

Comparison of material removal in micro and conventional EDM

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Abstract

Micro-electrical discharge machining is an evolution of conventional EDM used for fabricating three-dimensional complex micro-components and microstructure with high precision capabilities. However, due to the stochastic nature of the process, it has not been fully understood. In this study, alternating machining parameters and thus various discharge energies were used in experiments to compare anode, cathode and total material removal rate (MRR) as well as MRR ratio between anode and cathode. The discharge energies were relatively low as used in micro EDM and relatively high as used in conventional EDM. It was found that the quotient between anode and cathode MRR significantly changes when machining with micro and conventional EDM parameters.

Keywords: EDM, micro technology, electrode, material removal rate, wear mechanism.

1 Introduction

In conventional electrical discharge machining (EDM), it is generally accepted that the main removal mechanism is based on a thermal conduction process [1,2,3,4]. Similar thermal models are used also in micro EDM to describe the MRR [5,6], but some authors emphasise that there is a difference when machining with discharge energies below certain value.

Wong *et al.* [7] found that at lower-energy (<50 μJ) discharges, the energy required to remove the unit volume of material, defined as the specific energy, is found to be much less than that at higher-energy discharges. Additionally, the ratio of the standard deviation to the measured microcrater size is found to be lower at lower discharge energy, indicating greater consistency in shape and size when the discharge occurs at lower energy. The fundamental erosion mechanism of material is discussed by considering melting and evaporation phenomena using theoretical modeling. The average efficiency of erosion, when estimated to be due primarily to melting or evaporation alone, is found to be up to an order of magnitude higher at lower-energy discharges than that at higher-energy discharges.

For machining with energies below 100 μJ , Tsai *et al.* [8] found that the boiling point of the electrode material plays an important role in the wear mechanism. They introduced a new function where the latent heats are taken into account as a modified type of the temperatures. Their experimental data obtained in micro EDM performance shows strong correlation with this new index. Ivanov *et al.* [9] proposed a simple

thermal model of material removal also based on latent heats. They assumed that in micro EDM the removal mechanism is only due to vaporisation. In the case of the same anode and cathode material, the volumetric ratio of material removed on anode and cathode equals to the ratio of the energy transferred to anode and cathode. Experiments with the same anode and cathode materials showed that the ratio of anode/cathode material removal depends on anode/cathode material [9,10]. Furthermore, equal wear ratio variations for different materials showed that the material removal phenomenon was the same for all the materials. But is the removal phenomena the same in the case of various discharge energies?

In this paper, MRR on anode and cathode were examined where copper was used as anode and cathode material. Alternating machining parameters and thus various discharge energies were used in experiments to compare anode, cathode and total MRR as well as MRR ratio between anode and cathode obtained at relatively low discharge energies as used in micro EDM and relatively high discharge energies as used in conventional EDM.

2 Experimental setup

The experiments were performed on a IT E 200M-E machine with isoenergetic generator. Anode and cathode material was electrolytic copper to avoid any influence of material irregularities. The dielectric was Erozol 25, which is suitable for all machining regimes. Rod electrodes of 5 mm diameter were used. Anode and cathode were weighted before and after each experiment as well

as the time of machining was recorded. The MRR was calculated from these data. Since very low discharge energies were used, the time needed for each experiment was around 72 hours in order to achieve a significant mass reduction of anode and cathode. During all experiments, a good flushing of the gap between anode and cathode was achieved by selection of equally shaped electrodes, external flushing of the gap and by employing periodical jump of the electrode.

Machining parameters used in experiments were selected based on experiences and literature review in section 1 and they are summarised in Table 1.

Table 1 Machining parameters

Machining parameters	Experiment No.				
	1	2	3	4, 5	6, 7
Ignition voltage [V]	180	180	180	180	280
Discharge current [A]	0.6	0.6	0.6	2.6	3.6
Pulse on [μ s]	2	8	8	2	45
Pulse off [μ s]	8	25	8	8	16
Discharge voltage [V]	18	18	18	18	18
Discharge energy [μ J]	20	80	80	84	3000

Experiments were carried out in order to examine MRR ratios between anode and cathode at various machining parameters that define discharge energies (Eq. 1) as given in Table 1. Discharge energies were selected according to the findings presented in section 1, i.e. below 50 μ J, between 50 and 100 μ J and above 100 μ J. Further on, suitable machining parameters were selected to achieve the specified discharge energies. Note that some of the discharge energies were obtained with different sets of machining parameters in order to test the influence of various parameters on anode/cathode MRR ratio.

$$\text{Energy} = \frac{\text{discharge}}{\text{current}} * \frac{\text{discharge}}{\text{voltage}} * \frac{\text{pulse}}{\text{on}} \quad (1)$$

The experimental results were measured through the following parameters:

- MRR on anode: $MRR_{anode} = m_{anode} / t$,
- MRR on cathode: $MRR_{cathode} = m_{cathode} / t$,

- Total MRR that is sum of anode and cathode MRR: $MRR_{total} = MRR_{anode} + MRR_{cathode}$,
- $\Pi = MRR_{anode} / MRR_{cathode}$.

Machining time is denoted as t and mass of the removed material on anode and cathode is marked as m_{anode} and $m_{cathode}$ respectively.

Additionally, voltage signals were acquired during the experiments to get the information about discharges at different discharge energies.

3 Results

Total MRR strongly depends on the discharge energy. As expected, higher the discharge energy higher the total MRR (Figure 1). But for the energies below 100 μ J (experiments 1 to 5) the MRR is not significantly different.

