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Modeling of the Transport Phenomena in GMAW Arc under the Shielding of Ar-He Mixtures

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Abstract

Gas metal arc welding (GMAW) is one of the most widely used method to assemble parts together in various industries. Argon and helium are the most common shielding gases used in GMAW to protect the molten metal from oxidization. The shielding gas composition is a critical parameter in the GMAW process, which affects the efficiency, quality, and overall performance of the welding operation. In this project, a numerical investigation was conducted to study the transport phenomena in the GMAW arc under the shielding environments of pure Ar and three Ar-He mixtures. The detailed description of the transient arc plasma generation and interactions with moving droplets and weld pool surface provides insights into how the thermal physical properties of the two shielding gases affect the arc characteristics.

Mathematical Model

- Mass Conservation Equation

$$\nabla\cdot(\rho\boldsymbol{V})=0$$

- Momentum Conservation Equations

$$\frac{\partial}{\partial t}(\rho u)+\nabla\cdot(\rho\boldsymbol{V}u)=\nabla\cdot\left(\mu_l\frac{\rho}{\rho_l}\nabla u\right)-\frac{\partial p}{\partial r}-\frac{\mu_l}{K}\frac{\rho}{\rho_l}(u-u_s)$$
$$-\frac{C\rho^2}{K^{1/2}\rho_l}|u-u_s|(u-u_s)-\nabla\cdot(\rho f_s f_l\boldsymbol{V}_r u_r)-J_z\times B_\theta$$

$$\frac{\partial}{\partial t}(\rho v)+\nabla\cdot(\rho\boldsymbol{V}v)=\nabla\cdot\left(\mu_l\frac{\rho}{\rho_l}\nabla v\right)-\frac{\partial p}{\partial z}-\frac{\mu_l}{K}\frac{\rho}{\rho_l}(v-v_s)$$
$$-\frac{C\rho^2}{K^{1/2}\rho_l}|v-v_s|(v-v_s)-\nabla\cdot(\rho f_s f_l V_r v_r)+\rho g\beta_T(T-T_0)+J_r\times B_\theta$$

- Energy Conservation Equation

$$\frac{\partial}{\partial t}(\rho h)+\nabla\cdot(\rho\boldsymbol{V}h)=\nabla\cdot\left(\frac{k}{c_s}\nabla h\right)+\nabla\cdot\left(\frac{k}{c_s}\nabla(h_s-h)\right)$$
$$-\nabla\cdot\left(\rho(\boldsymbol{V}-\boldsymbol{V}_s)(h_l-h)\right)-\Delta H\frac{\partial f_l}{\partial t}+\frac{J_r^2+J_z^2}{\sigma_e}-S_R+\frac{5k_b}{e}\left(\frac{j_r}{c_s}\frac{\partial h}{\partial r}+\frac{j_z}{c_s}\frac{\partial h}{\partial z}\right)$$

- Current Conservation Equation

$$\nabla^2\phi=\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\phi}{\partial r}\right)+\frac{\partial^2\phi}{\partial z^2}=0$$

