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Analysis of Reactions Determining Current Efficiency in Electrochemical Machining

Garg Mayank[a], Chu Fuchen[a], Kunieda Masanori[a]*

[a]*The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8654, Japan*

* Corresponding author. Tel.: +81-3-5841-6462; fax: +81-3-5841-1952. *E-mail address:* kunieda@edm.t.u-tokyo.ac.jp

Abstract

In electrochemical machining (ECM), it is widely accepted that the current efficiency of NaCl is 100% and is independent of pulse duration. Moreover, it is also known that the current efficiency of $NaNO_3$ is not 100%. It was found in the experiments that the current efficiency using both the electrolytes depended upon the pulse duration and in case of NaCl, it reduced as the pulse duration was shortened. In this study, the reason for the above behaviour of the electrolytes is investigated. For that, transparent electrodes like semi-conductor Ga_2O_3 wafer were utilized to observe the inter-electrode gap phenomenon while machining. The gas generated was also collected and analysed by gas chromatography to know the reactions occurring in the gap. Finally, simulation was performed considering ion transport equations and reactions to verify the theory. The suppression of oxygen generation on anode as the pulse duration was increased was found to be the main reason why the current efficiency increased with the pulse duration.

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Keywords: Electrochemical machining, gas chromatography, simulation

1. Introduction

Electrochemical machining (ECM) is a non-traditional manufacturing process belonging to the electrochemical category. It has a lot of advantages such as machining without any burr or crack, no heat affected layer, no tool wear etc. It can be used to machine most of the conductive materials regardless of their hardness, as the metal is removed by electrochemical dissolution.

In ECM, on cathode, hydrogen gas is generated. On the other hand, apart from metal dissolution, gas generation also proceeds in parallel at anode. Gas (oxygen, chlorine etc.) generation at anode consumes part of the machining current and reduces the current efficiency of ECM. Since, it plays an important role in the process, its analysis is necessary.

Chikamori et al. [1] conducted a stoichiometric investigation with gas chromatography to check the influence of current density on the electrochemically machined products. However, they did not investigate the influence of the pulse duration. Van Damme et al. [2] developed a numerical model to predict the current efficiency during pulse electrochemical machining of steel in $NaNO_3$. They presented the relationship between current efficiency, current density and pulse duration. However, another kind of neutral electrolyte is widely used in ECM i.e. NaCl. It is widely accepted that the current efficiency in it is nearly 100% and is independent of pulse duration and current density. Few researches have been done to investigate the relationship using NaCl.

So, the purpose of this study is to investigate whether it is true or not that current efficiency of NaCl is 100% and independent of pulse duration. Moreover, to investigate the influence of the pulse duration on the gaseous products with NaCl and $NaNO_3$ electrolytes, gas chromatography experiments were performed.

It was found through the experiments that the current efficiency decreased as the pulse duration was shortened in both the electrolytes. Through the observation of inter-electrode gap, it was found that the suppression of oxygen gas generation was taking place at anode. So, it was thought to be

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one of the reasons why current efficiency increased with pulse duration. To verify the results, simulation was performed considering ion transport equations and reactions

2. Observation of ECM gap

To check whether there is any gas generation at anode surface when NaCl electrolyte is used, observation of ECM gap was performed using a transparent electrode Ga_2O_3 as shown in Fig. 1. The machining conditions and high speed camera settings to observe the gap are shown in Table 1.

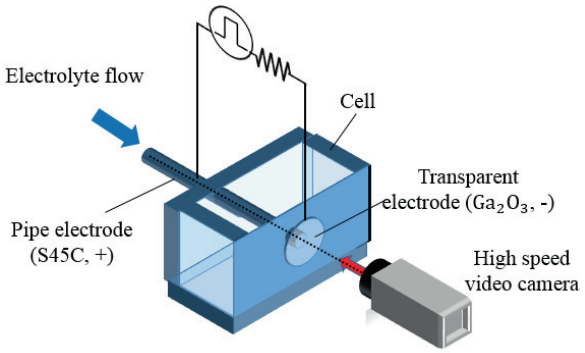

Fig. 1. ECM gap observation set-up

Table 1. Experiment conditions

Parameters	Values
Gap width	50 µm
Machining current	5 A
Flow rate	4.5 ml/s
Electrolyte	NaCl 5% wt.
Pulse duration	10 ms
Pulse interval	50 ms
Resolution	640 x 640 pixels
Frame rate	20,000 fps
Objective lens magnification	10

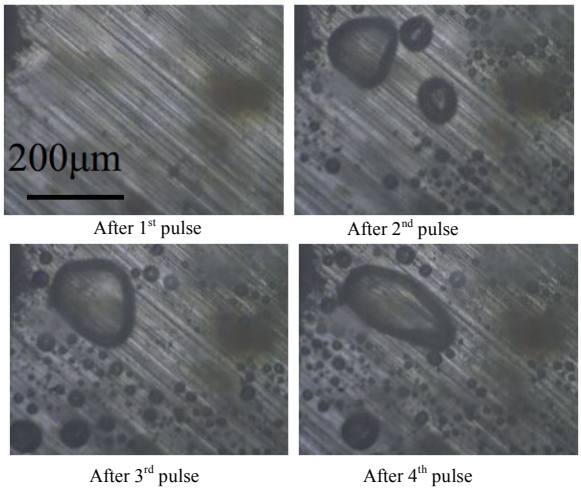

Fig. 2. Observation results

The results of observation are shown in Fig. 2. During the initial two pulses, large amount of bubbles were observed to be generated from the surface of anode. However, from the third pulse, the generation rate of bubbles decreased significantly. The generation of bubbles even stopped during the following pulses.

3. Gas chromatography

From the observation of gap, it was found that bubbles generated from the anode surface in case of NaCl electrolyte as well. However, in the observation of gap, transparent electrode Ga_2O_3 was utilized, because of which the results might differ from the practical applications because of different cathode material. So, to check the composition of gases in practical ECM, the gas chromatography experiments were performed. Moreover, the experiments were performed under $NaNO_3$-electrolyte as well for comparison.

The experimental set up for gas chromatography is shown in Fig. 3. The electrodes were inserted in a sealed cell and ECM was conducted at the bottom of the cell. The generated gaseous products accumulated at the top. The sample was taken from the sampling port and was analyzed. Constant current settings were again used to keep the current density constant. The machining conditions and gas chromatography conditions are shown in Table 2.

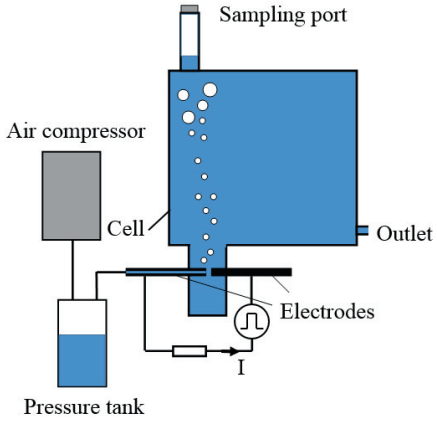

Fig. 3. Gas chromatography set-up

Table 2. Machining and gas chromatography conditions

Parameters	Values
Current density	20 A/cm^2
Machining current	5 A
Pulse duration	0.5, 1, 10, 100 ms, DC
Total machining time	90 s
Carrier gas	Argon
Carrier gas flow rate	20 ml/min
Column temperature	35° C
Detector temperature	80° C
Analysis time	10 min