Simulation of weld pool dynamics in stationary pulsed gas metal arc welding process and final weld shape

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Introduction

During arc welding processes such as gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW), fluid flow and heat flow are key factors that determine the final weld shape. While currently-available welding heat flow and distortion simulations are quite comprehensive and accurate enough for many practical purposes, phase change and fluid flow phenomena occurring in arc welding are complex and have still not been realistically simulated. In particular, accurate numerical model-based prediction of the dynamic changes in shape of the liquid weld pool surface would be useful in many applications.

In this paper, the pulsed gas metal arc welding (GMAW-P) process was modeled numerically using the Volume of Fluid (VOF) technique, which was chosen primarily for its ability to accurately calculate the shape and motion of free fluid surfaces. According to the mathematical models with parameters obtained from analysis of high-speed video images and data acquisition (DAQ) system, stationary GMAW-P was simulated and then validated by comparison of measured and predicted weld deposit geometry, transient radius, and temperature history.

Approach

GMAW-P stationary (spot) welds made for 1.8s on ASTM-A36 steel. DAQ systems and high speed camera were used to collect welding parameters, needed for use in the simulation. Diagram of the experiment was given in Fig.1.

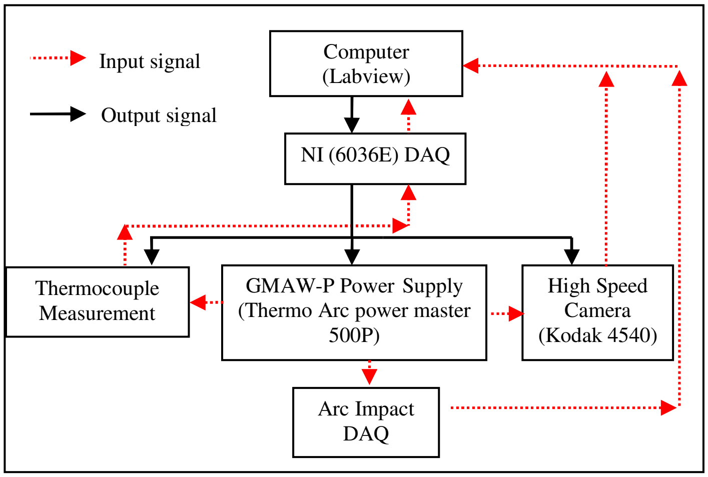


Figure 1 Diagram of the stationary GMAW-P weld experiment

The GMAW-P weld pool and bead deposit were mathematically molded using 3D Cartesian coordinate system, and the governing equations were solved numerically to simulate the arc welding process using Flow3D commercial code. Simulation parameters for Gaussian heat input, arc pressure, drag force, drop generation and other physical parameters needed to conduct GMAW-P stationary weld simulations were based on analysis of experiment of results and published literatures. Simulation results were validated with experimental results. After then, more simulations were performed for a parameter study.

Results

The simulation results were validated by following methods; comparison of weld geometry, transient weld pool radius and temperature (figure 2, 3 and 4). Summary of the weld geometry comparisons of was given in the table 1.

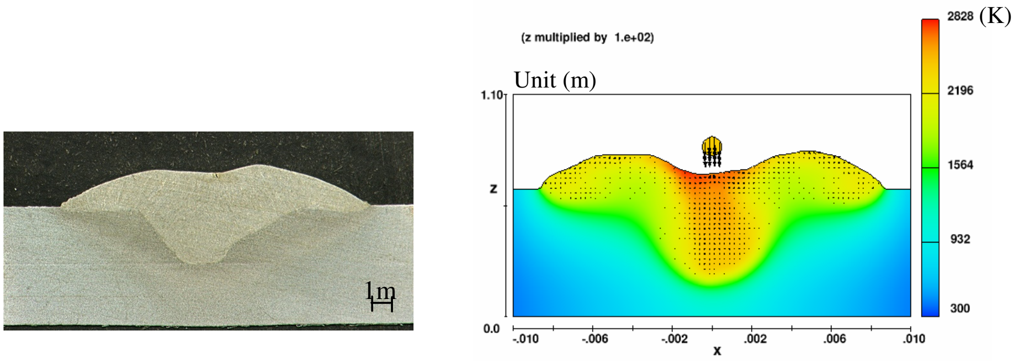
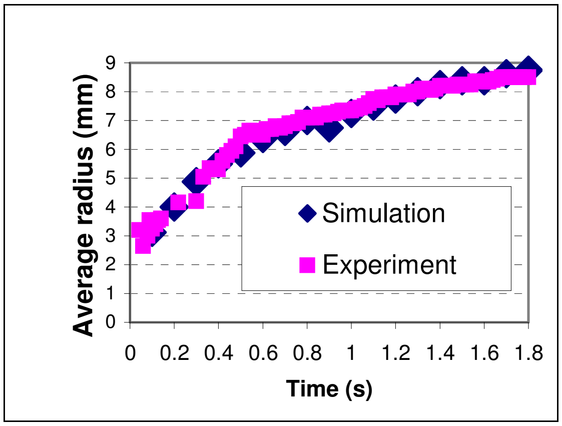


