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Girth Welding Development for X120 Linepipe

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ABSTRACT

This paper discusses the development of a girth welding technique for X120 linepipe. The solid-wire, pulsed gas metal arc welding (PGMAW) process with Ar-based shielding gas was selected for its process control, and low oxygen and hydrogen potentials. The weld metal microstructure was designed using fundamental metallurgical principles and verified through the evaluation of about 20 experimental wires and several commercial-scale heats of wire. Weld metal chemistry and shielding gas composition were optimized. The developed microstructure is termed acicular ferrite interspersed in martensite (AFIM). Transmission electron microscopy was the primary tool used for microstructural analysis and weld metal inclusion design.

INTRODUCTION

A significant challenge in the deployment of higher-strength linepipe such as X120 is the development of girth welding technology that is compatible with existing pipeline construction methods. Successful girth welding of high-strength linepipe requires sufficient hydrogen cracking resistance, good welding productivity and ease of welder use, while maintaining the proper balance between strength and toughness. This paper concerns the development of girth welding technology intended for use in the field construction of high-strength, large-diameter gas pipelines. Although primary focus was on X120 due to a parallel linepipe development effort (Fairchild et al., 2002; six X120 papers in ISOPE 2003 proceedings), the results have applications to X80 and X100. Many topics have been addressed within this welding research program, but due to space limitations, this paper will only cover the topic of mainline girth welding. Specifically, it will cover the metallurgical design of the weld metal, the selection/optimization of welding process and parameters, and the evaluation of candidate welding wires. The topics of tie-in and repair welding, hydrogen cracking, HAZ toughness and fracture control will be the subject of future publications. Suffice it to say that tie-in and repair welding procedures have been developed, the mainline welding techniques are for use with a preheat of 100°C, and the fracture control approach has been validated using curved wide plate tests.

At the start of the program, several guiding principles and target properties were established:

- Use a welding method within the scope of industry practice that produces consistent properties and low levels of diffusible hydrogen.
- Design a consumable and welding procedure with acceptable ease of use to avoid weld pool characteristics that cause defects.
- Minimum design temperature: −20°C.
- All-weld metal properties: yield > 828 MPa, tensile > 931 MPa, total elongation $> 18\%$.
- Charpy: 84 J @ −30°C, ductile-to-brittle transition temperature (DBTT) < -50°C.
- Crack tip opening displacement (CTOD): 0.13 mm @ −20°C.
- Pipeline fluid: dry gas, no H_2S.

The −20°C design temperature represented the lower end of potential service applications. The Charpy target of 84 J @ −30°C is a strength-based extrapolation (to X120) of the DnV Offshore Standard for Submarine Pipeline Systems (section C301 and Table 6-3). The DBTT target was to ensure upper-shelf fracture behavior at the design temperature. The fracture mechanics target evolved from calculations using a variety of design conditions, BS 7910, and finite element analysis. Both installation loads and service loads (72% SMYS) were considered. Assumptions included 100% yield-level residual stresses and a surface breaking defect 2 mm deep by 100 mm long.

Metallurgical Design and Welding Process Selection

Traditionally, linepipe girth welds and structural welds of similar strength depend on acicular ferrite (AF) as the base microstructure. For the X120 application, AF was anticipated to be too weak. It was decided that martensite, bainite and/or their derivatives should be the primary weld metal components. Although too weak on its own, a minor presence of AF was planned. Specifically, it was thought that AF could be used to break up the prior austenite grains into sub-units, thus creating an effective reduction in grain size. It was decided to experiment with AF volume fraction and morphology.

The decision to use a martensitic/bainitic design with a minor presence of AF led to concerns about toughness, property consistency and hydrogen cracking. In fact, weld metal toughness and hydrogen cracking were anticipated to be the primary challenges. Toughness concerns were associated with the inevitable presence of nonmetallic inclusions in field girth welds, and the fracture

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KEY WORDS: Welding, pipelines, high strength, toughness, microstructure, martensite, acicular ferrite.