

A Models for Microstructure Evolution in Pipeline Welds – A review

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Introduction

There is a growing impetus to design optimum steel chemistry, welding process and consumables for better performance and productivity. Since microstructure evolution in both weld metal (WM) region and heat-affected region (HAZ) will affect the properties of pipeline welds, there is a need to describe the same as a function of steel composition and welding process parameters. This paper will review the published modeling techniques that describe steel weld microstructure and properties.

Procedure

Weld metal region experiences melting, solidification, and solid-state transformation. In contrast the heat-affected region experiences only solid-state transformation. In the weld metal region, the important phase transformation events are as following [see Fig. 1] inclusion formation, solidification to delta-ferrite or austenite, transformation of delta-ferrite to austenite, austenite grain growth, and solid-state transformation of austenite to different ferrite morphologies.

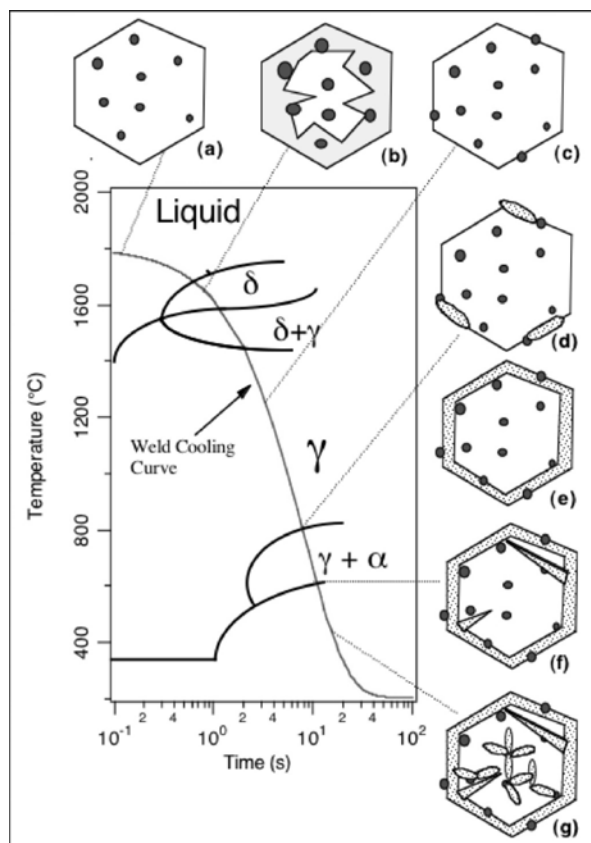


Figure 1. Schematic Illustration of Phase Transformation Sequence in the Weld Metal Region

In case of the heat-affected-zone, the phase transformation events will include the following: tempering of preexisting microstructure, nucleation and growth of austenite, dissolution of precipitates, growth of austenite grains and subsequent transformation of austenite to different ferrite morphologies. To model all the above it is possible to couple existing empirical, analytical and phenomenological models and develop an integrated framework to describe microstructure evolution in HAZ and WM.

Results and Discussion

Microstructure Evolution in Weld Metal Region

The inclusion formation in liquid steel welds could be described by coupling ladle thermodynamics and overall transformation kinetic models. This model allows for the estimation of number density, size and composition of the inclusions as well as, the sequence of oxidation reactions. The sequence of oxide formation is important to evaluate the capability of inclusion to nucleate acicular ferrite during austenite to ferrite transformation. The solidification to delta-ferrite or austenite can be described by using diffusion controlled growth models for normal cooling rate and interface response function models for rapid cooling conditions. In the next step, the austenite grain size is related to the driving force for austenite nucleation from ferrite. The solidstate transformation of austenite to allotriomorphic (grain boundary) ferrite can be modeled based on paraequilibrium transformation models. Later on the displacive transformation models can be used to describe the kinetics of Widmanstätten-, Bainite- and acicular-ferrite. By using simultaneous transformation kinetic models one can evaluate the relative fractions of these ferrite morphologies.

Microstructure Evolution in HAZ Region

Tempering reactions during weld heating are very difficult to distinguish from the onset of austenite formation during heating. Recent synchrotron diffraction results in steels indicate the austenite formation is indeed rapid. It is possible to couple diffusion controlled growth of austenite into ferrite and overall transformation kinetic theories to describe austenite formation in the HAZ. The importance of initial microstructure on the transformation kinetics of austenite can be deduced from these models and also experimentally observed extensive microstructural heterogeneity in pipeline steels. The dissolution of carbides or carbonitrides also can be described by extending diffusion controlled growth models. The relative dissolution rates of carbide and nitride in ferrite or austenite can be estimated by these models. By extending, classic research by Ion, Easterling and Ashby one can describe the austenite grain growth and its interaction with carbide or nitride stability. The models for austenite to ferrite transformation developed for the weld metal region can be extended to heat-affected-zone region. In addition, one could use other semi-empirical published methods based on carbon equivalence.

Integrated Models

By coupling different sets of models, it is possible to describe the overall microstructure evolution in steel welds. Demonstration of the individual models for typical pipeline and other welded steels will be shown and comparison to the published data will be made. The challenges including the methodology to predict the retained austenite stability and microstructure-property correlations will be highlighted.

Conclusions

The final performance of the pipeline is related to microstructural evolution in different regions of the weld. The microstructure evolution is influenced by various sequences of phase transformations events that occur during weld heating and cooling. Based on the extensive review of literature, it is concluded that it is possible to develop comprehensive model to describe microstructure evolution in both HAZ and WM of pipeline welds. Demonstration of individual models and comparison to the published pipeline weld research will be shown.

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