# Modeling of temperature distribution with metal vapour in pulsed TIG including influence of radiative absorption†

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## 1. Introduction

Most reports to date have addressed the case of a constant arc current. However, pulsed arc currents are widely used in high-speed welding, and in general to control the heat input and droplet transfer in arc welding. In the case of TIG welding, in which the electrode rod does not melt and no droplet transfer occurs, pulsed currents are used to control the heat input to the arc and weld pool, and to facilitate high-speed welding. There are few if any cases in which the time variation of the metal vapour distribution has been discussed for pulsed TIG welding. It is important to understand the time dependence of the metal vapour distribution, since the mixing of metal vapour with the shielding gas affects fundamental properties such as the arc temperature and the radiative emission. Furthermore, because the self-absorption of the radiation strongly influences the arc temperature and the heat transfer to the weld pool [1]-[4], it is necessary to take into account the self-absorption of the arc radiation.

In this paper, the time dependence of the distribution of temperature with vapour from the anode is analyzed using an electromagnetohydrodynamic simulation that includes the influence of self-absorption of radiation. Iron is the main component of stainless steel, which is often welded using TIG welding. Using plasma thermophysical data that take into account the iron vapour concentration, the effects to the temperature distribution are investigated, with the influence of self-absorption included.

## 2. Method of Calculation

Electromagnetohydrodynamic simulations of arcs are performed using a two-dimensional cylindrical coordinate system. However, it is difficult to treat radiative transfer in the cylindrical coordinate system, because the circular grid does not conform to the linear propagation paths of light. To solve this problem, a three-dimensional Cartesian coordinate system is introduced to calculate the radiation power distribution while considering self-absorption. A two-dimensional axisymmetric cylindrical coordinate system is used for all other aspects of the electromagnetohydrodynamic model. It is also important to note that the iron vapour concentration, the arc temperature and the radiative properties of the arc all affect each other. Therefore, a self-consistent modelling approach is required.

Tungsten is used for the cathode and stainless steel for the anode. The iron vapour is generated from the molten region of the anode. The spacing between the electrodes is 5 mm, the shielding gas is argon, the gas flow rate is 10 slm, and the pressure is 0.1 MPa. The following assumptions are made: 1) local thermodynamic equilibrium, 2) laminar flow, 3) incompressible fluid, 4) only the anode is melted, and 5) the surface of the welding pool remains flat. The model allows the temperature, fluid flow and distribution of electromagnetic properties in the electrodes and the arc to be calculated simultaneously.

The pulsed current waveform is used in the calculation as follows. The peak current is 150 A, the base current is 50 A, the duty ratio is 0.5, the transient time of the current is 0.2 ms, and the frequency is 100 Hz. The characters denote the following: A, the time of transition to base current; B, the time immediately before the transition from the base current to the peak current; C, the time of transition to peak current; and D, the time immediately before the transition from the peak current to the base current. The distribution of temperature at each time is calculated self-consistently.

In the present calculation model, the electrode and the arc are combined into one system and simultaneously analyzed. The transfer of energy between the arc and the electrode is obtained from the equation below and added as a localized source term in the equation for conservation of energy.

The iron vapour concentration on the surface of the anode is determined by the saturation vapour pressure and the ambient pressure. The saturation vapour pressure is determined by the temperature at the surface of the welding pool. The concentration distribution is obtained by solving the conservation equation of the iron vapour, using the iron vapour concentration on the anode surface as a boundary condition. Changes in the fundamental characteristics of the arc caused by mixing of iron vapour are studied taking into account the influence of the iron vapour concentration on the thermophysical properties.

The transfer of radiation to and from a control volume is calculated using two different methods. In the simple self- absorption model, the calculation domain is the same cylindrical coordinate system used for the

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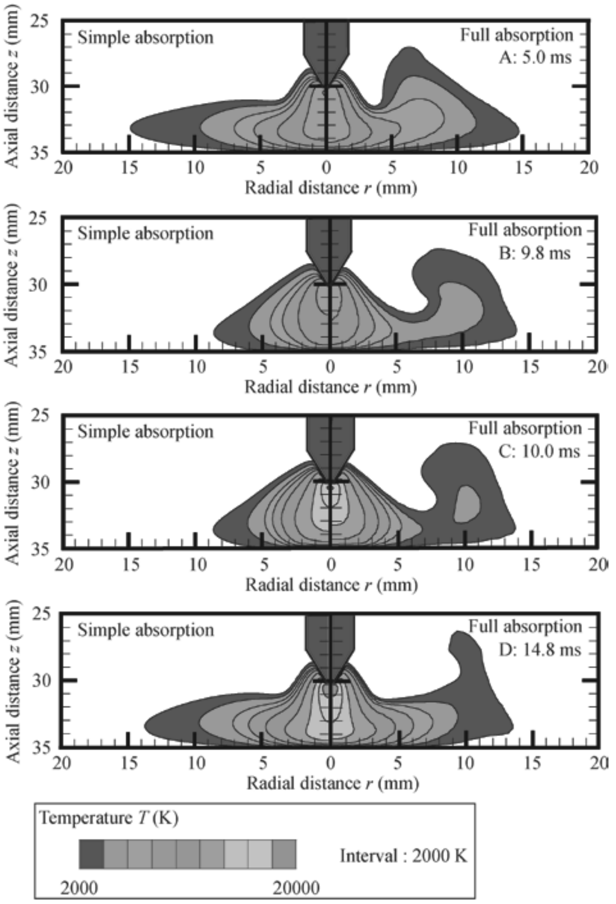


