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Girth Welds for Strain-Based Design Pipelines

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ABSTRACT

From the standpoint of structural integrity, girth welds are the weakest link in strain-based design pipelines. Girth welds (weld metal and heat affected zone) contain inherent defects, are a common location for geometric eccentricities like high-low misalignment, and potentially contain less resilient microstructures compared to linepipe steel. For these reasons, work was undertaken to study the effects of welding process on X80 girth welds. In the first part of this study, welds were produced using a number of shielded metal arc welding (SMAW) electrodes. Both low hydrogen, vertical down (LHVD) and traditional low hydrogen uphill electrodes were tested. It was found that most of these electrodes did not meet the target properties. Additionally, diffusible hydrogen measurements indicate that the LHVD electrodes tested can generate relatively high levels of hydrogen. It is concluded that typical SMAW electrodes should be enhanced for high-strain X80 applications, although some electrodes might be suitable for less demanding strain-based scenarios. In a second part of the study, gas tungsten arc welds (GTAW) were produced as a laboratory exercise to investigate the influence of this clean process on weld metal toughness (tearing resistance) and strain performance. Single edge notch bend specimens and curved wide plate tests were conducted using unloading compliance to quantify tearing resistance. These welds demonstrated dramatic improvements in structural performance. Despite the practical limitations of the GTAW process for field pipeline welding, these results provide significant insight for future welding developments.

KEY WORDS: Strain-based design; pipeline girth welds; weld consumables; weld metal; toughness; tearing resistance.

INTRODUCTION

In the coming decades, the oil and gas industry will be constructing a significant number of new pipelines. Many resources will be in remote environments where the service loads will impose plastic strains on the pipeline in the longitudinal direction. Examples of such service loads include ground movements due to seismic events, iceberg gouging, melting of permafrost (thaw settlement), and the freezing of unfrozen ground (frost heave). The term strain-based design (SBD) refers to pipelines for which the design loads and capacities are quantified in terms of strain and the pipelines are designed to sustain a prescribed level of plastic strain without rupture. It is imperative that the oil and gas industry develop suitable design technology, resilient materials, and robust construction methods for SBD pipelines.

Future SBD pipeline construction will often involve the deployment of significant manpower and equipment into remote regions, and this creates tremendous costs. Perhaps the most labor intensive component in this process is girth welding. There is an inherent relationship between pipeline economics and weld quality. The difficult working environment of remote construction and the necessity for all-position (5G) welding make it nearly impossible to economically apply the highest quality welding technology available. While welding technology exists that can deliver strong, tough, and essentially defect free welds, these welding methods can be too slow, too costly, and/or too delicate for the rugged conditions of remote pipeline construction. As a result, economic welding techniques like shielded metal arc welding (SMAW) and gas metal arc welding (GMAW) will remain a mainstay of pipeline construction in the near future, and addressing weld defects will also be a key requirement. Girth weld flaw tolerance is at the forefront of SBD pipeline research.

For conventional stress-based pipeline designs, it is generally desirable that the girth welds be at least as strong as the specified minimum yield strength (SMYS) of the pipe and tough enough to prevent fracture. Fracture prevention is often addressed using engineering critical assessment (ECA) whereby a minimum level of toughness is specified in terms of crack tip opening displacement (CTOD). CTOD provides quantifiable cleavage fracture control. It also provides some control against ductile fracture, but due to a lack of crack growth monitoring, ductile fracture control is not quantified. For pipeline service loads in the elastic regime, this approach has proved adequate because once a reasonable level of brittle fracture resistance is specified and achieved, the welds typically possesses sufficient ductile fracture resistance. This is inherently the case for acicular ferrite dominated weld metals that are common for pipeline applications.

For SBD applications where the loads extend into the plastic regime, failure by ductile tearing becomes a more likely failure mode even if the potential for brittle fracture is eliminated. Ductile tearing can