- Free Surface Tracking Equation

$$\frac{dF}{dt}=\frac{\partial F}{\partial t}+(\boldsymbol{V}\cdot\nabla)F=0$$

Thermalphysical Properties of Shielding Gases

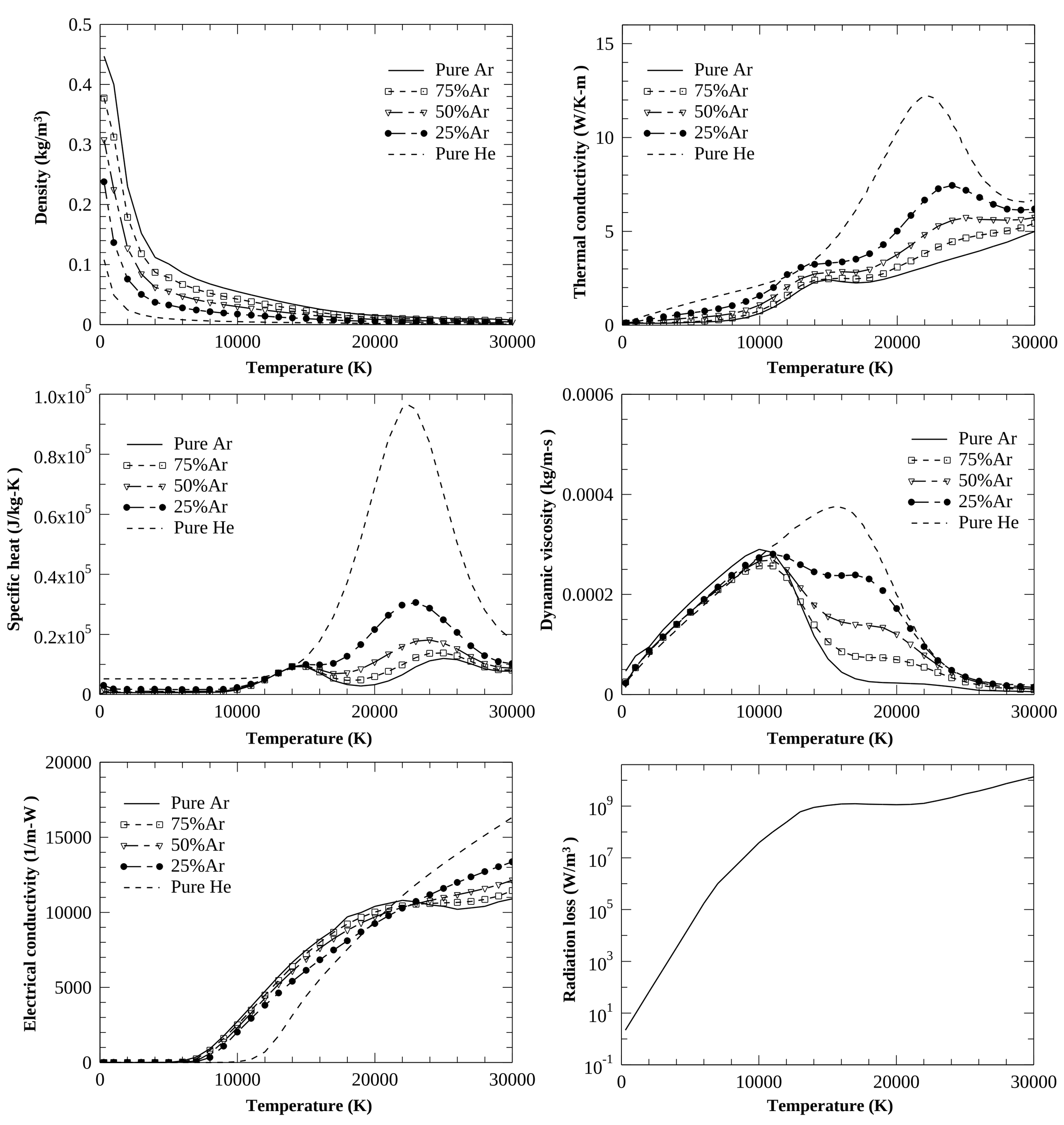

Fig. 1. Thermalphysical properties of shielding gases

Arc Structure at t = 90 ms

