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Influence of tool material and electrolyte on characteristics of Wire ECM with raised low-level voltage

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Abstract

In this paper, the influences of the diameter and the material of the tool electrode, and the kind of electrolyte on the machining characteristics were experimentally investigated in the case of wire-ECM with a raised low-level voltage. The optimal pulse waveform for preventing the tool electrode wear, as well as improving machining accuracy was also investigated. As the results, the following conclusions were obtained. (1) A raised low-level voltage not only prevents the tool electrode wear, but also improves the machining speed regardless of the kind of materials. (2) The electrode diameter and material have influence on the machining accuracy because of electric resistance.

Key words: Electrochemical machining, pulse voltage, tool wear, machining accuracy

1. Introduction

In wire ECM, the workpiece is cut by a thin wire as the tool electrode, and it is possible to realize the micro machining with a pulse power supply. Although tool wear occurs when the pulse supply is used, Terada et al. [1] reported that a raised low-level voltage of the pulse supply is effective to prevent the tool wear. In addition, Yamaguchi et al. [2] tried to elucidate the reason for improvement of the machining accuracy with pulse supply through multi-physics simulation. However, under various machining conditions, there are many unclear points about the influence of the low-level voltage on the machining accuracy and machining speed.

In this research, the influence of tool conditions, the kind of electrolyte and the low-level voltage on the machining characteristics was experimentally investigated.

2. Process principle and experimental method

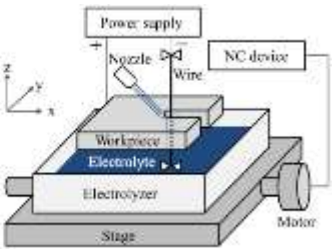


Figure 1. Schematic of experimental device

The schematic of the experimental device is shown in Figure 1. A sheet workpiece is cut by feeding the workpiece in the +x direction. The gap-width between the wire electrode and the sidewall of the machined groove is defined as the side-gap width (equation (1)). The smaller the side-gap width is, the higher the machining accuracy becomes.

$$\delta = (w - d) / 2 \qquad (1)$$

where, δ is the side-gap width, w is the groove width and d is the wire electrode diameter.

The waveform of the pulse voltage used in the experiment is shown in Figure 2. The value of the higher portion of applied pulse voltage is called the high-level voltage (V_H) and that of the lower portion is called the low-level voltage (V_L).

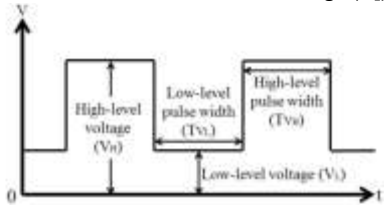


Figure 2. Waveform and definition of applied voltage

3. The influence of tool diameter and tool materials

In order to investigate the influence of tool diameter and tool material on the machining accuracy, tool electrodes made of two different materials with two different diameters were used in experiments. The tool materials are tungsten (W) which tolerates higher wire tension, and titanium (Ti) which is of lower wear in ECM. In of these experiments only machining accuracy was evaluated. The parameters of the pulse waveform are shown in Table 1, and the main experimental conditions are listed in Table 2.

Table 1 Applied pulse conditions

High-level voltage	10 V
Low-level voltage	2 V
High-level pulse width	100 μs
Low-level pulse width	100 μs
Pulse rise/fall time	7 ns
Duty ratio	50%

Table 2 Experimental conditions

Tool	W and Ti (ϕ100 and ϕ50 μm)
Workpiece	Fe (t 100 μm)
Electrolyte	$NaNO_3$ aq 10 wt%
Initial position	20 μm from side of workpiece
Tool feed rate	50 μm/min
Tool feed amount	820 μm

The experimentally obtained side-gap width is shown in Figure 3. The figure shows that the side-gap width increases with the tool diameter. When the tool diameter increases from ϕ50 μm to ϕ100 μm, the increase ratio of side-gap width for W electrode is about 1.4 times, while that for Ti electrode is about 2.4 times.

The reason for the different increasing ratio for different tool material is thought to be caused by the electric resistance. To confirm this consideration, we measured the current value during the period of applying high-level voltage. As shown in Figure 4, when the diameter is changed from ϕ50 μm to ϕ100 μm, the current increasing amount in the case of W electrode is approximately 4 %, while that in the case of Ti electrode is approximately 50 %. Since the electric resistivity of Ti material is 55 μΩ・cm, ten times higher than that of W material [3], the change in current with the electrode diameter is larger in the case to Ti electrode. Because of the higher electric resistance of Ti material, the current is smaller, and thus the removal amount and the side-gap width become smaller when the Ti electrode is used (see Figure 4), comparing to the W electrode. Also, Ti electrode has stronger influence of the change in the electrode diameter on the side-gap width than W electrode.

