Precise electrochemical reaming of long holes

Precyzyjne elektrochemiczne rozwiercanie długich otworów

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The paper presents results of experiments of electrochemical reaming of long holes. During performed experiments, there was verified the physico-mathematical model of the machining process used for initial selection of the range of technological parameters applied for the machining tests. There were also conducted experiments focusing on the optimization of the machining parameters of electrochemical reaming process in order to achieve holes with desired geometry and proper inner surface quality.
KEYWORDS: electrochemical machining, long holes shaping, machining efficiency, electrochemical reaming

Precise shaping of long holes, fot the needs of i.e. heat exchangers of nuclear reactors or barrel ducts, is a multi-stage process. The pre-drilled hole is subjected to reaming operations, which are to increase its dimensional and shape accuracy and to improve the quality of the surface. Usually, in order to achieve the desired diameter, reaming is carried out by cutting. Due to small allowances removed during single operation (in the order of 0.05÷0.15 mm), obtaining the desired diameter requires performing at least several reaming operations (roughing, semi-finishing and finishing). As a result of the machining, after finishing reaming, there may be transverse cracks and a reinforced top layer on the inner surface of the shaped hole. These phenomena are undesirable, therefore the product must be subjected to the subsequent treatment [1]. One of the effective ways of eliminating these adverse effects of machining, which at the same time improves production efficiency, is the use of electrochemical reaming instead of the mechanical finishing reaming. Electrochemical machining, in single operation, allows to increase diameter by approximately 0.5÷1 mm with an accuracy of 0.01 mm and maintaining a high surface quality. The process of removal of the allowance results from the electrochemical dissolution phenomena , proceeding without changes in the top layer of the machined material. During the ECM process, no additional stresses are created in the material. Since in the case of ECM processing, the cathode (working electrode) is not worn, it is possible to apply it repeatedly to shape the workpiece.

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Research position

As part of the research, a series of experiments related to electrochemical reaming of holes were carried out. A simplified machining scheme is shown in fig. 1. The tests were carried out on a test stand based on an electrochemical CNC machine (fig. 2) and a DC power supply with a maximum voltage of 24 VDC and a maximum current of 2000 A. The power supply allowed operation in constant current mode or constant voltage.

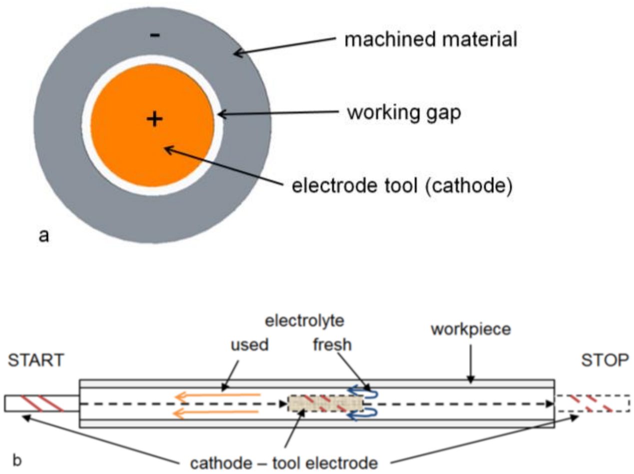

Fig. 1. Simplified diagram of the electrochemical reaming process: a) cross-section, b) kinematics of the machining process [2]

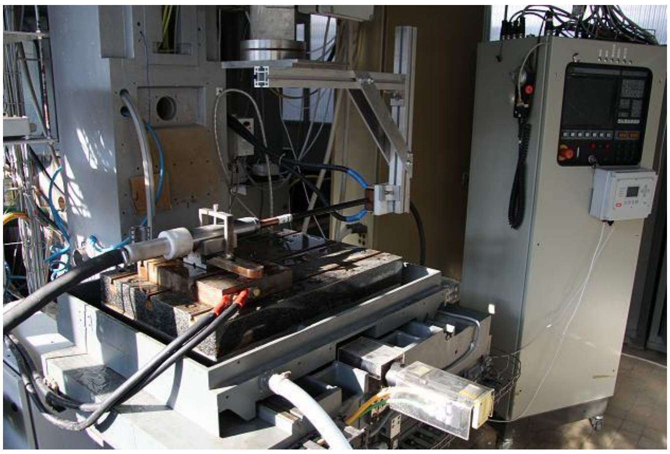

Fig. 2. Stand for testing electrochemical reaming of holes

Two types of samples were machined, i.e. pipes made of 30HN2MF steel with the following dimensions:

- inner diameter 22.8 mm and length 300 mm,
- inner diameter 12.6 mm and length 300 mm.

