Pipeline Strain Capacity Prediction of Multi-Process Fill Pass Girth Welds

ExxonMobil Upstream Research Company
Houston, Texas, United States

ABSTRACT

Strain-based design (SBD) of oil and gas pipelines has supported the development of frontier energy sources by permitting cost-effective designs that can withstand large longitudinal strains imposed by discontinuous permafrost, active seismicity, and offshore ice gouging. A key element of SBD is the proper characterization and prediction of pipeline strain capacity in the presence of large plastic deformation and ductile tearing. Recently, a strain capacity prediction tool has been developed that accounts for a wide range of input parameters including pipe geometry, flaw geometry, base pipe and weld material properties, and high-low misalignment. The tool has been validated with more than 50 full-scale pipe tests. However, in all of these tests, the girth weld fill and cap passes were conducted using a single filler metal chemistry. Therefore, the girth weld was considered to have similar material properties throughout its thickness.

This paper will review recent work on strain capacity predictions of a pipe whose girth weld fill passes were deposited using both flux-core arc weld (FCAW) and pulsed gas-metal arc weld (P-GMAW) processes. Biaxial full scale testing (FST) was performed on the welded pipe with surface breaking notches located in the OD weld center line. Pipe failure occurred due to significant ductile tearing (~8mm) that predominantly occurred in the FCAW weld. Different combinations of tensile properties and R-curves of the FCAW and P-GMAW welds were considered in the prediction of the pipe strain capacity. It was found that the strain capacity achieved during full-scale biaxial testing could be successfully predicted by considering the lower mechanical properties of the FCAW material. Proper assessment of the various weld material properties can therefore permit the successful SC prediction of a pipe welded with multiple fill pass materials.

KEY WORDS: Pipelines; girth welds; strain-based design; strain capacity prediction; full-scale testing.

INTRODUCTION

As part of the weld procedure qualification for a major offshore pipeline construction project, a series of full-scale tests (FST) were performed in order to demonstrate the strain capacity of each pipe/weld combination. Eight of the nine 20" outer-diameter (OD) FSTs passed the 5% strain capacity requirement. The final test was halted at 4.98% global strain due to accelerated ductile tearing observed in one of the OD weld centerline (WCL) notches. Micrographs and test data from the FST are shown in Fig. 1. The upswing behavior displayed in the crack mouth opening displacement (CMOD)-strain curve shown in Figure 1(c) indicates accelerated ductile tearing.

The girth weld in question was fabricated using two different fill pass weld procedures and 33 mm wall thickness (WT) API 5L X60 line pipe. The first six fill passes (25 mm total fill) were completed using pulsed gas metal arc welding (P-GMAW); the final two fill passes and cap pass (8 mm total fill) were deposited using flux-cored arc welding (FCAW). The initial testing and strain capacity predictions conducted prior to full-scale testing did not account for the unique properties within each weld material. The strain capacity predictions were conducted by using the strain capacity tool developed based on a tangency approach [Minnaar, 2007; Kibey, 2008; Kibey, 2009; Fairchild, 2011; Fairchild, 2012; Wang, 2009; Wang, 2010; Cheng, 2009]. All-weld-metal tensile (AWMT) tests sampled material near the mid-thickness of the girth weld, as shown by the Procedure Qualification Record (PQR) data shown in Table 1. Single edge notch tension (SENT) toughness tests only sampled the P-GMAW weld metal. For the 4.5 x 100 mm notched condition under consideration, historical, weld property data not specific to this project was used to estimate a strain capacity approaching 5.7% prior to full scale testing. The historical strength data was similar to the mid-thickness strength measured above, and the historical toughness closely matched the R-curve derived from P-GMAW material.

A post-FST metallurgical investigation conducted on the 4.98% strain capacity FST specimen revealed significantly different properties in each type of weld metal. Since prior strength testing did not account for each weld metal, AWMT coupons were prepared from each layer of weld metal in the pre-strained FST girth weld. The resulting strength data, listed in Table 1, is therefore likely higher than would be measured in the as-welded condition (as measured in the PQR data). Since the FST girth weld strength was overmatched to the base metal, it can be assumed that the girth weld contributed very little to the 4.98% global strain and therefore any strain hardening would be marginal. Similar efforts were made in measuring the Vickers hardness of both weld metals from the pre-strained material. The only PQR testing that did independently assess each weld metal was the Charpy toughness testing. The properties listed in Table 1 indicate that the FCAW metal