How to cite this article:

Authors: Adam Ruszaj, Mariusz Cygnar, Marcin Grabowski

Title of article: "Abrasive machining process supported by electrochemical dissolution and electrical discharges – state of the art and directions of development"

Mechanik, No. 10 (2019)

DOI: <https://doi.org/10.17814/mechanik.2019.10.85>

Abrasive machining process supported by electrochemical dissolution and electrical discharges – state of the art and directions of development

ADAM RUSZAJ
MARIUSZ CYGNAR
MARCIN GRABOWSKI *

* Prof. dr hab. inż. Adam Ruszaj, ruszaj@mech.pk.edu.pl, <https://orcid.org/0000-0002-1809-3271> – Państwowa Wyższa Szkoła Zawodowa w Nowym Sączu, Polska; Politechnika Krakowska, Polska
Dr hab. inż. Mariusz Cygnar, mcygnar@pwsz-ns.edu.pl, <https://orcid.org/0000-0002-3688-0244> – Państwowa Wyższa Szkoła Zawodowa w Nowym Sączu, Polska
Dr inż. Marcin Grabowski, marcin.grabowski@mech.pk.edu.pl, <https://orcid.org/0000-0003-1482-6738> – Politechnika Krakowska, Polska

For finishing machining parts made of alloyed steels, composite or ceramic materials hybrid methods as abrasive machining supported by electrochemical dissolution or/and electrical discharges are often applied. The range of these processes practical applications in industry significantly increases. Because of this fact in the paper results of investigations and examples of practical applications of the mentioned hybrid abrasive processes are presented.

KEYWORDS: *special materials, hybrid methods, electrochemical abrasive machining, electrodischarge abrasive machining*

Introduction

In modern industry, it is very important to ensure dimensional accuracy and wear resistance of manufactured elements. Ensuring high wear resistance usually requires the use of modern high-alloy steels, ceramic or composite materials on a ceramic or metal base. The paper limits the considerations to the case of abrasive machining ensuring obtaining elements with adequate dimensional accuracy and surfaces with satisfactory microstructure and good mechanical properties (high hardness, strength, fatigue strength, wear resistance, etc.).

Such requirements are common in the aviation, medical or automotive industries. Hybrid processes play an important role in finishing shaping operations made of high-alloy steel, ceramic materials and composite materials on a ceramic or metal matrix. According to the CIRP definition: hybrid manufacturing processes are based on simultaneous and controlled interaction between process mechanisms and/or energy sources/tools, having significant impact on the course and results of the process. Simultaneous and controlled interaction means that processes, energy sources or tools should interact roughly in the same process area and at the same time. Electrochemical or electrodischarge grinding or electrochemical-electrodischarge grinding can be used – mainly for machining electrically conductive materials. The paper includes special cases of processing the non-conductive materials.

Special alloy steels, ceramic materials, composite materials based on metal or ceramics with properly selected composition have very good mechanical properties (high: hardness, strength, fatigue strength, wear resistance, etc.). Such properties make it difficult, and in many cases impossible for conventional machining (milling, grinding). Often, the only solution in finishing treatment is the use of grinding assisted by electrochemical dissolution or electric discharges [1–3].

Electrochemical abrasive machining

In the electrochemical-abrasive machining process, the allowance is removed as a result of electrochemical dissolution and micro-cutting using abrasive grains. As a result of electrochemical reactions, a layer of oxides and hydroxides with significantly lower mechanical properties than the native material is created on the surface of the workpiece. This layer can be easily removed by abrasive grains. These processes support each other. Removal by abrasive grains oxide and hydroxide layers has a de-passivating effect on the machined surface and facilitates access of the electrolyte to still not machined material. In turn, in the micro-cutting process, there are smaller forces than in the classic grinding, which increases the life of the abrasive grains, and thus the life of the grinding wheel [2, 3].

