Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

Thermal and Microstructure Simulation of High Strength Pipeline Girth Welds

Yaoshan Chen and Yong-Yi Wang
Center for Reliable Energy Systems
Dublin, OH, USA

James Gianetto
CANMET Materials Technology Laboratory
Natural Resources Canada
Ottawa, Ontario, Canada

ABSTRACT

Pulsed gas metal arc welding (P-GMAW) is one of the most effective joining methods for mainline field girth welding of large-diameter and long-distance pipelines. Most of the current applications are single-wire processes coupled with narrow-groove weld geometry. Multi-wire variants, such as tandem-wire and dual-torch processes, have been developed to increase welding productivity and reduce overall project cost. The P-GMAW processes have some unique characteristics that need to be considered in the heat transfer and microstructure analyses of the processes. This paper presents integrated thermal and microstructure models for P-GMAW processes with a consistent heat source model and its associated thermal boundary conditions. The objective of this study is to extend the existing numerical welding modeling approaches to cover wider range of P-GMAW processes, such as the multi-wire variants. To validate the integrated models, the predicted cooling times and hardness for welds produced under different preheat temperatures and different P-GMAW processes were compared to actual thermal cycle and hardness measurements. Generally good agreements were achieved and certain areas of continued improvements were identified.

KEYWORDS: GMAW, narrow groove, heat transfer, microstructure, cooling time, hardness, finite element analysis

INTRODUCTION

There is a general trend toward application of high-strength steel pipe for modern high-pressure and long-distance pipelines. One of the major challenges in the application of high-strength steel pipes for pipeline construction is achieving balanced properties of the circumferential field girth welds. Mechanized P-GMAW process has been gaining popularity because of its higher productivity and lower heat input. A number of process and procedure variables have to be set properly to ensure high-quality girth welds. Understanding of the relationship between the weld metal and heat-affected zone (HAZ) mechanical properties and the welding parameters should be very useful in process selection and control. The mechanical properties in the weld metal and the HAZ are closely related to their microstructures, which in turn are dependent on the chemical composition of the material and the thermal histories (cycles) from the welding processes.

Thermal analyses of welding processes have covered a wide range of features for different types of welding processes. From the early Rosenthal conduction mode [Rosenthal, 1941] with moving heat source to the latest computational fluid dynamics (CFD) models that account for the liquid metal fluid flow, phase change, mass transfer, and arc-pool interaction [Zhu, 1998; Chen, 1997; Zhang, 2004], continuous advances have been made in both model sophistication and the range of welding processes these models cover. Some of the finite element thermal models with distributed heat source, such as Goldak's double ellipsoid heat source model [Goldak, 1984], have been successfully used for welding process simulation.

The microstructure models for weld metal and the HAZ have been a diverse area of research. Over the years a number of modeling approaches have been proposed for different materials and different welding processes [David, 1996]. In microstructure modeling of HAZ, a kinetics model initially developed by Kirkaldy [1983] proved to be quite successful. The focus of this model was on the austenite decomposition into its daughter products of ferrite, pearlite, bainite, and martensite upon cooling. Empirical equations were proposed and correlated to experimental measurements for reaction rates from austenite to each of its daughter products. Grain growth was also an important part of the model and it followed the formulation proposed by Easterling [1982]. This model was later modified and improved by several authors [Watt, 1988; Henwood, 1988; Li, 1998] for its versatility and applications to multi-pass welds where repeated heating and cooling takes place.

For the weld metal Bhadeshia [1993] proposed a comprehensive approach to model the microstructure evolution. This approach was used by several authors in combination with sophisticated heat transfer and fluid flow analyses in the weld [Yang, 1999; Zhang, 2002; Zhang, 2005]. Because of the complicated phase changes and microstructure evolution in the weld, a number of modeling tools were used in these studies to calculate the austenization and grain growth during cooling, the δ-ferrite to austenite transformation upon cooling, and the austenite decomposition. Among these thermal and microstructure models, a number of them performed the thermal and