,* vol. 49, pp. 969-973, 2010.

[30] J. Chan Hee, H. K. B. and C. Nam Chu, “Micro electrochemical machining for complex internal micro features,” *CIRP Annals,* vol. 58, no. 1, 2009.

[31] K. Rajurkara, M. Sundaram and A. P. Malshec, “Review of Electrochemical and Electrodischarge Machining,” *Procedia CIRP* , vol. 6, pp. 13-26, 2013.

[32] K. N. D.Zhu, “Micro Wire Electrochemical Cutting by Using In Situ Fabricated Wire Electrode,” *CIRP Annals,* vol. 56, no. 1, pp. 241-244, 2007.

[33] K. Saxena, M. Bellotti, J. Qian, D. Reynaerts, B. Lauwers and X. Luo, “Overview of Hybrid Machining,” in *Hybrid Machining,* Academic Press, 2018, pp. 21-41.

O RECENZIE PRIVIND PRELUCRAREA ȘI MICRO-PRELUCRAREA ELECTROCHIMICĂ

Rezumat: Actuala lucrare de recenzie tratează stadiul tehnicii prelucrării și micro-prelucrării electrochimice. Există mulți cercetători care au făcut investigații experimentale asupra nivelului optim al parametrilor de prelucrare, care afectează rugozitatea suprafeței și rata de îndepărtare a materialului, care sunt revizuite pe scurt în această lucrare. Pentru analiză au fost luați în considerare parametrii procesului electrochimic precum materialul piesei de prelucrat și sculei, forma și dimensiunile acestuia, parametrii electrici și electroliții utilizați. Parametrii de intrare și de ieșire, metodologia cercetării, tendințele în stadiul tehnicii și diferența dintre micro și macroprelucrare (inclusiv procesele hibride) au fost principalele criterii pentru recenzia actuală.

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