

THE EXPERIMENTAL RESEARCH OF ELECTRODISCHARGE DRILLING OF X5CrNi18–10 STAINLESS STEEL

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ABSTRACT

One of the most important trends in manufacturing technology deals with the miniaturization of products and components. Microelements must be shaped with high accuracy and high surface quality what is difficult when machining of new materials such as stainless steel, titanium alloy, ceramics, especially by traditional machining. In this paper presents EDM drilling of high aspect–ratio holes in X5CrNi18–10 stainless steel. In article has been described the analysis of electrodischarge drilling with used deionized water as dielectric fluid. The experiment involves the impact of selected parameters as current amplitude, discharge voltage and pulse time on the following technological parameters: hole depth and side gap, linear tool wear and mean drilling speed.

Key words: EDM drilling, micromachining, stainless steel

1. INTRODUCTION

Nowdays in different fields of industry the miniaturization of products is noticed. Hence, the demand of micromachining technologies significantly increase. The microelement is generally defined as a part with the range of dimensions 1 – 999 μm [1]. It is required that performed microparts should have high accuracy and good surface quality. It is worth to underline that advanced engineering materials (such as superalloys, titanium alloys, steel alloys, ceramic and composite materials) are more and more applied in micromanufacturing industry. The machining of microparts made of advanced engineering materials is very difficult by using conventional machining methods. One of difficult–to–cut material is a stainless steel, which has a wide of application in the fields of industry, such as electronics, aerospace, automotive and medical.

During mechanical drilling more amount of the heat diffuses into the drill than to the chips what causes that the cutting edge is subjected to deformations and reduced tensile strength [2]. Additionally, high toughness of the stainless steel contributes to formation of built–up edge from molten material what causes lower cutting speed. Cutting force during the drilling causes also bending and buckling of the drill. The poor chip control affects short tool life and lower surface roughness. In many case, the drilling problems are associated with burr formation on the workpiece what decreases accuracy and quality of machined surface. Due to material properties and connected with this difficulties of drilling of the stainless steel, the nontraditional machining methods plays an important role in the shaping of difficult–to–machine materials.

In this article the results of experimental research on electrodischarge microdrilling in X5CrNi18–10 stainless steel are presented. The experiment involves the impact of such machining parameters as current amplitude, discharge voltage and pulse time on the following technological parameters: hole depth and side gap, linear tool wear and mean drilling speed.

2. CHARACTERISTIC OF EDM DRILLING

In electrodischarge machining (EDM), the material is removed and eroded from the workpiece due to the energy from a series of electric discharges generated between the tool electrode and the workpiece immersed in a dielectric medium. The erosion of material takes place by the changing of electrical energy into the thermal energy and the allowance is removed by material evaporation, melting and disruption. The both of electrodes are connected to the pulse generator with the discharge voltage up to a few hundred volts and current ranges up to tens of amperes [3, 5].

Following EDM methods have been used for manufacturing micro-features, depending on the electrode tool shape and applied machining kinematics [6]:

- wire cutting (electrode tool is a wire with diameter up to 0,02 mm, precision cutting of conductive materials),
- die – sinking (an electrode shape is mirrored in the workpiece),
- milling or machining with universal electrode tool (shape of workpiece results from a cylindrical electrode tool trajectory reproduction, machining of complex 3D cavities),
- drilling (kinematic similar to conventional drilling, the electrode tool has tubular shape).

EDM process is alternative method for shaping difficult-to-machine and electric conductive materials (hardened steel, carbides, composite materials, ceramics, etc.). The machining is thermo – electric process, what causes that mechanical force between the electrodes in the machining area are insignificant. As a main advantage of EDM one can state that material can be machined regardless of its hardness.

In EDM drilling, the electrode tool as drill has rotary and feed motion. Electrode tool can have tubular shape (the dielectric fluid is flushed through the interior hole of the tube in order to remove machining debris) or solid rod shape (the dielectric is fed to the machining zone by either suction or injection through pre-drilled hole). During EDM drilling due to wear the shape of electrode tool changes. Wear occurs both at the tip and on the side of the electrode (it is called *carrot effect*) [6]. The wear of electrode tool causes deformation of the bottom of the hole. High wear affects on stability, accuracy and efficiency of the process. The electrodischarge drilling enables to machine high-aspect ratio holes up to 1/400. The drilling of high-aspect ratio holes is limited only by machining debris accumulation which can cause abnormal electrical discharges. Additionally, machining of the deep holes requires a correct dielectric flow into the discharge area what can be difficult by generated bubbles in the interelectrode gap [7]. In case when microdrilling of metallic materials, the EDM drilling is one of the most effective method [8]. The process gives possibility to produce holes with high accuracy (less than 5 μm) and high quality of machined surface (with roughness R_a less than 0.1 μm). The holes characterize regular shape and high accuracy of burr-free surface. It is worth to underline that electrodischarge machining is high temperature process what in some cases cause poor surface layer with heat affected zone [5].

