BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 62 (66), Numărul 2, 2016
Secția
CONSTRUCȚII DE MAȘINI

CONSIDERATIONS ABOUT MATHEMATICAL MODELLING OF ELECTROCHEMICAL GRINDING PROCESSES

BY

CĂTĂLIN UNGUREANU[1,*] and RADU IBĂNESCU[2]

“Gheorghe Asachi” Technical University of Iași,
[1]Department of Machine Tools
[2]Department of Theoretical Mechanics

Received: July 26, 2016
Accepted for publication: November 29, 2016

Abstract. Electrochemical machining belongs to unconventional technologies category. This method is used for machining hard and extremely hard materials, employed, for example, in construction of tools for cutting and deformation. The machining process by electrochemical erosion is characterized by a very great number of working parameters, by electrical, mechanical or chemical nature. The mathematical modelling of the relationship between the machining parameters is a difficult problem. This paper presents experimental researches results accomplished by the authors for determining the dependence equations of some parameters that characterized the electrochemical grinding machining.

Keywords: unconventional technologies; electrochemical machining; mathematical modelling.

[*]Corresponding author; *e-mail*: cungurea@yahoo.com

1. Introduction

The process of electrochemical erosion-abrasive machining is based on the simultaneous pursuit of electrochemical dissolution processes combined with abrasive processes and electro discharge phenomena. In other words, the process occurs under the simultaneous action of the continuous electrical current, which leads to electrochemical decomposition of the metal under the action of the abrasive grains and which let off both the anodic dissolution products thus creating a mechanical deactivation and soluble components. Electro discharge phenomena, which generally have a negative impact on process performance, however contributes to improved productivity by pulling particulate matter by lightning. The literature indicates different values for the share of the two main factors (electrochemical and abrasive) in overall productivity by 98% material removed electrochemical and 2% removed about abrasive to equal shares of 50% for each factor (Kozak *et al*., 2001). This can be explained by the share of different electrical parameters and mechanical processing technology in the process.

2. The Structure of Electrochemical Abrasive Machining System

According to the general theory of systems, electrochemical erosion-abrasive is a system in which the input quantities are represented by all the conditions of work, and the outputs are represented, in the most general case, by the criteria for performance process evaluation. Detailed analysis of electrochemical grinding allowed separating and highlighting working conditions and criteria for performance process evaluation.

Electrochemical erosion-abrasive is characterized by a large number of operating parameters, which are system input quantities and describes and dictates the machining performances (Mc Geough, 1988). Compared to conventional grinding processes, this machining method involved besides electrical and chemical parameters. Working parameters representing system input quantities are represented by:

• electric regime: voltage, current, current density, flare mode;

• mechanical regime: abrasive wheel speed, longitudinal feed rate, oscillation stroke length, transverse advance;

• force: contact pressure, working electrodes gap width;

• abrasive disc electrode: the abrasive nature, grain size, concentration, nature of binder;

• electrolyte solution: chemical composition, concentration, specific gravity, specific heat, electrical conductivity, temperature, flow rate;

• the workpiece: composition, structure, physical and mechanical properties;

• machine-tool;

• fixtures.

Literature (Qu *et al.*, 2015) presents a great number of criteria for evaluating performance for electrochemical abrasive machining processes. Process analysis concluded that the criteria for evaluation process performance can be:

• the total amount of material removed;
• total working time;
• amount of abrasive used;
• temperature of the electrolyte solution;
• forces developed in processing;
• power consumption to drive the grinding wheel;
• the power consumed by the electrochemical process;
• surface roughness processed;
• maximum form deviation;
• the total power consumed;
• cost spent for grinding wheel wearing;
• the total cost of processing.

3. Experimentals

For determining the depending equations of the criteria for assessing the performance of the electrochemical grinding process to the working parameters, the authors conducted an experimental program in the Department of Machine Tools and Tools to “Gheorghe Asachi” Technical University of Iaşi.

The research focused on determining the influence of voltage on productivity (Q) and the machining surface roughness (Ra), two of the most important criteria for process system evaluation.

The working parameters were: 0-14 V supply voltage, direct current, alternating double recovery, average processing speed 26 m/sec, contact pressure between abrasive disc electrode – workpiece 5 daN/cm^2, longitudinal advance 12 cd/min, height of the contact surface abrasive disc electrode - workpiece 6 mm.