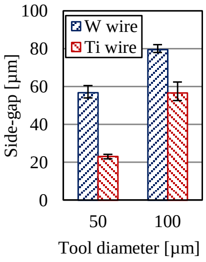


Figure 3. Side-gap with for different tool material and diameter

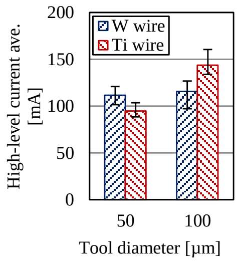


Figure 4. Relationship between tool material and high-level current

4. The influence of electrolyte and low-level voltage

In order to investigate the influence of electrolyte and low-level voltage on the machining characteristics, sodium chloride solution (NaCl aq) and sodium nitrate solution ($NaNO_3$ aq) were used in experiments, while the low-level voltage was changed in the range of 0 to 5 V. A ϕ50 μm W wire is used for the tool electrode. The other parameters of the pulse waveform and the main conditions are the same as shown in Tables 1 and 2.

The experimentally obtained machining states for different conditions are summarized in Table 3. In the table, the symbol "○" means the machining can be successfully carried out, "×" means the tool wear occurs, and "△" means that the edge of the cut groove is serrated, although the machining can be carried out. The photos of machined grooves under some conditions are shown in Figure 5, and the low-level current under each condition is shown in Figure 6.

As shown in Figure 5, the machining accuracy is worse in the case of using NaCl aq because the groove becomes very broad, comparing to the case of using $NaNO_3$ aq. The reason for this difference is thought to be caused by the current efficiency. That is, the current efficiency of $NaNO_3$ aq becomes very small in the low current density area, while current efficiency of NaCl aq is approximately 100 % regardless of current density [4]. Accordingly, machining occurs even in the low current density area and the groove becomes very broad, in the case NaCl aq.

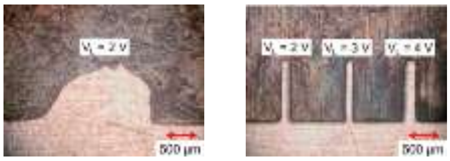
As shown in Table 3 and Figure 6, large reverse current (the negative current value) flows in the case of using $NaNO_3$ aq and low-level voltage 0, 1 V, and the tool wear occurs. Figure 6 shows that the reverse current for $NaNO_3$ aq is larger than that for NaCl aq, and the reverse current becomes smaller and finally disappears with the increase in the low-level voltage. Comparing Table 3 and Figure, 6 we can say that the reverse current is the cause of the tool wear, and the tool wear occurs when the reverse current is larger than a certain value.

From the above results, it is known that raising the low-level voltage is an effectual way to eliminate the tool wear in pulse ECM. However, if the low-voltage is higher than 4 V in the case of $NaNO_3$ aq and 2 V in the case of NaCl aq, the edge of the cut groove becomes irregularly serrated and the machining accuracy decreases. Also, Figure 5 shows that the side-gap width is smallest which means the highest machining accuracy is obtained under low-level voltage 3 V in the case of $NaNO_3$ aq. Based on the above experimental results and discussions, it can be concluded that a certain raised low-level voltage is effective not only to eliminate tool wear but also to improve the machining accuracy.

Table 3 Machining state under different conditions

	Low-level voltage [V]					
	0	1	2	3	4	5
NaCl aq	○	○	△	△	△	△
$NaNO_3$ aq	×	×	○	○	△	△

○: Could be machining ×: Tool wore
△: The edges was serrated



(a) NaCl aq (b) $NaNO_3$ aq
Figure 5. Machined grooves

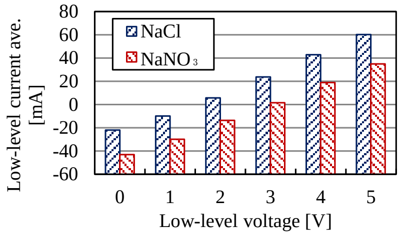


Figure 6. Low-level current under different tool diameter and low-level voltage

5. Conclusions

In this study, the influence of tool conditions, the electrolyte and the low-level voltage were experimentally investigated. It was found that machining accuracy is changed by the tool material and tool diameter. It was considered that the electric resistivity of tool is one of the factors. On the other hand, it was found that machining characteristics is changed by the value of low-level voltage, and a suitable low-level voltage improves the machining accuracy while preventing tool wear.

Acknowledgements
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