SIMULATION OF HYDRODYNAMIC DEPASSIVATION IN ELECTROCHEMICAL CUTTING USING THIN ROD-TYPE ELECTRODE WITH HELICAL GROOVES

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ABSTRACT: In the case of electrochemical machining, an important problem is to ensure the possibility of effective removal of the passivation layer that appears near the surface of the workpiece, as a result of the chemical reactions between the material of the workpiece and the electrolyte. When cutting slots by electrochemical machining with a thin cylindrical rod electrode, depassivation can be hydrodynamically carried out. A usable solution involves rotating a thin cylindrical rod-type tool electrode provided with helical grooves on its outer cylindrical surface. To highlight how the rotation of the tool electrode contributes to the recirculation of the electrolyte, a modeling of the process using the finite element method was resorted to. Later, experimental tests were carried out to confirm the effect of rotating the thin rod tool electrode with helical grooves on the circulation of the electrolyte in the machining area. By resorting to an experimental procedure to simulate the rotation of the tool electrode in a liquid, the hypothesis of recirculation of the liquid solution due to the rotation of the tool electrode was confirmed.
KEYWORDS: electrochemical cutting, depassivation simulation, tool electrode, thin cylindrical rod, helical grooves, tool electrode rotation

1. INTRODUCTION

Electrochemical machining is based on the removal of material from the workpiece as a result of chemical reactions between the material of the workpiece and the electrolyte, under the conditions of including the workpiece and the tool electrode in a direct current electric circuit and the immersion of the processing area in the electrolyte [1-8]. Thus, the metal ions contribute to the formation of independent compounds, which can remain near the workpiece. The separation of ions during the process takes place due to the presence of direct electric current, the workpiece being connected to the positive terminal of the current source, and the tool electrode to the negative terminal.

If not removed, the formed compounds tend to form a film on the surface of the workpiece to be machined, which can be an obstacle to the further development of machining, by slowing down or even stopping the development of chemical reactions between the workpiece material and the electrolyte. The removal of the passive film from the work area can be done naturally, in which case it is due to the movement of the hydrogen bubbles generated by the process towards the upper surface of the electrolyte. Sometimes, however, natural depassivation does not ensure effective results, and hydrodynamic forced depassivation or mechanical forced depassivation through abrasion is used.

When cutting by electrochemical erosion, a metal wire, a thin rod, or a thin disk can be used as the tool electrode, but other constructive solutions are also being studied that would allow an improvement of the process results from certain points of view.

It was thus found that there are concerns of the researchers to identify some solutions that allow the efficient creation by electrochemical erosion of some slits in plate-type workpieces.

As a result of the research carried out, Kong et al. have proposed a solution to improve the cutting conditions by electrochemical erosion of plates characterized by a thickness much greater than the size of the working gap specific to electrochemical erosion processing [9]. They considered the case of cutting some workpieces by wire electrode electrical machining, then resorting to a wire electrode electrochemical machining (WECM) surface finish. As a tool electrode, they used a structure consisting of two molybdenum wires of different diameters and twisted to facilitate the formation of helical surfaces. The rotation of such a tool electrode contributes to an intensification of the circulation of the electrolyte in the working gap and therefore to a faster removal of the passivating film, this action joining that of depassivation by raising the hydrogen bubbles. Also, due to the different diameters of the wires, when rotating the mentioned electrode, the thin wire does not touch the workpiece, contributing to the electrochemical machining process, while the thick wire contacts the material of the workpiece, which means creating the conditions for processing by electrical discharge machining. Simulations and experimental research were carried out on Inconel 718 alloy samples, concluding that the use of the proposed solution is effective. A higher precision of the resulting surface when cutting a plate with a thickness of 30 mm was thus obtained, the processing speed being of the order of a few micrometers per second. The diameters of the two wires had values of 0.1-0.12 mm. Combining processing by electrical discharge and electrochemical erosion leads to obtaining certain advantages, being possible, for example, to cut workpieces with greater thicknesses than those corresponding to a cut by electrochemical erosion alone. Also, a decrease in the thickness of the thermally affected areas by the electrical erosion process is observed. In the areas where the wires are joined, it is possible to accumulate hydrogen bubbles that will be more easily evacuated from the working gap.

