Precision Engineering 47 (2017) 480–486

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Micro electrical discharge machining using high electric resistance electrodes

Tomohiro Koyano[a,*], Yuki Sugata[b], Akira Hosokawa[a], Tatsuaki Furumoto[a]

[a] Institute of Science and Engineering, Kanazawa University, Kakuma-machi, Kanazawa, 920-1192, Japan
[b] Graduate school of National Science and Engineering, Kanazawa University, Kakuma-machi, Kanazawa, 920-1192, Japan

ARTICLE INFO

Article history:
Received 6 April 2016
Received in revised form 2 September 2016
Accepted 30 September 2016
Available online 25 October 2016

Keywords:
Electrical discharge machining
Miniaturization
High electric resistance materials
Discharge crater
Surface roughness

ABSTRACT

In micro electrical discharge machining (EDM), because the material removal per single pulse discharge mainly determines the minimum machinable size of a micro EDM, decreasing the material removal per single pulse discharge is important. In this study, in order to decrease the material removal per single pulse discharge, high electric resistance materials such as single-crystal silicon are used for electrodes. Analytical results show that when the electrode resistance increases, the peak value of the discharge current decreases, whereas the pulse duration increases. In addition, the discharge energy decreases when increasing the resistance. Silicon is used as a tool electrode, and the effect of resistivity of the silicon tool electrode on the diameter of discharge craters generated on the stainless steel workpiece is examined. Experimental results reveal that with increasing silicon electrode resistivity, the diameter of discharge craters decreases. Because the diameter of discharge craters can be decreased to 0.5 μm, improved finished surfaces of R_z 0.03 μm are obtained.

1. Introduction

In micro electrical discharge machining (EDM), because the material removal per single pulse discharge (or the diameter of discharge craters) determines the minimum machinable size or the roughness of the machined surface of a micro EDM, decreasing the material removal per single pulse discharge is important. Typically, the diameter of discharge craters is determined by the discharge energy. In a relaxation-type pulse generator typically used for micro EDM, because the energy stored in the capacitance of discharge circuit is discharged when the dielectric breakdown occurs, the minimum discharge energy is mainly determined by the stray capacitance of the discharge circuit [1]. This stray capacitance is formed between two of several possible components: for example, between the tool electrode and workpiece, the tool electrode holder and workpiece, or between electric feeders, and so on. Then, the minimum value of the stray capacitance is determined by the machining equipment and is thus limited. Kunieda et al. [2] minimized discharge energy by reducing the influence of the stray capacitance using the electrostatic induction feeding method. This method made it possible to decrease the diameter of the discharge craters to 0.43 μm, and then the surface roughness of R_z 0.23 μm was obtained. In addition, the minimum machinable diameter of the micro rod was decreased to 0.8 μm [3]. Egashira et al. [4] miniaturized the discharge energy by using low open-circuit voltage under 20 V, and a micro rod with a diameter of 1 μm was obtained. However, because decrease of the open-circuit voltage causes difficulty of dielectric breakdown to occur, the material removal rate diminishes.

Uno et al. [5] investigated the machining characteristics of single crystal silicon in normal sinking EDM, and they reported that the diameter of a discharge crater was smaller with a higher resistivity silicon workpiece because of the decrease of the discharge current. Mohri et al. [6] used single crystal silicon as a tool electrode for machining a large workpiece, and they obtained a glossy surface because the discharge current that flows from the stray capacitance formed between the workpiece surface and electrode decreased as a result of the resistivity of the tool electrode.

From these results, it is expected that when high electric resistance materials are used for the workpiece or tool electrode, the discharge current flowing from the stray capacitance is limited. In addition, material removal per single pulse discharge of a micro EDM can be decreased. In this study, to reduce the material removal per single pulse discharge in a micro EDM, high electric resistance

---

* Corresponding author.
E-mail address: koyano@se.kanazawa-u.ac.jp (T. Koyano).

http://dx.doi.org/10.1016/j.precisioneng.2016.10.003

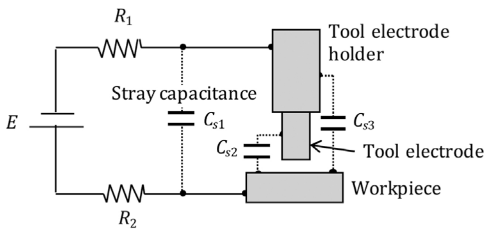


Fig. 1. Discharge circuit.