Figure 2 Cross section view of experiment result (left) and simulation result (right)



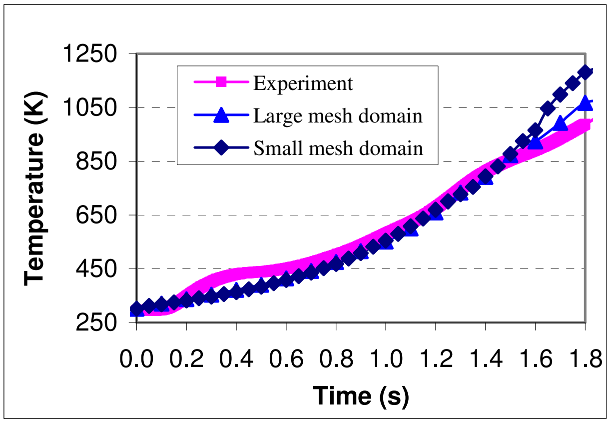


Figure 3 Comparison of transient radius

Figure 4 Comparison of temperature history

Table 1The summary of weld geometry from the experimental results and the simulation

Deposit characteristics	Measured	Simulated	Difference
Height (max/middle)	2.3/1.9mm	1.88mm	0.42/0.02mm
Average radius	8.25mm	8.5mm	0.25mm
Center Penetration	3.2mm	4.6mm	1.4mm
Edge Penetration	0.5mm	0.6mm	0.1mm
Left side toe angle	30.4^{o}	31.8^{o}	1.4^{o}
Right side toe angle	32.6^{o}	33.2^{o}	0.6^{o}

Differences in weld radius, the height of weld reinforcement, weld toe angles, and penetration at the edge are 10 percent or less, but the simulated weld penetration at the center is significantly deeper than the experimental measurement. This discrepancy is attributed to the stability and higher efficiency of drop momentum-induced fluid convection and heat transfer in the simulation as compared to experiments.

The time-varying radius from high-speed video measurements and simulation predictions are plotted versus weld time in Fig. 3. According to both experimental and simulated results, the deposit radius increased rapidly at the beginning of the weld. This is presumed to be due to direct arc heating. The spreading quickly transitions to a more gradual increase. At the later stage of spreading, heat conduction and convection are the main factors to increase the temperature at the liquid-solid junction to allow spreading of the molten metal. Heat conduction is likely less effective for heat transfer to the weld pool edge than thermal convection by fluid motion at longer weld times.

Thermocouple measurements taken during welding were also used for simulation validation. In Fig. 4, three curves showing temperature history at a location 0.4 mm away from the final weld edge are plotted to compare the experimental and predicted thermal history. The difference between the two simulation curves is due to a small mesh domain (2.4 cm by 2.4 cm) and a large mesh domain (3 cm by 3 cm). Both simulation curves are closely matched with the experimental results until 1.5 s, but the small mesh domain results are considerably mismatched after 1.5 s due to an edge effect. A larger simulation domain was needed to more accurately model the weld deposit at larger welds time.

Since simulation results showed good agreement with the experiment results, a parametric study of weld simulation was performed to demonstrate and understand the effectiveness of individual simulation parameters on heat and fluid flow in the molten weld pool and the final configuration of stationary welds. Increasing the heat input radius decreased the weld penetration due to the lower heat input intensity at the weld center. Constricted current density drastically increased the weld penetration and decreased the weld radius. Decreased arc force and increased arc pressure radius both decreased the weld penetration.

Conclusion

A VOF-based simulation that included non-isothermal free-surface fluid flow was used to predict weld shape and temperature histories during stationary P-GMA welding. Buoyancy, Marangoni, arc pressure, drag, and Lorentz forces were mathematically modeled and implemented in the numerical simulation.

Direct comparisons of predicted and measured weld cross-section geometry, time-varying deposit radius, and temperature history from thermocouple measurements showed general agreement and validated the P-GMA stationary welding simulation. Simulation tests with individual changes of variables provided insight into the effects of these variables on fluid flow patterns and weld pool shape. Understanding of the effects of these variables on weld pool fluid flow and weld shapes provided key insights that are useful for future investigations that use the simulation as a tool to assist in weld process development.