Electromagnetic Thermofluid Dynamics Analysis of Electrical discharge Arc Plasma

Initial electrons, which are generated by the ultraviolet ray, x-ray, cosmic ray and radiation from the earth crust, are accelerated by the electric field and ionize the neutral species due to collision, resulting in an electron avalanche. Thus, the electric field is distorted and streamers are developed toward both the anode and cathode, resulting in an established discharge [1]. In EDM, since discharge duration is normally over several μs and current density is 10^8 - 10^9A/m^2, the established discharge is an arc discharge. An arc discharge is sustained by electron emission from the cathode spot which is due not only to the secondary emission but also to the thermionic and field emissions. Since both temperature and electrical field are strong, the emission process is strongly dependent on both variables (*T-F* theory) [2]. Thus the plasma is highly ionized resulting in high current densities with the comparatively low discharge voltage of about 20 V. The discharge voltage is composed of an anode, cathode and channel voltage drop, and its value will slightly change depending on electrode materials, dielectric fluids, gap width and pulse conditions.

Because of the complicated physical phenomena occurring in the discharge gap, precise analysis of the EDM plasma is difficult. Eubank et al. [3] analyzed the expansion of the cylindrical plasma considering the evaporation of water dielectric and enthalpy increase in plasma due to dissociation and ionization of water. The fraction of energy distributed to the plasma was obtained by subtracting the fractions of the energy transferring to the anode and cathode from 100%. The fractions of the anode and cathode were obtained from comparison between the measured material removal per pulse discharge and molten material volume calculated using the point heat-source on cathode model [4] and expanding circular heat-source on anode model [5]. However, the plasma itself was not analyzed.

Hayakawa et al. [6-8] first conducted magnetohydrodynamics analysis in the steady state of a DC arc between parallel plane copper electrodes. The arc was assumed to be in air under a constant discharge current and gap width as those used in the actual EDM process. They assumed that the species in high-temperature air which includes copper electrode vapor are N_2, O_2, NO, N, O, Cu, NO^+, N^+, O^+, Cu^+, N^{2+}, O^{2+}, Cu^{2+}, and electrons. Considering the temperature dependence of the thermophysical properties of the plasma, the electromagnetic field, temperature, pressure, and velocity distributions were calculated for the regions including both the electrodes and discharge gap. The conservation equations of mass, momentum and energy, Ohm’s law and Maxwell’s equations were solved. The energy equation contained the Joule heating, conduction, convection, and radiation terms. Figure 1 shows an example of the calculated temperature fields. It was found that most of the discharge power is distributed in the electrodes, and heat transfer due to convection and radiation is negligible. It was also found that the plasma is extinguished within a few microseconds after the end of the discharge duration as shown in Figure 2 [6,8]. However, the arc which they analyzed was not in dielectric liquid but in air. The arc was not in transient but in steady state, and removal of the electrodes, i.e. mass transfer from the electrode surfaces, was not taken into consideration. Furthermore, the arc was assumed to be in thermoequilibrium, and the equations of motion of the three species: electrons, ions, and neutral particles, were not solved separately. The gap phenomena were simplified to be symmetrical between the anode and the cathode regions. Therefore, the fractions of energy distributed to anode and cathode were equal. Thus, the energy distribution was obtained experimentally as shown in the next section “Measurement and Analysis of Energy Distribution Ratio in EDM GAP”.

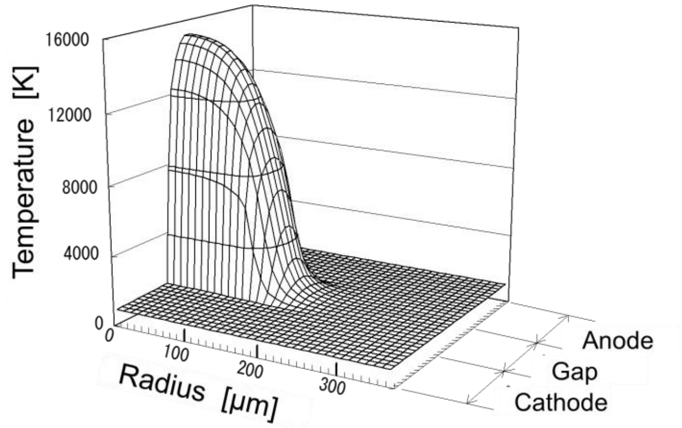

Figure 1: Temperature distribution in electrodes and gap obtained by magnetohydrodynamics analysis.

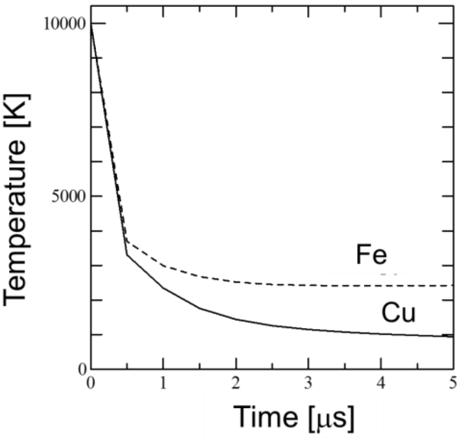

Figure 2: Calculated plasma temperature decrease during discharge interval when material used for both anode and cathode is steel or copper.

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