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Investigation of the Fundamentals of Tool Electrode Wear in Dry EDM

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Abstract

The fundamentals of the tool wear in dry electrical discharge machining (DEDM) were investigated by plasma optical emission spectroscopy. Interpretation of the spectral lines suggests that single DEDM discharges with point-type cathode tool (Cu) and anode workpiece (Al) present characteristics of hot anode vacuum arcs (HAVA). The anode is active and the cathode is passive in a HAVA, which is probably the main reason for the relatively large workpiece erosion and very small tool wear reported for DEDM in the literature. The plasma characteristics change substantially inverting the electrodes polarity, thereby both electrodes have an active role in the discharge.

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Keywords: Electrical discharge machining (EDM); wear; mechanism; optical emission spectroscopy; plasma in microgaps

1. Introduction

Electrical discharge machining (EDM) is a well-established manufacturing process, widely applied in production of dies and moulds. EDM commonly works with de-ionized water or oil dielectric media, depending on the application.

The research effort in dry electrical discharge machining (DEDM) has increased during the last years due to its much better environmental conditions and process strengths. Depending on the process application, DEDM is able to provide higher material removal rates, better surface roughness, lower tool electrodes wear and less heat-affected zones on the workpiece surface than EDM in liquid dielectric, as shown by Kunieda et al. (2003) [1]. Moreover, he infers that the greatest advantage of DEDM is the very low wear of the tool electrode, which is independent of electrical discharge pulse duration. This result has been reported with the tool as cathode and the workpiece as anode, which leads to higher material removal rates and lower tool wear ratio.

Further development of the DEDM technology depends on the elucidation of the physical phenomena involved in this process. According to Li et al. (2004) [2], stronger energy is absorbed by the anode electrode than by the cathode electrode in DEDM. However, the mechanisms of the discharge energy distribution over the electrodes are not properly explained yet.

The open voltages (U_{open}) applied in DEDM are normally lower than the gaseous dielectric strength. Roth et al. (2012) [3] proposed that the discharges under this condition are triggered by a mechanism similar to a vacuum breakdown in gaps smaller than 5 µm. Ion-enhanced field emissions take place in such small gaps, as reported by Klas et al. (2011) [4]. It occurs due to the high electric fields combined with lowering of the potential barrier seen by the electrons in the cathode as ions approach. Thus, the electron emission process depends primarily on the electric field (E) rather than on its relation with the density of neutral particles in the gap (E/N).

According to Timko et al. (2010) [5], vacuum discharge plasmas develop first by building-up a density of neutral particles in the gap. Whereas neutrals slowly fill the gap, charged particles leave the system quickly, accelerated by the high electric field. The avalanche of ionization starts when the neutral density reaches a critical value. The increased ion flux results in further sputtering or evaporation, creating even more neutrals. The coupled phenomena of evaporation, sputtering, ion flux and erosion are the sustaining mechanism for the discharge. The electrode erosion mainly occurs due to the bombardment of its surface by charged particles passing through micro electrical discharge plasmas. Thus, the understanding of the fundamental properties of microplasmas is necessary to explain the erosion mechanisms in DEDM.

The aim of the present work is the investigation of the tool electrode wear fundamentals in DEDM under different

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electrode polarities. Electrical discharge plasmas are characterized by optical emission spectroscopy and electrical parameter analysis. The results are associated to the tool electrode wear reported in the literature.

Nomenclature

U_{open}	Open voltage [V]
I	Current [A]
t	Pulse duration [µs]
E	Electric field [$V.m^{-1}$]
N	Density of neutral particles [cm^{-3}]
T	Plasma temperature [K]
N_e	Density of electrons [cm^{-3}]
λ	Wavelength (nm)

2. Materials and methods

The experimental setup for discharge generation consists out of a Form 1000 EDM Agie machine, adapted to perform single electrical discharges. Electrical data from the sparks were acquired and measured by a LeCroy Wave Runner 44MXi-A oscilloscope.

Light optical emission spectroscopy was performed using an Acton Research Spectrograph 0.275 m connected to a Vision Research Phantom V12.1 high-speed camera (1 million frames/s and 300 ns exposure time). An optical fibre is positioned near the erosion gap and guides the light emitted by the sparks into the spectrograph.