Electrochemical abrasive machining can be used for various advanced materials (Inconel, Nimonic, titanium alloys, nickel alloys, PCD-Co, Al-SiC, Al-Al₂O₃ or Ti-6Al-4V) and in various kinematic varieties (grinding, electrochemical burnishing, electrochemical machining using loose abrasive). Depending on the treatment variant, one can even get surfaces with $Ra < 0.1 \mu\text{m}$. Electrochemical grinding was used, among others, for finishing the surface of elements made of Ti-6Al-4V after rough EDM [4, 5].

Titanium alloys are popular in many industries due to their good corrosion resistance. However, their machining is difficult due to the low thermal conductivity, chemical activity and low plasticity modulus. EDM drilling is often used for roughing. However, the surface after rough EDM machining has relatively high roughness, heterogeneous properties and local damage (e.g. micro-cracks) and usually does not meet the requirements for aviation or medical components. To improve the surface properties, electrochemical grinding is used as a finishing treatment.

As a tool, a grinding wheel was used on the copper binder: EC BOND A100V4CD – diameter $\varnothing 350 \text{ mm}$ and width 70 mm . Electrochemical grinding tests were carried out for the voltage $U = 2\div 8 \text{ V}$, working feedrate: $6\div 24 \text{ mm/min}$, NaNO₃ electrolyte at concentration 180 g/l . Thickness of the allowance removed was several dozen micrometers [4, 5]. In electrochemical grinding operations, damage to the surface layer (e.g. micro-cracks) was removed, and the Ra value was reduced to $0.06 \mu\text{m}$. This surface meets the requirements of aviation, automotive and medical industries.

Other applications of electrochemical grinding are, for example, finishing machining of slots for fixing blades in turbines of flow motors after rough machining with abrasive water jet (AWJM) [6] or bevel gears [7]. If the grinding depth increases in some areas, the workpiece material and the metal bond of the grinding wheel come into contact and, as a result, short-circuit discharges occur. Then the probability of filling the gap with hydrogen increases, and thus the appearance of electric discharges analogous to those in the EDM process. This state of the electrochemical grinding process is called electrochemical-electrodischarge grinding (ECDM). It is characterized by increased machining efficiency compared to ECM grinding, but usually associated with deterioration of the surface layer properties.

An important technological problem is the processing of small components made of non-conductive ceramics (e.g. Al₂O₃). The solution here is the original use of electrochemical phenomena and electrical discharges (as in fig. 1). Electrochemical phenomena (hydrogen evolution on the surface of the cathode-grinding wheel) are used not to remove the allowance, but to create conditions for electrical discharges to occur in the gap between the workpiece and the cathode tool. Therefore, this method is also called electrochemical-electrodischarge machining (ECDM).

Fig. 1. Scheme of electrochemical-electrodischarge machining (ECDM) of elements made of non-conductive ceramics [1, 14]

If the material to be ground does not conduct electricity, then the current flows between the cathode grinding wheel and the auxiliary electrode. In this case, also electrochemical reactions of hydrogen evolution occur on the cathode surface. The space between the abrasive grains and the ground material is small and easily fills with hydrogen, in which electrical discharges occur when pulsed, removing excess material from the ceramic workpiece.

Removal of allowance as a result of discharges results in satisfactory machining efficiency. Unfortunately, the surface layer of the surface formed as a result of discharges is characterized by relatively high roughness and numerous defects (e.g. micro-cracks). However, removal of material as a result of discharges reduces the mechanical properties of the surface layer, which allows abrasive grains to shape its geometric structure (reducing roughness and removing local defects). This variation of the ECM process is called spark assisted chemical engraving (SACE) by some researchers [1–3].

