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Full-size Testing and Analysis of X120 Linepipe

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ABSTRACT

A new high-strength steel with a specified minimum yield strength of 120 ksi has been developed for linepipe applications. Because existing specifications were not originally intended for the X120, and no service experience exists for this grade, full-size pipe tests and finite element analyses were conducted to evaluate structural performance. The full-size testing included burst, pure bending, collapse, bending + collapse, ring expansion, curved wide plate and crack arrest tests. In addition to these tests, bending trials were performed on the X120 using commercial pipeline construction equipment to verify cold deformability. This paper presents the burst and fracture arrest studies. Results from burst tests and analyses demonstrate sufficient pressure containment capacity. For crack arrest, full-size tests were conducted to evaluate the intrinsic arrestability of the material and the effectiveness of crack arrestors. Although the X120 pipe did not have sufficient toughness for intrinsic arrest for the prescribed test conditions, tight-fitting sleeve crack arrestors were shown to be effective in stopping propagating fractures.

INTRODUCTION

The demand for natural gas is growing worldwide. In order to meet it, remotely located resources must be developed economically. Often, the high cost of delivering the gas to market eliminates the financial incentive for developing the resource. If the cost of the pipeline is reduced, project economics can be improved; one method of transporting natural gas to market is through large-diameter, gas transmission pipelines (Corbett et al., 2003). The trend over the years has been to use pipe with increased strength so that smaller amounts of steel are required for the line. In addition, the reduced wall thicknesses and corresponding lighter weight can result in lower construction costs. In the mid-1990s, ExxonMobil initiated a program to develop the next-generation linepipe steel with a specified minimum yield strength (SMYS) of 827 MPa (120 ksi) and a specified minimum tensile strength (SMTS) of 931 MPa (135 ksi) (Fairchild et al., 2002). Shortly after, ExxonMobil entered into similar but independent agreements with Nippon Steel Corporation (NSC) and Sumitomo Metals Industries (SMI) to develop and commercialize X120 linepipe. The X120 pipe is made from TMCP plate and formed using the UOE process. Additional information about the manufacturing of the plate and pipe is available in Asahi et al. (2003a and b) and Okaguchi et al. (2003). A pipe size of 914 mm (36 in) × 16 mm was the primary focus of the development program and was used for full-scale testing. A few tests have also been conducted on other X120 pipe sizes.

Small-scale laboratory tests—such as tensile, Charpy toughness and crack-tip-opening-displacement (CTOD) tests—were conducted to evaluate the performance of the material throughout the project (Asahi et al., 2003a and b; Okaguchi et al., 2003). After the project advanced to the stage where the critical material properties satisfied small-scale testing targets, full-size testing was conducted to verify the structural integrity of the pipe under realistic pipeline loads. The testing also verified finite element models used to establish new design criteria.

The following full-size tests were conducted:

Burst	Full Scale Crack Arrest
Ring Expansion	Crack Arrestor (Mojave Test)
Curved Wide Plate	Collapse (External Pressure)
Pure Bending	Bending + External Pressure
Cold Bending Trials	

The primary load in most pipelines is the internal pressure. Design pressures that result in hoop stresses in the pipe as high as 80% of the specified minimum yield strength are allowed by many pipeline codes. To provide economic incentive for the higher-strength materials, the properties of the X120 pipe must allow it to be safely operated at pressures resulting in comparable stress levels. To ensure sufficient pressure capacity, a series of burst tests was conducted on X120 pipe. Supporting finite element analysis (FEA) was also used to further understand and develop a burst limit state design criteria.

In addition to adequate strength, the pipe body, seam weld and girth welds must possess enough fracture initiation toughness to avoid failure in the presence of defects. The X120 has been subjected to an extensive small-scale fracture testing program. The results are compared to the requirements calculated using fracture mechanics analyses to determine the material's suitability. In addition, large-scale fracture tests were conducted to verify sufficient structural integrity under realistic loading conditions. The seam weld initiation toughness was evaluated using ring expansion tests. In these tests, ring specimens with crack-like defects placed in the seam weld were pressurized until failure. Similar verifications of the girth weld fracture toughness were conducted using the curved wide plate test (Denys, 1990).

If a failure is initiated in a pipeline, a propagating crack can develop and destroy extended lengths of the line. As a result, designing for crack arrest is of the utmost importance for gas transmission pipelines. Theories that predict the amount of fracture resistance required to arrest a propagating crack are largely

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KEY WORDS: High strength, pipelines, full-size testing, burst, crack arrest, crack arrestors.