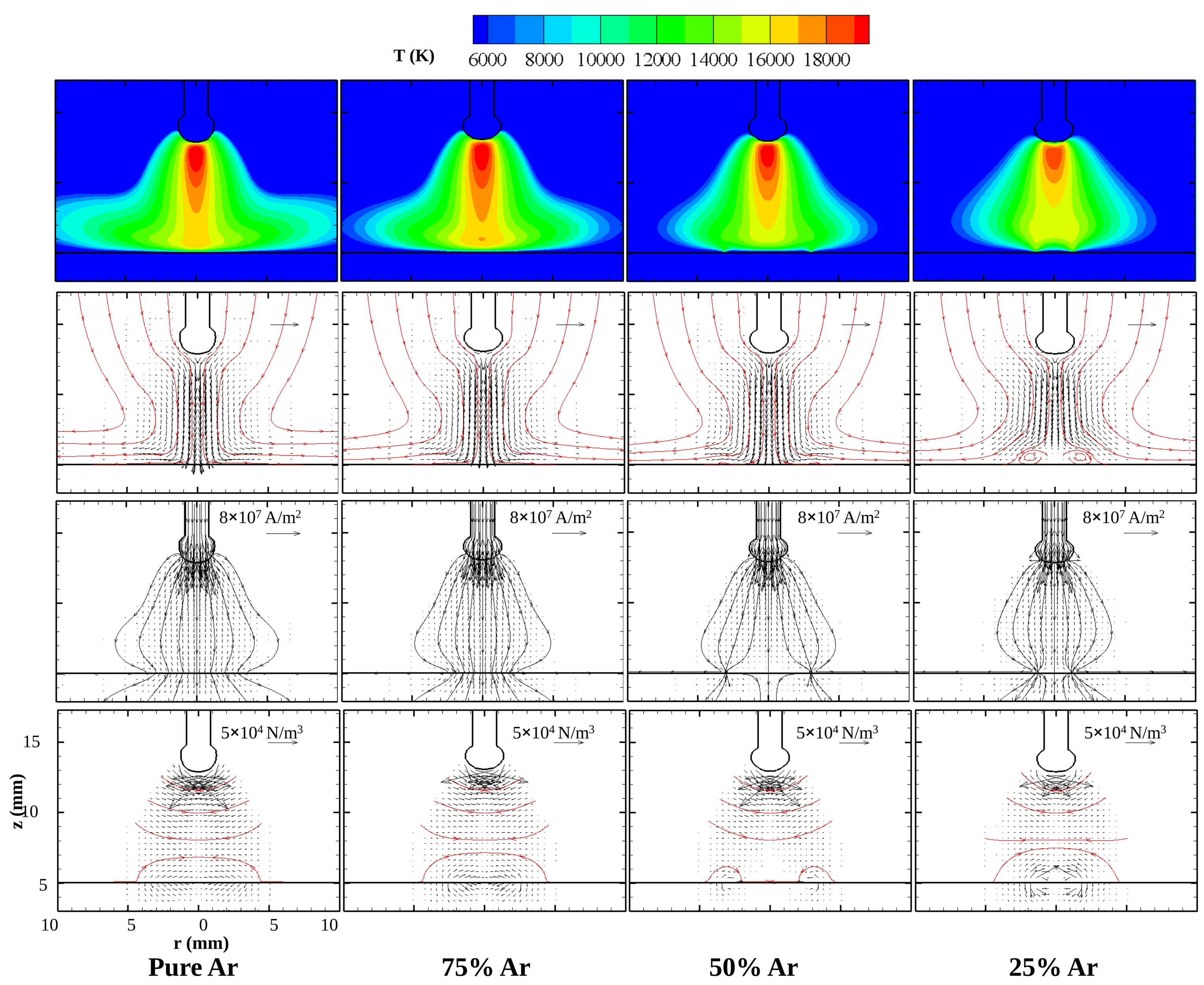

Fig. 2 Distribution of temperature, velocity, current density, and electromagnetic force in the arc at t = 90 ms.

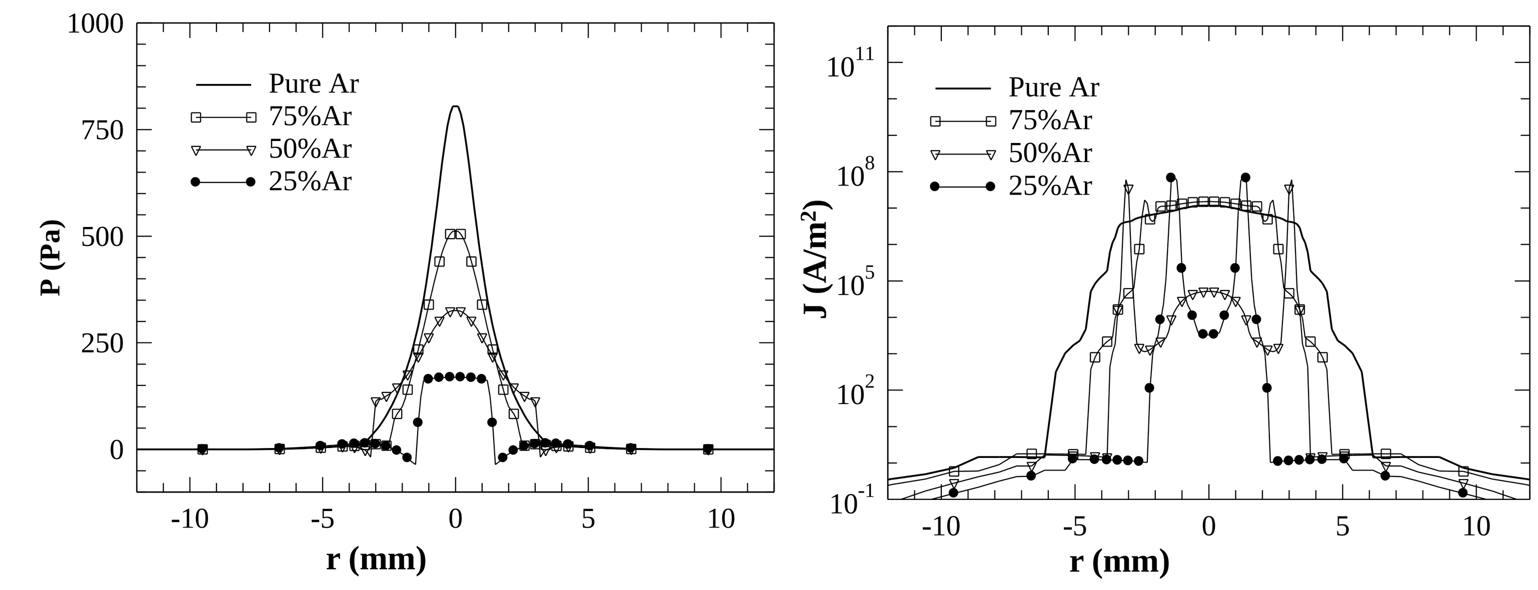

Fig. 3 Distribution of current density and arc pressure at the workpiece surface at t = 90 ms.