As the electrolyte, an aqueous NaCl solution with a concentration of about 12% was used. Electrolyte temperature was stabilized in the range of 25÷30 °C. Working electrodes (fig. 3) were made of copper.

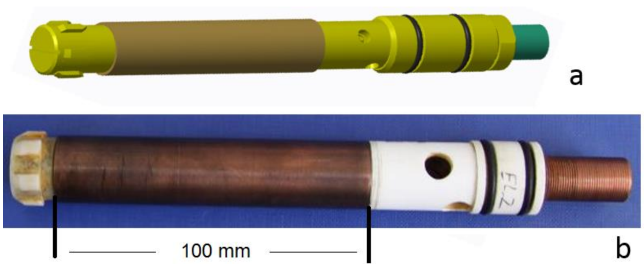

Fig. 3. Electrode for reaming the holes with diameters >20 mm: a) design, b) electrode used during experiments

The experiments were aimed at determining the optimal (from the point of view of the geometry of holes obtained and the time of their machining) conditions of the electrochemical reaming process. Variable parameters were the feedrate of the working electrode and the working current setpoint (operation in constant current mode, with operating voltage limited to approximately 18 VDC). Variability ranges of parameters, estimated on the basis of the process model, are presented in Table I.

TABLE I. Range of variability of parameters for individual holes / initial diameters

Initial diameter of the hole, mm	Electrode feedrate, V_f mm/min	Working current, *I*, A
22,8	100 ÷ 150	1200 ÷ 1500
12,6	100 ÷ 150	480 ÷ 580

Analytically determined parameters of electrochemical reaming with a moving electrode

The basic purpose of modeling and simulation of the electrochemical reaming process was to determine the thickness of the final gap S_k (after machining) and thus the final diameter of the borehole to be machined. A detailed model was presented by Kozak et al. in 2015 [2]. For the needs of tests we used the following equations describing:

- diameter of the hole after electrochemical reaming (D_k):

$$D_k = d_e + 2\sqrt{S_0^2 + 2\kappa \cdot K_V \frac{U-E}{V_f} L} \qquad (1)$$

- current in the steady state of electrochemical reaming (I_f):

$$I_f = 0.25\pi\left(D_k^2 - D_0^2\right)\frac{V_f}{K_V} \qquad (2)$$

where: d_e - diameter of the cathode (working electrode), D_0 - initial diameter of the hole, $S_0 = (D_0 - d_e)/2$ - initial gap, κ - electrical conductivity of electrolyte, K_v - electrochemical workability factor, U - inter-electrode voltage , E - potential drop in the sub-electrode layers, v_f - feedrate of the working electrode, L - length of the active part of the working electrode.

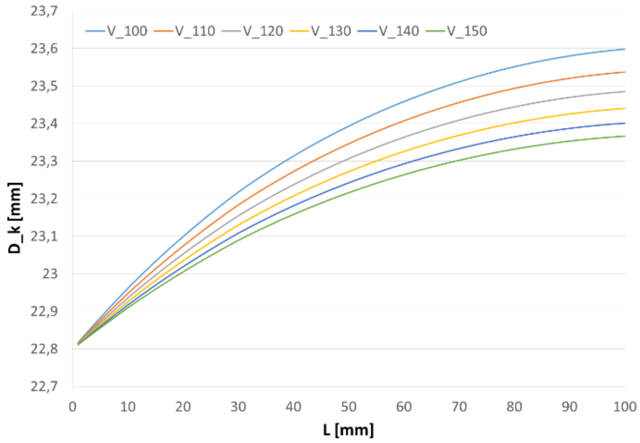

Fig. 4. Diameter of the hole (D_k) after electrochemical reaming of the hole with D_0 = 22.8 mm depending on the position along the working electrode and for various electrode feedrates: v_f = 100, 110, 120, 130, 140 and 150 mm/min (at constant U = 15 V and E = 0.3 V)

