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Numerical Model with Arc Length Variation of Welding Arc with Constant Voltage Power Source[†]

TASHISRO Shinichi*, TSUJIMURA Yoshihiro**, TANAKA Manabu***

Abstract

In the present paper, Tungsten Inert Gas (TIG) arc with Constant Voltage (CV) power source is modeled if arc length changes. And TIG arc with Constant Current (CC) power source is also modeled if arc length changes. The TIG arc is assumed on base material of water-cooled copper. For the CV power source, Maximum temperature of arc plasma and arc current increase with decrease of arc length. For the CC power source, arc voltage changes but maximum temperatures of arc plasma is almost constant in spite of change of arc length. Arc power increases with decrease of arc length for the CV power source. On the other hand, arc power decrease with decrease of arc length for the CC power source. For the CV power source, arc power changes largely if arc length changes. However, for the CC power source, arc power changes little if arc length changes. Heat input from welding power source more stable using a CC power source than a CV power source at TIG welding with a change of arc length.

KEY WORDS: (Simulation), (Arc), (TIG), (Power source)

1. Introduction

There are constant current (CC) power source and constant voltage (CV) power source in welding power source. A CC power source supplies electric current stably. A CV power source supplies the self-adjusting of arc length for consumable electrode arc welding like a MIG/MAG^{1,2)}. In MAG welding, arc length changes by wire feeding and metal transfer. As arc length changes, arc current changes to keep arc voltage constant for a CV power source. A stability of arc current depends on the characteristics of power sources. Arc current has a big influence on arc welding process¹⁾. During the arc welding process, four states of matter, solid, liquid, gas and plasma, simultaneously exist and mutually interact³⁾. Such complex arc phenomena are affected by conditions, like an arc length, an arc current, a characteristic of power source, a gas composition and so on^{1,2,4-6)}. Aim of this study is to understand effects of power source characteristics, like a CC power source or a CV power source, on arc phenomena when dynamic change arises, like a time-dependence of arc length. Simulation technology is helpful to understand such phenomena⁷⁾. There are many reports that performed numerical analysis of gas metal arc (GMA) welding or tungsten inert gas (TIG)

welding^{8, 9)}. These models only have CC characteristics. In this study, TIG arc with CV power source is modeled if arc length changes at artificially controlled frequency. And TIG arc with CC power source is also modeled if arc length changes. We assume TIG arc on a base material of water-cooled copper at atmosphere pressure in argon.

2. Simulation model

The tungsten cathode, the arc plasma and the water-cooled copper anode are described relative to cylindrical coordinates, assuming rotational symmetry around the arc axis. The calculation domain is shown in **Fig. 1**. The diameter of the tungsten cathode is 3.2 mm with a 60 degrees conical tip. The time-dependence of arc length is shown in **Fig. 2**. In this model, number of mesh is constant. However, mesh size changes if arc length changes. For the CV power source, the arc voltage is set to be a 10 V. For the CC power source, the arc current is set to be a 150 A. Argon shielding gas is introduced from the outside of the cathode on the upper boundary at the flow rate of 10 L/min. The flow is assumed to be a laminar flow, and the arc plasma is assumed to be under the Local Thermodynamic Equilibrium (LTE).

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For the CV power source, a temporary arc current is firstly set and then the temporary arc current is modified till an output arc voltage becomes 10 V under the implicit iterative calculation.

We conduct the time dependent two-dimensional calculations. The governing equations used in the model are shown as follows:

The mass continuity equation is,

$$\frac{\partial \rho}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (r \rho v_r) + \frac{\partial}{\partial z} (\rho v_z) = 0 \quad (1)$$

The radial momentum conservation equation is,

$$\begin{aligned} \frac{\partial \rho v_r}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (r \rho v_r^2) + \frac{\partial}{\partial z} (\rho v_z v_r) = \\ -\frac{\partial p}{\partial r} - j_z B_\theta + \frac{1}{r} \frac{\partial}{\partial r} (2r\eta \frac{\partial v_r}{\partial r}) + \frac{\partial}{\partial z} (\eta \frac{\partial v_r}{\partial z} + \eta \frac{\partial v_z}{\partial r}) - 2\eta \frac{v_r}{r^2} \end{aligned} \quad (2)$$