The experimental results are shown in the diagrams of Figs. 1 and 2.

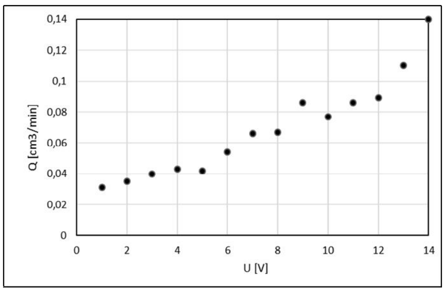

Fig. 1 – Voltage influence on productivity.

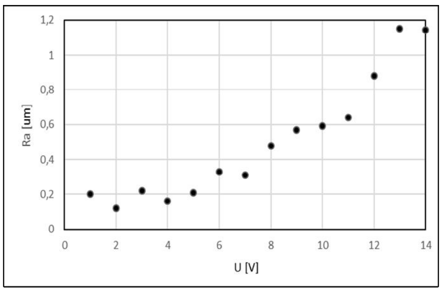

Fig. 2 – Voltage influence on surface roughness.

As shown in Fig. 1, increasing the voltage has a favorable effect on process productivity. But Fig. 2 shows that the same voltage increasing has an unfavorable effect on surface roughness.

These phenomenon, confirmed by the literature (Kozak, 2014), can be explained by the fact that voltage increase leads to enhanced electrochemical anodic dissolution, with positive influence on process productivity. At the same time, electric factor increasing leading out the development electro discharge phenomena, electric sparks appearance induces adverse effects on surface roughness.

4. Regression Functions Determination

Regression function means a mathematical expression, derived from processing experimental data, which approximates (estimated) dependencies between two or more variables of a system or process. Determining a regression function is required when the dependencies of those variables cannot be determined precisely enough about theoretical (Todincă and Geantă, 1999).

The method often used in such situations is to achieve an initial exploratory study, measuring the dependent variables for different values of process variables.

If we consider that the exact relationship (theoretical) dependency of a variable depending on other n variables in the process could be represented graphically by a surface in a space with n + 1 dimensions, the values derived experimentally can be represented by points in the space near this area. The points will not belong experimental area due to imprecision theoretical knowledge of process variables (*e.g.* due to measurement errors).

Thus, in situations where the relationship depends on one variable studied process and is expected to form the regression function to be determined fall within one category, it can use the method of least squares. If the relationship is dependent on many variables, it can get a polynomial regression function form using the response surfaces. In the cases where the two previous methods cannot be used, one of the methods derived from the iterative algorithms to solve the differential equation system can be applied.

Some of the above methods are sufficiently evolved so as not to be limited to determining expression of the regression function but also allows drawing conclusions concerning the correctness with which they were selected process variables and adequacy of accuracy with which they were performed measurements during experimental tests.

Thus, as an indicator of the adequacy of the model can be used model R^2 accuracy indicator expressed by the Eq. (1) (Todincă and Geantă, 1999):

$$R^2 = \frac{\sum_{i=1}^{n}\left(y_{icalc} - \bar{y}\right)^2}{\sum_{i=1}^{n}\left(y_{i\exp} - \bar{y}\right)^2} \tag{1}$$

In Eq. (1) y_{icalc} represents the values calculated using regression function, y_{iexp} - experimental values - average values of the objective function.

For experimental values shown in Figs. 1 and 2, several types of regression functions, shown in Figs. 3-10 were determined by using the Excel program.

A exponential regression type for the objective function Q is presented in Fig. 3. The determined relationship is shown in Eq. (2), the accuracy of the model and the indicator has the value (3).

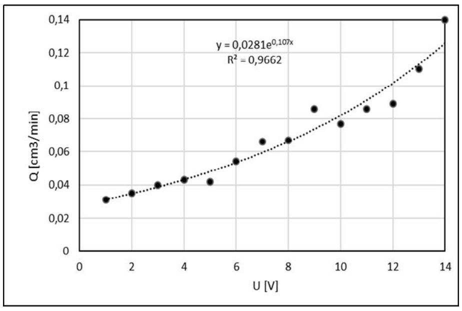

Fig. 3 – Exponential regression function.

