![The University of Osaka Institutional Knowledge Archive]

**The University of Osaka**
**Institutional Knowledge Archive**

# Simulations of weld pool dynamics and theis visualization[†]

NA Suck-Joo [*], CHO Won-Ik [*] and CHO Dae-Won [*]

## 1. Introduction

Numerical simulations of weld pool dynamics in GMA welding and laser-GMA hybrid welding can show information of fluid flow characteristics and alloy element mixing in detail. The necessary condition for the validity of simulation results is, however, the accurate description of complex welding phenomena occurring during heating, melting, solidification and cooling. This paper introduces effective ways to describe the heat flux distribution from arc plasma to the base metal in GTA and GMA welding, and the laser heat transfer through the surface of keyholes with arbitrary shapes. The simulation result is visualized by the animation technique and some meaningful snapshots and compared with the experimental one to verify the validity of the developed model. The whole simulation model is then applied to GHTA welding in vacuum, GMA welding of pipes and laser-GMA hybrid welding of thick plates to understand the weld pool dynamics of various welding conditions.

## 2. Arc Welding: GHTAW and Pipe Welding

Previous simulations of arc welding processes generally adopted the axis-symmetry arc heat flux model [1]. These studies, however, do not consider the effect of various conditions such as ambient pressure and joint shape, which can deform the arc plasma characteristics. In this study, the arc heat flux model was obtained from the Abel inversion method [2], and applied for weld pool simulations to compare with the results of the generally adopted axis-symmetric arc heat flux model in numerical simulations of arc welding processes.

Figure 1 shows the arc heat flux distributions measured by Abel inversion of CCD images of arc light intensity under various shielding gas flow rates in GHTAW (gas hollow tungsten arc welding), the corresponding characteristic weld pool flows and the resulting bead shapes.

It is clearly visible that the increase of shielding gas flow rate results in the intensified and concentrated arc heat flux, which stimulates the strong downward flow along the center axis. Accordingly the simulated and experimental bead shapes are in a very good agreement for different conditions.
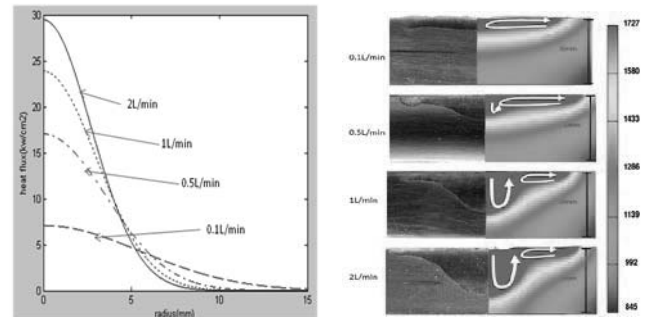


Fig.1 Arc heat flux and bead formation under various shielding gas flow rates in GHTAW

Figure 2 shows the arc light emissivity, which is the result of Abel inversion and a Gaussian fitted line for the front and side views in GMA pipe welding. To conduct the Gaussian fitting, the effective radius should be obtained by taking the integral of arc light emissivity.
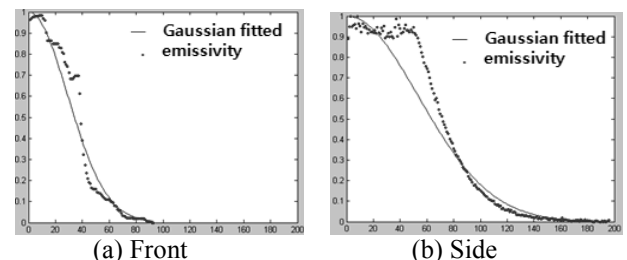


(a) Front          (b) Side

Fig.2 Result of Abel inversion of arc light intensity in GMA pipe welding

Figure 3 shows the experiment and simulation results for the different welding positions. Due to the gravity effect, molten pool behavior affects the variable surface profile shapes for different welding positions. In flat and overhead positions, the molten pool circulated counterclockwise, which makes a uniform bead along the welding direction.

In the vertical position, however, the molten pool cannot circulate well because the gravity force moves the molten pool to the rear direction, which makes an unstable bead shape like humping.
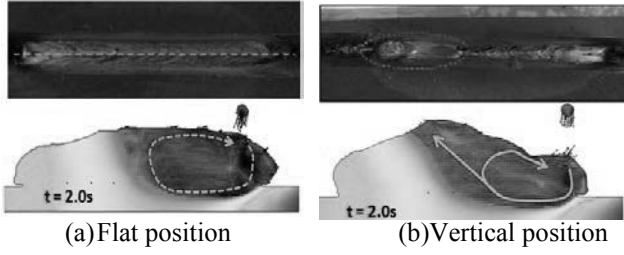
(a)Flat position          (b)Vertical position

**Fig.3** Result of simulation and experiment for different welding positions

## 3. Keyhole Welding: Laser and Laser-Arc Hybrid Welding

The three-dimensional molten pool formed in laser and laser-arc hybrid welding is analyzed by numerical simulation. All mathematical models for laser and arc welding are combined together without the interaction between the arc and laser heat sources.