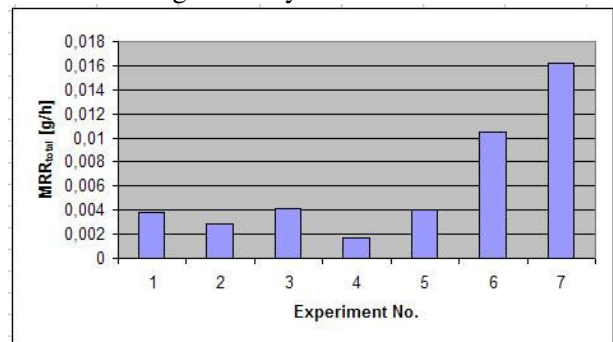


Figure 1 Total MRR for each experiment

The MRR on anode and cathode depends on the discharge energy (Figure 2). The MRR ratio when machining with discharge energies lower than 100 μ J (tests 1 to 5) is bigger than 1 (MRR is greater on cathode) whereas higher discharge energies (tests 6 and 7) causes greater MRR on anode and the MRR ratio drops below 1 (Figure 3). The discharges on voltage signals were acquired when machining with discharge energies below and above 100 μ J. The difference in shape of discharges could be due to the pulse generator or gap conditions and it is reflected in the MRR ratio.

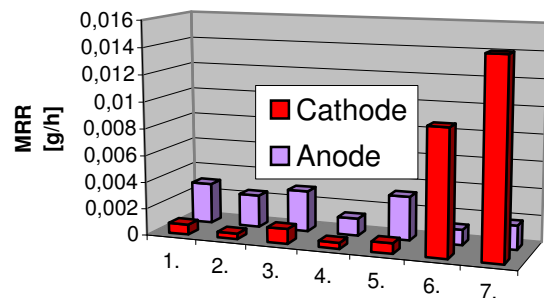


Figure 2 MRR on anode and cathode for experiments 1 to 7

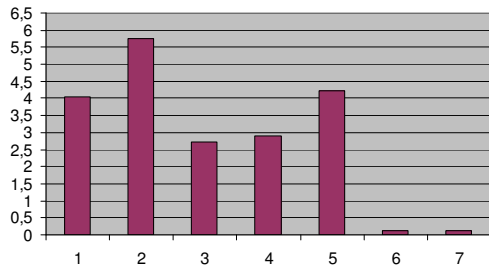


Figure 3 MRR ratio between anode and cathode (II)

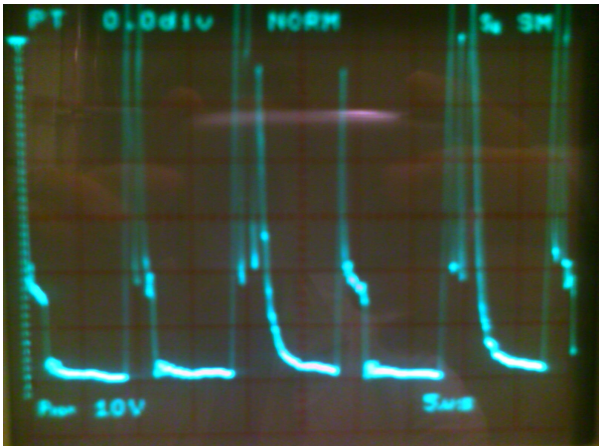


Figure 4 Discharges on voltage signal at discharge energy 80 μ J

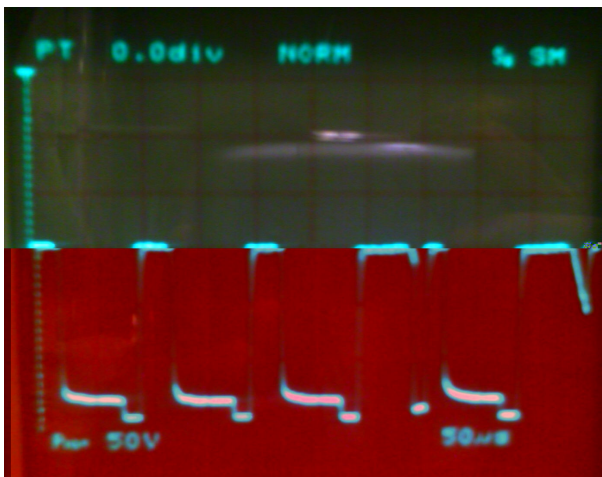


Figure 5 Discharges on voltage signal at discharge energy 3000 μ J

In experiment No. 2, where pause between discharges (pulse off time) was 3 times longer in comparison to experiment No. 3, a higher MRR ratio between anode and cathode is noticed (Figure 3). It could be due to more stable machining caused by longer pauses between discharges.

4 Conclusions and future work

According to the presented results, the following conclusions can be drawn:

- Measuring of MRR results in micro EDM is rather difficult due to really low MRR. To reduce disturbances in weighting of the electrodes, the experiments have to last for a long time and thus they are time consuming. Alternative method for MRR measuring should be applied.
- When both anode and cathode materials are copper anode has higher MRR in the case of low discharge energy values whereas in the case of conventional EDM higher MRR is noticed on cathode. This could be due to different phenomena in material removal mechanism, but it is also possible due to the effect of longer discharge time.
- Thus, additional research should be carried out in order to investigate influences of individual machining parameters on the material removal in micro EDM process.

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