The electrical discharge experiments were performed with a point-to-plane electrode configuration. The tool is a cylindrical copper electrode of 1 mm diameter with conical extremity, while the workpiece is a larger aluminium electrode with flat surface, as presented in the Figure 1.

High purity materials were adopted in the experiments for optical emission spectroscopy, since impurities can hamper the spectra interpretation. Moreover, aluminium was used as workpiece material due to its relatively low excitation and ionization energies, which provide clear atomic and ionic emission lines. The dielectric used in the experiments was air at atmospheric pressure.

Single electrical discharge experiments were done applying U_{open} = 250 V and I = 20 A. Optical emission spectroscopy was performed for electrical discharges with pulse durations of 316 µs.

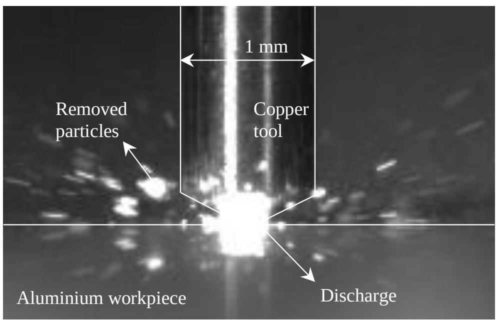

Figure 1: Copper and aluminium electrodes configuration (I = 20 A; U_{open} = 250 V; t = 316 µs)

3. Experiments and results

3.1. Time-resolved optical emission spectroscopy analysis

Time-resolved optical emission spectroscopy provides information about fundamental properties of electrical discharge plasmas and their species. It shows that the microplasmas obtained from discharges with cathode tool present very weak Cu spectral lines intensities, while the Al lines are very strong. The situation changes significantly with the tool as anode. The Cu lines have relatively high intensity already at the first microseconds of the discharge and they increase during the time in comparison with the Al lines. The Figures 2 and 3 present the emission spectra of both cases.

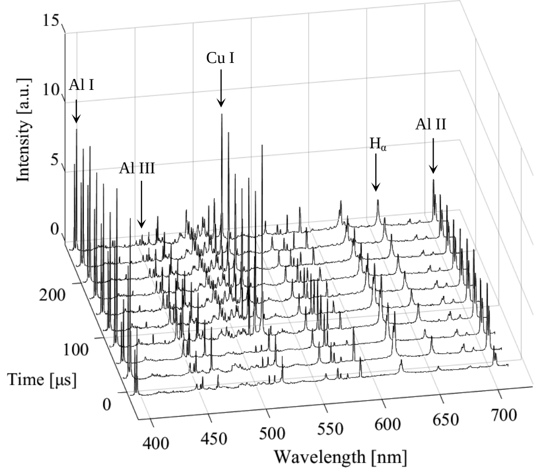

Figure 2: Emission spectra of a single electrical discharge with anode tool

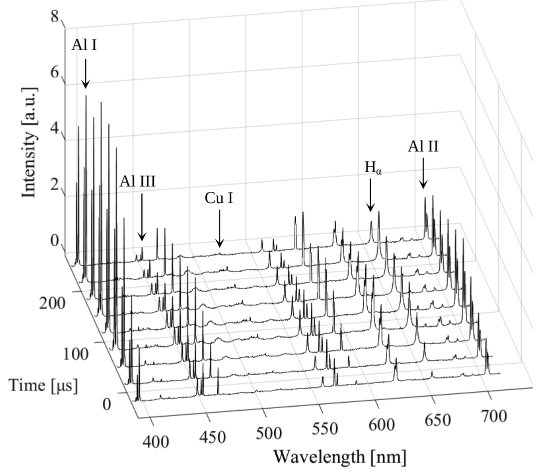

Figure 3: Emission spectra of a single electrical discharge with cathode tool

The intensities of the emission lines are linked to the populations of different excited species in the plasma. Thus, in order to obtain indications of the proportion of species coming from anode and cathode materials, ratios between the different lines were calculated. The strongest intensity lines of the metallic species, Cu I (521.82 nm), Al I (396.15 nm), Al II (704.21 nm) and Al III (452.9 nm), were selected and used as