In practice, the use of an abrasive tool in the SACE process of difficult-to-process non-conductive ceramics allows for deeper holes (up to 1.5 mm). The surface quality is definitely better, because the abrasive process reduces roughness and removes surface layer defects. The parameters adopted in practice are: number of revolutions of the grinding wheel electrode $275 \div 600$ rpm, voltage amplitude up to 300 V, current ~ 15 A, voltage impulse time $\sim 0.25 \div 1000$ ms, feedrate $\sim 0.002 \div 2.00$ mm/min. The Al_2O_3 machining efficiency for these parameters is $5 \div 30$ mm³/min. It is worth emphasizing that the SACE process may find application in the machining of non-conductive materials (e.g. glass) in wire cutting operations using a mixture of electrolyte and abrasive grains. The presence of abrasive grains stabilizes the process and allows for greater efficiency and better surface quality compared to the process carried out in a clean electrolyte [1].

Electrodischarge abrasive machining

Electrodischarge abrasive machining is a hybrid process, in which the allowance is removed as a result of the impact on the machined surface of the abrasive grains. The properties of the removed layer were changed as a result of electrical discharges (figs. 2, 3).

The abrasive electrodischarge grinding process (AEDG) was also used in wire cutting operations with an abrasive layer on the surface [9]. The AEDG process works well when using a mixture of dielectric with abrasive grains [10]. Satisfactory interaction of TiC grains on the machined surface was obtained then due to the phenomenon of cavitation generating locally high pressure and high temperature. The phenomenon of cavitation is usually intensified by the introduction of ultrasonic vibrations [10].

Fig. 2. Scheme explaining the principle of the abrasive process with bound grains and supported by electrical discharges [8]

Examples of the use of discharge-assisted abrasive machining are shown in figs. 4 and 5. In the case of fig. 4, electrical discharges occur between steel elements and the workpiece. The surface after EDM treatment is characterized by high roughness and numerous damages (e.g. micro-cracks). Abrasive segments smooth the surface and remove its damage. If the use of a segmented electrode (fig. 4) is impossible, then SiC ceramics are processed in two stages, as shown in fig. 5. First, the main allowance is removed as a result of electrical discharges. At the second stage – without discharges – the roughness is reduced and damage caused by electric discharges is removed.

Published results of experimental studies indicate the effectiveness of the AEDG process for both high-strength alloys as well as technical ceramics and MMC based on Al: whisker-SiCp and SiCp/A356, SiC/Al and based on Cu-Fe-C (graphite) [11, 12]. Detailed tests of MMCs machining: Cu (60%) – Fe (30%) – C (10%) are presented in [12].

Fig. 3. As a result of electrical discharges, abrasive grains remove the re-melted layer, which has better machinability than native material [4]

Fig. 4. Electrodischarge abrasive machining of ceramic elements (e.g. SiC) with a special segment electrode (a tool) [14]

Fig. 5. Scheme of two-step microelement treatment with SiC [14]

The effects of EDM are primarily: reduction of grinding forces, improved removal of cutting products from the grinding wheel surface, thus preventing its sticking, exposing new abrasive grains and increasing the free space between them, thereby improving the cutting properties of the grinding wheel and extending its life by reducing friction between workpiece and grinder binder.

Summary

Hybrid processes, such as abrasive machining assisted by electrochemical dissolving and electrical discharges, are widely applied in finishing operations of elements made of difficult-to-cut materials. These processes use abrasive grains connected with a binder (grinding wheels) or forming a mixture with an electrolyte or dielectric. In the latter case, loose abrasive grains affect the process by changing the distribution of the electric field and dynamic impact on the surface being machined as a result of flow or cavitation. In the cavitation area, high pressure and high temperature can be observed locally. Supporting the grinding process with both electrochemical digestion and electric discharges consists mainly in reducing the mechanical properties of the layer removed by abrasive grains. This allows to effectively machine materials that are impossible or difficult to shape by traditional grinding methods.

