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# Numerical analysis of weld pool formation mechanism in TIG welding in consideration of the influence of emitter material adding to the tungsten cathode†

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**KEY WORDS**: (Arc) (TIG welding) (Numerical simulation) (Unified model) (Emitter material)

## 1. Introduction

Generally, $ThO_2$ or $La_2O_3$ are added to a tungsten cathode for prompting electron emission from the cathode and preventing cathode consumption [1]. Tungsten employed as a cathode emits thermoelectrons enough for providing arc current acting as thermionic cathode near the melting point of tungsten (3680K). The work function required for electron emission from the cathode surface depends on the emitter material added to the tungsten cathode. Therefore, the emitter material strongly affects current characteristics near the cathode. **Figure 1** shows a photograph of the cathodes during TIG welding at 200A in cases of pure tungsten (W) cathode and tungsten cathode adding 2% $ThO_2$ (2%$ThO_2$-W) [1]. Although the cathode tip maintains a solid phase in the case of 2%$ThO_2$-W cathode, it was melted in case of a pure W cathode. In case of a W cathode, the cathode temperature increases due to decrease in cooling effect by thermionic electron emission because of the large work function. It is considered that the arc properties change through the redistribution of arc current due to change of cathode shape. In this study, the influence of adding 2% $ThO_2$ to the tungsten cathode as emitter material on arc properties and weld pool formation mechanisms in TIG welding were investigated by employing a numerical simulation model considering treatment of current attachment on the cathode surface and heat and mass transfers among the cathode, the arc and the weld pool.

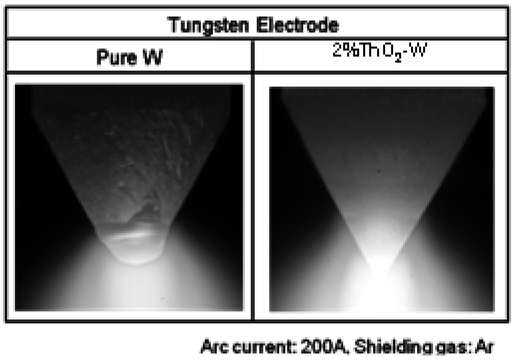


**Fig. 1** Appearances of W cathode and W-2% $ThO_2$ cathode

## 2. Simulation model

**Figure 2** shows the simulation region. Pure tungsten (W) and tungsten with added 2%ThO2 (2%ThO2-W) are selected as cathode materials. An arc current is 150A. Helium is introduced at flow rate of 30L/min as shielding gas. The laminar flow is assumed, and the arc plasma is considered to be in the local thermodynamic equilibrium (LTE). The anode material is stainless steel with low sulfur (30ppm). As driving forces of convective flow in the weld pool, electromagnetic force, Marangoni force, shear force and buoyancy force are considered. **Figure 3** shows the assumption of surface tension of weld pool [2]. The conservation equations of mass, momentum, energy and current are solved iteratively by the SIMPLEC numerical procedure [3]. The other numerical modeling methods are

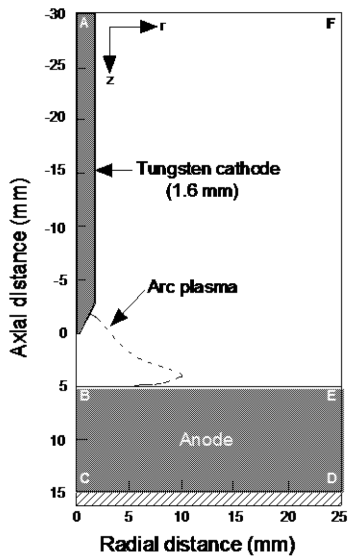


**Fig. 2** Simulation region

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given in detail in our previous paper [4]. The area of current attachment on the cathode surface was modeled by the same treatment in Ref [5]. The cathode surface has the work function of the emitter material where the surface temperature exceeds the melting point of the emitter material. Except for this region, the surface has the work function of the tungsten.

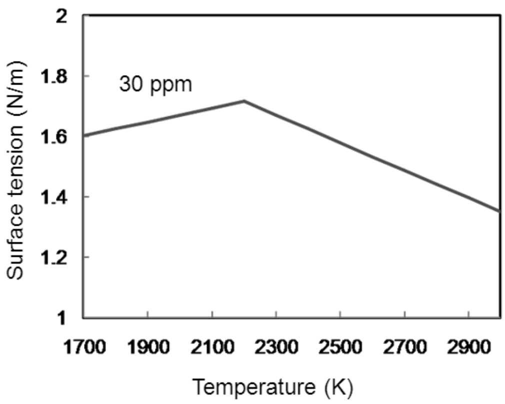


**Fig. 3** Assumption of surface tension [3]

## 3. Results and discussion

**Figure 4 and 5** show two-dimensional temperature distributions in the cathode, the arc and the anode in case of 2%$ThO_2$-W and W cathodes, respectively. The maximum temperatures of the arcs in both cases were 21740 K and 18580 K, respectively. It was found that difference between the maximum temperatures was approximately 3000K. It was also found that the maximum velocities of the cathode jets were 156 m/s for 2%$ThO_2$-W cathode and 497 m/s for W cathode. It was seen that the arc temperature decreased due to lower current density in the case of a W cathode because the cathode tip was melted and became spherical in shape.

