Microstructure Modeling of HAZ Softening in Microalloyed High Strength Linepipe Steels

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ABSTRACT

The heat-affected zone (HAZ) of modern low-carbon low alloy TMCP linepipe steels can soften in the presence of welding thermal cycle, even at the relatively low heat input of pipeline girth welding. The possibility of strain concentration in the softened zone and low HAZ toughness can have negative impact on the integrity of pipelines.

The present study describes a microstructure model capable of predicting HAZ softening. Modern pipeline steel grades X70, X80, and X100 were selected to study their propensity of HAZ softening. The model was first benchmarked against the hardness measurements of X70 and X80 steels which underwent simulated thermal cycled with different peak temperatures. It was further applied to a multi-pass girth-weld made on an X100 steel. The predicted HAZ hardness was compared to the microhardness mapping obtained from the girth weld.

KEY WORDS: Heat-affected zone (HAZ), grain size, TMCP steels, HAZ softening, microhardness.

INTRODUCTION

The heat-affected zone (HAZ) which forms adjacent to the weld in steels is one of the most common regions of weld failure. For modern TCMP steels, because of their lean chemistry, in particular, the low carbon content, require carefully controlled welding parameters in order to achieve adequate strength in the weld HAZ. For conventional low-carbon steels and some TMCP pipeline steels such as X70 and X80, HAZ softening is often the result of high heat-input welding procedure because of the slow heat dissipation in the HAZ (Denys and Lefevre, 2000 and Yurioka 1995). For higher grade TMCP steels such as X100, HAZ softening can happen even under moderate welding heat-input because of the base metal’s ultra fine grain size and its bainite- and martensite-dominated microstructure. This reduction in hardness and strength in HAZ makes it a weak point in a welded pipeline structure. Consequently it is important to know the degree and extension to which this softening takes place, given the nature of the base metal and the welding conditions.

There have been many theoretical and numerical methods and models for the determination of hardness in HAZ (Abson, 1999). The early methods focused on the prediction of maximum hardness in the HAZ as it is a good indicator of potential stress corrosion cracking (Suzuki, 1985, Yurioka, 1981, 1987). These methods, all given in the form of empirical formulae, however, do not apply to the calculation of HAZ softening since they all targeted at the estimation of the maximum hardness. Over the years, there have been microstructure models that are capable of simulating phase transformation and determining hardness in metals given their chemical compositions and the thermal cycles they are exposed to. The early works by Kirkaldy and Venugopalan (1983) showed that phase transformation in metals with relatively low alloying elements can be modeled with a rate-based kinetics algorithm. Li et al. (1998) modified the reaction kinetics model of Kirkaldy to allow better phase transformation prediction under continuous cooling condition. Watt et al. (1988) developed a numerical algorithm based on Kirkaldy’s model for the microstructure development in HAZ. Because of the importance of the prior-austenite grain size in the coarse-grained heat-affected zone, a grain growth model by Ashby and Easterling (1982) was used to include the effects of precipitate dissolution and the gain growth in the austenite region. This algorithm was later applied to a numerical model for the prediction of microstructure and hardness in HAZ with multi-thermal-cycle (Oddy et al., 1995, 1996). Because the HAZ experiences repeated heating and cooling under this circumstance, re-austenization and tempering were considered in the model. An important factor in Kirkaldy’s model is the prior-austenite grain size, which greatly affects the reaction rates of the child products during austenite decomposition. In the characterization of phase transformation and microstructure in HAZ for HSLA steels, Shome et al. (2004, 2006) correlated the grain growth and the austenite-regime area which is the area of the thermal cycle above the austenite temperature. While the Kirkaldy model has been proven to be an effective framework for microstructure simulation and prediction, there have been modifications and improvements over the years for its application to specific types of steels.

The objective of the present work is to develop a numerical model for the prediction of HAZ softening in modern high strength microalloyed linepipe steels. The current model is based on Kirkaldy’s empirical model and its later modifications. In particular, the different aspects of the grain growth models are examined and incorporated into the present model for better predictions of the microstructure and hardness in HAZ.

PHASE TRANSFORMATION MODEL

Overall, the model takes a thermal cycle, i.e., temperature as a function of time, and the chemical composition of the material as inputs. The