The laser model is modified to consider the optical geometry of the laser system, and an additional conservation equation having the form of a general scalar advection equation is used for simulating the alloy element distributions [3].

**Figure 4** shows the temperature and Cr distributions with the flow patterns in the longitudinal cross sections during hybrid welding. In the figures, maximum temperature and content values of Cr are set to 1768K and 8%, respectively. At the keyhole front, where a high intensity laser beam is directly irradiated, the material is removed without a thin molten layer, a process that resembles the laser cutting and drilling process. The laser beam reflected at the keyhole front reaches the other position of the keyhole wall and is then absorbed. As shown in the figures, not only can the incident beam reach the keyhole wall easily, but also the reflected beam can be collected around a specific point, if the shape of the keyhole is not smooth but rather has a bulge.
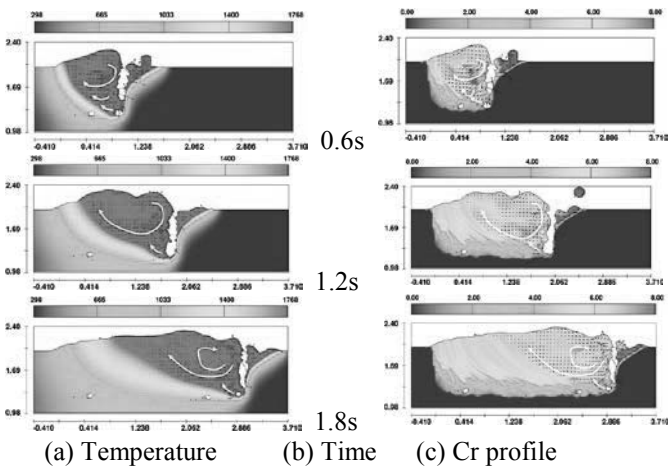


(a) Temperature     (b) Time     (c) Cr profile

**Fig.4**     Simulation results in longitudinal cross sections during hybrid welding

In particular, the region is rapidly expanded by the excessive recoil pressure, if the reflected laser beam is concentrated at the rear part of the keyhole surrounded by the molten metal. For this reason, complex flows with relatively high velocity are observed near the keyhole and can make the keyhole unstable. Meanwhile, it is observed that clockwise-rotating vortices form a quasi-steady state flow pattern in the wide molten region located away from the keyhole. It can be inferred that these vortices are driven by the strong flow at the keyhole. Because the vortices extending a relatively wide range of the molten pool not only have high Cr content but also rotate in the same direction, they help mix Cr in the molten pool and thus Cr is distributed uniformly in the wide molten region. However, the outer clockwise-rotating vortex with relatively high or low Cr content passes through around the solid-liquid interface, and thus Cr can be entrapped and make a pattern like the teeth of a comb. For the region around the keyhole bottom, strong up-and-back flow arises and pushes out the flow having high content of alloying elements because of the fast cooling rate and small accompanying molten region. Therefore, low content of alloying elements exists in the keyhole bottom.

## 4. Conclusions

The conclusions of this study can be summarized as follows.

(1) With a CCD camera and Abel inversion method, it is possible to calculate the effective radius of arc plasma in different arc welding processes.

(2) The arc heat flux models obtained as above could be effectively applied to the numerical simulations of weld pool in GHTAW and GMA V-groove pipe welding. The simulated and experimental results of bead shapes are in good agreement to show a validity of the proposed models.

(3) Although the theoretical $\varepsilon$ value of 0.08, rather than the numerically compensated $\varepsilon$ value of 0.2, is used in the simplified Fresnel's reflection model for the steel and $CO_2$ laser, the bead shape of laser-arc hybrid welding could be predicted very accurately by numerical simulations.

(4) For the alloying elements in laser-GMA hybrid welding, a relatively low content of alloying elements is observed in the low molten region, because the flow with a large content of alloying element is pushed out by the excessive flow at the rear part of the keyhole.

**References**

[1]J.H. Cho and S.J. Na: Weld. Jourmal, 88(2009), pp.35s-43s.

[2] Y.T. Cho and S.J. Na: Meas. Sci. Technol. 16 (2005), pp.878-884.

[3] W.-I.Cho, S.-J.Na, M.-H.Cho and J.-S.Lee: Comput. Mat. Sci., 49(2010), pp.792-800