Zhang et al. considered the use as a tool electrode of a rod with a diameter of 1 mm and having a triangular thread for electrochemical erosion finishing of a surface previously obtained by electrical discharge machining [10]. It was found that the use of a threaded cylindrical rod contributes to increasing the recirculation speed of the electrolyte in the working gap, favoring an increase in the cutting speed.

Another interesting solution was proposed by Zou et al. and it is based on the use of a cylindrical rod-type tool electrode on which circular grooves have previously been machined [11]. The realization by this electrode of a rotational movement and an alternating rectilinear movement along its axis leads to a more efficient refreshment of the electrolyte in the working gap and the provision, in this way, of better conditions for carrying out the electrochemical cutting process.

It has been observed that many times, it is necessary to ensure high precision of the tool electrode since its precision exerts influence on the quality of the surfaces processed by electrochemical erosion). In this regard, Xu et al. proposed the use of a tubular tool electrode, equipped with radial holes, through which the electrolyte can be sent into the working gap, in a pulsating regime [12]. Making the radial holes in the tubular tool electrode was possible, in turn, by using an electrochemical micro-drilling process. As a tool electrode for electrochemical microdrilling, a thin rod with helical grooves like those of a helical drill was considered.

Through this paper, it is proposed to highlight the results of some research that aimed to investigate the possibility that the rotation of a thin rod-type tool electrode with helical grooves contributes to an intensification of the recirculation of the electrolyte in the working gap, to the cutting of slits by electrochemical machining. First, a simulation by the finite element method of how the electrolyte is recirculated in the working gap, because of the rotation of the tool electrode of the thin cylindrical rod type with helical grooves (without there being a feed movement along the axis of the tool electrode). Later, experimental attempts to simulate the effect exerted by rotating the tool electrode on the circulation of the electrolyte confirmed, to a certain extent, the hypothesis of an additional advance in the movement of the electrolyte by rotating the thin rod-type tool electrode with helical grooves.

2. HYPOTHESES ABOUT THE FORMATION AND REMOVAL OF THE PASSIVATE FILM

Experimental research has shown that in electrochemical machining, i.e., processing that involves the removal of material from the workpiece because of the chemical reactions between the electrolyte and the material of the workpiece, the formation of the passivation layer can lead to a significant decrease in the intensity of the chemical reactions and therefore to a decrease in productivity processing. It was necessary to identify ways to reduce the negative effects generated by the appearance and development of the passivation layer. One of the solutions proposed in this regard was forced hydrodynamic depassivation, based, as mentioned previously, on a more intense circulation of the electrolyte at the level of the processing area, to bring here electrolyte unpurified with products of the generated chemical reactions by immersing the two electrodes connected in the circuit of a direct voltage source in the electrolyte.

Figure 1 shows a schematic representation of an electrochemical cutting process, in which a tool electrode is used in the form of a thin cylindrical rod, which performs a rotational movement n_{TE} around its axis. Another v_W work movement is

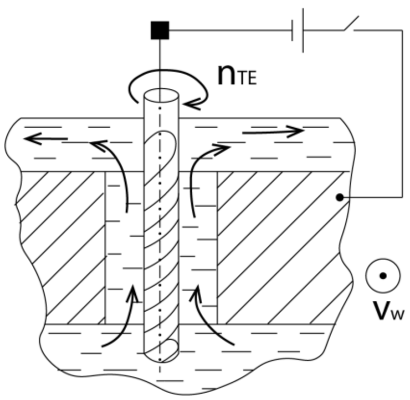

Figure 1. Intensification of electrolyte circulation by rotating the tool electrode in the form of a thin rod equipped with helical grooves

performed by the workpiece in the form of a plate. The electrolyte can be an aqueous salt solution.

Due to the working movement v_W made by the workpiece and the fulfillment of the other conditions specific to electrochemical machining, a slot is gradually generated in the material of the workpiece. The fact that the tool electrode in the form of a rod is very thin led to the inclusion of such a process in the wider group of *wire electrochemical machining processes*.