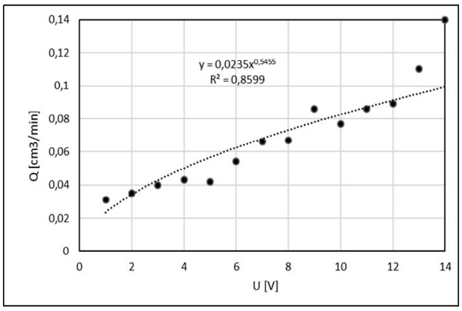

Fig. 4 – Power regression function.

$$y = 0.0281\mathrm{e}^{0.107x} \tag{2}$$

$$R^2 = 0.9662 \tag{3}$$

A power type regression function for the objective function Q is presented in Fig. 4. The determined relationship is shown in Eq. (4), and the R^2 indicator has the value (5).

$$y = 0.0235x^{0.5455} \tag{4}$$

$$R^2 = 0.8599 \tag{5}$$

A linear regression function is presented in Fig. 5, and a polynomial one in Fig. 6. The determined relationships are shown in Eq. (6) and (8), and the R^2 indicator has the values (7) and (9).

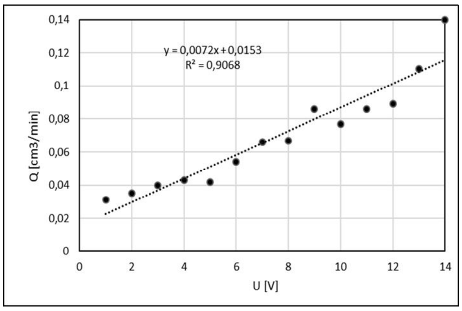

Fig. 5 – Linear regression function.

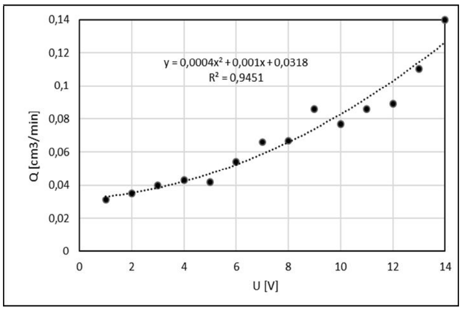

Fig. 6 – Polynomial regression function.

$$y = 0.0072x+0.015 \tag{6}$$

$$R^2 = 0.9068 \tag{7}$$

$$y = 0.000x^2 +0.001x+0.0318 \tag{8}$$

$$R^2 = 0.9451 \tag{9}$$

A exponential regression type for the objective function Ra is presented in Fig. 7. The determined relationship is shown in Eq. (10) and the model's accuracy indicator has the value (11).

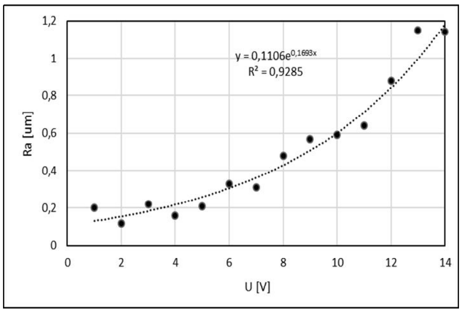

Fig. 7 – Exponential regression function.

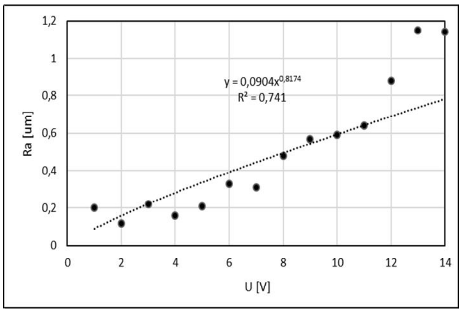

Fig. 8 – Power regression function.

$$y = 0.1106e^{0.1693x} \tag{10}$$

$$R^2 = 0.9285 \tag{11}$$

A power type regression function for the objective function Ra is presented in Fig. 8. The determined relationship is shown in Eq. (12), and the R^2 indicator has the value (13).

$$y = 0.0904x^{0.8174} \tag{12}$$

$$R^2 = 0.741 \tag{13}$$

A linear regression function for Ra criteria is presented in Fig. 9, and a polynomial one in Fig. 10. The determined relationships are shown in Eq. (14) and (16), and the R^2 indicator has the values (15) and (17).