3. METHODOLOGY OF RESEARCH

The research on EDM drilling was carried on at Institute of Production Engineering at Cracow University of Technology. A machined material was X5CrNi18–10 stainless steel. The EDM drilling research was carried on the machine tool designed at the Institute of Production Engineering of Cracow University of Technology (detailed

description in [4]). The drilling was carried out with copper dual-channel electrode with diameter 1 mm and deionized water as dielectric fluid. High-pressure flushing (30 bar) through the tube electrode was applied (Fig. 1a, 1b).

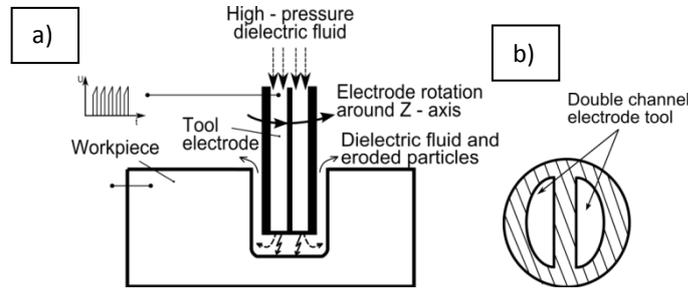


Fig. 1. Scheme of EDM drilling: a) scheme of machining area, b) the end of the dual channel electrode tool

The research was performed according to the theory of the experiment which involves plan of Box-Benken. The research takes place according to plan containing machining input and output parameters presented in table 1.

Table 1. Research input and output parameters

The input parameters	The output parameters
– Time of the pulse (t_i : 100 – 500 μ s),	– Linear tool wear (v),
– Current amplitude (I: 1.05 – 3.15 A),	– Side gap (S_b),
– Discharge voltage (U: 20 – 40 V).	– Drilling speed (v).

The goal of the tests was to examine the impact of selected machining parameters on hole accuracy (measured by side gap), tool wear and drilling speed.

The linear tool wear v was calculated according to the following formula:

$$v = \frac{h_t}{h_h} \cdot 100\% \quad (1)$$

where: h_t – is shortening of the electrode and h_h – is hole depth.

The side gap S_b was defined as;

$$S_b = \frac{D - d_t}{2} \quad (2)$$

where D – hole diameter and d_t – diameter of the tool.

Drilling speed v was calculated, according to following formula:

$$v = \frac{h_h}{t_m} \quad (3)$$

where t_m – is the time of machining.

The constant parameters were given as: workpiece material (X5CrNi18–10 stainless steel), material of the tool electrode (dual-channel, diameter 1 mm, made of copper), dielectric fluid (deionized water), dielectric pressure (30 bar), rotating speed of the tool electrode (500 1/min), machining time $t_m = 30 \text{ min}$, pause time $t_p = t_i$.

The relation between input and output parameters were approximated with assumption of following full quadratic polynomial with constant, linear, interaction and squared terms:

$$F(x_1, x_2, x_3) = b_0 + b_1 t_i + b_2 I + b_3 U + b_{11} t_i^2 + b_{22} I^2 + b_{33} U^2 + b_{12} t_i I + b_{13} t_i U + b_{23} I U$$

To calculate polynomial coefficients and perform regression analysis function *regstats* in the Matlab (Statistic Toolbox) software was used. The statistic analysis of research indicated adequacy of relations for linear tool wear and drilling speed (statistical significance $\alpha = 0.1$). However, the least defined parameter was the side gap what was related with errors of calculating of the side gap was caused by eccentric attachment of the electrode (radian run-out).

4. ANALYSIS OF RESULTS

The results of research indicates that the output parameters depend mainly on discharge voltage and current amplitude (Fig. 2) and the pulse time has rather an insignificant effect on investigated technological factors (Fig. 3).