**Fig. 1** Temperature distribution

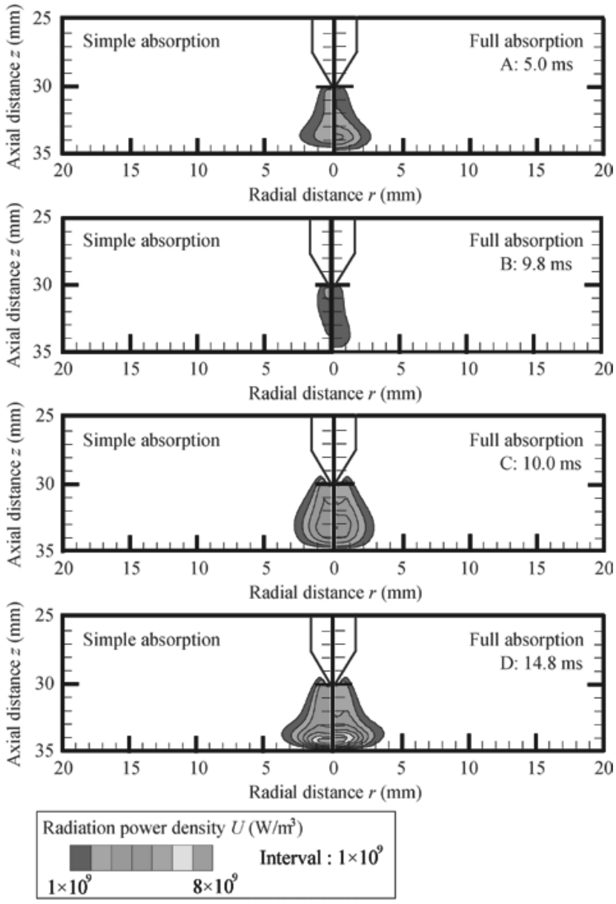


**Fig. 2** Radiation distribution

electromagnetohydrodynamic model. Absorption is calculated only within the control volume in which emission occurs, and depends only on the temperature and the radial dimension of the control volume (the absorption length). In the full self-absorption model case, the calculation domain is divided into a three-dimensional Cartesian grid. Incident radiation entering a control volume from all three adjacent control volumes is considered. The flux of incident radiation from each direction is normalized to the area of the interface relative to the control volume's total surface area. With each passage through the control volume, the incident radiation intensity decreases because of self-absorption and increases according to the influence of the radiative emission from within the control volume.

## 3. Temperature Distribution with Changing Current Including Influence of Self-absorption

**Figure 1** and **2** show the distribution of the arc temperature and radiation, for the simple model that takes account of one control volume and directions, and full self-absorption model that takes account of all three adjacent control volumes and directions.

The results show that the iron vapour diffuses upwards toward the cathode at the time of the peak-to-base current transition. Furthermore, it diffuses during the period in which the base current is constant. The concentration near the anode is low. At the time of the base-to-peak current transition, the increase in the downward convective flow in the arc, driven by the magnetic pinch force, causes the iron vapour to be transported in the direction of the anode. This continues during the period in which the peak current is constant.

When self-absorption is considered, its effects are expected to be more pronounced in the low-temperature region than in the high-temperature region. Therefore, the absorption is greatest at locations where a large amount of metal vapour is present at low temperatures. This corresponds to the regions in the periphery of the arc near the anode, and it is therefore these regions whose temperature is increased. The temperature gradient is also important; a high gradient favours localized absorption, since low-temperature absorbing regions are closer to high-temperature emitting regions.

## 4. Conclusions

A time-dependent electromagnetohydrodynamic simulation of pulsed TIG arc welding was performed, with the electrodes and arc included in the computational domain. The distribution of temperature with vapour generated from the anode was calculated, using thermophysical properties that take into account the iron vapour concentration. The influence of self-absorption of radiation was calculated using a Cartesian grid, allowing radiation from all three adjacent control volumes and directions to be taken into account. Arc temperature distribution was calculated self-consistently.

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