Liu, M., Wang, Y.-Y., and Horsley, D., Significance of HAZ Softening on Strain Concentration and Crack Driving Force in Pipeline Girth Welds, Proceedings of 24th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2005), Halkidiki, Greece, 2005

Abstract

Modern micro-alloyed, control-rolled TMCP steels generally have good strength, high toughness, and good weldability. However, these valuable properties come along with certain undesirable features, such as low strain hardening (high yield to tensile ratio), low ductility as measured by uniform elongation (elongation at ultimate tensile strength), and possible heat-affect-zone (HAZ) softening due to reduced hardenability. These undesirable features are particularly detrimental in strain-based design of pipelines.

Although the phenomenon of HAZ softening has been known for a long time, the impact of the HAZ softening on the integrity of pipeline girth welds was not well understood. The objective of this work was to understand the impact of HAZ softening on girth weld integrity. Finite element analysis was conducted to investigate the effects of HAZ softening on crack driving force and strain concentration in girth welds under longitudinal tensile loading. The material properties of WM and BM were obtained from an X100 girth weld. The HAZ was modeled as a functionally graded material based on its measured hardness. The models contained surface-breaking defects located at the fusion boundary simulating lack-of-sidewall fusion defects.

The analysis results showed that increased CTOD driving force can be expected due to HAZ softening. The extent of increase is positively related to the width and degree of softening of the HAZ. On the other hand, weld strength overmatch reduces the total CTOD driving force. The strain concentration in the softened HAZ circumferentially remote from a surface-breaking defect was small. However, high strain concentration existed over the circumference covering the length of the defect. This concentration was primarily attributable to the existence of the defect and secondarily to the HAZ softening.

One significant result from this work was that the relative increase in CTOD driving force and strain concentration due to HAZ softening was independent of defect size. In other words, on a relative basis, HAZ softening was no worse on large defects than on smaller defects. This result should be helpful in rationalizing the effects of HAZ softening for defects of various sizes that exist in field applications.

Non-symmetrical crack-tip deformation occurred with softened HAZ. A large proportion of the crack-tip deformation was located in the HAZ. The magnitude of non-symmetric deformation increased with the increase of HAZ width and degree of softening. Even higher degree of non-symmetric deformation occurred with the increase of weld overmatching level. The structural significance of reduced total CTOD driving force and increased un-symmetric deformation at the crack tip due to weld strength overmatch warrants further study. The reduction in total CTOD driving force alone does not necessarily results in a higher level of weld integrity if the “intrinsic” toughness of the HAZ is substantially lower than the weld metal.

Keywords

Heat-affected zone (HAZ), HAZ softening, Girth weld integrity, Crack driving force, Tensile strain limit (capacity), Strain-based design (SBD), Pipeline