The appearance and development of the gap occur because of a work movement v_W executed by the workpiece, in the opposite direction to the development of the gap. To achieve a forced hydrodynamic depassivation in such a situation, the idea of using a thin cylindrical rod with helical grooves on the outer surface appeared. It was hypothesized that by rotating such an electrode in the form of a thin rod equipped with helical grooves, an intensification of the circulation of the electrolyte in the working area would be possible. It was hypothesized that those helical grooves could force the liquid working medium up (fig. 2) or down along the rod, depending on the helix direction corresponding to the helical groove and the direction

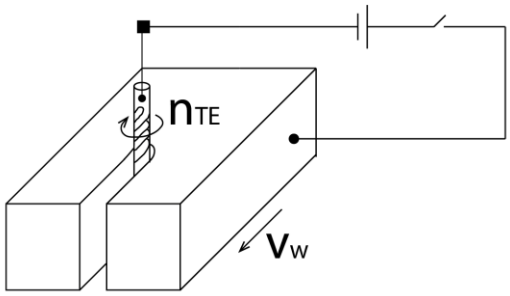

Figure 2. Schematic representation of the electrochemical cutting process using a thin cylindrical rod tool electrode with helical grooves, driven in rotational motion around its axis

of rotation of the tool electrode.

As a tool electrode in the form of a thin cylindrical rod, it was found that thin drills can be used, as they have the helical grooves necessary to generate a more intensive process of electrolyte circulation, especially in the space between the tool electrode and the surface on which material is to be removed from the workpiece.

In a paper published by Fang et al., the use of a tool electrode in the form of a thin rod provided with helical grooves is mentioned, the authors showing that in this case, it is possible to obtain certain benefits, at least from the point of view of improving accuracy processing [13]. The name of *wire electrochemical micromachining* was assigned to the process. It is also worth noting that Fang et al. simulated the way the electrolyte moves using, for this purpose, the finite element method, by exploiting the facilities offered by the COMSOL software and resorting to highlighting the differences that appear when using a thin cylindrical rod type tool electrode and, respectively, an electrode of a drill-type. They also carried out experimental research designed to highlight the variation of the electric current density in the machining area, the size of the working gap, and the machining speed to the rotation speed of the tool electrode.

The experimental research also aimed at analyzing the dependence between the cutting speed and the rotation of the tool electrode in different conditions of current, voltage, current frequency, and electrolyte concentration, including in the case of cutting slots along complex contours. The authors of the research demonstrated, in this way, the efficiency of using a drill that had the role of electrode tool in the process of wire electrochemical micromachining, a process that has many similarities with the process of wire electrochemical machining. It was appreciated that the proposed solution improves the machining accuracy, allowing, at the same time, to increase the cutting speed and to improve the uniformity of the current distribution in the gap.

The mentioned work led to the idea of developing additional research on how the circulation of the electrolyte takes place under the conditions of the rotation of the tool electrode in the form of a cylindrical rod with helical grooves, an electrode that can be materialized using a long and thin drill.

Based on the mentioned paper, the idea arose to analyze the behavior of the described solution at a macro level, bringing into question other parameters following practical experiments, which denote its efficiency, such as visual assessment of the behavior of the electrolyte during processing, the influence of the speed of the work movement and the rotation speed of the electrode-tool, etc.

Following the use of the thin cylindrical rod with helical grooves, it is expected that the circulation speed of the electrolyte in the machining area will be higher, due to the grooves with helical edges of the drill, which contribute to establishing the way of displacement of the electrolyte. It is also assumed that due to the helical shape of the grooves, the electrolyte is either attracted from the outside or pushed to the outside of the machining groove. All these effects could be beneficial for speeding up the electrochemical erosion process and especially in removing the compounds formed more quickly, thus reducing the possibility of the formation of the passivation layer.

To carry out the experimental tests, a solution could be considered that would include an experimental stand for observing the movement of the liquid and simulating through the finite element method, with the involvement of a drill and a groove created in a part of a plastic material, without to take into account the metallic properties necessary for the electrochemical erosion process, since no actual machining will be carried out, but only how the helical grooves act on the electrolyte will be observed.