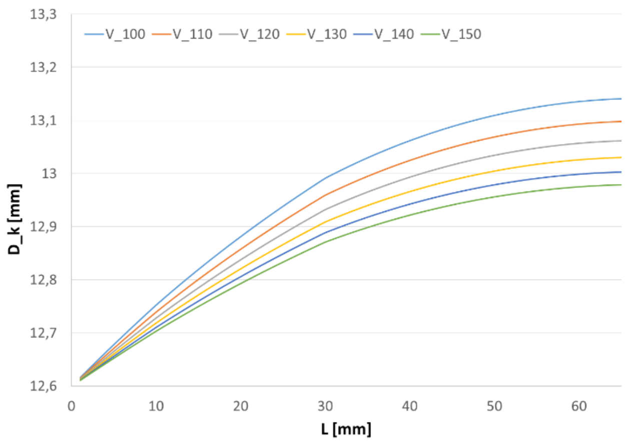

Fig. 5. Diameter of the hole (D_k) after electrochemical reaming of the hole with D_0 = 12.6 mm depending on the position along the working electrode and for various electrode feedrates: v_f = 100, 110, 120, 130, 140 and 150 mm/min (at constant U = 15 V and E = 0.3 V)

The simulation assumed constant values of parameters resulting from the dimensions of the materials and samples used as well as from the literature data [1, 4]: κ = 0.02 1/Ω·mm, K_v = 2.17 mm³/A·min. The simulation shows that in case of holes with an initial diameter D_0>20 mm, the final diameter will be formed along the electrode, depending on its feedrate, as shown in fig. 4: d_e = 21.3 mm, D_0 = 22.8 mm, L = 100 mm. In case of holes with initial diameter $D_0 \approx$ 12.5 mm, the final diameter will be formed along the electrode, depending on its feedrate, as shown in fig. 5: d_e = 11.2 mm, D_0 = 12.6 mm, L = 65 mm.

For the conditions presented in fig. 4 and fig. 5, the calculated value of current intensity varied depending on the feedrate, as presented in Table II.

TABLE II. Determined current (I_f) in steady state of electrochemical calibration

V_f mm/min	I_f,A	
	D_0 = 22,8 mm	D_0 = 12,6 mm
100	1340	530
110	1360	536
120	1378	542
130	1393	547
140	1407	551
150	1420	555

Results of experiments

Theoretically determined current and feedrate settings of the working electrode have been checked in the course of experiments. The following electrolyte flow rates were used:

- 45 l/min for D_0 = 22.8 mm,
- 30 l/min for D_0 = 12.6 mm.

Diameters of holes after electrochemical reaming were measured by means of a hand-operated three-point device (micrometer) equipped with a micrometer screw, with a nominal accuracy of ±5 μm.

Due to widening of the hole outlet and inlet, for further analyzes, measurements were made in the central part of samples, where the electrochemical reaming process runs steadily, in a steady state. The comparison of machining results with analytically values determined is presented in Tables III and IV.

TABLE III. Results of electro-chemical reaming of holes with starting diameter of 22.8 mm

Settings		Final diameter of the hole				
		After machining	The simulation for E, V			
V_f	I_f		*E = 0*	*E = 0,5*	*E = 1*	*E = 2*
100	*1340*	23,61	23,62	23,58	23,54	23,47
110	*1360*	23,55	23,56	23,52	23,49	23,41
120	*1378*	23,48	23,50	23,47	23,44	23,37
130	*1393*	23,44	23,46	23,43	23,40	23,33
140	*1407*	23,41	23,42	23,39	23,36	23,30
150	*1420*	23,37	23,38	23,35	23,33	23,27

TABLE IV. Results of electro-chemical reaming of holes with starting diameter of 12.6 mm

Settings		Final diameter of the hole				
		After machining	The simulation for E, V			
V_f	I_f		*E = 0*	*E = 0,5*	*E = 1*	*E = 2*
100	530	13,24	13,25	13,22	13,20	13,14
110	536	13,19	13,20	13,18	13,15	13,10
120	542	13,15	13,16	13,14	13,11	13,06
130	547	13,11	13,12	13,10	13,07	13,03
140	551	13,08	13,09	13,07	13,04	13,00
150	555	13,05	13,06	13,04	13,02	12,97

Conclusions

Results of the experiments carried out and their comparison with simulation results made it possible to estimate the value of parameters for the purposes of further simulations of electrochemical machining of holes made in 30HN2MF steel. It may be stated that both in case of holes with a large (>20 mm) and smaller initial diameter (about 12.6 mm), the potential drop in the sub-electrode layers is negligible during the analytical determination of technological parameters of the electrochemical machining process. The test results were the basis for development of technological process and selection of parameters for electrochemical reaming in industrial practice.

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