C. A Semi-Empirical Model for Prediction of Fusion Zone Shape

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Introduction

Prediction of fusion in welding is essential for obtaining adequate joining quality and improving productivity. Although there are a number of published numerical solutions, there still remain some difficulties in the practical application of numerical models because of many complex parameters. Our knowledge with regard to the fluid flow in T-joint of two perpendicular plates is limited at present.

The purpose of this study is to present a practical methodology for the prediction of fusion. This study adopts a method that achieves approximation of fusion depth and width by heat conduction solution with semi-empirical corrections obtained from experiments. The semi-empirical model obtained from bead-on-plate weld also shows good agreement with T-joint fillet weld. The model is useful in a simple and easy manner for designing welding procedures and also enhances adaptive control in automated welding systems.

Procedure

This study applies heat conduction solution of a moving point heat source to approximate fusion depth and width. A theoretical fusion area including depth and width, were initially compared with experimental results in dimensionless basis using the operating parameter *n*; a product of heat intensity and welding speed (Figure 1). The experimental welding process employed in this study is gas metal arc welding for bead-on-plate weld with/without weaving, plate thickness 5 mm and 12 mm, and for T-joint fillet weld without weaving, plate thickness12 mm.

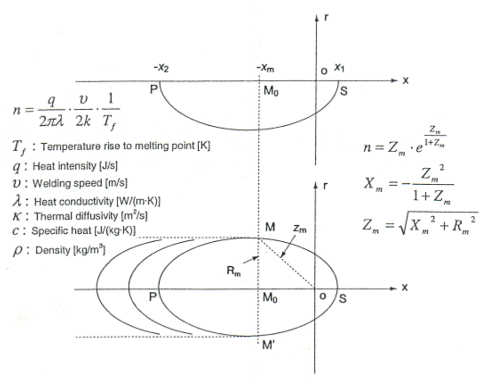

Fig. 1 — Theoretical weld pool outer line by a moving point heat source

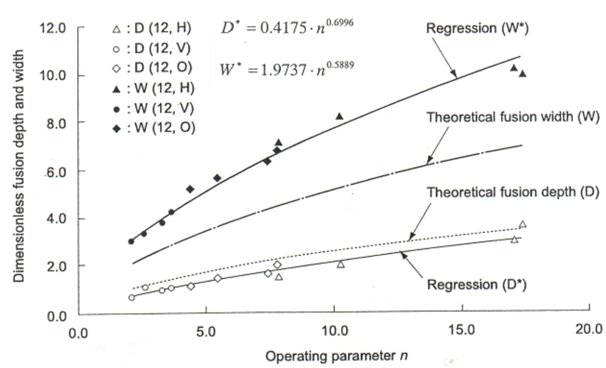

Fig. 2 — Fusion depth and width in bead-on-plate welding

As the theoretical fusion area agrees well with the experiment, this study estimates arc efficiency from comparing the theoretical fusion area with the experiment. The estimated arc efficiency is 80%, 75%, and 70% for horizontal, vertical, and overhead position respectively. The errors between theoretical calculation and experiment are found systematic for both fusion depth and width. This study applies the least squares regression for the experimental fusion depth and width of bead-on-plate weld without weaving, plate thickness 12 mm, resulting in a model for corrections (Figure 2).

This study also applies the same model to T-joint fillet welding. Since the joint is composed of two separate plates, the heat distribution for each plate and the excessive temperature rise at the plate edge surface is to be considered. This study approximates the distribution ratio by the ratio of experimental fusion area in web and flange as 2/5: 3/5 (Figure 3). In addition, web has a material end surface. The heat reflected at the surface raises temperature higher near the surface boundary. This study also includes the effect of heat reflection, so that the theoretical fusion depth meets well with experimental fusion depth. This results in making an assumption that there is an additional 60% of the heat intensity (Figure 4).

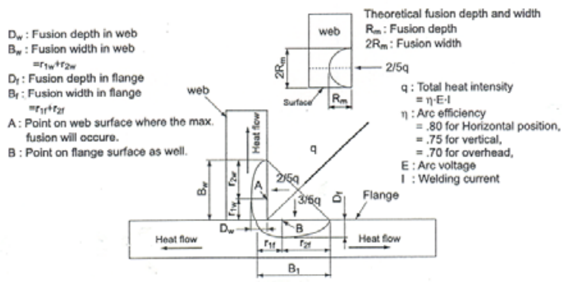

Fig. 3 — Conceptual model of heat flow and fusion In T-joint fillet welding

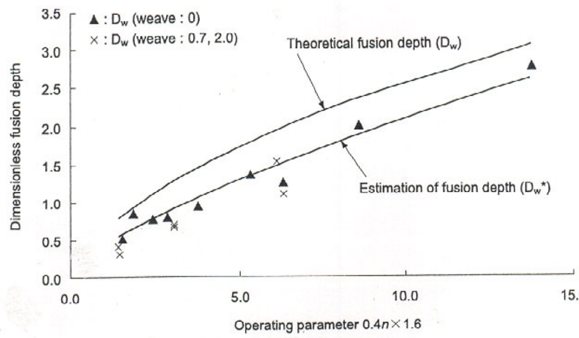

Fig. 4 — Fusion depth in web

This study also examines fusion depth and width both in welding thinner plate thickness (5 mm) and welding with weaving.

Results and Discussion

As postulated, the experimental fusion depth is smaller, and conversely, the fusion width is larger than required by the calculation. A major cause of the errors is fluid flow from center of molten pool toward outer boundary. As the least squares regressions show high correlations of determination, the prediction by this model shows good agreement with the experiments for the operating parameter *n* less than 15. The fusion depth/width ratio in a higher *n* value will vary considerably; accordingly the model will be developed separately in the same manner as this study.

The mechanism of fusion in T-joint fillet welding is much more complicated than in bead-on-plate welding. Nevertheless, prediction by the model using the estimated arc efficiency, heat distribution ratio, and surface effect shows good agreement with the experiments in both web and flange.

In welding a 5 mm thick plate, the experimental fusion depth shows a wider scattering than in a 12 mm thick plate. It is attributed to the excessive temperature rise near the plate's back surface boundary. The surface condition on temperature rise is not negligible in welding a thinner plate thickness than 5 mm.

The result of regression analysis indicates little effect of the weaving when width of weaving is less than 2 mm. The effect of weaving will be concealed with the other driving force in weld pool. While a wider weaving width may increase the fusion width and decrease the fusion depth by changing the heat source properties and fluid flow, this requires further investigation.

Conclusions

The proposed model incorporates an approximation using heat conduction solution with appropriate corrections obtained from experimentation. The prediction of fusion depth and width by the model shows good agreement with experiments both in bead-on-plate weld and T-joint fillet weld. As excessive computation is not required, the model is useful in a practical manner for designing welding procedures, and it also enables adaptive control in an automated welding system. Models for welding with a higher operating parameter than 15 and welding with root opening will be obtained with ancillary experiments. A model for materials other than steel will be achieved through the same approach.