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Fast Determination of the Material Removal Characteristics in Pulsed Electrochemical Machining

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Abstract

Electrochemical machining (ECM) of metallic materials is a complex manufacturing process. Currently the design of the process parameters and the cathode geometry is determined by expensive and inefficient experiments. This paper introduces a method for a fast determination of the material removal characteristics in pulsed electrochemical machining (PECM). The determination is performed by help of removal experiments using a PEMCenter 8000. As example the material removal characteristics of stainless steel 1.4301 under PECM conditions are shown. Based on the resulting mathematical description of the material removal characteristics a design of PECM processes by analytical calculations or multiphysics simulation is feasible.

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1. Introduction

The manufacturing process of ECM is based on the principle of anodic metal dissolution and enables processing of metallic materials regardless of their mechanical properties [1-4]. This makes it possible to process difficult to machine materials, since the removal behavior is influenced only by the chemical properties of the materials in combination with the applied electrolyte.

Currently it is a high challenge to describe material-specific removal when deducing the cathode geometry and the process parameters [5]. Thus, most users of ECM conduct extensive empirical test series as basis for designing the cathode geometry regarding the precise representation of geometrical shapes in workpieces and the machining process [6,7]. These test series are time-consuming and inefficient concerning the consumption of workpiece material and energy.

Therefore, this study presents a method to deduce the material-specific dissolution characteristics of materials by characterizing the material removal. The removal function is determined by systematic removal experiments using the ECM variant PECM.

The PECM process is characterized by an oscillating working distance and a pulse current. Due to these facts a higher stability as well as smaller working distance are achievable. [1,6]

2. Method

Certain research [5,6] showed that in ECM the description of the occurring working distance between anode and cathode is characterized by the effective material removal rate V_{eff}. Currently V_{eff} is determined by the mass removal m_a and the transported charge quantity Q according to equation 1 [1,5,8,9,10,11,12].

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$$V_{eff} = \frac{m_a}{Q \cdot \rho} \quad (1)$$

In order to determine the removal mass m_a, the anode has to be weighed before and after every experiment. This method of weighing is time-consuming.

Using the dissolution rate in z-direction v_a and current density J, V_{eff} can be determined faster. Equation 2 shows this connection resulting from Faraday's law.

$$V_{eff} = \frac{v_a(J)}{J} \quad (2)$$

Since the material-specific dissolution rate in z-direction v_a is not directly available as a measured variable, it was reproduced onto the feed rate v_f of the cathode in the desired characterization of the material removal.

For PECM the feed rate is superimposed with an oscillation of the cathode. As shown in figure 1, the applied pulsed current is only triggered on the bottom dead center of the oscillation during processing. Thus, the dissolution takes place with a minimum working distance. This pulsed current is characterized by the duty cycle c which is identified by the frequency f_p and by the pulse on time t_{on}.

$$c = f_p \cdot t_{on} \quad (3)$$

Due to the pulsed current the dissolution rate in z-direction v_a takes place in the pulse on time and stop in the pulse off time. In contrast the cathode has also a feed rate during pulse off time. Therefore the feed rate v_f and dissolution rate in z-direction are only equal on average. Considering the pulsed current the prerequisite of an equilibrium distance is according to equation 4.

$$v_f = v_a(J) \cdot c \quad (4)$$

Considering the duty cycle, the resulting V_{eff} for PECM is defined as follows:

$$V_{eff} = \frac{v_f(J)}{J \cdot c} \quad (5)$$

In order to explicitly relate the transported charge Q to the prevailing current density J, a constant current I_{max} over process time t_{Proc} is required as well as a constant removal surface A_a. Consequently, a selected feed rate has to be constant during a removal experiment.

Furthermore, a homogeneous current density is required for the investigated working distance s. Thus material removal shall be reduced to front face removal so that only a front working distance s_F results. When considering these determinations, the current density J can be calculated by the process current I_{max} and the transported charge Q can be calculated by the trend of the process current $I = f(t_{\text{Proc}})$.

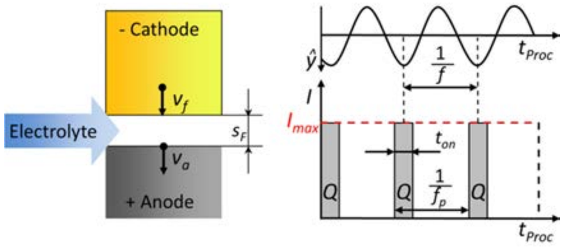

Fig. 1. Schematic representation of removal concept (left) and required current characteristic $I = f(t_{Proc})$ during process (right)

Figure 1 (left-hand side) shows the concept of an EC process with front face removal and transverse flushing.

3. Experimental Setup

The removal device derived from the preliminary considerations was designed to be used in the EC manufacturing machine PEMCenter 8000. Using this removal device it is possible to determine the dissolution characteristic of cylindrical specimens. Figure 2 presents a cross-section of the removal device.

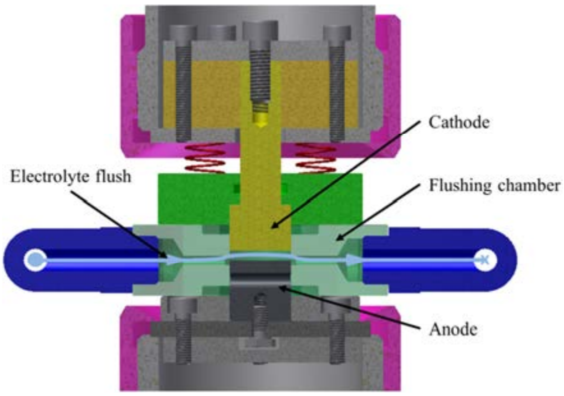

Fig. 2. Sectional representation of removal device with shown flushing direction of the electrolyte

Figure 2 shows the removal device with a cathode (yellow) and an anode (gray) with identical diameter and surface area. The flushing chamber allows for electrolyte flow to provide material removal preventing slag formation.

During the performance of experiments under PECM conditions, the process parameters are measured such as electrical current, characteristic parameters of the electrolyte and the final working distance.

4. Design of Experiments

Several process parameters were kept constant throughout the investigations. These process parameters are summarized in Table 1. Stainless steel 1.4301 was selected to demonstrate the fast determination of the material removal characteristics in PECM. Its specific removal volume V_{sp} was calculated of $2.33 \cdot 10^{-5}$ cm³/C. A solution of $NaNO_3$ with a salt content of