The deionized water can be treated as dielectric fluid and also as electrolyte with low conductivity what contributes that material is removed by simultaneous interaction of electrochemical dissolution and electrical discharges. Therefore, when discharge voltage is low ($U = 20 V$), the electrochemical removal component takes important part in material removal, what causes significant increase of drilling speed and simultaneously higher material removal rate. Lower discharge voltage provides simultaneous interaction of electrochemical dissolution and electrical discharges on the workpiece surface (hybrid process called as electrochemical discharge machining).

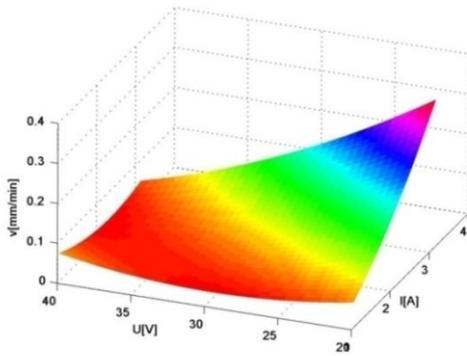


Fig. 2. Relationship between drilling speed v , current amplitude I and discharge voltage U , $t_i = 300 \mu s$

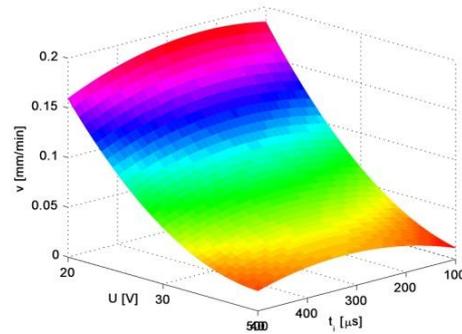


Fig. 3. Relation between drilling speed v , discharge voltage and time of the impulse t_i , $I = 2.1 A$

Electrochemical discharge machining gives possibility to improve efficiency of process and accuracy and quality of surface of holes [9]. One can state that hole machined with $U = 20 V$ has more regular shape and higher diameter and also is deeper (Fig. 4). When discharge voltage is high ($U = 30 - 40 V$), drilling speed decreases because the material is removed in a typical way for the EDM process.

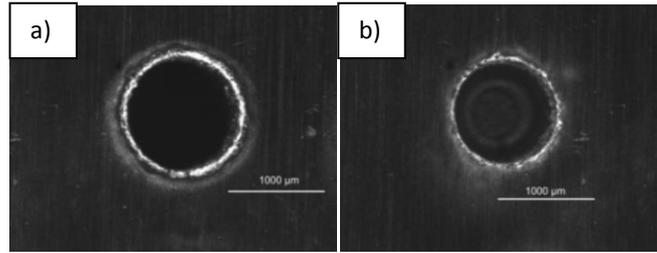


Fig. 4. Photographs of the holes drilled in X5CrNi18–10 stainless steel: a) parameters of machining: $t_i = 500 \mu\text{s}$, $I = 2,1 \text{ A}$, $U = 20 \text{ V}$, hole depth $h_h = 4381 \mu\text{m}$, $D = 1154 \mu\text{m}$, b) parameters of machining: $t_i = 100 \mu\text{s}$, $I = 2,1 \text{ A}$, $U = 40 \text{ V}$, hole depth $h_h = 738 \mu\text{m}$, $D = 1051 \mu\text{m}$

In case when discharge voltage achieves high values, up to critical value, the water begins to boil and to evaporate. The gas bubble is generated on the tool electrode surface and at the critical conditions the electrode surface is fully covered with bubbles. The result is a decrease in the interelectrode gap thickness and to produce electrical discharges. It is observed when high value of discharge voltage is applied ($U = 30 - 40 \text{ V}$) and causes a decrease in the gap thickness (Fig. 5).

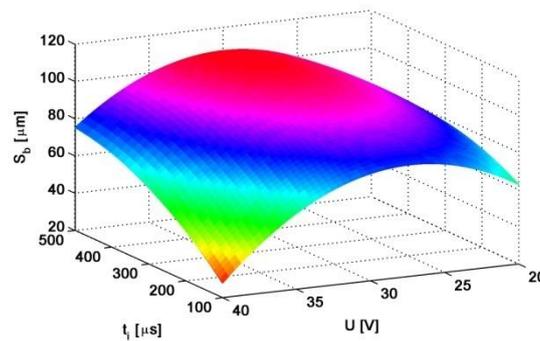


Fig. 5. Relationship between side gap S_b , discharge voltage U and time of the impulse t_i , $I = 2.1 \text{ A}$

The amount of removed material depends on single discharge energy which is related to discharge current amplitude. Applied of higher current amplitude causes higher single discharge energy and a increase drilling speed. Drilling velocity with $U = 20 \text{ V}$ is significant higher what indicates that the material is removed in a typical way for the EC/EDM process. This results from bigger interelectrode gap thickness for this value of U which causes that dielectric flow is more uniform and debris from discharge area are removed more efficient. When machining is carried out with high voltage the gap thickness is lower therefore removing of debris is more difficult and sparking in the interelectrode gap occurs.