The axial momentum conservation equation is,

$$\begin{aligned} \frac{\partial \rho v_z}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (r \rho v_r v_z) + \frac{\partial}{\partial z} (\rho v_z^2) = \\ -\frac{\partial p}{\partial z} - j_r B_\theta + \frac{\partial}{\partial z} (2\eta \frac{\partial v_z}{\partial z}) + \frac{1}{r} \frac{\partial}{\partial r} (r\eta \frac{\partial v_r}{\partial z} + r\eta \frac{\partial v_z}{\partial r}) + \rho g \end{aligned} \quad (3)$$

The energy conservation equation is,

$$\begin{aligned} \frac{\partial \rho h}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (r \rho v_r h) + \frac{\partial}{\partial z} (\rho v_z h) = \\ \frac{1}{r} \frac{\partial}{\partial r} \left(\frac{r\kappa}{c_p} \frac{\partial h}{\partial r} \right) + \frac{\partial}{\partial z} \left(\frac{\kappa}{c_p} \frac{\partial h}{\partial z} \right) + j_r E_r + j_z E_z - U \end{aligned} \quad (4)$$

The current continuity equation is,

$$\begin{aligned} \frac{1}{r} \frac{\partial}{\partial r} (r j_r) + \frac{\partial}{\partial z} (j_z) = 0 \\ j_r = \sigma E_r, j_z = \sigma E_z \end{aligned} \quad (5)$$

where, t is time, h is enthalpy, p is pressure, v_r and v_z are radial and axial velocities, j_r and j_z are the radial and axial components of the current density, g is acceleration due to gravity, c_p is specific heat, κ is thermal conductivity, ρ is density, η is viscosity, U is radiative emission coefficient, and σ is electrical conductivity. E_r and E_z are the radial and axial components of the electric field defined by:

$$E_r = -\frac{\partial V}{\partial r}, \quad E_z = -\frac{\partial V}{\partial z} \quad (7)$$

where, V is electric potential.

The azimuthal magnetic field, B_θ induced by arc current is evaluated by Maxwell's equation:

$$\frac{1}{r} \frac{\partial}{\partial r} (r B_\theta) = \mu_0 j_z \quad (8)$$

where, μ_0 is the permeability of free space.

It is necessary to consider the effects of energy transfer at the electrode surfaces. The additional energy fluxes at the cathode and anode are described as:

$$\text{Cathode : } F_K = -\varepsilon \alpha T^4 - |j_e| \phi_K + |j_i| V_i \quad (9)$$

$$\text{Anode : } F_A = -\varepsilon \alpha T^4 + |j| \phi_A \quad (10)$$

where, ε is surface emissivity, α is the Stefan-Boltzmann constant, ϕ_K is the work function of the tungsten cathode, V_i is the ionization potential of the plasma gas, j_e is the electron current density, j_i is the ion current density, ϕ_A is the work function of the anode and T is the temperature. For the cathode surface, F_K needs to be included in Equation (4) to take into account the thermionic cooling by emission of electrons, radiative cooling and ion heating. Similarly, for the anode surface, F_A is required in Equation (4) to take into account radiative cooling and thermionic heating. Furthermore, for the cathode surface, the electron current and the ion current are considered separately and defined based on the Richardson-Dushman equation of thermionic emission as follows:

$$j_R = AT^2 \exp\left(-\frac{e\phi_K}{k_B T}\right) \quad (11)$$

where, k_B is the Boltzmann's constant and A is the Richardson's constant, which depend on the cathode material. The ion current density, j_i is then assumed to be $j_i = j - j_R$, where the total current density, j is $|j| = |j_e| + |j_i|$.

The gas properties are referred from 5). And the electrodes properties are given in 10). The other approximations, governing equations and boundary conditions are given in detail in our previous papers^{6, 11, 12}.