3. SIMULATION USING THE FINITE ELEMENT METHOD OF ELECTROLYTE CIRCULATION IN ELECTROCHEMICAL CUTTING

The possibility of highlighting the process of hydrodynamic depassivation in electrochemical cutting has multiple benefits, one of which being the numerical results related to volume dislocation. A way to achieve this is by using the finite element method (FEM). The authors have turned to Ansys, a researcher licensed to obtain results. The module of choice was Discovery for its ability to produce visual results with a proper setup.
The first step consisted of designing the 3D model of the rod-type electrode in a drill-shaped form. Only the cutting edges were designed as they are actively participating in the process of stirring. The medium has to be water-tight, therefore a need for a container arises. It was designed as a container with thick walls that would incorporate the drill-shaped electrode (fig. 3).

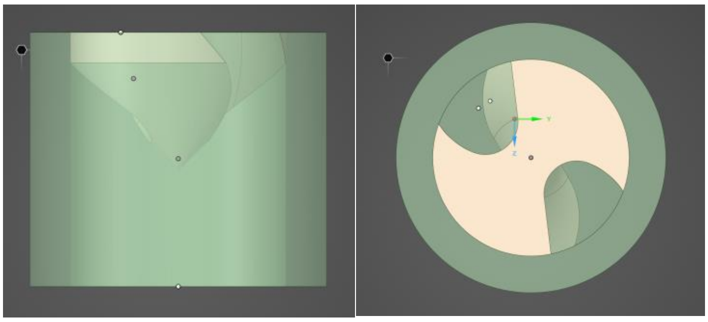

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Figure 3. 3D model for simulation of drill-shaped electrode performing hydrodynamic depassivation: a - front view; b - top view.

The next step is the assignation of materials to components. Both, the electrode and the container received a default structural steel type of material. The simulation aims to highlight the way active edges can direct the flow of liquid as the rod-type electrode operates. Thus, a standard liquid was assigned to the interior of the container as the main environment. The properties of the liquid are of interest only if the analysis moves forward towards a more intricate one performed in Fluent. A standard gravitational acceleration was also introduced. The inner wall of the container was set to a non-slip wall as no friction of particles is intended. A rotational movement of the drill was set to simulate the stirring of the liquid.
Results show that the simulation can predict the amount of total pressure exerted by the electrode in motion at a peak value of 4.59 MPa as can be observed in figure 4. The visual distribution was set to contours.

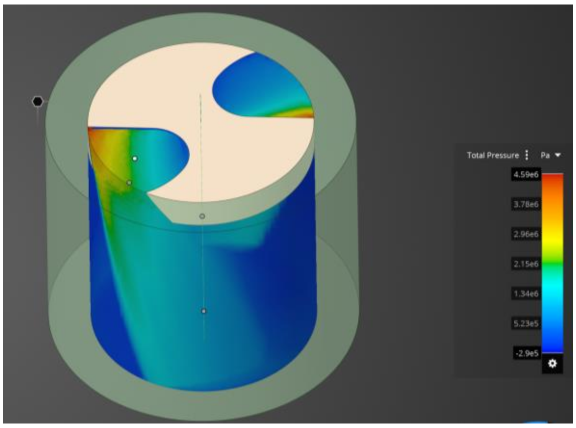

Figure 4. Total pressure visual distribution

It can also observe how the drill-shaped electrode is moving the volume of liquid along its cutting edges.
A better visualization of the entire process is obtained using vectors. Vortices appear as the electrode moves forward as can be seen in figure 5.

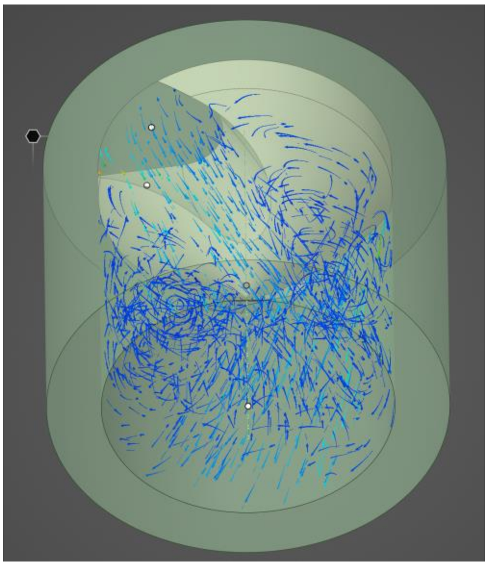

Figure 5. Visualization of vortices inside the stirred liquid.