High linear tool wear for low discharge voltage, indicates effective machining (the maximal value of linear tool wear reaches about 8% for $U = 20 \text{ V}$). An increase of linear tool wear also takes place for longer time of the impulse ($t_i = 500 \mu\text{s}$). Discharge in electrochemical discharge machining (ECDM) occurs when the voltage achieves the critical breakdown voltage φ_2 (Fig. 6). During Stage I the voltage between the anode and cathode increases, the spark is produced and the voltage reaches critical value

(Stage II). The electrical discharge occurs till the end of the pulse time. Longer time of the impulse provides good conditions for discharge what is related with increase linear tool wear [8].

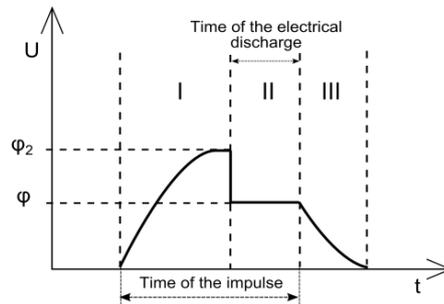


Fig. 6. Scheme of typical ECDM voltage characteristic [10]

During the EDM drilling research, dual-channel electrode-tool was applied which enables easier the dielectric flow and better evacuation of eroded particles from discharge area. However, the side of the tool electrode wear causes conical shape of the hole after drilling. The diameter of the hole decreases along the length of hole (Fig. 7a). During the drilling, the tool wear also occurred at the centric tip of the electrode tool what caused deformation of the bottom of the hole (Fig. 7b, 7c). The tip of the electrode wears irregular. In the center of electrode tip the wear is most intensive due to the lack of dielectric flow (it is called *dielectric stagnation zone*) (Fig. 8).

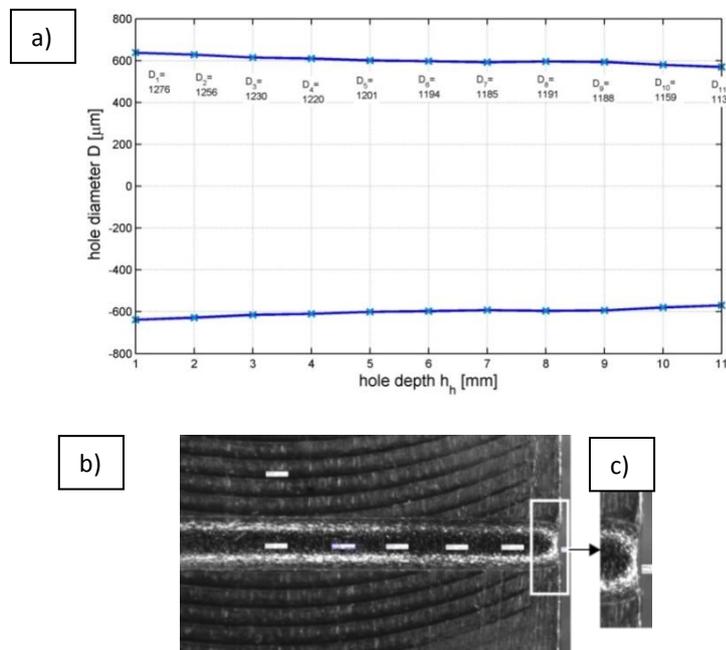


Fig. 7. Change of shape of the hole after drilling: a) graph representing change of the hole diameter with the hole depth, b) photograph of the shape of the hole and c) the deformation of the hole bottom

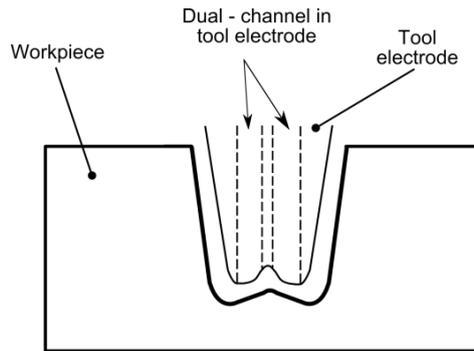


Fig. 8. Scheme of the shape of the tool electrode and hole after EDM drilling

Conical shape of the hole is also observed during drilling of the through hole. The output diameter of the hole is significant smaller than the input diameter which is result from tool electrode wear and machining without additional technological plate on the underside of material workpiece (Fig. 9). In such case when the through hole is drilled, dielectric fluid flew out of machining zone what causes poor machining.