REFERENCES

- [1] Ruszaj A. „Niekonwencjonalne procesy kształtowania materiałów ceramicznych i kompozytowych”. *Mechanik.* 90, 3 (2017): 188–194, DOI: <https://doi.org/10.17814/mechanik.2017.3.39>.
- [2] Lauwers B., Kocke F., Klink A., Tekkaya A.E., Neugebauer R., Micintosh D. “Hybrid processes in manufacturing”. *CIRP Annals – Manufacturing Technology.* 63, 2 (2014): 561–583, <https://doi.org/10.1016/j.cirp.2014.05.003>.
- [3] Lauwers W. “Surface integrity in hybrid machining processes”. *Procedia Engineering.* 19 (2011): 241–251, <https://doi.org/10.1016/j.proeng.2011.11.107>.
- [4] Hascalik A., Cydas U. “A comparative study of surface integrity of Ti-6Al-4V Alloy machined by EDM and AECG”. *Journal of Materials Processing Technology.* 190, 1–3 (2007): 173–180, <https://doi.org/10.1016/j.jmatprotec.2007.02.048>.
- [5] Ruszaj A., Skoczypiec S. „Wybrane zagadnienia obróbki elektrochemiczno-ściernej”. *Mechanik.* 88, 2 (2015): 103–105, <http://dx.doi.org/10.17814/mechanik.2015.2.20>.
- [6] Curtis D.T., Soo S.L., Aspinwall D.K., Sage C. “Electrochemical superabrasive machining of a nickel – based aeroengine alloy using mounted grinding points”. *CIRP Annals – Manufacturing Technology.* 58, 1 (2009): 173–179, <https://doi.org/10.1016/j.cirp.2009.03.074>.
- [7] Shaikh J.H., Jain N.K. “Modelling of material removal rate and surface roughness in finishing of bevel gears by electrochemical honing process”. *Journal of Materials Processing Technology.* 214, 2 (2014): 200–209, <https://doi.org/10.1016/j.jmatprotec.2013.08.010>.
- [8] Koshby P., Jain V.K., Lal G.K. “Grinding of cemented carbide with electrical spark assistance”. *Journal of Materials Processing Technology.* 72, 1(1997): 61–68, [https://doi.org/10.1016/S0924-0136\(97\)00130-1](https://doi.org/10.1016/S0924-0136(97)00130-1).
- [9] Menesis I., Koshy P. “Assessment of abrasion-assisted material removal in wire EDM”. *CIRP Annals – Manufacturing Technology.* 57, 1 (2008): 195–198, <https://doi.org/10.1016/j.cirp.2008.03.135>.
- [10] Chen Y.F., Lin Y.Ch. “Surface modification of Al-Zn-Mg alloy using combined EDM with ultrasonic machining and addition of TiC particles into dielectric”. *Journal of Materials Processing Technology.* 209, 9 (2009): 4343–4350, <https://doi.org/10.1016/j.jmatprotec.2008.11.013>.
- [11] Ruszaj A., Skoczypiec S. „Obróbka elektroerozyjno-ścierna – wybrane zagadnienia”. *Mechanik.* 88, 3 (2015): 210–215, <http://dx.doi.org/10.17814/mechanik.2015.3.107>.
- [12] Hrivastava P.K., Dubey A.K. “Experimental modeling and optimization of electric discharge diamond face grinding of metal matrix composite”. *International Journal of Advanced Manufacturing Technology.* Volume 69. Issue 9–12 (2103): 2471–2480, <https://doi.org/10.1007/s00170-013-5190-8>.
- [13] Sanjay K., Chak P., Venkateswara R. “Trepanning of Al₂O₃ by electro-c discharge Machining (ECDM) process using abrasive electrode with pulsed DC supply”. *International Journal of Machine Tools & Manufacturing.* 47 (2007): 2061–2070, DOI: 10.1016/j.ijmachtools.2007.05.009.
- [14] Liew P.J., Yan J. “Micro-electrical Discharge Machining of Hard Brittle Materials”. *Micro and Nano Fabrication Technology* (ed. Yan Jiwang). Singapore: Springer Nature, 2018.