4. Results and discussion

Figures 3 and 4 show calculated results of temperature fields for the CV power source and the CC power source at 0.15 s and 0.2 s after arc ignitions. For the CV power source, the maximum temperature of arc plasma is 18000 K for 5 mm in arc length and the maximum temperature of arc plasma is 23000 K for 3 mm. For the CC power source, the maximum temperature of arc plasma is constantly 19000 K even if the arc length changes.

Figure 5 shows calculated results of time-dependence of arc current with arc length for the CV power source. The arc current is 130 A for 5 mm in arc length and the arc current is 200 A for 3 mm.

Figure 6 shows calculated results of time-dependence of arc voltage with arc length for the CC power source. The arc voltage is 10.5 V for 5 mm in arc length and the arc voltage is 9.1 V for 3 mm.

Figure 7 shows calculated result of time-dependence of arc power with arc length for the CV power source and the CC power source. In this figure, arc power increase with decrease of arc length

for the CV power source. Because arc current increase with decrease of arc length. On the other hand, arc power decrease with decrease of arc length for the CC power source. Because arc voltage decrease of arc length. For the CV power source, arc power is 1300 W for 5 mm in arc length and arc power is 2000 W for 3 mm. For the CC power source, arc power is 1600 K for 5 mm in arc length and arc power is 1400 K for 3 mm. For the CV power source, arc power changes largely if arc length changes. However, for the CC power source, arc power changes little if arc length changes. From this, heat input from welding power source more stable using a CC power source than a CV power source at TIG welding with a change of arc length.

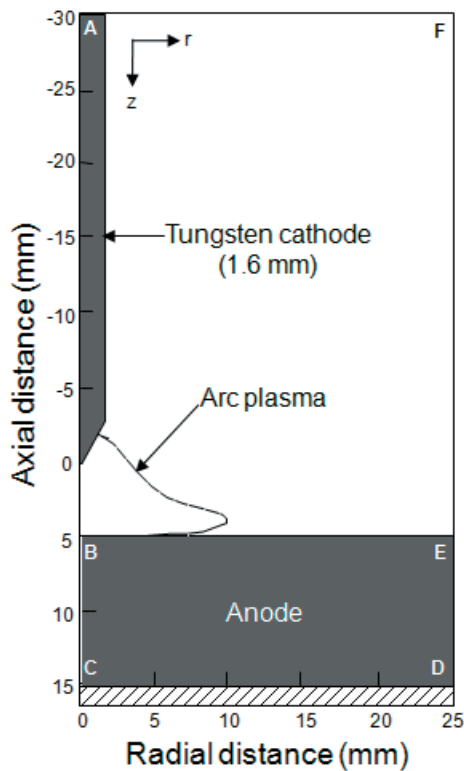


Fig. 1 Schematic illustration of simulation domain

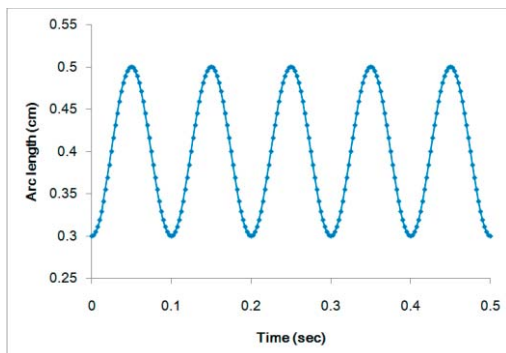
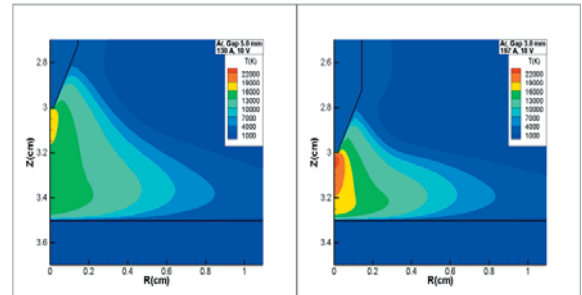
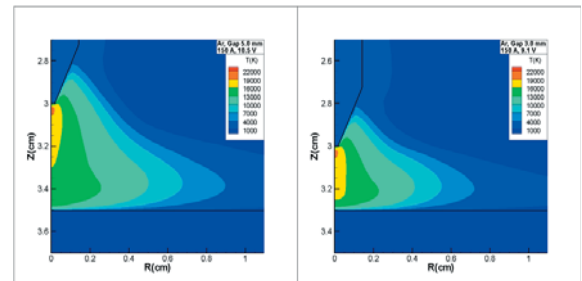