**Figure 6 and 7** show cross section of the welding bead for both cases. For evaluating validity of the simulation model, those obtained from experiments were also presented. It was found that the shape of the weld pool became shallow and wide in case of 2%$ThO_2$-W cathode. On the other hand, that was deep and narrow in case of a W cathode. Although the maximum flow velocity in the outward radial direction close to the anode surface was 11.2 m/s in the 2%$ThO_2$-W cathode, that decreased to 5.2 m/s in a 2%$ThO_2$-W cathode. For the reason of the difference in weld pool shapes, it is considered that because shear force acting on the weld pool surface for 2%$ThO_2$-W cathode was larger than that of a W cathode due to higher cathode jet velocity, the heat transport in the weld pool near the surface in radial outward direction increased.

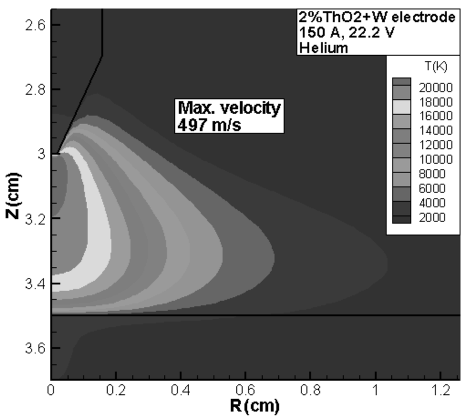


**Fig. 4** Calculation result of temperature for a 2%$ThO_2$-W electrode

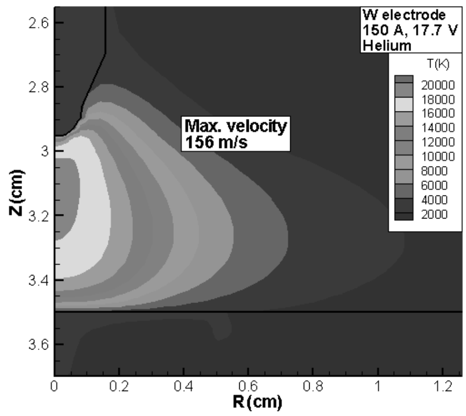


**Fig. 5** Calculation result of temperature for a pure W electrode

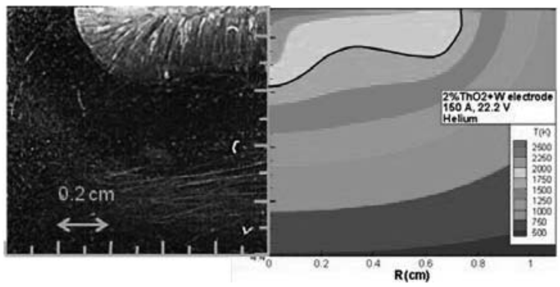


**Fig. 6** Cross section of the welding bead for a 2%$ThO_2$-W electrode

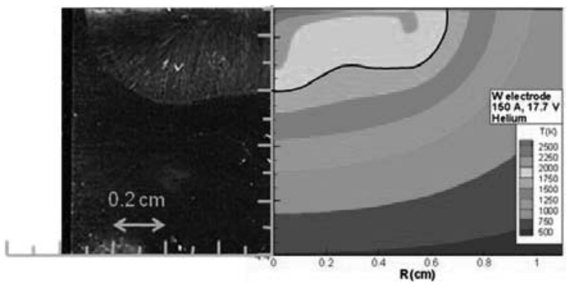


**Fig. 7** Cross section of the welding bead for pure a W electrode

## 4. Conclusions

It was found that although the maximum cathode jet velocity in case of a 2%$ThO_2$-W cathode was 497 m/s, that in case of pure W cathode was only 156 m/s because of low current density caused by the flattened surface of the melting cathode tip. In case of a 2%$ThO_2$-W cathode, the depth and the width of the weld pool became shallow and wider than those in case of a pure W cathode. For the reason of the difference in weld pool shapes, it is considered that because shear force acting on the weld pool surface for a 2%$ThO_2$-W cathode was larger than that of a

W cathode due to higher cathode jet velocity, the heat transport in the weld pool near the surface in radial outward direction increased.

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