The simulation also allows users to highlight only the way liquid reacts to cutting edges by suppressing results for the entire container filled with liquid thus making it possible for engineers to predict flow volume imposed by a certain feature (fig. 6).

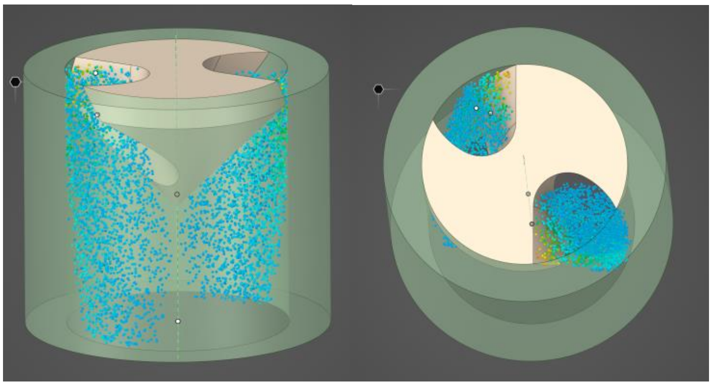

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Figure 6. Visualization of volume flow triggered by cutting edges: a - front view; b - inclined top view.

Future analyses may consider the transfer of the current setup to a more complex computational environment such as Ansys Fluent for accurate representations and better results.

4. EXPERIMENTAL SIMULATION OF HOW DEPASSIVATION WILL OCCUR WHEN USING A THIN CYLINDRICAL ROD TOOL ELECTRODE WITH HELICAL GROOVES

In experimental tests, several ways have been tried to capture the usefulness of the helical grooves of the thin rod electrode in the electrochemical cutting process.

The use of tubs or a container made of glass or transparent plastic materials was considered, which could facilitate the observation of the behavior of a liquid near the electrode in the form of a thin rod with helical grooves.

As an electrode, a helical drill with a diameter of 3.2 mm was used, and to achieve the rotation movement, direct current electric motors were used, which allowed changing the speed by varying the supply voltage. The power source was a type of transformer-rectifier group, intended to be used for charging car batteries. Such equipment allows obtaining continuous voltages up to 45 V, in variable steps, so that it is also possible to achieve low rotation speeds of the drill used to simulate the behavior of a thin cylindrical rod-type tool electrode with helical grooves.

The use of low rotation speed was considered, to avoid the liquid near the tool driven in rotational motion being quickly removed from the axis of the rod corresponding to the tool, under the action of centrifugal force.

The tool electrode role drill was located in a chuck attached to the main shaft of a Proxxon BFW 40/E-type drilling and milling machine, manufactured in Germany (fig. 7).

To observe the behavior of the liquid during the rotation of the drill bit (when it is not impressed with the feed movement along its axis, as happens when using the drill bit in the case of ordinary drilling), it was considered to use substances whose color would allow to be distinguished easily to the transparency of ordinary water, starting from the hypothesis that the displacement of these substances could make visible the displacement of the liquid when rotating the tool electrode in the form of a thin cylindrical rod materialized by the drill.