Evolution of Arc Plasma

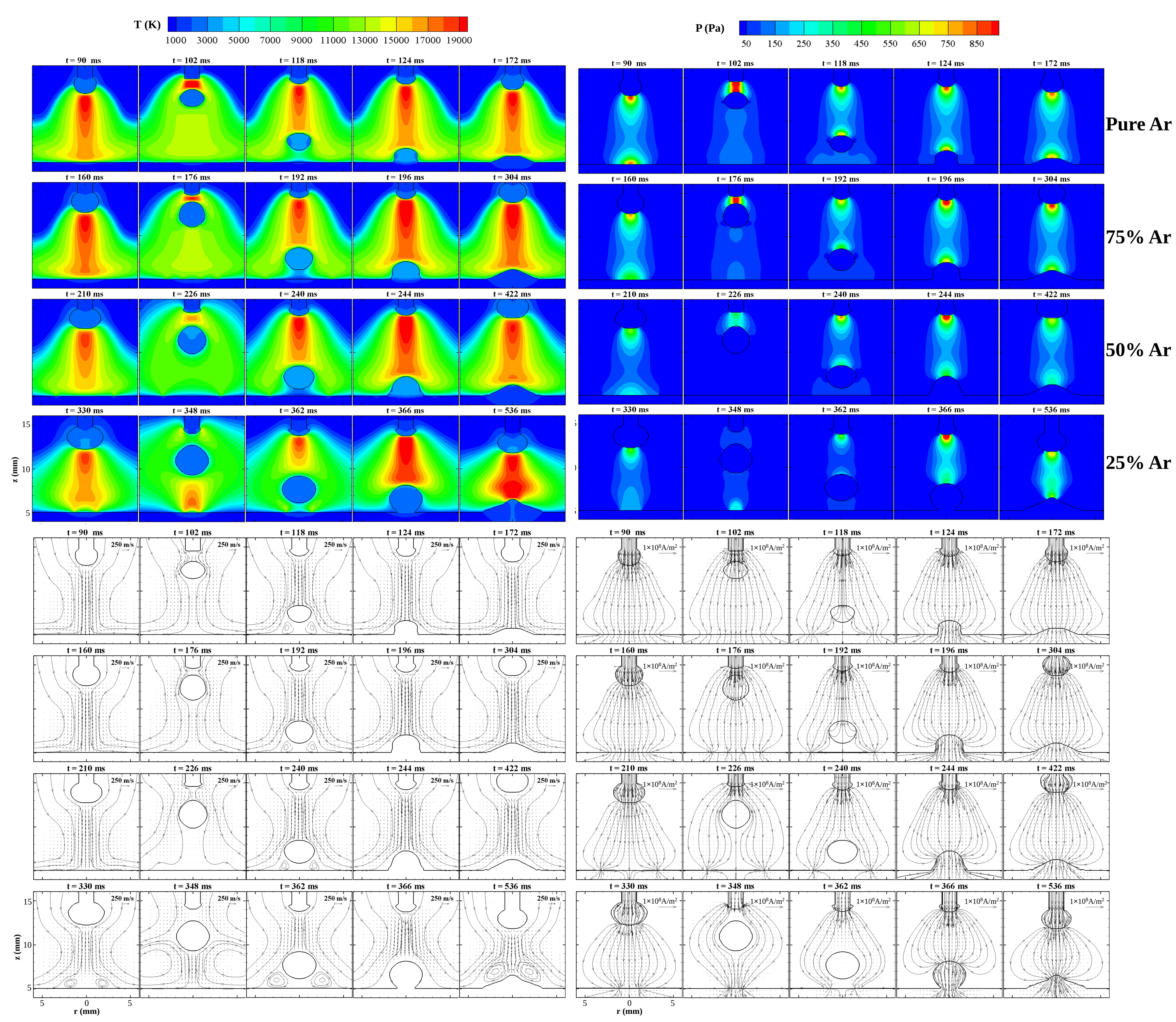

Fig. 4. Distributions of temperature, pressure, velocity and current density at some selected time instants to show the evolution of arc plasma in different shielding gases.

Conclusion

A comprehensive model have been developed to study the effects of shielding gas compositions on the transient transport phenomena in the GMAW arc. Compared to He, Ar has relatively lower ionization potential, thermal conductivity, specific heat, and viscosity, but higher electrical conductivity. Therefore, it is easy for Ar to establish a stable plasma arc. The increase of He may lead to insufficient ionization of gas and, hence, a shrinkage of hot plasma arc column. When He increases to an extent, a strong upward plasma flows from the workpiece, leading to the distortions of temperature, velocity, pressure and current distributions. The higher He content in the mixture leads to the higher degree of arc contraction, longer time to generate a droplet and thus larger droplet size.