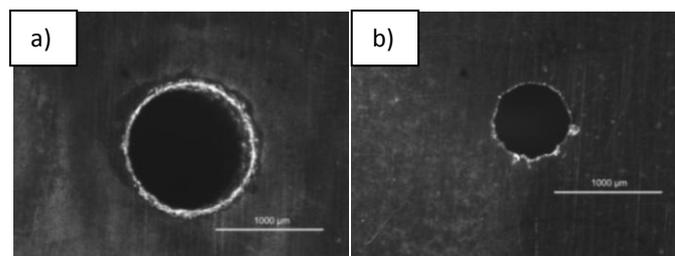


Fig. 9. Photographs of the input hole drilled in X5CrNi18–10 stainless steel for parameters of machining: $t_i = 300 \mu\text{s}$, $I = 3,15 \text{ A}$, $U = 40 \text{ V}$, depth of the hole $h_h = 12885 \mu\text{m}$, a) input of the hole b) output of the hole

5. CONCLUSION

The analysis of literatures provides that EDM drilling is a good alternative and most often used nonconventional method when machining difficult-to-cut materials. Research carried out proved, that EDM is efficient method of stainless steel drilling. Applied of deionized water as dielectric fluid and drilling with low discharge voltage ($U = 20 \text{ V}$), gave the best result. From presented discussion results that electrodischarge erosion is accompanied by electrochemical dissolution what causes an increase of drilling velocity. However, these conditions give also high tool electrode wear. Tool wear is the main disadvantage of the process. It is worth to underline that in case when deionized water is applied as working fluid, the process is safer and cheaper than machining in kerosene.

Machining enables drilling high-aspect ratio holes (ratio of the diameter to the depth of the hole more than 1/10) and through holes. However, efficient drilling of through holes requires the application of additional technological pad on the underside of workpiece.

6. REFERENCES

- [1] Chavoshi S. Z., Luo X.: Hybrid micro-machining processes: A review, *Precision Engineering* 41, 2015, pp. 1–23
- [2] Dolinsek S.: Work-hardening in the drilling of austenitic stainless steel, *Journal of Materials Processing Technology* 133, 2003, pp. 63–70
- [3] El-Hofy H.: *Advanced Machining Process. Nontraditional and hybrid machining process*, Alexandria University, Egypt, 2005
- [4] Skoczypiec S., Ruszaj A.: A sequential electrochemical-electrodischarge process for micro part manufacturing, *Precision Engineering* 38, 2014, pp. 680 – 690
- [5] Ho K.H., Newman S.T.: State of the art electrical discharge machining (EDM), *International Journal of Machine Tools & Manufacture* 43, 2003, pp.1287–1300
- [6] Pham D.T., Dimov S.S., Bigot S., Ivanov A., Popov K.: Micro-EDM—recent developments and research issues, *Journal of Materials Processing Technology* 149, 2004, pp. 50–57
- [7] Jianzhong L., Guoqiang Y., Cong W., Xuejie G., Zuyuan Y.: Prediction of aspect ratio of a micro hole drilled by EDM, *Journal of Mechanical Science and Technology* 27 (1), 2013, pp. 185–190
- [8] D’Urso G., Maccarini G., Ravasio C.: Process performance of micro-EDM drilling of stainless steel, *The International Journal of Advanced Manufacturing Technology*, 2014, Volume: 72, Issue: 9-12, pp. 1287–1298
- [9] Nguyen M. D., Rahman M., Wong Y. S.: Enhanced surface integrity and dimensional accuracy by simultaneous micro-ED/EC milling, *CIRP Annals - Manufacturing Technology* 61, 2012, pp. 191–194
- [10] Liu J.W., Yue T.M., Guo Z.N.: An analysis of the discharge mechanism in electrochemical discharge machining of particulate reinforced metal matrix composites, *International Journal of Machine Tools & Manufacture* 50, 2010, pp. 86–96