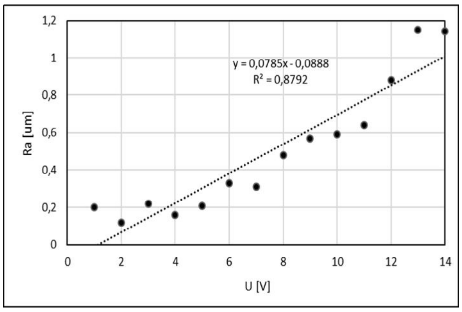

Fig. 9 – Linear regression function.

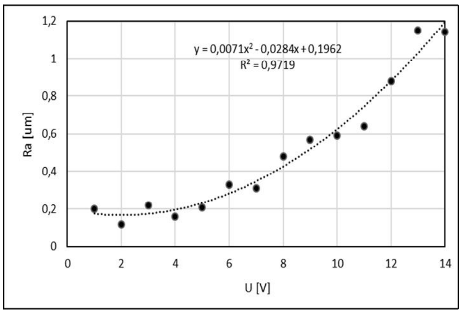

Fig. 10 – Polynomial regression function.

$$y = 0.0785x – 0.0888 \tag{14}$$

$$R^2 = 0.8792 \tag{15}$$

$$y = 0.0071x^2 – 0.0284x + 0.1962 \tag{16}$$

$$R^2 = 0.9719 \tag{17}$$

5. Conclusions

Based on calculate adequacy coefficients is possible to determine the precise regression function for the studied criteria.

Thus, the most precise regression function for Q objective is exponential function (R^2 = 0.9662) and for objective Ra polynomial function (R^2 = 0.9719).

Because in Ra case the regression function is a second degree polynomial, it is interesting to find out if a polynomial of degree higher than two provide a more accurate model. So, Eq. (18) show a third degree polynomial function for Ra criteria and (20) a four-degree polynomial function. The R^2 coefficients are shown in (19) and (21).

$$y = –0.00001x^3 + 0.0074x^2 – 0.0299x + 0.1985 \tag{18}$$

$$R^2 = 0.9719 \tag{19}$$

$$y = 0.00003x^4 – 0.001x^3 + 0.0167x^2 – 0.0635x + 0.2314 \tag{20}$$

$$R^2 = 0.9721 \tag{21}$$

As can be seen, the coefficient R^2 does not have a significant increase so that it is considered as a second degree polynomial function provide a sufficiently accurate mathematical model.

REFERENCES

Kozak J., Oczos K., *Selected Problems of Abrasive Hybrid Machining*, J. of Materials Processing Technology, Vol. 109, No. 3, pp. 360-366 (2001).

Kozak J., *Analysis of Abrasive Electrochemical Grinding Process* (*AECG*), Proceedings of the World Congress on Engineering, 2014, Vol. II, July 2-4, London, U.K.

Mc Geough J.A., *Advanced Methods of Machining*, 1st Ed. Chapman and Hall, USA, 1988.

Qu N.S., Zhang Q.L., Fang X.L., Ye E.K., Zhu D., *Experimental Investigation on Electrochemical Grinding of Inconel 718*, 15th Machining Innovations Conference for Aerospace Industry, Procedia CIRP 35 (2015) pp. 16-19.

Todincă T., Geantă M., *Modelarea şi simularea proceselor chimice*, Ed. Politehnica, Timişoara, 1999.

CONSIDERAȚII PRIVIND MODELAREA MATEMATICĂ A PROCESELOR DE PRELUCRARE ELECTROCHIMICĂ ABRAZIVĂ

(Rezumat)

Procedeul de prelucrare prin eroziune electrochimică-abrazivă se bazează pe desfăşurarea simultană a unor procese de dizolvare electrochimică combinate cu procese de abrazare şi cu fenomene electroerozive. În vederea determinării ecuațiilor de dependență ale criteriilor de evaluare a performanțelor procesului de prelucrare față de parametrii de lucru, autorii au efectuat un program experimental. Astfel s-a urmărit influența tensiunii de alimentare asupra productivității prelucrării şi asupra calității suprafețelor prelucrate. Datele astfel obținute au fost prelucrate cu ajutorul programului Excel şi s-au gasit mai multe tipuri de funcții de regresie. Cu ajutorul criteriului R^2 s-a determinat cel mai adecvat model matematic.