

A Systematic Microstructure-Level Modeling Approach For Designing High Performance Welded-Joint

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Introduction

The integrity and performance of weld joint depends on its bead geometry, microstructure, material property, and weld residual stress distribution. During fusion welding processes, high-intensity heat sources create steep thermal gradients that rapidly heat and cool materials to and from their melting point. The rapid thermal cycling induces various phase transformations and changes in grain structure. The welding induced microstructural evolution can significantly affect not only the weldment properties such as hardness and yield strength, but also weld residual stress and final weld joint performance such as fatigue strength.

The objective of this research is to develop a through procedure to predict welding induced weld bead formation, microstructure evolution, material property change, and residual stress distribution for designing structurally sound and defect free weld joint. A systematic understanding of the relationship of process-microstructure-property-performance was established for welding process by coupling thermal-metallurgical-mechanical modeling.

Description of Modeling Approach

The systematic modeling approach was based on interdisciplinary applied sciences including heat transfer, computational fluid dynamics, materials science, and engineering mechanics. As shown in Figure 1, the modeling approach combined four sub-models: a weld thermo-fluid model, a weld microstructure model, a weld material property model, and a weld residual stress model. The integrated model was based on

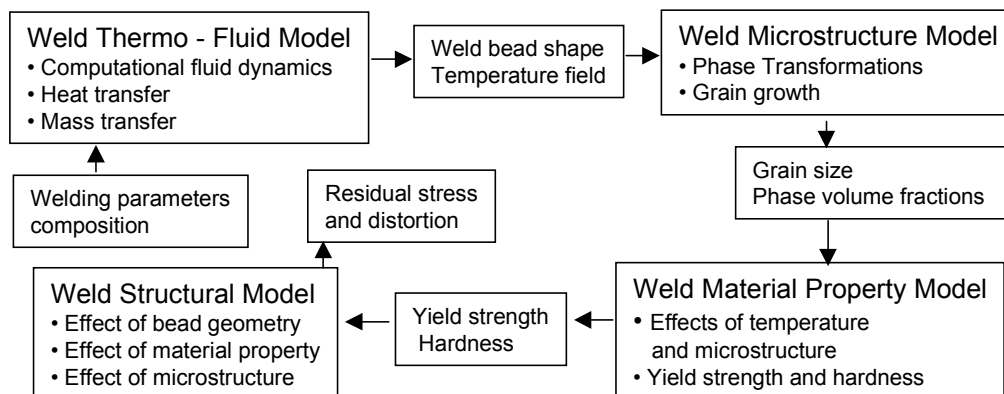


Figure 1: Flow chart of the modeling approach.

existing codes with further development of new features such as prediction of free surface weld bead geometry with metal droplet impact, integrated prediction of weld microstructure and material property in both fusion zone (FZ) and heat affected zone (HAZ), and incorporation of the effects of phase transformations into weld residual stress prediction.

Results and Discussion

The weld bead geometry and transient temperature field were predicted using a 3D free surface weld thermo-fluid model. The predicted weld bead geometry from both GTA and GMA welding as functions of heat inputs were in fairly agreement with the experimental results. The phase transformations and grain growth during welding of C-Mn and low alloy steels were predicted by coupling the thermal model with microstructure model. The predicted spatial distribution of grain size and phase volume fractions (ferrite, bainite, and martensite) in both the FZ and the HAZ were comparable with the corresponding experimental results. The change of microstructure as functions of thermal cycles and chemical composition were effectively illustrated at each material point in the weldment. Accordingly, the weld material properties (yield strength and hardness) were predicted based on the thermal cycles, chemical composition, and the weld microstructure. The prediction of weld residual stress was based on an existing model by adding the effect of phase transformation induced plasticity. The predicted weld bead geometry, transient temperature field, and detailed microstructure and material properties were used as inputs for weld residual stress prediction. Initial results have been obtained for prediction of weld residual stress by coupling thermal-metallurgical-mechanical modeling.

Conclusions

1. Weld bead geometry and transient temperature field from various welding processes can be predicted from a 3D free surface thermofluid model, in which metal droplet impact can be considered.
2. The spatial distribution of weld microstructure (grain size and phase volume fractions) in steel weldments can be effectively predicted by coupling thermal model with microstructure model.
3. The material properties (yield strength and hardness) at each material point in the weldment as functions of thermal cycles, chemical composition, and microstructure can be well predicted.
4. The development of weld residual stress was predicted by coupling thermal-metallurgical-mechanical modeling.

The modeling approach in this research represents the first effort to predict weld bead geometry, microstructure, material property, and residual stress distribution as functions of heat inputs and chemical composition using a thorough process simulation procedure. The results from the presented modeling approach will be used as inputs for weld fatigue life prediction and thus provide guidance for design high performance welded-joint by optimizing weld parameters and consumable composition.