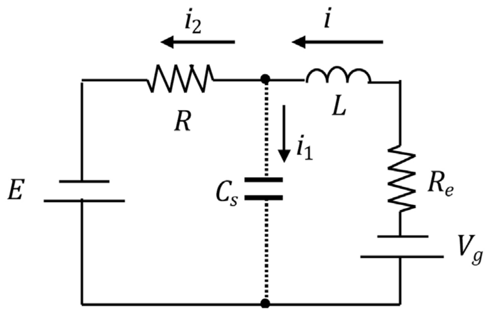


Fig. 2. Equivalent circuit.

Table 1
Analysis conditions.

Voltage of power supply E [V]	60
Resistance R [Ω]	3000
Stray capacitance C_s [pF]	6.1
Inductance L [μH]	0.29
Discharge voltage V_g [V]	20
Resistance of electrode R_e [Ω]	0.1 ∼ 200

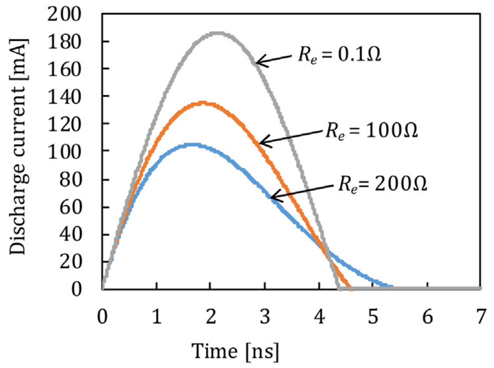
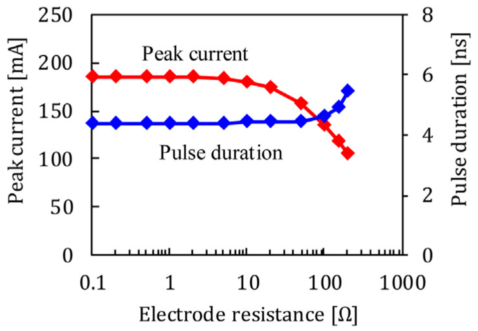
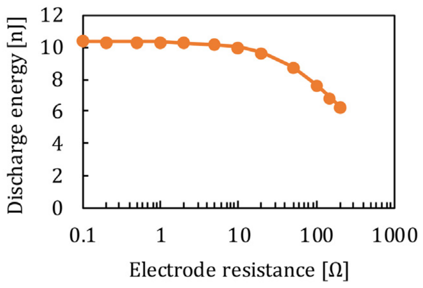


Fig. 3. Influence of resistance of electrode.



(a) Peak discharge current and pulse duration



(b) Discharge energy

Fig. 4. Influence of resistance of electrode on discharge current and discharge energy.

materials such as single-crystal silicon are used as electrodes. In this study, the theoretical analysis of discharge circuit was conducted to determine the effect of electrode resistance on discharge current, and the discharge current was then measured using silicon as the electrode. Silicon was used as the tool electrode, and the effect of resistivity of the silicon tool electrode on the diameter of discharge craters generated on the workpiece was examined. In addition, the roughness of the machined surface by a silicon tool electrode was investigated.

2. Equivalent circuit analysis

2.1. Equivalent circuit

A theoretical analysis of discharge current is conducted to examine the effect of electrode resistivity. Fig. 1 shows the relaxation-type pulse generator. The stray capacitance C_{s1}, C_{s2}, and C_{s3} were formed in the discharge circuit. In fact, both the stray capacitance and inductance are distributed in the discharge circuit. However, for simplicity, a modified equivalent circuit shown in Fig. 2 was used. C_s is the stray capacitance, and L is the inductance. The resistance R_e is the resistance of silicon electrode which is used as the workpiece or tool electrode. In both cases, the same equivalent circuit can be used. From the equivalent circuit, the following equations can be derived:

$$E + \frac{1}{C_s}\int i_1 dt - Ri_2 = 0 \tag{1}$$

$$\frac{1}{C_s}\int i_1 dt + L\frac{di}{dt} + R_e i + V_g = 0 \tag{2}$$

$$i = i_1 + i_2 \tag{3}$$

where i, i_1, and i_2 are current and V_g is the discharge voltage. By means of (1)–(3), the discharge current i that flows through the machining gap was calculated using the finite difference method, and the effect of the resistance R_e on the discharge current was investigated. Analytical conditions are shown in Table 1. It was assumed that the capacitor is charged to the full voltage of the power supply before the discharge occurred. The inductance L and stray capacitance C_s were determined in such a manner that the theoretical results of the discharge current nearly coincide with the experimental results when using the stainless steel workpiece and a tungsten tool electrode as described in Section 3.

2.2. Analytical results

Fig. 3 shows the calculated discharge current waveforms. When the electrode resistance R_e increases, the peak value of the discharge current decreases, whereas the pulse duration increases. Fig. 4(a) shows the relation between the peak discharge current