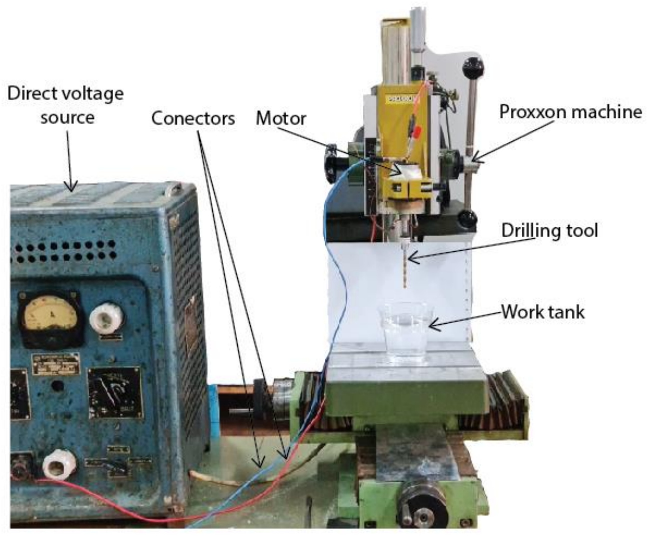

Figure 7. The equipment used to carry out the experimental research

Figure 8. Rapid dissipation of the aqueous solution of blue ink dropped with the pipette in the area near the driven drill in rotational motion

Thus, it was resorted to, first, introduce a few drops of oil using a pipette, the oils used to have a yellow or brown color. It was considered that oil has a lower density than water and will rise to the surface of the water. In the hypothesis that the oil would constitute a drop of partially spherical shape, it would have become possible to observe its behavior when the drill rotates inside the oil drop. It was found, however, that due to the probably rather low surface tension, the oil does not remain in the form of a drop, but spreads over the entire surface of the water, in the form of a thin layer, and it is not possible to follow any movement of the liquid mass near the drill which it rotates.

Another set of experimental trials considered the introduction of ink-colored water droplets near the drill (fig. 8). However, it was found that this aqueous ink solution dissipates relatively quickly into the mass of liquid in the tank, even before the bit rotation process is initiated.

Figure 9. Rotation of the drill bit and highlighting the introduction of a quantity of water without coffee granules by removing the coffee granules as a result of the rotation of the drill bit (diameter of the drill bit: 3.2 mm; speed of the drill bit: 30 rev/min)

Among several tests with different substances, a somewhat better result was obtained with ground coffee granules. In the first phase, these granules spread over the entire surface of the water in the tank. Now when the rotation of the drill was initiated, it was found that a removal of the ground coffee granules to the axis of the drill took place. It was estimated that this removal is due to a continuous bringing of water to the surface of the liquid in the tank, due to the action of the grooves in the rotating drill (fig. 9).

It was appreciated that in this way the hypothesis was confirmed, to a certain extent, according to which the rotation of a thin cylindrical rod-type tool electrode with helical grooves will cause an intensification of the circulation of the electrolyte in the case of an electrochemical cutting that will use such type of electrode.

5. CONCLUSIONS

One of the processes that allow the execution of some slits by electrochemical machining is that of cutting with the help of thin rod-type electrodes. Such a process belongs to the wider group of *wire electrochemical machining processes*.

The objective of the research, the results of which have been presented in this paper, was to confirm that when the thin rod tool electrode has helical grooves and is driven in a rotational movement around its axis, it will have there is an intensification of the circulation of the liquid (of the electrolyte, in the real case), so a more adequate development of the depassivation process. For this purpose, a simulation of the processes taking place near the thin rod tool electrode with helical grooves was first resorted to, using the finite element method. The application of the finite element method confirmed the fact that, from a theoretical point of view, there is a recirculation of the liquid located near the thin rod that has helical grooves, when the rod rotates in a certain direction. For the practical verification of the hypothesis that the liquid near the rod-type electrode with helical grooves driven in rotational motion will move in a certain way, various experimental solutions have been tried.

One of these solutions was based on the placement of ground coffee granules on the surface of the liquid. A small diameter drill bit was used as the tool electrode having helical grooves. It has been found that, when rotating the drill relatively slowly, a removal of the drill granules occurs, because of bringing in a quantity of water without coffee granules, through the action of the helical grooves. It was considered that, in this way, a confirmation of the originally formulated hypothesis took place. In the future, it is planned to continue the research related to the possibilities of demonstrating the recirculation of the liquid by a thin cylindrical rod with helical grooves, in rotational motion, a process by which the behavior of the electrolyte in wire electrochemical cutting is simulated, as well as the research in real conditions of a wire electrochemical cutting process.

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