Fig. 2 Assumption of time-dependence of arc length at 10 Hz



(a) $t = 0.15$ s (Arc length : 5 mm) (b) $t = 0.2$ s (Arc length : 3 mm)

Fig. 3 Calculated results of temperature field for the CV power source



(a) $t = 0.15$ s (Arc length : 5 mm) (b) $t = 0.2$ s (Arc length : 3 mm)

Fig. 4 Calculated results of temperature field for the CC power source

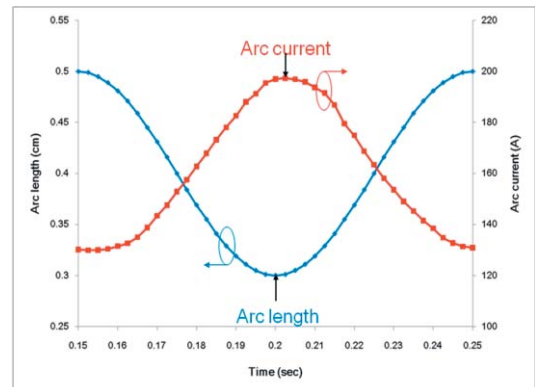


Fig. 5 Calculated result of time-dependence of arc current with arc length for the CV power source

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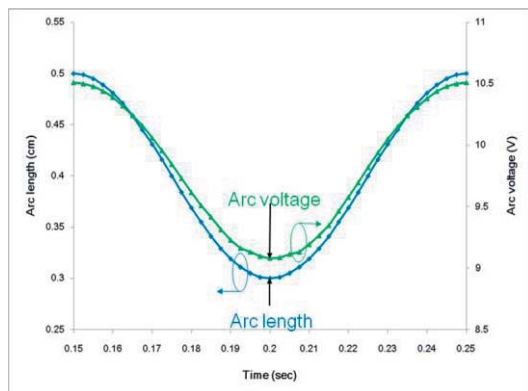


Fig. 6 Calculated result of time-dependence of arc voltage with arc length for the CC power source

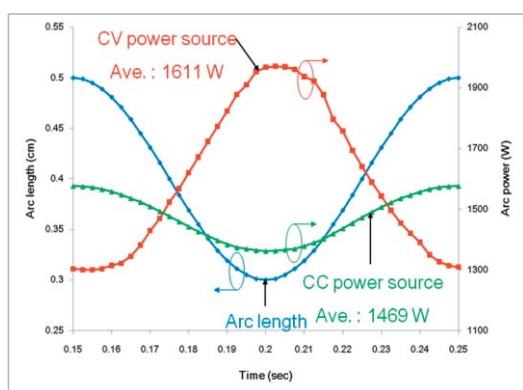


Fig. 7 Calculated result of time-dependence of arc power with arc length

5. Conclusions

Main conclusions are summarized as follows:

- (1) TIG arcs with a CV power source and with a CC power source are modeled when arc length changes from 3.0 mm to 5.0 mm at 10 Hz.
- (2) Maximum temperature of arc plasma and arc current increase with decrease of arc length for the CV power source.
- (3) For the CC power source, arc voltage changes but maximum temperatures of arc plasma is almost constant in spite of change of arc length.
- (4) Arc power increase with decrease of arc length for the CV power source. On the other hand, arc power decrease with decrease of arc length for the CC power source.
- (5) For the CV power source, arc power changes largely if arc length changes. However, for the CC

power source, arc power changes little if arc length changes.

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